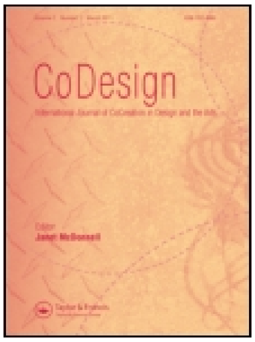

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Used and rejected decisions in design teamwork

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Decision making in design requires careful consideration, as any inaccuracies or faults can have serious consequences for the producer, the user and/or the competitiveness of the company. Research investigating decision making in design so far has mainly focused on the selection of decisions as part of technical choices and classical optimisation problems. In recent years, further research has been started to discover the characteristics of successful decision making in industry. These later, mostly single case studies shed light on some general influences on decision making but so far have not identified different relevant patterns of decision-making processes in design teams which are influential on the result and the process of decision making, such as the constituents of rejected decisions. The research study reported here was initiated to further analyse the components of decision-making processes in teams, with special emphasis on the question of how decisions develop during the design process. For example, what happens to rejected decisions in the course of the design process? The observed processes should be analysed in detail by assessing all utterances in an interaction protocol which can be used as indicators of underlying cognitive processes in decision making; this research approach is usually called protocol analysis. In this experimental study using protocol analysis, rejected decisions were compared against those that were chosen to be used in designing the final outcome. The findings show how the designers develop the solution space and illustrate the analysis of decisions as a promising approach to analyse both the individual cognitive process and the contribution of the individual to the decision-making process in design teams.

Keywords: design process; teamwork; decision making; protocol analysis

1. Introduction

As a result of increased market demands and rapid technological developments, today's design problems are becoming much more complicated and require the contribution of several specialists rather than that of one single designer. In industrial practice, the majority of designers work as a member of one or often more than one team. Following this change in work practice, the emphasis in design research has shifted from the question 'How does a designer design?' in the 1960s to the research question: 'How do designers design as a team?' (Tang and Leifer 1989; Cross, Christiaans, and Dorst 1996; Badke-Schaub and Frankenberger 1998).

During the product development process design teams have to make many decisions, which should be as flawless, accurate and satisfying as possible. Decisions have been defined by Badke-Schaub and Frankenberger (1999) as critical situations in the product

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development process, because they have a decisive impact on the quality of the design solution and consequently on the success of the product on the market. Mistakes, drawbacks or failures resulting from design decisions have far-reaching consequences.

In a team, multi- or mono-disciplinary, each team member has his or her way of communicating, negotiating, interacting and deciding depending on his or her personal knowledge, responsibilities and experience in order to reach the subgoals on the way to the common agreed goal. During the design process the designer develops a mental model of the problem; this representation is not stable as it is adjusted by external information as well as by the designer's cognitive processes, such as reasoning and remembering, and not necessarily in an explicit way. Many different activities occur in teams before a decision is made. Therefore, more in-depth analyses of behaviour in design teams are necessary to be able to describe and eventually support the decision making in design teams more accurately. This study aims to contribute to this knowledge gap with an investigation of a collaborative decision-making process exploring two research questions:

(1) Which kind of decisions can be identified during the design teamwork?
(2) How do rejected and used decisions impact the design solution space, the further decision making and the result?

2. Teamwork in design research

The number of studies aimed at understanding how designers design in teams has increased over the past three decades; however, research on teamwork in design has not yet provided a satisfactory answer to allow a comprehensive understanding of design decision making in teamwork.

Tang and Leifer's (1988) research can be counted as one of the earliest studies of design teams in industry; they analysed meetings of design teams in order to understand collaborative workspace activity. In 1994, the seminal Delft Protocols Workshop (Cross, Christiaans, and Dorst 1996) brought together a number of researchers from all over the world with an interest in design research to apply their own analysis approaches to a common dataset. Valkenburg (2000, 42) classified the studies following the workshop according to three dimensions: 'Information processing aspects', 'comparison of group protocols with the individual protocols' and 'team design aspects that do not appear in individual designing'. The last category includes research issues of teamwork in design which have since remained as continuously important aspects, such as the structure of communication (Carrizosa and Sheppard 2000; Chiu 2002; Stemple and Badke-Schaub 2002), collaboration (Kalay 2001) and interaction (Brereton et al. 1996).

A study using continuous non-participatory observation and a thorough analysis of design teams over several weeks in industry studying the influencing factors of teamwork in design was conducted by Badke-Schaub and Frankenberger (1998); in a combined qualitative and quantitative research approach mechanisms of distinct interdependencies in different types of critical situation were derived. This research procedure was subsequently applied by Wallmeier, Badke-Schaub, and Birkhofer (1999) to develop training for designers which enabled them to assess and analyse their own critical situations.

3. Decision making in design teams

As stated before, designing is only partly a concern of the individual designer because most of the time designing takes place within a group of designers, often encompassing several disciplines. In these cases a design team is a group of experts brought together to work towards a common goal, which enhances the complexity of the design process as not only are the objectives often ill defined but the different viewpoints, background and experience of the team members bring an additional difficulty in arriving at a shared understanding and a common goal.

Most of the time designers are involved in different teams (Kleinsmann 2006) belonging to different projects. Whereas in the conceptual design phase a group of designers usually constitutes a mono-disciplinary team responsible for developing design ideas and concepts, the planning phase at the front end of product development is mostly executed by more heterogeneous teams.

