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DESIGN PERFORMANCE: HOW CAN WE MEET HUMAN LIMITATIONS WITH HUMAN RESOURCES?

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1 Introduction

The topic of ICED 05 has been chosen deliberately: "Engineering design in the global economy". All over the world we experience globalisation as a development changing the societal, economical, political and technical conditions in a revolutionary sense [1]. This situation may be compared with the innovation of steam power launching the first industrial revolution in the mid 18th century and with mass production and mass transport launching a second industrial revolution in the 20th century. Thus, the very basic question arises: What are the implications of the global development for design? In the conference overview two characteristics of global design are mentioned:

- manufacturing fluency: referring to the opportunities linked to competitive manufacturing all over the world
- design fluency: referring to the opportunities of cooperation and interaction across time and space, such as video-conferences of geographically dispersed members of a design team.

However, attempting to deal with consequences of global design, with benefits and costs, with limitations and benefits, this discussion cannot be restricted to the issues of material, mechanics and components influencing design performance. We need to take into account the resources and limitations of human beings confronted with the main characteristics of globalisation. Limitations can result in failures in design which may become extremely expensive in terms of cost and sometimes even in terms of life [2]. Therefore, efforts should be taken to strengthen the resources in order to reduce the probability of failures. But, until now, we do not know enough to prevent failures. We know that all design failures can be 'explained' as caused or at least contributed by human behaviour. However, the occurrence of design failures does not provide an understanding of the causes of human failures - and the occurrence of human failures does not provide enough knowledge to forecast how, when and in which context design failures will occur. But the occurrence of human failures is giving insights in the way humans think and act. From this knowledge concepts can be derived that support the abilities of the human being in dealing with the requirements of global design in a more secure and effective way.

2 Globalisation: Forecasts and its implications on design

Although we can state that globalisation has started many years ago it is only since few years that there is a general awareness of the substantial changes caused by globalisation. Assuming that in the next 20 years we have to cope with a similar high-speed development as we experienced in the last 20 years we should be able to be better prepared for this situation. A short glance at main characteristics related to design [1], shall underline the major trends, to name only four:

- **Increasing investment in technology** will lead to further breakthroughs in the disciplines of biotechnology, materials science, and nanotechnology, what will stimulate the innovation of new products, of longer lasting products and of environmentally safe products.

  Thus, designers need profound knowledge in their discipline on the one hand and abilities in creative decision-making on the other.

- **Increasing competition** will speed up the design process. As it becomes more and more important to raise competitiveness the time-to-market of products, especially of low-cost and high volume products will be reduced. With increasing time-pressure the quality of design processes is decreasing and the probability of failures runs the risk to increase.

  Thus, designers need to be able to deal with situations of conflicting goals such as time-pressure and high quality standards in design.

- **Increasing knowledge-based development:** Knowledge, creating new knowledge and transfer of knowledge will still gain in importance. International cooperation, complex products, highest technology in products and processes, all these characteristics reflect knowledge as key factor of future engineering design in the global economy.

  Thus, designers need to cooperate with different disciplines and groups all over the world.

- **Increasing information technology:** The most significant advances in technology were and are continuing in information technology. Thus, ways of communication and information exchange in design will change. Work groups, project groups, and other types of working units will be more often geographically dispersed and less stable.

  Thus, designers need to learn in less stable social work environments.

These four important characteristics imply that due to future developments in global design the requirements for designers in their daily work are increasing. More than ever the designer will be confronted with complexity and intransparency, with uncertainty and instability. Therefore, it is highly important to support the designer in his/her daily work and to prepare the students to cope with these requirements adequately.

3 Design performance

3.1 Design performance = designer's performance

Summarizing the major future trends in global design we can state that meeting the challenges of the future in the global economy depends on human abilities and resources in dealing with complex and uncertain environments. Hence, the ability of dealing with complex problems is influencing the output, the design performance. Analysing design performance, we start from the general assumption that design performance is human behaviour (B) which is according to Lewin [3] a function of person variables (P) and environment variables (E), B = f (PE).

Related to the person, cognitive and motivational properties, and related to the environment characteristics of the design problem and of the social context are essential determinants of human behaviour (see Figure 1). Furthermore, characteristics of the process and procedures such as rules of coordination as well as techniques and methods within the organisational environment are equally important [4].

