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EXPLORING THE DECOMPOSITION OF TEAM DESIGN ACTIVITY

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Abstract

Presented research explores the nature of teamwork activity in the conceptual design phase with an aim to unfold the patterns of team behaviour during execution of a specific design task. Teamwork activity process is observed as a sequence of analysis, synthesis and evaluation design operations applied to the problem and solution spaces. Design operations are used to represent abstract and fine-granularity steps of exploring and modifying the problem-solution space. Protocol study was conducted to investigate if teamwork activity can be decomposed into patterns of design operations and problem-solution alternation. Brainstorming sessions of two design teams were coded by employing an operation-based coding scheme. Protocol segmentation revealed the distribution of design operations and problem-solution related discussion, as well as the distribution of transitions between design operations. The emphasis is placed on the cycles of synthesis and analysis that appear within both problem and solution space, but also in-between the two spaces, thus indicating the co-evolution of the problem-solution space. These findings support and complement what has been reported in the literature.

Keywords: Design process, Conceptual design, Protocol analysis, Teamwork, Human behaviour in design

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1 INTRODUCTION

Teams are the core building blocks of organisational structures in modern product development companies. Coping with the complex engineering projects requires the contribution of several specialists rather than that of a single designer (Ensici et al., 2013). Although workspace cultures differ, many engineers see their work as almost always done in explicitly organised teams and open collaboration with others (Anderson et al., 2010). Teamwork is of particular importance during the conceptualization, where teams have to put effort into tasks such as goal formulation, ideation and decision-making (Andreasen et al., 2015). If built on a well-developed conceptualization strategy, design is fundamentally teamwork (Andreasen et al. 2015).

Understanding team processes and gaining insight into actions and interactions of team members is important for both researchers and practitioners responsible for the formation of teams and allocation of team members within the domains of design and product development. The number of studies aiming at understanding how designers design in teams is continuously increasing over the last decades. However, there are still open calls for research which will frame the comprehensive understanding of team behaviour. Researchers identified several aspects of teamwork design that require further studying e.g. team behaviour during creative design activities (Sosa, 2016) and decision-making (Ensici et al., 2010), or explanation of the way team behaviour is driven by the underlying thinking processes of designers (Jiang et al., 2012).

The motivation for the research presented in this paper was a widely-recognised need to build computational models and simulations of product development (please consult Perišić et al., 2016 for more information). The computational teamwork simulator should enable experimentation and generation of extensive data about the team behaviour that should complement empirical studies of teamwork conducted with humans. As one of the first steps toward this goal, the aim of this paper is to explore the nature of activity performed by design teams in the conceptual design phase and unfold the patterns of team behaviour once the team is confronted with a specific design task. The examination of team behaviour is approached through the lens of team's design process and the fine-granularity steps designers apply to progress within design activities. From this point on the steps of designers are referred to as design operations. This perspective is aligned with the generate-stimulate-produce (GSP) cycle of Jin and Benami (2010), in which design operations result from cognitive processes of designers and are used to generate design content (design entities), including initial raw ideas as well as mature concepts of a design artefact. Following this, the teamwork activity can be defined as a set of design operations performed by a team and driven by the same goal, e.g. producing solution ideas during the idea-generation activity or selecting the concept during a decision-making activity. Design operations can be applied to two distinctive spaces – problem space and solution space (Dorst and Cross, 2001), where the content being generated is either the formulation of the problem or the solution that meets the requirements. This study aims to explore both the nature of applying design operations and team's focus on problem-solution space during the conceptual activity. The results are planned to be utilised when building computational models of teamwork. The following research questions guided the study:

- How can teamwork activity within conceptual design be decomposed into sequences of team’s design operations?
- What is the relation of identified design operation sequences and the alternation of the problem space and the solution space?

Research questions are approached by exploration of teamwork activities in conceptual design that are described in the available literature as presented in Section 2. Findings from the existing studies are supplemented by an empirical study of design teams. The methodology of the study is presented in Section 3. Results are reported in Section 4 and discussed in Section 5 before conclusions are drawn within the last section.

2 BACKGROUND AND RELATED WORK

Three aspects are considered within this review. The first aspect describes the research of patterns within the phenomena of design activity if the design process is observed at the lower level of abstraction and granularity. The second aspect is the alternation of the problem space and solution space – and the co-evolution of these two spaces. The third aspect refers to reported empirical research of design team behaviour to gather the relevant findings and identify elements that need further exploration.