Nevertheless, decision-making issues have mostly been part of the empirical research of individual designers rather than design teams (but see also Badke-Schaub and Frankenberger 1999). Ullman (2002) stresses the fact that before the mid-1980s, product development research focused on the final product in a kind of 'black-box approach', meaning that the research focused completely on the correlation between input variables and result without further recognition of the process. In the 1990s, the emphasis moved towards how people interact, either face to face or across distances, to make decisions, and as a result standards such as ISO 9000 (Cagnazzo, Taticchi, and Fuiano 2001) were developed.

While we cannot claim that designing as an individual activity has yet been fully understood, still there are even more factors affecting team decision-making processes: ' [team decision making] is often complex and difficult to structure' (Ullman 2002). There is no doubt that the diversity of team members' professional background, experience, age and skills affects decision making in teams. Decision making in a team is also a complex individual cognitive process of developing shared understanding by perceiving, modifying and adapting others' input.

Group decision-making models involve processes of defining, developing, choosing and execution steps (Pugh 1996); these steps do not differ from individual problem solving, but each step requires the consensus of the team. Badke-Schaub and Gehrlicher (2003) state that teams as well as individuals rarely follow the proposed steps of step-sequence theories (Figure 1) to come to a decision, but develop their own pattern of decision making.

Classical decision theory (CDT) (Simon 1956) is based on the assumption of the rational problem solver who chooses a decision by comparing and evaluating its utility or value with an alternative. In CDT, decision making is typically conceptualised as selection of a course of actions, having evaluated them according to a certain set of criteria and

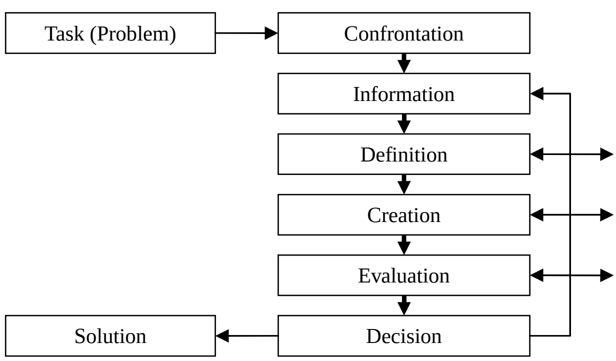

Figure 1. General process for finding solutions (Pahl and Beitz 1996, 63).

consequences. In recent decades, design process models have been dominated by prescriptive approaches that proposed certain steps or phases to structure the design process and reduce the anomalies usually associated with ill-defined complex problems. Furthermore, CDT assumes that the decision maker possesses all the information needed and that he or she knows the outcomes of each probable choice that he or she could make. Phase models that indicate the sequences of decisions that designers should follow usually indicate general models of decision making (Roozenburg 1990, 185); thus, the term 'decisions' is being interpreted as a very broad category. However, there are also models which define decisions as only one step in the problem-solving process (Badke-Schaub 2003). According to Simon, decision making cannot be separated from the problem-solving activity as a decision is a cognitive step in the context of the design process. Herbert Simon (1977) developed the following well-known three-phase model of problem solving (Figure 2):

- First phase: Intelligence: problem analysis, development of goals.
- Second phase: Design: finding, developing, analysing alternatives.
- Third phase: Choice: selecting a solution.

Simon (1992, 32) states that 'it is work of choosing issues that require attention, setting goals, finding or designing suitable courses of action, and evaluating and choosing among alternative actions. The first three of these activities are usually called problem solving; the last, evaluating and choosing, is usually called decision making' (Figure 2).

Bayazıt (2004) points out that every design problem has a certain number of components including goals, decision criteria, constraints, alternatives and results. These components reflect a holistic view of factors affecting the design problem-solving process. In an attempt to identify a generic set of design activities from the published literature, Eris et al. (1999) defined a set of subattributes of decision making, which are examining, analysing, synthesising, reasoning, inferring and deducing. These decision-making activities constitute cognitive elements of design thinking. Overall, these general descriptions and assumptions do not provide information on how designers in the team context make design decisions and how these decisions influence the further design process. We claim that in order to understand how decisions evolve or are planned and executed they should be traced throughout the process, from their first moment to the final moment of decision.

Reaching a final decision usually requires many preceding decisions, and most decisions are linked with other decisions in different ways (Goldschmidt 1990, 1992). Decisions are sequential, in such a way that one decision yields another, which may pertain to a different topic or lead to another decision that belongs to another subtopic. Decisions during the design process occur at different levels, in a continuous flow and within the context of different topics. 'After each information output, it might become necessary to improve or increase the value of the result of the last working step. That is to repeat the working step at a higher information level or to execute other working steps, until the necessary improvements have been achieved' (Pahl and Beitz 1995, 62). Most, if

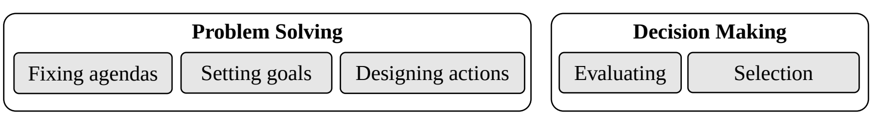

Figure 2. Problem solving and decision making as stages of choosing (Simon 1992).

not all, design researchers agree upon the repetitive nature of the design process at different levels. ‘Such iteration loops are almost always required and occur continuously within and between steps’ (Pahl and Beitz 1995, 62).