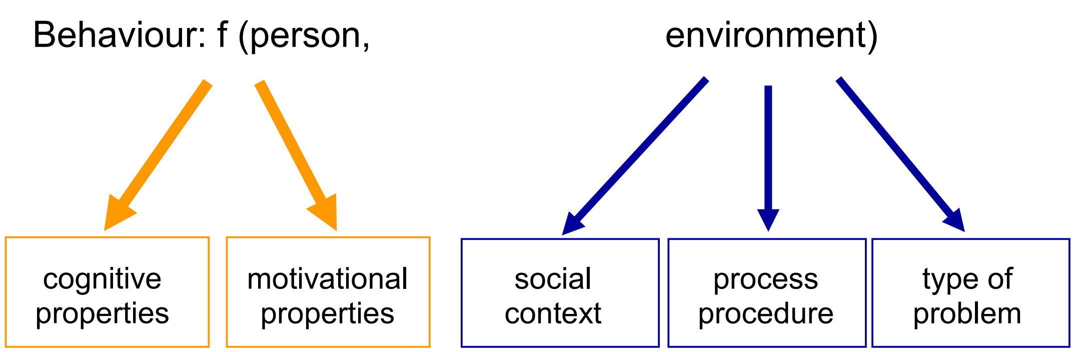

Figure 1. Determinants of human behaviour according to Lewin [3]

3.2 Design performance = a dynamic interplay of individual and situational determinants

A comprehensive theory of design performance has to be based on the interrelations of the basic fields of influence. The following statements enrich the above equation:

[1] PERSON: Design performance depends on the interplay of cognitive, emotional and motivational components during the designing process. The designing process itself is a stream of activities such as goal elaboration, forecasting activities, hypotheses formulation, planning, decision making and self reflection. Thus, deficiencies in deign performance can be related to cognitive properties of the human information processing system. Many cognitive theories assume that the limited capacity of consciousness, the working memory [5], is the key to human failures in complex information processes. However, thinking, planning and acting are much more than purely cognitive processes with the consequence that the analysis of human failures cannot be restricted to mental processing capacities but has to take into account motivational and emotional components [6].

[2] ENVIRONMENT: The apparent necessity to consider design performance as situated and contextualized requires the need to identify the main areas which represent the situatedness and context. In light of empirical studies there are three primary aspects that tends to reflect disparate areas, the social context, the problem context, and the context of procedures:

SOCIAL CONTEXT: this descriptive may be criticized as an oxymoron because there is hardly any context conceivable without social impact. Hence, the context relating to the designer's work is social in the sense that information processing and information transfer is influenced by others and is influencing others. The social context modifies the representation of the situation, adding new possibilities but also holding special risks.

One major aspect of the social context refers to the context of collaboration in teams, project groups, etc. With increasing demands of technology and marketplace working in groups has become the common way of working in most companies and thus in most design departments. However, the group context is manifold: Cross-functional teams, geographically dispersed teams, face-to-face-teams, cross-cultural teams, joint ventures, inter-organizational partnership, virtual teams, to name only a few types of group collaboration which refer to different social context with implications on communication and collaboration. The often-cited advantage of group collaboration is summarized in the synergy concept which refers to the phenomenon that two or more agents acting in common create an effect which is greater than the sum of the effects each is able to create independently (http://encyclopedia.laborlawtalk.com/Synergy).

But although the need for collaboration is evident the outcome is not always what the expectation of synergy effects would predict. The rates of unsuccessful collaboration and cooperation is very high [7] and communication problems seem to be one of the major reasons for deficient outcomes in critical situations. Due to culture, discipline and tradition groups are often connected to different mental models and thus to different perspectives, what is hampering the development of shared mental models and coordinated activities. Thus, working in groups or being responsible for creating the right mix of people for a specific project group leads to the question: Which factors related to the social context influence the design process and thus design performance in which way?

Of course, there are several studies in social and organizational psychology which determine the impact of dynamic variables such as the developmental phases of groups as well as the influence of structural variables such as leadership, group size, etc. on group performance. However, there are few empirical data about breaking down the influencing mechanisms in working groups where designers are involved. Nevertheless, results of empirical studies reveal that there are major communalities between results of studies analysing groups in other disciplines and design groups. For example, studies tell that information quality, information sharing, participation in planning, and goal setting are essential behavioural patterns of communication between leaders and employee [8]. In an investigation leadership processes in three engineering design departments were observed and altogether 321 situations were analysed related to behaviour patterns and performance [9]. These data confirm that there is no standard pattern of leadership in design groups which proved to be successful at all times and in all situations. Relevant leadership situations in design departments can be related to different types of requirements (content, process, relation) which are managed differently in terms of information transfer and success. Poor leadership qualities arise especially in situations of conflict management mainly connected with deficient information transfer.

