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WHY DO ENGINEERS ERR WHEN THEY DESIGN?

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1. Introduction

Design is a complex and creative human activity. From a psychological point of view, it essentially consists of thinking. It is evident that human mind designs as a whole. Our motives, emotions, and personalities are necessarily involved when we design, but our thought processes form the core of that design. Thinking takes place when people have goals but do not know how to reach them (Newell and Simon 1974). Having no means or solutions to reach their goals people have to think first in order to find them. Though there are many routines in design, design brings about something new practically always. What is brought in may be small but, at the same time, very complex.

Design errors are one of the main risks in design activity. Super tankers with very complex designs have had their structure destroyed by very small faults, such as gas pockets in the oil tank (Perrow 1999). It is always possible to err in design and for this reason, it is vital to systematically investigate the factors which explain errors in engineering design thinking. This may help to eliminate design risks.

Error in design thinking can be defined based on the success of the outcome. Design thinking has failed or designers have made thought errors if the realized outcome is poorer than what was originally expected (Saariluoma 2002). This means that the realized outcome is the crucial criterion for the success of thinking. However, if the deviation is not negative as in the case of Nokia's sales forecasts in 1992, we do not speak about errors but inaccurate thinking. We differ from some other authors in that here we classify only negative deviations as errors. The explanation is that it is better to be cautious than to cause accidents.

It is hard to remedy thought errors, because they belong to history. They have already taken place and therefore cannot be eliminated. However, these thought errors are due to some reasons and these reasons will persist after the errors have taken place. They are risk-casing factors or thought risks and they can mostly be eliminated by teaching, information technology and organizational means (Saariluoma 2002).

These definitions provide us with important conceptual tools, because they enable us to investigate design errors. They make it possible for us to ask how people recognize design errors in their surroundings that may affect the circumstances of their work. Thus, the people involved can easily recognize what is meant by thought errors or faulty thinking in design.

In this paper, we are interested in the kinds of factors designers see as the reasons of design errors. We sent, to a group of designers, a questionnaire about possible causes of design errors. The topics of the questionnaire were adopted from design and economic thought literature. We hoped to be able to extract global explanatory factors to ground our future analysis of thought errors in design on the results.

2. Method

Participants

A survey was conducted on the Internet server. The participants were professional designers. For this study we selected only those respondents who were professional engineers (n=294) in various fields ranging from mechanical and municipal to electrical engineering. The participants were selected from the registers of SKOL (The Finnish Association of consulting firms). Of the participants in this sample, 260 were men and 34 were women, 72 % worked in small and middlesized companies with less than 250 employees and 28 % worked for large companies, 8 % worked as CEO`s, 47 % as project leaders and 44 % as project workers.

Procedure and design

The survey was conducted with the help of a questionnaire, which was based on theoretical assumptions and empirical evidence reported in literature (see e.g. Saariluoma, 2002, Lawson, 1997; Busby, 2001; Robbins, 2005). The questionnaire consisted of 39 questions and one open-end question. The participants were asked: "to which extent would the following factors have a negative effect on reaching the design goals". These factors were graded on a 4-point Likert-type scale, ranging from *very little* (1) to *very much* (4) and *no opinion* (5).

3. Results

An explorative factor analysis (main component, varimax rotated) resulted in 7 organizational psychological components, which describe explain the design risks.

Variable	α
Faulty Thinking	.81
Organisation structure And leadership	.91
Motivation and Commitment	.78
Competence	.77
Distribution of Information	.74
Occupational Stress	.70
Intention related Factors	.76

Table 1. Organizational psychological factors

Table 1 lists the alpha coefficients for each summed scale. The compenent matrix can be found in Appendix. The components are: *faulty thinking, organizational structure and*

leadership, motivation and commitment, competence, distribution of information, occupational stress, and intention related factors. These components or psychological factors give us an overall idea about the problem areas and they can be elaborated by using qualitative knowledge. In this way, they provide us with knowledge for organizing future research work.

Faulty thinking

Thinking must be seen as the first explaining factor for thought errors. It refers to all thought procedures and ways of thinking which are unconstructive. This referred to such issues as too keen focussing on partial solutions, fixating incorrect images, using uncritically old solution models, or too early commitment to an unworkable solution. These are all signs of unproductive and risky ways of thinking.
In a way, one may think that this factor actually describes faulty thinking itself. It would thus be rather the variable, which should be explained or which operationalizes or fleshes out erring itself. On the other hand, we may also think that it expresses important cognitive properties of risky design thinking. Even in this case the other factors might partly explain the problematic thought strategies expressed by this factor.