2.1 Patterns within design process

The process of designing may be observed at different granularity levels. One can see it as a complex system representing the overall design process, while the opposite would be to observe the micro-steps of thinking during design (Lindemann, 2014). In addition, different disciplines and stakeholders have their own particularities and requirements in the design process (Gericke and Blessing, 2012; Costa et al., 2015). It is hence difficult to generalise the description of the design process. Only at a certain level of granularity and abstraction can patterns of design process elements be recognised (Eckert and Clarkson, 2005). For example, (Cross, 2001) identified domain-independent similarities and patterns within empirical research on a cognitive aspect of design. This research utilises a micro-scale representation of the design process to identify regularities and patterns of designer's cognitive processes. In this paper, the focus is shifted from cognitive processes to design operations, which are defined as results of cognitive processes applied to modify design entities (e.g. problem formulation or solution concept). Design operations can be external (observable) such as writing and sketching or internal such as questioning and suggesting.

In order to be applicable independently of domain and development context, design operations require a representation on a sufficient level of abstraction. The common direction of attaining abstraction is prescribing elementary design operations of analysis, synthesis and evaluation (ASE) (Cross, 2001; Liu and Lu, 2014). The analysis is defined as the study of parts and interrelations of a problem and as an examination of a potential solution (Jin and Benami, 2010). Synthesis corresponds to the generation of the design solution, while evaluation is corresponding to assessing the validity of the solutions (Afacan and Demirkan, 2011). These three elementary concepts can be traced back to Asimow (1962), who proposed ASE model as a general problem-solving strategy, and Watts (1966), who presented the design process as a constant cycle through ASE. Analogous cycles can be identified across eminent models of design, e.g. within the "basic design cycle" (Roozenburg and Eekels, 1995), "design steps" within function-behaviour structure (FBS) ontology (Gero and Kannengiesser, 2004), "iterative processes" of creative design (Dorst and Cross, 2001), and other.

2.2 Problem and solution alternation

In addition to design operations as means of creating and modifying the design entities, various studies attempted to describe designer's process as oriented towards problems and solutions. Dorst and Cross (2001) thus differentiate the problem space and the solution space in-between which a constant iteration of analysis, synthesis and evaluation processes exists. The division into problem-solution space has been introduced within the co-evolutionary model of designing by Maher et al. (1996) and has been present in many studies ever since, especially within the creative design research. In the model of problem-solution co-evolution, designers are iteratively developing concepts and exploring the two spaces, with each space informing the other. The generality and applicability of the problem-solution space co-evolution have not been comprehensively tested across different design domains, problem types and expertise levels (Wiltschnig et al., 2013). In this paper, problem-solution space co-evolution is used to describe and compare the focus towards problem or solution, as many of the studies see problem-solution co-evolution as an important drive for creativity and innovativeness in design.

2.3 Empirical studies of design activity

For decades, design researchers have been conducting empirical studies of designers such as think-aloud and conversational methods, case studies and controlled experiments, to discover thinking patterns during execution of design tasks (Dinar et al., 2014). Of all the varied range of methods for fine-grain investigation of design activity, protocol analysis has been regarded as the most suitable method to reveal the cognitive abilities of designers (Cross, 2001). Reported protocol studies of teams are mainly employed as concurrent and conversational (Jiang, 2009), meaning that the participants concurrently report on their cognitive acts using conversation during task execution. Only a small portion of the relevant design research based on protocol analysis is considered due to the limited extent of this paper. Stempfle and Badke-Schaub (2002) established a generic model of design team activity and employed protocol analysis to capture regularities in thinking and reasoning processes as the underlying operations of the problem-solving process of three laboratory teams. The result is a two-process-theory of thinking in design teams. Mc Neill et al. (1998) studied ten individual electrical engineers with a wide range of experience. They produced interesting findings on how designers cycle between the activities of