- PROBLEM: Design performance depends on the requirements of the particular problem. Attempting to define the requirements of design, design tasks are usually described as complex and wicked or ill-defined [10]. However, this characterization is too general as it reflects two criteria, which itself are not sufficiently defined.

  Complex: There have been several attempts in different disciplines such as computer science and psychology to define complexity. Referring to design the concept of complexity is useful in case that the objective factors which contribute to task complexity can be defined. But, furthermore the degree of complexity depends on the designer's knowledge and experience related to the task.

  Ill-defined: The characterization of design tasks as ill-defined refers to the goal definition which is usually not giving clear evidence what to do: Even if in a design task goals are well-defined it is necessary to think about contradictory goals which cannot be realized at the same time. In a broad empirical study attempting to analyse influencing factors in design practice 895 critical situations in ten observed design projects have been analysed in terms of influencing factors and mechanisms [11]. Different behaviour patterns responsible for positive or negative outcomes of different types of critical situations were identified. The results provide some evidence that basic requirements of design problems designers struggle with in design practice are the novelty of the task and the frequency of changes of requirements.

- RULES and PROCEDURES: The environment in which designing occurs is also shaped by defined procedures and practices which structure the activities and set constraints on the designing process. For example, the particular CAD- system used in a design department, or the economic pressure of a company which determines procedures such as the degree of outsourcing are setting possibilities and constraints on the designer's activity. However, there are also 'informal' rules and procedures known by some people but not necessarily communicated to others.

[3] TIME: In addition to the two-dimensional function of behaviour as determined by the characteristics of the person and the environment the time perspective has to be taken into account. Design performance is an activity and activities have the character of a process with interdependent actions extended over a period of time. Studies investigating human activities in terms of an input-output-model neglect important information of time-related dependencies. For example, if a study reveals that a deficient design output was the consequence of missing domain specific knowledge of the designer, it is essential to know when during the process which kind of domain specific knowledge was missing and which strategies then have been used by the designer to cope with the missing knowledge. Furthermore the cognitive capabilities of a person vary greatly over time because of fatigue, distractions, or emotional stress. Thus, studies need to collect data and analyse the results of longer sequences of design processes.

3.3 Design performance = (human resources minus human limitations) + (resources of the environment minus limitations of the environment)

Summarizing the above explanations design performance defined as human behaviour is the additive result of human resources minus human limitations plus the difference of the resources and the limitations of the environment. Thus, design performance can be improved by increasing the designer's resources and decreasing his limitations and the same is valid for the resources and limitations of the environment. However, in order to solve this equation we need to know more about human limitations and resources, about beneficial and hindering environmental conditions. Are there 'typical' human limitations in dealing with different types of requirements of design problems?

In the following chapter an example illustrates some limitations based on characteristics of the human mind and the environment.

4 Basic assumptions about human limitations

4.1 An example

"Mercedes is shifting into a higher gear": That was the advertisement of Mercedes Benz in 1997 to push the at that time youngest product - the small car 'A' class. But then nearly overnight Mercedes as the distinctive sign of technological infallibility was blamed: During a test track, after only 500 meters the car overturned and the dream of Mercedes - building the safest small car - was smashed. The Swedish test driver Collin declared the car as a misconstruction and required the immediate production stop of the A-class. In the following year Mercedes succeeded in turning the flop into a top-seller by setting highest resources into the crises management of the A-class-disaster.

Although this example of an obvious disaster of a product start is rather seldom, there are many smaller scale failures that are also very expensive in terms of money and status. Almost every week recalls of products due to minor or major design problems arise - to quote only a few which are published in http://irishcar.com/01febnews.htm:

- *5 February 2001:* "Opel is recalling about 890,000 Tigra and Corsa model B cars in different countries due to possible problems with seat fixtures. The cars affected were made before mid-2000, a spokesman for Opel said. The Tigra was the sporty coupe (left) built on the Corsa underpinnings and was a highly successful niche car for the brand in Europe."