The design process obviously consists of countless minor and major decisions and other repetitive problem-solving activities. Not all types of decision are of equal value in regard to solving the design problem. Thus, design decisions differ in their importance as to how they influence the final result. Akın and Lin (1995) ‘consider design decisions to be any and all intentional declarations of information as valid for the design problem at hand’ and categorise design decisions as routine and non-routine decisions that turn out to be critical for the progress of the entire design. Badke-Schaub and Frankenberger (1999) distinguish between routine situations and critical situations: ‘Critical situations are defined as “turning-points” with an important influence on the further direction of the design process and the product’. They claim that non-routine decisions are always critical situations. In this respect, design decisions have a significant influence on the design process and on the definition of the solution space.

4. Method

4.1. Research design

In order to observe and record design decisions, an empirical study comprising a group design task in a laboratory environment was set up. The group interaction was recorded, transcribed and then coded according to a predefined categorisation system. The controlled laboratory setting was chosen because it enables the researcher to reduce the influence of context variables usually occurring in a natural field setting, where they cannot be controlled. Observing a group provides the advantage that the cognitive processes can be obtained easily through verbal articulations.

Participants with comparable backgrounds were selected from industrial design students. Before the experiment started the participants were invited to a warm-up session. The intention was two-fold: to test the coding scheme described in the following, and to provide team members with an opportunity to familiarise themselves with each other and with the laboratory setting.

4.2. Research procedure

After being briefed about the experimental set-up, each team member received their assignment individually. The whole interaction of the design team was recorded with two video cameras. In the assignment, the task was described as a design competition. The team had to design a product for the Third Leitz Innovation & Design Award Competition. The purpose of the competition is stated as follows:

> Leitz invites students and young designers to develop and submit ideas for new office products for today and tomorrow’s working environments. New products can be designed, or existing products and designs as well as their function and use can be optimised – especially integrating new technology and materials. If you choose to present system or mobile organisational concepts as models, the idea must be clearly recognisable. This year, Leitz has expanded the thematic spectrum to include hardware and software products as well.

The experiment was limited to two hours. Owing to time constraints, the assignment was reformulated as desktop equipment instead of office equipment, although all the given specification and criteria of the competition assignment were kept. The final task was to design ‘a product for organising documents to be used on desks in offices’.

4.3. Method of analysis

In this study, protocol analysis was used as a research approach to analyse the structure and process of design decisions. Simon (1992) states that choice behaviour researchers should use an experimental setting that is as realistic as possible and think-aloud protocols to track decision behaviour step by step, instead of relying only on information about the outcome or querying respondents retrospectively about their choice processes. Among other methods of data analysis, protocol analysis is accepted as the most valid approach to gain insight into human cognitive processes and has been widely used for investigating decision processes of individuals as well as teams (e.g. Cross, Christiaans, and Dorst 1996; Dorst 1997; Valkenburg 2000; Stemple and Badke-Schaub 2002).

During the experiment the participants produced distinctive forms of data: verbal–conceptual and visual–graphic (Akın and Lin 1995). While the analysis of verbal data may be sufficient for analysing processes in other domains, for the analysis of design processes it is indispensible also to consider other forms of externalisation such as drawing and sketching, and non-verbal periods of drawing and partly writing and thinking. During these intervals, drawings record the expressions of the team and its cognitive processes.

In the context of teamwork every verbal utterance can be defined as a separate communication message. Thus, each individual utterance is part of the decision-making process towards the desired goal of the design task. In this study each verbal utterance of each team member which transferred a meaningful segment (one or more consecutive sentences, a word or even an exclamation) was treated as a unit of expression. Designers in a team talk about different issues, develop more than one explanation and relate to different contexts, often even in one utterance. Therefore, one utterance may consist of one, two or more meaningful segments. Every meaningful piece of expression indicates a cognitive action. After the video has been transcribed, there is a protocol but still no protocol analysis. The further analysis of protocol data is a stepwise abstraction from the concrete singular protocolled behaviour to a meaningful reduction of complexity; here, a variety of qualitative research methods exists (see an overview in Denzin and Lincoln 2000). The general procedure is based on the definition of criteria, according to which different ways of procedure, interlinked patterns, etc., can be described as precedents or consequences of activities. A step in between is to define criteria according to which the data can be assessed and different patterns can be distinguished from each other. The definition of criteria must be based on knowledge which can be derived either from other empirical studies (inductive approach) or on theoretical considerations (deductive approach). Even the closest-to-the-data analysis, a description of the direct observation, requires a theoretical concept underlying the red draught of the 'story'; on a higher level of abstraction a segmentation of the transcription into meaningful pieces, categories connected to the research question, is required.

4.4. Categorisation system

As mentioned before, the important part of a protocol study is not so much the pure protocol but the analysis of the protocol which is aimed at the reduction of complexity. One of the most important and critical steps is the development of a categorisation. The categories in a coding system should be theoretically consistent, exhaustive and mutually exclusive, so that each segment can be assigned to only one category. In this case, the coding scheme was developed using a mixed bottom–up/top–down approach: categories were first formulated based on previous empirical studies, on theoretical models in cognitive psychology and on design methodology, and then tested and further refined based on the data of the experiment.

We developed three subsystems of categorisation: the action coding system, the decision components coding system and the design context coding system. The interrater reliability of the coding system was tested on a 15-minute section of the transcript, which was coded by another designer who trained as an urban planner. The level of agreement among the ratings of the two raters was 86%.

4.4.1. Action coding system

The action coding system comprised activities including talking, writing, drawing, listening and thinking. This coding system was used to analyse the activities of the designers in the team throughout the design process. Although this coding system was not primarily aimed at decision components, it was essential for considering the members' activities during the design process to obtain a complete picture of what was going on. Considering merely verbal record situations such as the following could be misinterpreted: two of three group members are engaged in a feverish discussion and the third does not talk at all, which may seem like she is sitting back and not engaging in the teamwork; however, she could have been converting their ideas to results by drawing. As this example shows, drawing can play a crucial part in non-verbal decision making in design.