analysis, synthesis and evaluation during the conceptual design stage. Kan et al. (2011) observed an industry team brainstorming session and measured frequencies of design operations and interactions on the individual and team level. Jiang et al. (2012) used protocol analysis to study designing styles of small teams within the context of different disciplines and tasks and classified their sessions into problem-focused or solution-focused. Following that, Gero et al. (2013) analysed design cognition during the implementation of different creativity techniques for the task of generating conceptual solutions. They coded the conceptual task execution of eleven design teams to find the correlation between structuredness of techniques used and the focus on the problem or solution-related aspects of designing. Mc Neill et al. (1998), Kan et al. (2011), Jiang et al. (2012) and Gero et al. (2013) all used the FBS ontology-based coding scheme in their studies. Finally, Wiltschnig et al. (2013) examined the validity of the problem-solution co-evolution model outside of a laboratory context with results supporting the existence of co-evolution episodes in design sessions.
Although research efforts mentioned above improved the understanding of designing in teams, the patterns of team behaviour within conceptual design remain outside the research focus. This paper aims to contribute by exploring the nature and regularities of design operations of teams in conceptual design, with an emphasis on fine-granularity and high level of abstraction for computational implementation.

3 RESEARCH METHODOLOGY

Guided by the related work and reported studies the empirical part of the research is designed in the form of a protocol study. Methodologically the study follows five main steps: (1) identification of available data (video recordings), (2) development of a coding scheme, (3) segmentation and coding of the recorded sessions, (4) analysis of captured protocols, and (5) discussion of the results. The methodological frame of the protocol study is illustrated in Figure 1. Steps 1-3 are briefly explained in this section. Steps 4 and 5 are presented within separate sections in the form of results and discussion.

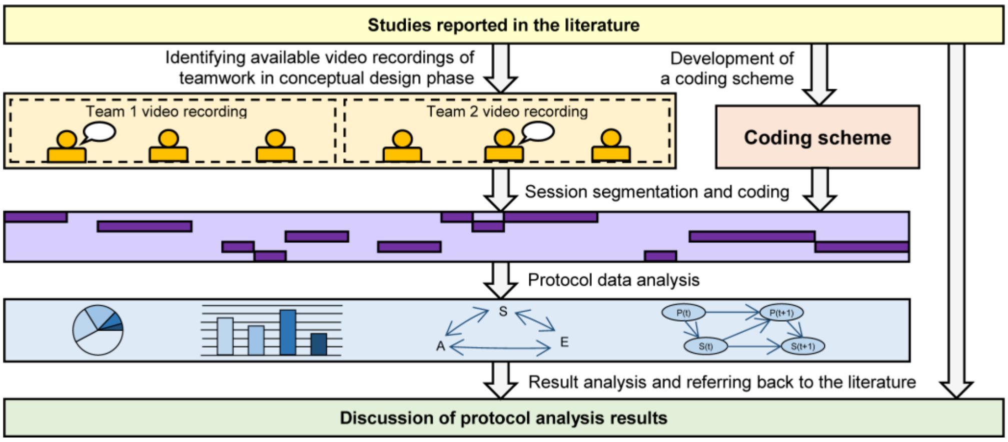

Figure 1. Methodological frame of the protocol study

3.1 Identification of video recordings data and analysis of the experimental set up

Video recordings of two idea-generation sessions in conceptual design phase were obtained from previously conducted studies by other authors (see Cash et al., 2013). The video recordings of idea-generation sessions were selected due to their availability and alignment to the defined research goals. The experiment set-up will be only briefly explained.
Two teams composed of three participants each were given a conceptual design task. They had 50 minutes for idea-generation using the brainstorming method to generate as many viable ideas as possible for a camera-mounting concept hanged under a helium balloon. The concept should be capable of mounting any camera and orienting it to any point in a hemispherical region and must be operated remotely. Teams should have recorded their ideas on the whiteboard. To reduce observation effects, the protocol was based on the participants' natural conversational acts, without verbalization requirements.
Team 1 was composed of students selected from a final year product design and development course. Such composition ensured a relatively homogeneous team with an average of 10 months industrial experience and four years of academic training background. Team 2 was composed of engineers selected in a small to medium size enterprise. Although all participants share a common domain knowledge, this

team was less homogeneous whereas members differ in the level of experience. For more information on the task and the formal comparison of the studied participants, please consult Cash et al. (2013) and Cash and Štorga (2015).