- *16 February 2001:* "DaimlerChrysler is to recall 55,000 A-Class Mercedes-Benz cars to deal with potential brake problems. The recall will cost the company about ten million euros. The problem is because a supplier changed the rubber sealing collar in the main braking cylinder without informing Mercedes-Benz. In below freezing temperatures, the braking system may not function on all four wheels if a driver does not test his brakes to soften the rubber sealing collar before setting off."

- *16 February 2001:* "A total of nearly 1.5 million units appear to be involved in current Mitsubishi recalls around the world, primarily Galant saloons and five-door hatchbacks and derivatives sold as the Chrysler Eclipse. It also affects some small

Pajero and Minica units in Japan because of concerns over their transmissions and airbag systems. The main recall has arisen because of a component defect which could allow water to get into the lower steering arm ball joints. The resultant corrosion could accelerate wear, with the risk of failure."

Failures, as cited above point to the deficiencies of the result but do not provide evidence about the limitations of the process and the human element of the designers involved. From a research point of view, we are interesting in an explanation of the phenomena on a process- and human-related level:

- What kind of human limitations cause failures in the process of designing products?
- What kind of support can be derived to escape from these limitations?

Both questions relate to the design **and** the psychological aspects of failures, their origins and consequences. Attempting to answer these questions it is necessary to analyse the particular cases and to find out which theoretical concepts may explain the phenomena. Although these cases are post-hoc-analyses, done after the failure is detected, they contribute to the empirical knowledge about the origin of failures. The more knowledge we gain about causes of failures the better we are able to prevent failures by supporting designers in all stages of product development. Of course, post-hoc analyses are also part of forensic investigations focusing on the question of guilt. However, the main approach of forensic engineering is to track the causal chain from the final technical deficiency of the disaster to the reasons in the use, the production or the design of the involved product. These analyses also are helpful in gaining information about frequent deficiencies. Hales [3] found that in one third of his analysed cases, the designed product did not meet the design specifications. Relating to the design process, design methodology offers a broad body of knowledge to support the designer in optimising the product in terms of quality (e.g. safety), cost and time to market. Obviously, the design specification is a crucial part in the design process which needs more or better support by design methods.

Hence, we ask in the A-class example: What has gone wrong? Although we can assume that the designers involved were well-educated and highly motivated, why didn't they become aware of the deficient development earlier during the 500 million tested kilometres?

4.2 Analysing the example

Knowing only a few important steps in the whole four year developmental process of the A-class it is not possible to determine critical situations in order to analyse the influencing factors in the ongoing design process. Nevertheless, we are able to analyse deficiencies related to the basic fields of influence on a more general level referring to publications of the A-class disaster [12]:

[1] PERSON: The designers involved in the A-class project were well qualified and had a university degree. As nearly all of the group members were young the experience was not that high as in former development processes. However, the motivation of each single designer was reported as very high.

[2] ENVIRONMENT:

1. SOCIAL CONTEXT: In 1992 the chief of the R&D department had left the executive floor of the organization. The more conservative way of thinking and designing was replaced by a charismatic leader. And as the R&D department was now composed of the rising generation, many of them directly from the university, what caused a complete new social climate. The group called themselves 'The Young Wild'. This self-assessment of the group as 'Young Wild' discloses on the one hand strong self-confidence and on the other high group cohesion with a shared common goal to change the traditional automobile sector - supported by a strong leader. These aspects refer to the theoretical concept of 'groupthink' [13], a group phenomenon which emphasizes the high priority of consensus-seeking in the group. A groupthink dominated situation leads to the suppression of deviant thoughts because each member pays more attention on group consensus than questioning the current group idea. The reinforcement of one another's confirmation that the group does everything right is mostly combined with the tendency to suppress self-criticism within the group.

- PROBLEM: The aim was to design 'real' new things, a dream which should be realized by the design of a small car offering the safety of a limousine - obviously contradicting goals. The technical breakthrough - the so called sandwich-concept - was the arrangement of the engine in that way that in case of an impact the engine was pushed under the passenger cabin. This innovation forced the separation of the passenger cabin by a double base with three major consequences: high centre of gravity - low distance of wheels - extremely rigid chassis.