4.4.2. Design context

The design context coding system was developed to trace the decisions and their components by considering the respective context. The context in which a decision is made determines the importance of that decision in a design solution. Priorities of design may change in terms of company goals, product specifications, constraints, project management aspects, etc. The design context coding system consisted of four different topics: project management, stakeholders, product environment and product; and each topic encompassed several subtopics. Although professional design problems are most often part of far more complicated contexts, here we chose a low level of granularity, because categories were limited to reflect the generic frame of a design task.

4.4.3. Decision components

We defined the design process as problem-solving activity that consists of different steps of information processing intended to arrive at a satisfactory solution by developing and choosing among alternatives which reduce the discrepancy between the existing state and the desired state (Dörner 1976). The decision components coding system was partly based on information processing theory (Newell and Simon 1972) and thus decision making was seen as a cognitive component of the design process.

Many decision process models include the evaluation stage as a step preceding a choice or decision. This is different in teamwork situations, where evaluation is a continuous activity within the information process since it happens in every stage as a continuous interaction among team members. The decision components were further categorised in terms of interaction between members of the team (Table 1). These categories reflect the mutuality of interaction. Mutuality of interaction in small group communication (Bales 1950) is used to define task-oriented acts of designers in teams when solving design problems, such as giving and asking for information, opinions and suggestions related to the given problem. Indicating the structural components of decisions, the 15 categories listed in Table 2 were chosen for assessment.

Table 1. Categorisation system for the analysis of team decision-making components.

Problem-solving phases (Simon 1977)	Problem-solving phases	Decision components	Decision components: details
Intelligence	Defining/analysing	Goal	Goal Problem definition
Design	Generating	Knowledge	Knowledge asking Knowledge sharing
		Alternative	Alternative elicitation Alternative suggestion Alternative evaluation
	Synthesising	Criterion	Criterion elicitation Criterion suggestion Criterion evaluation
		Idea development	Design development Integration
		Solution	Solution suggestion Solution evaluation
Choose	Deciding	Decision	Selection of a decision

5. Results

5.1. Some general results

The results presented in this section are based on the analysis of the complete design process, which was a 100-minute protocol generated by the team. The team discussed more than 71 decisions until they arrived at the final result for the given assignment to design a document organiser that will be used as desktop equipment. The team designed a deskware paper-storage product (Figure 3) that enables users to punch papers and store them in different layers of the product before putting them in folders at the end of the working day. The product has 10 layers for placing papers. Folding systems between layers provide the opportunity to keep levels closed in unused situations. Depending on the amount of papers to be stored, desired layers can be folded out. User aspects and handling of the product were other important issues that the team focused on. The product was innovative in terms of its folding system and the punching function. The team spent most of their time on the technical details of the folding system.

Within the 100-minute teamwork protocol, a total of 753 segments was identified and categorised. The mean duration of a segment was 7.7 seconds. The shortest segment lasted for only one second while the longest segment was 40 seconds. In the following, the results of the three coding systems will be explained.

5.1.1. Activities

In a design process decisions can be analysed with different research questions and at various levels (Stauffer and Ullman 1991). In this study decisions were identified as part of discussion topics verbalised by designers. In terms of verbal and non-verbal activities such as writing and drawing, the team spent 85% of their time talking and for the remaining 14.6% (859 seconds) no verbal data were produced during the teamwork session. In terms of variability between team members' activities, most of the time two of the three members interacted with each other in a dyadic manner: member H produced the highest number of verbal expressions (391), followed by member A. Considering the duration and

Table 2. Decision components coding system.

Goal	Goal	G	Expressions that include target notices
Problem	Problem definition	Pd	Defining problem issues in the context of alternatives, suggestion or goal
Knowledge	Knowledge asking	Ka	Knowledge requested of one of the members from others
	Knowledge sharing	Ks	Declaration of personal experiences, personal knowledge and information related to design task
Alternative	Alternative elicitation	AL	Requesting alternatives from other members
	Alternative suggestion	As	Proposing an alternative. Main difference from 'solution suggestion' is that the member expects an assessment, which may be a judgement or an argument
	Alternative evaluation	Ae	Evaluation of alternative suggestions, usually debate expressions about topic. Judging and reasoning alternatives that are suggested, usually including a positive or negative judgement
Criterion	Criterion elicitation	CRl	Criterion requested by one of the members. Mostly it is in a question phrase form
	Criterion suggestion	CRs	Criteria suggested for drawing up border of the design problem space. Constraints suggested for drawing up border of the design problem space
	Criterion evaluation	CRe	Evaluation and reasoning of criterion suggestions, usually debate expressions about criterion
Idea development	Design development	Dd	Any comment relating to converting knowledge, alternative, criterion or solution to a design feature
	Integration	I	Composing two or more components to form a solution
Solution	Solution suggestion	Ss	Any suggestion that leads to a discussion or reflection. It includes the decision of the proponent
	Solution evaluation	Se	Evaluation of criterion suggestions, usually debate expressions about topic. Reasoning solution judges the validation and accuracy of the solution includes exact positive or negative judgement
Decision	Decision	D	Selection of a decision

frequencies of utterances in the whole process, it can be stated that the team was highly engaged in fulfilling the given task.