3.2 Coding scheme development

The coding scheme was developed based on the comprehensive analysis of protocol studies reported in the engineering design literature. The literature review exceeds the space available within this paper. Thus only the main guidelines and the end result will be presented. Several guidelines were followed when developing the coding scheme. Firstly, the coding scheme should reflect the elementary design operations of analysis, synthesis and the alternation of the problem and the solution related discussion during an idea-generation session. Secondly, it should drive abstract and fine-granularity protocol segmentation. Finally, it should allow mapping of the generic-design-steps coding scheme (Stempfle and Badke-Schaub, 2002) and designing processes of the FBS ontology (Gero and Kannengiesser, 2004). Generic-design-steps coding scheme is relevant as it can be applied for the coding of different stages of the design process and different types of activities such as idea-generation or decision-making. On the other hand, most state-of-the-art protocol studies are based on the FBS coding scheme, meaning that the possibility of mapping between the two schemes provides support for discussion, comparison and combining of results. Table 1 defines the codes for design operations used in this study and their mapping to general-design-steps and FBS processes elements. Note that FBS transition processes are not directly used when protocols are coded using the ontological coding scheme. Transition processes represent shifts between issue codes of the FBS-based scheme (Gero and Kannengiesser, 2004).

Table 1. Codes used to capture design team activity during an idea generation session

<table>
<tr><th>Code</th><th>Definition</th><th colspan="4">Mapping</th></tr>
<tr><td>Problem formulation (Pf)</td><td>Synthesis operation applied on the problem space - proposing, adding, removing, and changing requirements</td><td rowspan="7">Generic design steps (Stempfle and Badke-Schaub, 2002)</td><td rowspan="2">Goal clarification</td><td rowspan="7">FBS transition processes (Gero and Kannengiesser, 2004)</td><td>Reformulation II, Reformulation III ($S \rightarrow F$, $S \rightarrow Be$)</td></tr>
<tr><td>Problem analysis (Pa)</td><td>Analysis operation applied on the problem space - deriving functions and expected behaviour from requirements</td><td>Formulation ($R \rightarrow F$, $F \rightarrow Be$)</td></tr>
<tr><td>Solution generation (Sg)</td><td>Synthesis operation applied on the solution space - proposals and solution ideas concerning the design task</td><td>Solution generation</td><td>Synthesis, Reformulation I ($Be \rightarrow S$, $S \rightarrow S$)</td></tr>
<tr><td>Solution analysis (Sa)</td><td>Analysis operation applied on the solution space - questions and explanations concerning the generated solutions</td><td>Analysis</td><td>Analysis ($S \rightarrow Bs$)</td></tr>
<tr><td>Evaluation (E)</td><td>Evaluation operation applied in-between the problem and solution space – checking whether the proposed solution meets the design problem requirements</td><td>Evaluation, Decision</td><td>Evaluation ($Be \rightarrow Bs$, $Bs \rightarrow Be$)</td></tr>
<tr><td>Planning (P)</td><td>Communicative acts concerning the teams process (where to start, how to proceed, etc.)</td><td>Process-related steps</td><td>-</td></tr>
<tr><td>Other (O)</td><td>All other communicative acts such as naming facts and joking</td><td>-</td><td>-</td></tr>
</table>

The coding scheme consists of seven codes in total. Five are used to incorporate ASE operations and the problem-solution space. “Problem analysis” and “Problem formulation” are used to code analysis and synthesis operations applied on the problem space, while “Solution analysis” and “Solution generation” are used for the solution space. “Evaluation” code concerns both problem and solution space as it is used to compare entities from both spaces. These five codes are referred to as problem-solution focused codes. The remaining two codes are used to capture communicative acts that are not related to the problem-solution space. The “Planning” code is used for team's discussions on planning the session process. Stempfle and Badke-Schaub (2002) provide specific codes of the process-related steps that are not considered here due to the shorter duration of the session. All remaining communicative acts such as naming facts and joking were coded as "Other".

3.3 Segmentation and coding

The developed coding scheme was applied on the transcripts of the experiment videos. The application involved the steps of segmentation and coding, following the "one-segment-with-one-code" principle (see Jiang et al., 2012). Every segment was assigned with only one of the seven codes based on the coder's critical judgment. All segments without verbal acts were not coded and as such represent periods without team communication. Once the coding was completed the coder reliability was evaluated by comparing segments to the protocol data which was encoded for the same video recordings during previously conducted studies (see Cash and Štorga, 2015). Although the situations in which more than one designer was talking were rare, these segments were coded based on the statement that was more dominant and to which the discussion was continued.

4 RESULTS

The results are presented from two perspectives. First is the overall view on the idea-generation session and second is within ten equal time fractions (deciles) of 5 minutes. The breakdown into deciles is an inspired by Jiang et al. (2012) and Gero et al. (2013). However, fractions here share equal time duration, rather than an equal number of coded segments to allow analysis of protocols over time.