Organizational structure and leadership

Our second explanatory factor for faulty design thinking in engineering is referred to as organizational structure and leadership. To get a clearer idea about the contents of this factor it is beneficial to look at some answers given to the open question:

> *Design and construction is divided into smaller and smaller pieces, so that projects do no longer know about each other*
>
> *The tasks, responsibilities and duties of consultants are unclear.*
>
> *There are too many leaders in a project, and they give different answers.*

We can see in these open answers that division of work and organization of management can give rise to poor management and poor organization. Leadership responsibilities may also be unclear and team spirit poor.

Distribution of information

Distribution of information is very closely related to poor organization and leadership. The open answers will shed light on this issue:

> *We lack basic information about the design goal.*
>
> *We may solicit information about the ongoing work but get only partially satisfactory answers. The initial error is multiplied with the advancing work process.*
>
> *Changes made in design by other partners are not made known.*
>
> *Design groups do not communicate internally.*
>
> *Risks may arise in communication between several partners, in coordinating tasks and checking outputs.*

To gain a competitive advantage in today's knowledge economy it is essential to manage knowledge sharing within and across the organization. This is one of the major challenges facing contemporary organizations.

Motivation and commitment

Our respondents felt that dynamic psychological factors such as motivation and commitment were important in explaining errors in engineering design.

> *Designers (young especially) often lack motivation and commitment*
>
> *It is characteristic to strategic design that the outcome is not clear in the beginning. Therefore, it is vital that the clients are committed to the project.*

Organizations that develop motivating and committed work environments avoid many design risks.

Competence issues

By competence we refer to the capacity to effective performance (Lucia, Lepsinger, 1999, Taatila 2004). Not surprisingly, in such a complex task as engineering design competence is seen as one of the main explanatory factors for errors.

> *Not everyone can become a true designer. One may have talent in mathematics while experiencing difficulties in practical judgement. Often this is due either to inexperience or to lack of risk-taking capacity.*
>
> *Head designers' insufficient knowledge about practical construction work and problems caused by non-standard details can form a risk. Do not design what you cannot realize by yourself –principle.*

Being an expert on something includes mastering the interpretation of task specific cues and procedures (Saariluoma, 1995). An inexperienced designer might get stuck in one sub-solution or unrealistic image (Hastings, 2004). People often overestimate their capacity to solve new problems (Brenner, Koehler, Lieberman & Tversky, 1996).

Occupational stress

To our respondents, the next risk causing factor was occupational stress. By this they apparently referred to various types of issues:

> *The most important single factor explaining design errors which have not been eliminated before the actual production is insufficient control of plans and calculations. This is caused by too tight time table leading to overburdening and stress.*
>
> *The unrealistic conception of builders and clients about the time needed in designing leads, from a holistic point of view, to poor solutions in construction design*

Several projects are done simultaneously so that it is always possible to get ready materials for the next meeting. Details of unfinished projects may be forgotten, and it takes time to restart an interrupted work.

Design as a creative thought process takes time. Rushing makes one unable to concentrate, decreases the performance level, and makes one use routines instead of creative thinking (Saariluoma, 2002).

Intention related factors

In an organization there are often situations, where specialists having distinct knowledge, have to combine their knowledge to realize its value (Okhuysen & Eisenhardt, 2002). A design process usually involves several participants (co-designers, client, constructor) who all have a slightly different image of the design goal.
Our respondents regarded confused intentions as a source of design risks in engineering:

If there are no common rules/understanding, everyone will design in her/his own style: the same error may propagate unless the next link in the chain gives feedback.

Different practices make it difficult for designers to co-operate and find good solutions.

In our field a client sometimes wants something not corresponding to the real needs, or asks something which is not really wanted. We also may design things not asked for by the client. Of course, the outcome is not precisely what the client would have sought.

If a designer doesn't know what the colleague does or how s/he perceives the actual problem, it is obvious that incorrect structuring of design goals and false assumptions about others' behaviour and motives takes place. According to Smith, Locke and Barry (1990), setting a specific organizational goal is positively related to high planning quality and organizational performance.

As a whole, design is directed towards the future because plans are realized after the design. This is why intentions have a specifically important role in designing. This means that it is important for management and organization to create a design culture in which the systems and intentions are under some rational control.