5.1.2. Decision context

The contextual coding system reflects the common content frame of the design task on which the team worked. Both the frequency of decisions in specific contexts and the amount of time spent on the specific context indicate the importance of the particular decision within the team design process, but these are not necessarily related to the 'real' importance for the design outcome. An overview of the findings on the decision context can be seen in Figure 4.

Figure 3. Final design.

The design team allocated the largest proportion of time (22%) to solving technical details and problems related to their core concept of punching paper and to discussing details of the mechanism. This means that the team spent a considerable amount of time on technical issues. Summarising the solution development, it can be stated that the team concentrated on one solution idea and as a consequence neglected most of the other topics of the design problem context, and by emphasising this idea, the team lost the overall view.

The form/dimensions topic ranked second in duration (15.4%). Only 9.5% of the time was spent on dealing with functions and 9.8% on the context of use. The material of the product was addressed only 0.4% of the time. Other important issues, such as manufacturing method, cost and safety, were not discussed at all. In the following the detailed results of the three categorisation systems are explained.

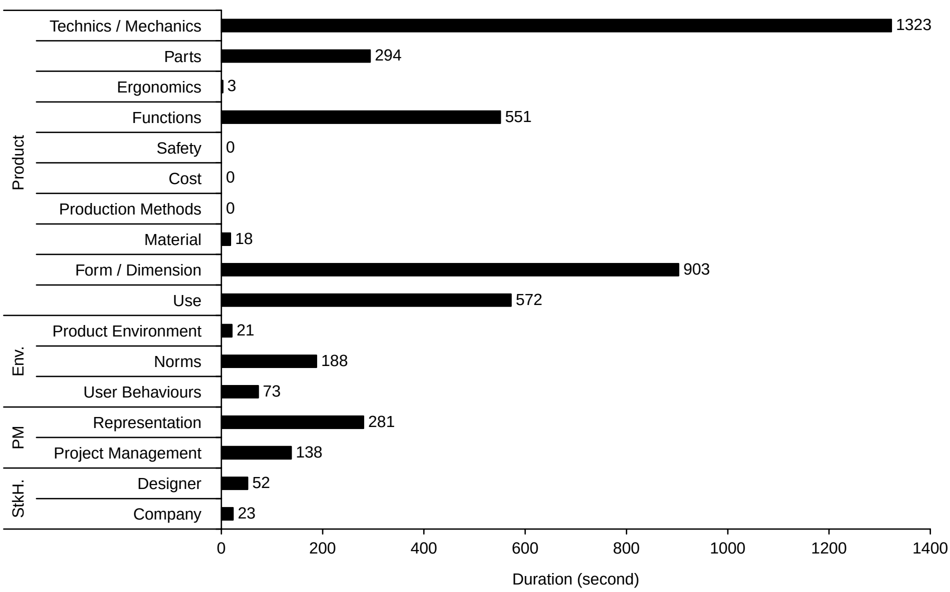

Figure 4. Duration of time the team spent on different design contexts. Env. = environment; PM = project management; StkH. = stakeholders.

5.1.3. Decision components

More details about the decision-making process in design can be assessed by the analysis of the communication of decision components. Decision components display a considerable role of social interaction among team members in the design process.

The coding results (Figure 5) reveal that the breadth of the decisions covered 21 different topics that can be classified within six contexts.

The topics are named according to the design ideas that the team members dealt with. In total, 71 decisions were made within 18 of the 21 topics, which shows that the team covered a broad range of different topics.

Each decision covered 207 seconds on average. The longest duration for a decision topic was for 'punching', which took 1036 seconds, equivalent to 17.6% of the total process with 18 decisions. The 'punching' topic was the dominant issue on which the entire design concept was based. The first punching discussion started eight seconds from the start and continued until 5 minutes before the end. The topic 'number of layers' consumed the least amount of time; the team decided the number of layers in 25 seconds.

The 'grip' topic was the most important issue, although it covered only 2.4% of the time of the process; the team made five decisions with a mean of one decision every 24.4 seconds. In contrast, the 'scanner' topic continued for 333 seconds, which equals 5.6% of the process, and led to one single decision occurring at the very end. The second most frequent number of decisions and second biggest amount of time were reserved for the 'accordion' topic. Ten decisions were made while the team was discussing a special mechanism related to the 'accordion' topic, which was to enable the product to fold in and out (Table 3).

Every decision in teamwork that emerges on a topic is composed of a set of decision components. Although the frequencies and duration of decision components were similar (Figure 6), there was one exception: 'concept development' extended over the longest time span, whereas it was second in terms of frequency, after the 'alternative evaluation'