4.1 Overall session perspective

In total, 407 segments were coded for Team 1, and 481 for Team 2. Aggregated duration of coded segments represents the amount of team communication during the session. The time-share of team communication in the overall duration of the session for Team 2 is significantly higher than the one of Team 1 (83,3% versus 52,2%). Furthermore, the time-share of Team 1’s verbal segments drops with the progress of the session, but for Team 2 it stays even during the entire session.
The distribution of segmented codes is presented in Figure 2. It is evident that Team 1 spent more time formulating and analysing problems and Team 2 spent more time generating, analysing and evaluating solutions (Figure 2a). Both teams spent the majority of the ASE operation related discussion only to synthesise and analyse, with the evaluation design operation being rarely performed (Figure 2b). The focus on solution space by Team 2 and the focus on both spaces by Team 1 can be seen in Figure 3c.

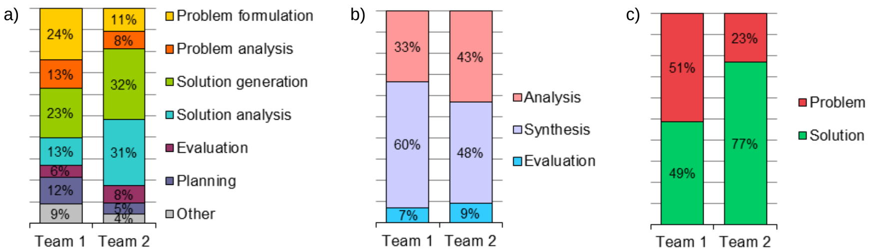

Figure 2. Distribution of segment codes for a) all verbal communication; b) ASE operation related communication; c) problem-solution related communication

Figure 2a also gives insight into time-shares of topics related to planning, during which teams discussed how to proceed in the session. Both teams referred to planning several times during the sessions. Among many short discussions, Team 1 had three lengthy discussions on how to proceed at the beginning, in the middle and at the end of the session. On the other hand, Team 2 planned the process extensively only at the start of the session, with several short planning discussions appearing later. Team 1 also spent more time discussing the content that does not contribute to the execution of the task (coded as "Other").

4.2 Design operations perspective

The process of Team 1 can be described as follows. Problem formulation appears during the entire session and gradually intensifies toward the end. Problem analysis is less present, with most appearing in the first half of the session. Solution generation and solution analysis operations intensively emerge during the first half hour. Evaluation rarely appears during the session - for the most part within the first 20 minutes (Figure 3a). A different approach is observed for Team 2. Most of their problem formulation and problem analysis take place in the first 20 minutes of the study and gradually decrease towards the end. Contrarily, the proportion of solution generation and solution analysis increases, as in the last 10 minutes more than 80% of communication is solution-focused. Evaluation appears more often and more evenly than with Team 1 (Figure 3a).

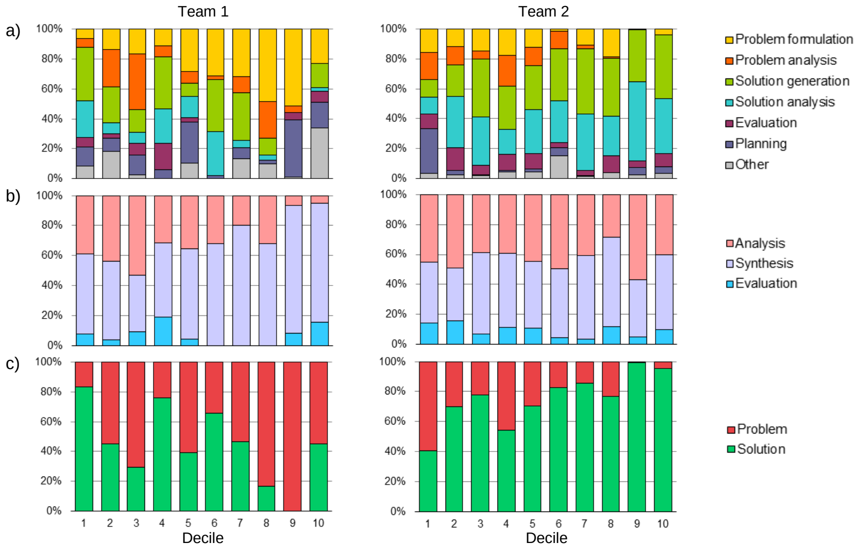

Figure 3. Distribution of segment codes across the deciles of the idea-generation session for a) all verbal communication; b) ASE operation related communication; c) problem-solution related communication

One could also analyse the amount of discussion which is not related to problem or solution spaces. For example, the last decile of Team 1 session contains less than 50% problem-solution-related discussion, since most of it is coded as planning-related or as "other". Team 2 kept the time-share of problem-solution-related conversation over 90% during most of the session.