  The design group concentrated and narrowed their view on the passive safety of the direct impact. And in a test-crash with 65 km/h this new concept revealed as highly reliable, and was thus seen as a milestone of safety in the development of small cars. But this partial success was also taken as a proof of the whole concept. The additional side-effects as a consequence of the new design were neglected. The safety of the car was reduced to one important case: an impact.

- PROCEDURES: Related to procedures two important aspects have to be mentioned which played a major role in the A-class design project: a) the time horizon of the A-class development was with less than 4 years very short. Major basic tests such as tests with different types of axes were omitted. And secondly, it was the first time that driving tests in the simulator had a more important role than driving tests in reality.

Obviously, there was not one single reason responsible for the deficient design performance but we are able to derive a network of mechanisms of different fields. It is not one error or one mistake but a chaining of several limitations which together caused the design performance.

4.3 Limitations

Although errors are observable the origin of failures is mostly not observable and may come from different sources. There are several theories which try to provide general explanations for different types of failures. Related to the origin of the failures, we can refer most theories to two basic assumptions:

a) The capacity of human conscious thinking is restricted

Human thinking is based on representations of reality that are built in order to understand, predict and explain the world. Reason [14] distinguishes two basic cognitive processes responsible for identification and selection processes: similarity matching and frequency gambling which he describes as 'computational primitives of the cognitive system' (p.103) and which are also seen as a major source of human errors. The identification and the selection of adequate actions are based on prior experience with the particular situation. The selection, which part of the experience is important for identification and action selection is based on the similarity between the given situation and the schemata stored in memory. If this similarity process doesn’t lead to a clear identification or adequate action selection, than prior knowledge is elicited, which often has been used and was successful in a related situation context.

Thus, behaviour is primarily steered by the recognition of (adequate or inadequate) schemata. Only in case there are no suitable schemata available new schemata will be generated. Although theses processes work very quickly in case of known material, problems occur in case of similar situations which have some characteristics in common with well-known situations but are different in few but important characteristics. According to the similarity matching and frequency gambling processes humans tend to react with the same behaviour pattern although the actual situation would require the generation of new schemata or the adaptation of existing schemata.

b) Humans are controlling the degree of their subjective feeling of competence

Solving complex tasks and problems demands not only cognitive competencies such as using adequate knowledge but also the confidence to be capable to solve the problem. Thus, a basic prerequisite for humans is the perceived competence of being able to act effectively what is reflected in a subjective feeling of competence. Humans are strongly motivated to guard this feeling. In cases of a negative feedback on one's actions, humans do not necessarily strive to elaborate in order to solve the problem in a more efficient way but often have a strong tendency to overlook the signals of failure. The reason may be that the implicit estimation of the subjective feeling of competence is too low to dare another trial with another negative feedback. Thus, humans are controlling the degree of their subjective feeling of competence and act according to the principle not to violate their perceived competence too much. We can assume that humans differ relating to the degree of accepting a decrease of their subjective feeling of competence. And humans differ in relation to the agreement between the actual competence and the subjective feeling of competence.

If we want to understand why humans tend to behave the way they do we have to ask, what the basic functions of these behaviour patterns are. We refer to two major functions which are essential to act in complex and opaque situations:

1. reduction of complexity
2. control of the ability to act

Ad 1: Human conscious thinking is not able to cope with parallel information in a limited span of time. This enforces economical tendencies that is the economically use of the limited resource ‘conscious thinking’. Humans are aiming to reduce complexity in order to reduce cognitive load. The motivation to reduce cognitive load directly causes behaviour patterns such as reductive analysis and information selection. Both processes increase the speed of thinking and acting and decrease the cognitive load; reductive analysis and information selection often lead to major deficiencies in the design process (see Table 1). Reductive analysis has been observed during goal elaboration and solution evaluation phases in designing. Especially experienced designers often fail to analyse their goals and solutions sufficiently; instead they react to obvious errors immediately in order to correct them but they do not work according to a goal-driven set of criteria [11]. In routine situations this way of procedure leads to quick decision upon goals and solutions what is time-saving compared to time-intensive evaluation techniques such as those proposed by design methodology; however in critical situations a thorough analysis helps preventing major failures.