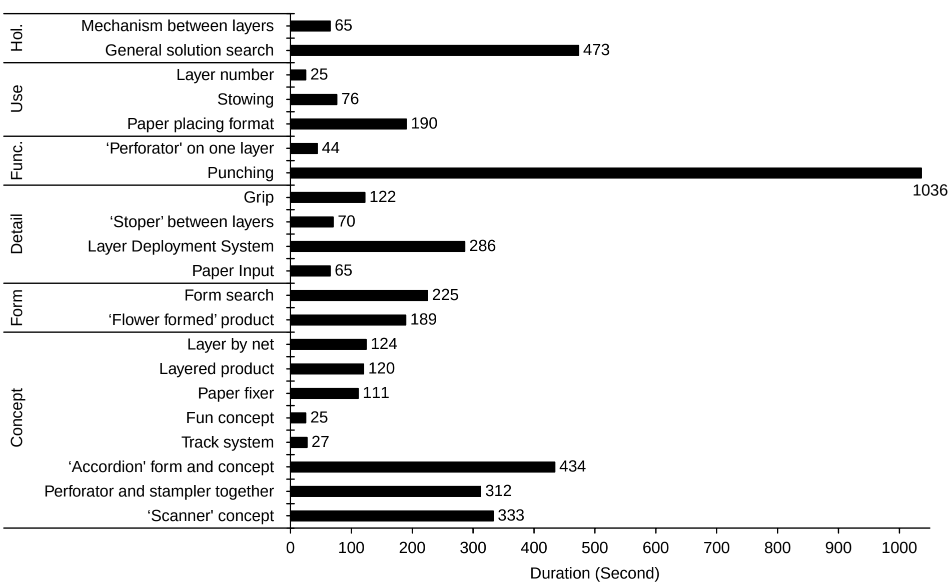

Figure 5. Decision topics and their duration. Func. = function; Hol. = holistic approaches.

Table 3. Number of decisions and mean durations.

	Decision topic	No. of decisions	Mean duration of a decision (seconds)
Concept	Scanner concept	1	333.0
	Perforator and stapler together	4	78.0
	Accordion form and concept	10	43.4
	Paper fixer	2	55.5
	Fun concept	1	25.0
	Track system	1	27.0
	Layer by net	–	–
	Layered product	3	40.0
Form	Flower form	2	94.5
	Form search	7	32.1
Detail	Paper input	–	–
	Layer deployment system	5	47.6
	'Stopper' between layers	2	35.0
	Grip	5	24.4
Function	Punching function	18	57.4
	Perforator on one layer	1	44.0
Use	Format of paper placing	2	95.0
	Stowing	1	76.0
	Number of layers	1	25.0
Holistic approaches	General solution search	5	94.6
	Mechanism between layers	–	–

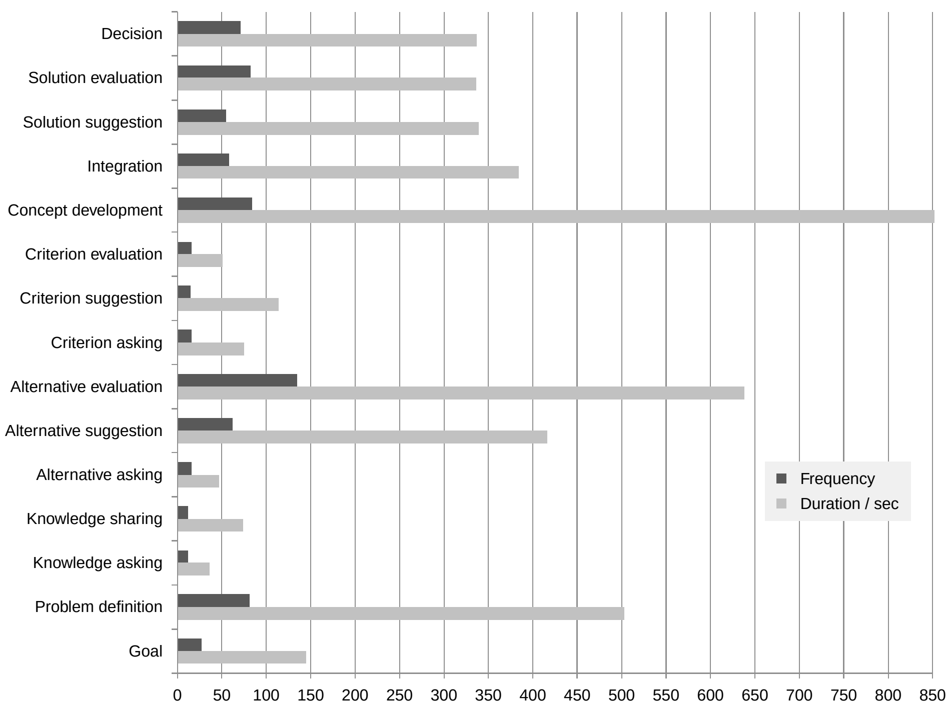

Figure 6. Duration and frequency of decision components.

component. 'Alternative evaluation' appeared as the most frequent component, occurring overall 135 times and for a total duration of 640 seconds.

'Concept development' occurred almost as often as 'solution evaluation', which covered 82 occurrences, but 'concept development' needed 2.5 times more time than 'solution evaluation'. Although these two components showed almost the same frequency, their different duration indicates that solution evaluations were mainly uttered as short judgements whereas concept development had to be explained by the owner to the other team members in more detail. Concept development is used to advance, enhance and elaborate on ideas.

A similar fact can be stated for the component 'problem definition', with similar frequencies to 'concept development' and also with a higher amount of time needed. There is another link between the two components 'problem definition' and 'concept development'. There are two group members in the team and each of them took responsibility for one of the two components, 'problem definition' and 'concept development'. While one member defined the problem the other member developed the idea subsequent to the previous problem definition. A striking point was that the majority of the decisions were made by the same person, who also contributed most to the category 'concept development'; and this was also the same person with the fewest utterances on criteria and constraints. This finding illustrates that individuals fulfil very different roles within a team and it is very important for the team to realise which components are mainly in the hands of which member of the team.

5.2. Used and rejected decisions

Analysing the design process by decision components is one way of describing the process in terms of how different topics were processed and discussed and the decisions made about these topics. As part of the design process many decisions were made in various manners, forms and numbers, but there were also situations when no decisions were made and decisions were made that did not turn into a feature in the final design.