4. Conclusions

There are no watertight procedures for design. It is a creative activity and a designer always works, in a stronger or weaker sense, with something unforeseeable and new. This makes engineering design as a work process psychologically difficult to manage. It has its own difficulties and critical points. This is why it is essential to develop psychological management of design work and design cultures. We do not yet know much about how to eliminate design risks, but our results give some idea about the direction to which to continue.
Organisation structure and leadership, distribution of information, motivation and commitment, competence, occupational stress, as well as intention related factors give us some idea about where to search for improvement in design environment with psychological means. While these factors give a rational structure to the field of eliminating design risk, we nevertheless need to deepen our understanding in all of these issues.
Psychological literature informs us that these kinds of factors influence human thinking. Unclear task definitions as a consequence of suboptimal management may lead designers to ask their design questions in a wrong way and in wrong contexts, lack of information may

cause some piece of task-necessary information to be missed resulting in designer errors or in design process going astray. Design is difficult and requires true commitment and effort, expertise and other types of competencies from the part of the designer. Finally, such organizational issues as timetables or confused intentions can also make people to err.
Our suggestion is to connect scientific expertise for understanding human role in design engineering…

References

Brenner, L, A., Koehler, D., J. ; Liberman, V., Tversky, A. (1996). Overconfidence in Probability and Frequency Judgments: A Critical Examination. Organizational Behavior and Human Decision Processes, 65, 212-219.

Busby, J.S. (2001). Error and distributed cognition in design. Design Studies, 22, 33-254.
Hastings, D. (2004). The Future of Engineering Systems: Development of Engineering Leaders, Engineering Systems Symposium. Mit Press: Cambridge, Mass.

Lawson, B. (1997). How designers think: Design process demystified. Architectural Press: Gillingham.

Lucia, A.D; Lepsinger, R. (1999), The art and science of competency models, Jossey-Bass: San Francisco, CA.

Newell, A. & Simon, H. (1974). Human problem solving. Engelwood Cliffs, N.J.: Prentice-Hall.

Okhuysen, G. ; Eisenhardt, K.. (2002). Integrating knowledge in groups. How formal Interventions enable flexibity. Organization Science, 13, 370-386.

Perrow, C. (1999). Normal accidents: Living with high-risk technologies. Princeton: Princeton University Press.

Robbins, S. P. 2005. Organizational Behavior (11. edition). Upper Saddle River, NJ : Prentice Hall
Saariluoma, P. (1995). Chess players' thinking. Routledge: London.

Saariluoma, P. (2002). Ajattelu työelämässä: erehdyksistä mahdollisuuksiin [Thinking in work life]. WSOY: Helsinki:

Smith, Ken G.; Locke, Edwin A.; Barry, David; Goal setting, planning, and organizational performance: An experimental simulation. Organizational Behavior and Human Decision Processes, 46, 118-134.

Taatila, V. (2004). The Concept of Organizational Competence- A Foundational Analysis. Jyväskylä Studies in Computing, (36). University Of Jyväskylä

Appendix: **Rotated Component Matrix(a)**

	Component						
	Organization and Leadership	Faulty Thoughts	Distribution of information	Compe-tence	Motivation and commitement	Intention related factors	Occupational Stress
1. Poor commitment of the participants on a project	22. ,803						
2. Lack of motivation	23. ,773						
3. Unawareness of the of the goal of a project	24. ,696						
4. Several simultaneous projects	25. ,691						
5. Unawareness of the ultimate goal of the organization	30. ,610						
6. Poor expertise	35. ,595						
7. Poor mathematical skills	37. ,586						
8. Unawareness of the needs of a client	31. ,549						
9. Misinterpretation of others actions	36. ,542						
10. Poor international related skills e.g. knowing cultures	26. ,540		,414				
11. Unawareness of others methods and skills	5. ,451				,425	,443	
12. Uncritical use of old solutions in new designs	33. ,427						
13. Focusing too much on single sub- solution and therefore missing the big picture	12.	,687					
14. Early commitment on solution, that did not work in reality	16.	,666					
15. Unawareness of the environmental factors in designing	15.	,662					
16. Unawareness of the social factors in designing	14.	,574					
17. Problems with tools	18.	,566					
18. Being stuck with unrealistic image	13.	,452					
19. Problems with calculations	21.		,710				
20. Problems with getting right information	20.		,638				
21. Outdated information	27.		,579				
22. Problems with organizational structure	19.		,542	,522			
23. Problems with managerial practices	7.			,652			
24. Organizational change	38.			,626			
25. Problems with division of work	17.			,612			
26. Problems in teamwork	6.			,577			
27. Problems with a the communication with a client	32.			,450			
28. Rush at work	1.				,753		
29. Stress	3.				,751		
30. Bad climate in the workplace	2.				,672		
31. Poor social support	9.					,601	
32. Impulsive decisions	8.				,503	,534	
33. Lack of feedback	11.	,412				,528	
34. Problems with schedules	39.					,513	
35. Lack of creativity	10.					,417	
36. Problems with collaboration with departments	28.						,825
37. Personal ambitions of others	4.						,719
38. Poor training	29.						,638
39. Distractions when working	34. ,408						,565

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