If the process-related and problem-solution aspects are removed from the segment analysis, one can analyse the distribution of ASE related communication (Figure 3b). Thus, it can be noted how Team 1 increased the time-share of synthesis operations and decrease in time-share of analysis operations as the session progressed, while Team 2 maintained a rather stable proportion of ASE related communication. In the same manner, if the process-related and ASE aspects are removed from the segment analysis, it is possible to analyse the distribution of problem-solution related communication (Figure 3c). On average Team 1 distributed discussion time almost equally on problem-related and solution-related content. But if problem-solution space focus is observed for each decile, it is evident that the first 30 minutes of the session were spent mainly in the solution space, while during the last 20 minutes the focus of the discussion shifted to the problem space. To the contrary, Team 2 spent on average significantly less time in the problem space. Only in the first decile were problem-related issues predominant, but as the session continued, the ratio of problem over solution related content decreased.

Finally, it is possible to analyse the transitions between the coded segments. Figure 4 shows the distribution of transitions between the ASE design operations for the two teams. Transition results show that for the Team 1 77,8% and Team 2 60,0% of transitions went in the following three directions: synthesis→synthesis, synthesis→analysis and analysis→synthesis (highlighted on Figure 4). A similar analysis of transitions between ASE design operations was performed within the problem-solution space. In short, the most dominant transitions for Team 1 were the cycles of problem formulation related discussion: Pf→Pf (20,1%). For Team 2 three transitions stand out: Sg→Sg (12,7%), Sg→Sa (11,9%) and Sa→Sg (11,3%). The complete transition table is not presented due to available space.

Team 1

	Analysis	Synthesis	Evaluation
Analysis	4.3%	20.9%	2.1%
Synthesis	20.1%	36.8%	6.4%
Evaluation	2.6%	6.0%	0.9%

Team 2

	Analysis	Synthesis	Evaluation
Analysis	7.6%	20.1%	6.8%
Synthesis	18.1%	21.8%	8.5%
Evaluation	8.8%	6.5%	2.0%

Figure 4. Distribution of transitions between ASE design operations

5 DISCUSSION

5.1 Decomposition of teamwork activity in conceptual design

The coded segments reveal variations of ASE design operation sequences appearing during idea-generation sessions. Protocol analysis of both teams revealed the average proportion of approximately 38% of analysis, 54% of synthesis and 8% of evaluation (based on Figure 2b). This distribution corresponds to the proportion of mapped design issue transitions reported for the brainstorming-driven idea-generation sessions in Gero et al. (2013). Thus, the combination of the method used (e.g. brainstorming) and the design stage (e.g. conceptual design) could potentially be related to the proportion of ASE design operations. However, protocol analysis of brainstorming sessions presented in Kan et al. (2010) shows a significantly higher rate of synthesis design operation, mainly in the solution space. Thus, a more comprehensive analysis is required to identify the factors responsible for this difference.

The distribution of transitions between the design operations (Figure 4) confirms that the often-disputed model of the consistent analysis-synthesis-evaluation sequence (Asimow, 1962) doesn't reflect the nature of idea-generation activity if the brainstorming method is utilised. Both teams show the most dominant transitions to be: from synthesis back to synthesis, from analysis to synthesis and from synthesis to analysis. Such alternation of synthesis and analysis in both problem and solution spaces is typical for idea-generation sessions (Liikkanen and Perttula, 2009; Afcan and Demirkan, 2010). The alternation of these two design operations can also be recognised as part of the GSP cycle of Jin and Benami (2010), where synthesis operations generate a change of design content, which in turn stimulates cognition processes to produce the analysis operation. The analysis is performed to understand better the new situation, which again stimulates cognitive processes to produce synthesis design operations, thus closing the cycle. Such cycles are repeated until the particular aspect of design entity evolves to a satisfactory level or the topic changes to another design entity aspect. This pattern is especially notable during the session of Team 2, as an alternation of solution generation and solution analysis during the entire session.