Throughout the process, the team made 71 decisions in total, for which 21 decision topics were identified covering six contexts (Figure 7). In the light of the results, we furthermore evaluated the decisions in two ways: used and rejected decisions, depending on whether or not they turned into an element of the product. The major part of the

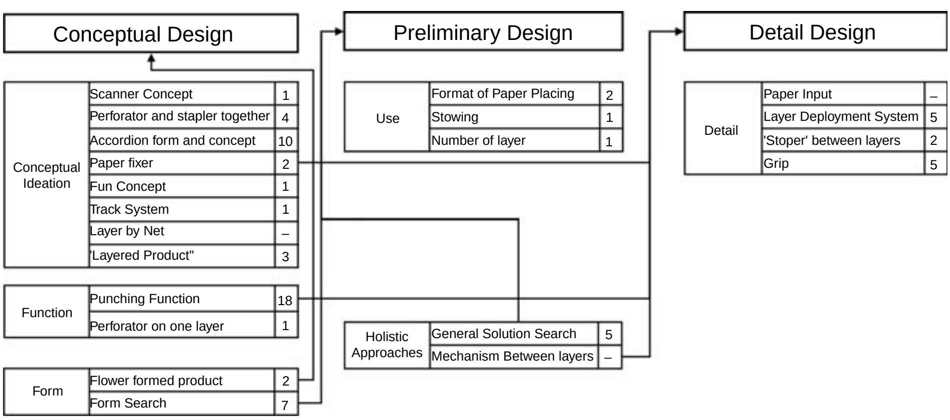

Figure 7. Decision topics and their contexts.

Table 4. Decisions and topics according to the design solution phases.

	Conceptual design	Preliminary design	Detail design	Total
Sum of topics	9	7	5	21
Topics with no decision	1	1	1	3
Sum of decisions	23	18	30	71
Rejected decisions	8	0	0	8

decisions of the investigated team belonged to the category of ‘used’ decisions: 63 of the 71 decisions materialised as a feature of the final design idea, whereas the remaining eight were decisions to reject an idea or a solution in the four different design topics. The purpose of exploring ‘rejected’ decisions is to detect the influence of this kind of decision on the following process and the design result.

Each design decision, whether used or rejected, is connected to previous and subsequent ones. Decisions, besides being linked to each other, occur at different information levels. In the conceptual phase, nine out of 21 decision topics were discussed, which gave rise to 23 decisions. In the preliminary design and detail design phases, 48 decisions were related to 12 topics (Table 4). In every design phase one topic did not result in a decision; that is, three topics, one in each of the three phases, did not involve a concrete decision used in the end product. Although the team had discussions on ‘level made from net’, ‘paper placing’ and ‘mechanism between layers’, they did not arrive at a decision about these issues. Altogether, 24 decision components were discussed without arriving at a decision.

The number of ‘used’ decisions increased gradually from the concept level to the detail design level, while ‘rejected’ decisions declined during the progression of the design solution (Figure 8). After developing the conceptual framework for the design solution, the design team discussed the issues and arrived at decisions without any rejections. This can be interpreted as reflecting the determining role of rejected decisions on the construction of shared understanding among the team members (Badke-Schaub et al. 2007) and on the design solution space.

Rejected decisions all occurred in the conceptual phase. The design team selected eight decisions related to four conceptual design topics, spending 856 seconds, which accounted for 17% of the total duration of the design process. In total, 117 decision components were part of the discussions when decisions were rejected. As a noteworthy point, decision components belonging to rejected decisions were only identified at the very beginning and at the very end of the design process.

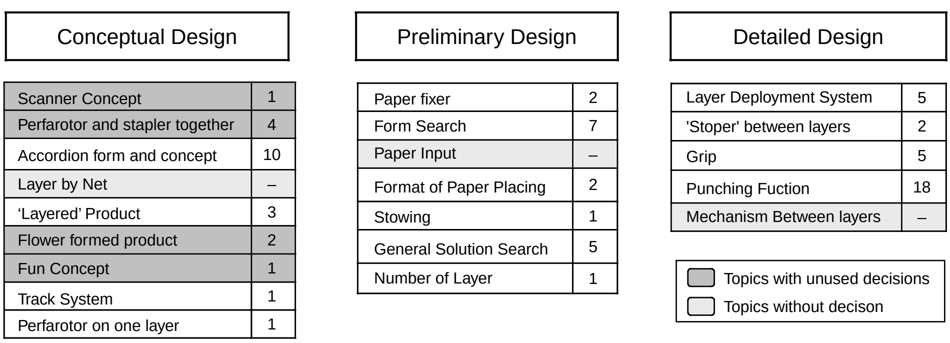

Figure 8. Decision topics according to design process phases.

The topic 'scanner', which was suggested by one of the team members while defining the design problem space, was the first decision topic that covered 333 seconds of discussion time and reached a unanimous decision without being interrupted by a contribution of another idea. The 'scanner' was also the first rejected decision not integrated as a feature of the final design. Within this topic, the team drew up their design solution space. It was not just an evaluation of the 'scanning' functionality. Furthermore, the team enlarged the discussion to add electronic attributions to the product. At the end, while rejecting the 'scanner' idea they also rejected designing an electronic-featured product by taking into account project management aspects and the objectives of the design task (Table 5).

The topic 'perforator and stapler together' covered four rejected decisions and 312 seconds. A total of 46 components about the idea of using a perforator and stapler together encompassed 6.1% of the total components. While the design work was carried out to resume this idea, the team was trying to find technical solutions for the idea. One of the team members developed a technical solution only for punching and grouping the documents, and they never returned to the dual function product idea (Table 6). From this episode, one condition for the rejection of ideas can be derived: in situations when the group could not come up with a feasible solution for designated ideas but found an acceptable solution, even if this alternative solution did not fit the primary objective, the team arrived at a consensus without any words.