Information selection is the basis of human's natural perception processes. Humans are not able to take into account the complete information but have to select information. However, in order to decide upon a particular course of action the selection processes often take a wrong direction. For example, humans pay attention on the most salient but not necessarily the most important information and humans pay more attention to information which arrives earlier in the process than later. The consequences are several kinds of wrong diagnoses, underestimation of probabilities, misjudgements. However, these procedures yield successful results quickly in quite a lot of situations, especially in dealing with simple problems; however, the more complex the problem is the more likely errors will occur.

Table 1. Behaviour patterns coping with complex problems

Function: Reducing complexity	
PROCESSES	EXAMPLES OF FAILURES
reductive analysis	insufficient goal elaboration
	insufficient solution elaboration
information selection	misjudgement
	underestimation of probabilities
Function: Control of the ability to act	
low feeling of competence	wishful thinking
	ignoring of feedback
high feeling of competence	risk-taking behaviour

Ad 2: The process of acting and problem solving and thus of designing is combined with motivational processes in so far as success and failure influence the motivational processes. Failures and missing feelings of success frustrate the need for control and thus the need for competence what as a consequence causes actions aiming at recovering competence. Failures pass on the information that one is not able to reach the desired goals whereas success delivers a positive evaluation of the subjective control and competence. The need for competence thus modifies the actual way how to deal with success and failure.

For example, if the feeling of competence is low and the problem to solve seems to be very difficult, humans are not interested in negative feedback because this information again would decrease the subjective feeling of competence. Thus, in situations of low control humans tend to avoid feedback and in the worst case they establish a kind of wishful thinking: instead of asking information about the situation people 'make their own reality' where things are such as they should be.

Of course, there are also subjects with a high feeling of competence what may in terms of failure result in over-confidence and risk-taking behaviour. And there are also situations where a subject believes to have control, but has not and is not able to act adequately. However, this behaviour will not remain stable over longer periods of time because the negative results will lead sooner or later to obvious failures, why subjects then usually re-evaluate their estimation.

Furthermore the individual history of failures and successes determines the estimation of the competence in a new situation.

5 Strengthening human resources

Although there is no complete theory about the origin of human errors there are several studies which reveal human difficulties in dealing with the challenges of complex and dynamic problems while less is known about human resources, about the impact of education and learning processes on the prevention future failures.

5.1 Competencies in design-related knowledge, problem solving abilities and social-related abilities

Designers are usually well trained in the knowledge of their discipline. However, it is often claimed that designers are missing the so-called soft skills, which are especially related to interpersonal and social competencies. Therefore education should focus on an integrative concept of the various exit qualifications, encompassing three major fields of abilities or key qualifications:

1. Design-related knowledge, skills and methods: this competence refers to the factual knowledge of the particular discipline.

2. General problem solving abilities: general problem solving as competence refers to the domain independent ability to deal adequately with complex problems. Due to the fact that designers face so different requirements it is necessary to educate students and designers in basic characteristics of complex problems and in general strategies of problem solving.

3. Social-related abilities: the third competence refers to collaboration in and between teams. Working in groups does not only affect communication but also the coordination of the relations in and between the groups. The network of the individual responsibilities within a design team needs coordination of measures and responsibilities to avoid collision of measures and people. Coordination (people using the same resources have to coordinate their activities), cooperation (people are mutually dependent in their work have to cooperate in order to achieve the common goal) and communication (determines formal and informal information flow) are thus the major requirements for efficient group work.

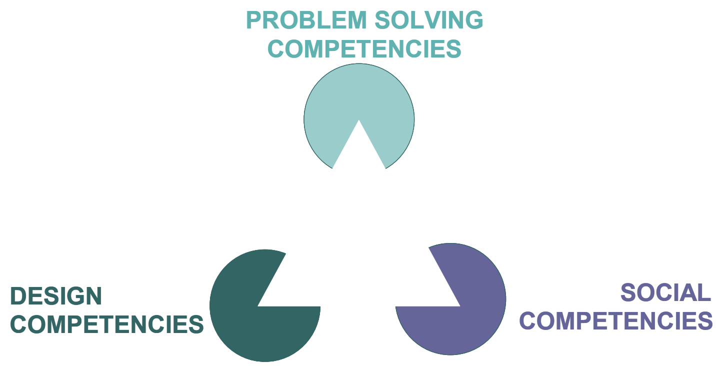

Figure 2. Human resources in design

5.2 Human centred design methodology

Although there are several reasons to state that the proposed procedural models of design methodology are useful to deal with problems more adequately, empirical studies evaluating design methods are seldom. And design methodology has not been as accepted in industry as it should be according to the claim of design methodology to support the designer. The major limitations of design methodology are that the methods do not relate to characteristics of the designer such as experience or cognitive and motivational properties and that the methods do not relate to situational characteristics such as group coordination, time-constraints or other constraints caused by through multiple projects that must be treated simultaneously.