Finally, both teams show a small proportion of evaluation operations. This behaviour can be explained as the nature of utilising the brainstorming method, where participants are guided to generate as many ideas as possible and avoid criticism of ideas. If the method or the task description encouraged any form of decision-making, the proportion of both evaluation design operations and correlated transitions is expected to increase (e.g. as reported in Mc Neil et al., 1998; or Stemfle and Badke-Schaub, 2002).

By referring to the first research question, it can be concluded that there exists a potential for decomposing design team activity within the conceptual design using ASE design operations as abstract and fine granularity design steps coupled with monitoring the alternation of problem and solution spaces. Concretely, support was found for dominant sequences between synthesis and analysis, and the proportion of analysis, synthesis and evaluation operations during an idea-generation session.

5.2 Alternation of problem and solution spaces

Results reveal the alternation of problem and solution related content within the discussions of both teams. Cross (2001) explains that since design problems are often regarded as ill-defined designers do not typically start by pursuing to define their problems rigorously. Instead, they progressively define the problem in relation to solution ideas they are developing. Furthermore, if brainstorming method is perceived as a tool of creative design, then the alternation of problem and solution related discussion supports the co-evolutionary models of designing (Maher et al., 1996) and creative design (Wiltschnig et al., 2013; Dorst and Cross, 2001).

Teams do not share a similar progress in the problem-solution space, as Team 2 is solution-focused and Team 1 is mainly problem-focused. The trend of time spent in the problem and solution-related discussion of Team 2 (Figure 3c) is qualitatively aligned with the findings of Jiang et al. (2012) and Gero et al. (2013). Their results show the decrease of problem-related in relation to solution-related issues as the brainstorming session proceeds. On the contrary, the ratio of Team 1 deviates, as the team shifts focus entirely on problem-related aspects towards the end of the session. The explanation for the different approach of Team 1 can partially be found in Cross (2001) as a consequence of a difference in experience. Cross points out that inexperienced designers spend more time on defining the problem, while designers with specific experience of the problem type tend to approach the task through solution conjectures. Furthermore, the need for a problem-focused approach of Team 1 can partially be explained as a consequence of less experienced team members. Liikkanen and Perttula (2009) demonstrate this in a way that the novices start developing a problem structure to solve individual problems if they cannot find a direct solution via recognition, while experts recognise and recall more complex solutions without performing extensive decomposition of the problem. Finally, the different time-shares of problem and solution related discussions can be the interpreted as a consequence of different designing styles of design teams (Jiang et al., 2012), which are the result of several characteristics including design task requirements and team members' background.

By addressing the second research question, it can be concluded that, within the extent of presented analysis, no direct relation was found between the distribution of ASE design operations and the alternation of problem and solution spaces. Nevertheless, some segments within the protocol analysis show the potential of correlating design operations and problem-solution co-evolution. For example, the intensive alternation of analysis and synthesis operations suggest the evolution of a single space (either problem or solution), while many transitions from problem analysis to solution generation and from solution analysis to problem formulation suggest bi-directional nature of co-evolution (see Wiltschnig et al., 2013). These segments require further, more thorough analysis.

6 CONCLUSIONS AND FURTHER WORK

The presented explorative study of the nature of teamwork activity in conceptual design phase produced insights on how design teams behave during the teamwork activities with regard to applying design operations in the problem-solution space. The approach of decomposing teamwork activity into abstract and fine-granularity design operations coupled with the alternation of problem and solution spaces has been tested using protocol analysis. The findings derived from the results support and complement what has been reported in the literature. The protocol analysis revealed cycles of synthesis and analysis within both problem and solution space during the idea-generation session when teams utilise the brainstorming method.

The potential of describing and modelling teamwork activities using the abstract design operations now has to be further explored. Firstly, the findings cannot be generalised due to limited sample size and configuration of teams. Additional studies with a greater sample size and are needed to draw general conclusions. Secondly, the analysis should also include the comparison of expert and novice designers to investigate the effect experience can have on the application of design operations and the alternation within problem-solution space. Finally, further work should explore the influence of team member discipline, background, knowledge, creativeness and other designer characteristics that could have a significant impact on team behaviour.

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