The third rejected decision topic, the 'flower formed product', covered 3.3% of the total design process. Although the team initially decided to design the product like a 'flower', the two rejected decisions about technical problems of adapting the form to the design made them change their mind. The team developed a shared agreement not to deal with complex forms (Table 7).

Table 5. Rejection of a solution with a 'scanner' function.

00:02:12 00:02:17	Designer A: [Reviewing brief] You are saying 'pleasant' and 'easier'. I am saying 'integrating new technology and material'.
00:02:18 00:02:23	Designer H: But it is not possible for us to solve this technology. It wouldn't come to a conclusion.
⋮	
00:06:57 00:07:08	Designer H: Why couldn't we develop a system where we can stow documents and get the papers when we needed them at the right moment, on the right day? Why, necessarily? I have not solved it yet. When it says 'desktop office furniture', it could be found on everyone's desk. Conversely scanners wouldn't be on every table.
00:07:09 00:07:23	Designer H: So, something like the 'Staplers' is always in my mind. I'm talking about something that is subtle and space-saving when not in use, but when you use it, a smart thing that allows stacking. That is all.

Table 6. Rejection of 'perforator and stapler together'.

00:21:45 00:21:55	Designer A: For instance, law stuff Consider a row of 50 folder with 3 pages each, all of them three pages at least... 150 pages in total.
00:21:56 00:22:09	Designer H: Only then, we'll do something. You might have the opportunity to punch all of them together. For the ones you want to staple, at the bottom, at a single stapling place, you might staple them by always doing the same motion.

Table 7. Rejection of the 'flower formed product'.

01:03:21 01:03:22	Designer A: The connecting detail would be as follows. This goes through like this, and this; then folds itself here; once opened, and once closed.
01:03:05 01:03:20	Designer H: We should not waste time on such a form. Those inclined things would not insert into each other.
01:03:22 01:03:24	Designer O: Yes, that's true

The 'fun concept' decision topic entailed one decision, which involved rejecting a design approach. In 25 seconds the team produced nine decision components, ending in a concrete decision. The idea of a more entertaining product did not find acceptance among the team members (Table 8).

These results indicate that rejected decisions set the boundaries of the solution space and thus reduce the complexity of design problems. Especially in the conceptual phase, rejected decisions denote the precluded approaches in solving the design problem.

6. Conclusions and discussion

The main purpose of this study was a decomposition of the decision processes of design teams, with a specific emphasis on rejected decisions. The design process of teams has been analysed by assessing cognitive components of decision making and their influences on the final output. Decision components have been described in terms of context, activities and components within the collaborative process. We considered decision making as a process

Table 8. Rejection of adding 'fun' to product.

00:23:51 00:23:55	Designer O: Oh, where will you add fun? For example, the 'concept of music' could be added. We started from the idea of an 'accordion'.
0:23:55 00:24:01	Designer H: But an accordion is beautiful. Viuww... [She makes a movement with her hands to imitate the accordion. Laughter].
00:24:01 00:24:04	Designer A: I'll go crazy, I cannot stand it. [Laughter]

rather than one step of problem solving. By acting in this way we could track every decision from the first suggestion to the final moment of selection or rejection; thus, it was possible to analyse the influences of decisions on the final product as being design features and interrelations of decisions. Thereby, it became obvious that analysing decision making at a high resolution provides insights into a variety of different processes, such as recursive relations among decision components, for example iterations occurring between suggestion- and evaluation-based components and between problem definition and concept development. Concurrently, decision moments generally appeared after evaluation- and suggestion-based components, and after problem definition components. Decisions are also followed by decisions. Especially in the detailing phase of the design process, many so-called micro-decisions were made; these micro-decisions often comprised decision components following each other but not belonging to the same topic.

Team members rejected decisions mostly because of not being able to solve the problems of that particular design idea. In the ‘flower formed product’ topic, even though it was within the conceptual context, the decision was declined because of technical obstacles. At the same time, the ‘scanner’ topic initiated discussions on a more abstract level about whether to make an electronic-based product. Rejected decisions led to a narrowing of the solution space by defining boundaries in the wide area of ideas.

Many topics were discussed in the design teamwork. The results showed that, particularly in the conceptual phase of design process, some discussion topics turned out to be rejected design decisions. Rejected decisions come with defining spaces that are excluded from the solution space. To summarise, we can state that among all other decisions, the rejection of decisions can be seen as a necessary part of decision making, with important effects: narrowing the solution space, decreasing the complexity of the design problem, and prioritisation and structuring of the design problem.

Besides these three problem-related aspects, rejected decisions also play an important role in the social dynamics of the team, utilised as conflict management within the team. For instance, the ‘fun concept’ idea did not gain acceptance among the members of the team, because this topic was likely to lead to a dispute. It has been observed that not every decision influences the design outcome, whereas rejected decisions may significantly affect the final design. Accepted design decisions depict the process and the behaviour of the team in reaching the final solution; however, when a decision is rejected this means more than a change in direction. This study reveals that rejected decisions are the determining factor in the continuous adaption of the design solution space. Rejected decisions are not just ordinary topics that are incompatible with the design task and goals. Thus, the rejected decision can provide answers to questions as: ‘How do designers configure the solution space with rejected decisions?’ and ‘What are the influences of issues discussed before decisions become rejected decisions?’

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