Thus, the question arises: how do these characteristics influence designer's behaviour and in case of limitations how can we encounter these limitations? The first step is to analyse empirically which limitations occur due to specific characteristics in the design process and the second step is to derive adaptations or to develop new methods in order to adjust design methodology to the designers' needs. Thus, in order to come up with fruitful support the design methodology needs to be more designer-oriented, starting from the general framework taking into account the various fields of influences:

- the characteristics of the given task or problem,
- the individual designer,
- the designer in the team, group or project context,
- the organisational context,
- the design process,
- and the product as the result of this interplay.

For example, many inefficient design processes and results can be led back to inadequate goal elaboration and inefficient group organisation. Both requirements are not emphasized in design methodology. There are theoretical concepts in each field although they are not connected and not integrated in design methods.

6 Conclusion

Despite of expert knowledge and good intentions, deficient outcomes in product development are not unusual. A comprehensive framework of human failures and resources in designing would be useful for design education and practice. An improved understanding of human failures and resources in dealing with different requirements in design should contribute to a theory of human design performance and thus could improve teaching and learning processes. Knowledge about important mechanisms of design failures can help to develop suitable precautions and may allow a practical and relevant designer education at university.

As design failures are seldom occurring in routine situations we need a deeper understanding of human action regulation in critical situations what means more empirical analyses taking a closer look at how designers think, communicate, collaborate and learn of coping with and preventing failures. Knowing mechanisms and consequences of failures will be a source for a human-centred design methodology which should be useful for designers coping with uncertainty and complexity in the design process.

References

[1] National Intelligence Council, "Global Trends 2015: A dialogue about the future with nongovernmental experts", 2000, NIC 2000-02. http://www.cia.gov/cia/reports/globaltrends2015/globaltrends2015.pdf

[2] Hales, C., "Forensic Analysis of the Engineering Design Process", in Frankenberger, E., Badke-Schaub, P., Birkhofer H. (eds.), "Designers – The key to successful product development", London; Springer, 1998, pp. 137-148.

[3] Lewin, K., "Behavior and development as a function of the total situation. Manual of child psychology" ed L. Carmichael, 1946, pp. 791-844, Wiley, New York.

[4] Andreasen, M. M. & Hein, L., "Innovating the product development organization", in Frankenberger, E., Badke-Schaub, P., Birkhofer H. (eds.), "Designers – The key to successful product development", 1998, London, Spriger.

[5] Hacker, W., "Improving engineering design", Ergonomics, 40, 1997, 1088-1096.

[6] Dörner, D., "The investigation of action regulation in uncertain and complex situations", in: Rasmussen, J., Brehmer, B., Leplat, J. (eds), "Distributed decision making: Cognitive models for cooperative work", New York, Wiley, 1991.

[7] Mohr, J. & Spekman, R., "Characteristics of partnership success: partnership attributes, communication behavior and conflict resolution techniques", Strategic Management Journal, 15, 1994, 135-52.

[8] Kelly, M.J., Schaan, J.-L., Joncas, H., "Managing alliance relationships: key challenges in the early stages of collaboration", R&D Management, 32, 1, 2002, 11-22.

[9] Badke-Schaub, P. & Stempfle, J., "Analysing leadership activities in design: how do leaders manage different types of requirements?", in: Marjanovic, D. (ed.), Proceedings of the Design 2004, 8th International Design Conference, 2004, 1-6.

[10] Newell, A. & Simon, H., "Human Problem Solving", New York, Prentice-Hall, 1972.

[11] Badke-Schaub, P. & Frankenberger, E., "Analysis of design projects", Design Studies 20, 1999, 481-494.

[12] Der Spiegel, “Mercedes A-Klasse, Stern mit Schrammen. Anatomie eines Debakels”, Nr. 47, 1997, S. 248-257

[13] Janis, I., “Victims of Groupthink”, Houghton Mifflin, Boston, 1972.

[14] Reason, J.T., “Human Error”, Cambridge, University Press, 1990.

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