ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

MEASURING SHAREDNESS OF MENTAL MODELS IN ARCHITECTURAL AND ENGINEERING DESIGN TEAMS

Hernan CASAKIN (1), Petra BADKE-SCHAUB (2)
1: Ariel University, Israel; 2: Delft University of Technology, The Netherlands

ABSTRACT

The study presented in this paper investigates the development of sharedness of mental models in situations of design problem solving. A basic assumption is that sharedness of individual mental models is attained through verbal communication. Thus, the basic theoretical framework we developed is based on the classification of verbal communication occurring during the design process. The application of the theoretically based classification focuses on the dynamic development of mental models in heterogeneous design teams. The empirical study is based on observational data from a meeting of two design teams belonging to the engineering and architectural discipline. Whereas sharedness is supposed to be attained from the earlier phases of the design process, this might vary for design acts in which explicit coordination is still necessary. We explore coordination in both teams through two main phases of the design meetings.

Keywords: design problem solving, teamwork, mental model, coordination, sharedness

Contact:
Dr. Hernan Casakin
Ariel University
Architecture
Ariel
44837
Israel
casakin@bezeqint.net

1 INTRODUCTION

Design can be understood as the integration of individual and collective work (Denton, 1997). When design is seen as the result of team activity, the analysis of the interactions of team members enables gaining insight into the way that team reaches successful or less successful outcome. As designing is a combination of individual and collective activities, the study of team behavior should consider social and cognitive factors. The former is concerned with coordination processes of the team members mainly by verbal communication (Badke-Schaub and Buerschaper, 2001; Cannon-Bowers, 1993), and the latter mirrors the individual cognitive representations, also known as mental models (Byme, 2002). Mental models are internal representations that designers develop in order to respond fast under changing conditions. The communication of individual mental models allows gaining a mutual, and occasionally a shared understanding when working collaboratively.

This study explores the role of mental models in design problem solving and focuses on differences in the development of mental models in two at first glance very different design disciplines, engineering design and architecture. The investigation intends to contribute further to the measurement of sharedness of mental models, which is a most important feature of team mental models affecting performance and coordination (Bierhals et al., 2007; Cannon-Bowers et al, 1993). Team coordination can be defined as the assortment of activities that take place in the different stages of design problem solving among team members. Team coordination can be explicit or implicit. The former is manifested mainly through verbalizations, gestures, and sketch representations (Goldschmidt, 2007), and contributes to share similar understanding of the design task among team members. The latter does not require overt information exchange of any kind, and is supposed to develop over time.

A number of studies have shown a causal relationship between test coordination and shared mental models, and between performance and shared mental models (Bierhals et al., 2007; Eccles and Tenenbaum, 2004). In this study we aim at exploring what kind of coordination can be observed during the development of different team mental models in the architectural and engineering disciplines. In a number of hypotheses concerned with the development and sharedness of team mental models, we postulate that explicit and implicit coordination are two forms of activities, which occurrence is affected by the types of design acts related to the different mental models. Accordingly, while for some design acts implicit coordination may be achieved over time, for others it may require an explicit coordination all through the design process. Another aim is to gain insight into how sharedness develops over time, and how changes in mental models influences the coordination and performance processes in each design discipline.

2 HOW DO MENTAL MODELS GUIDE THE BEHAVOUR OF DIFFERENT DESIGN TEAMS

The construct of mental model is helpful for enhancing the understanding of team processes. Mental models are referred to as internal representations that provide a quick check between reality and cognitive representations within the surrounding environment, which embraces both artifacts and designers (Gentner and Stevens, 1983). Mental models are a basic structure of cognition necessary for understanding, and representing cognitive processes in problem solving (Craik, 1943), as well as for predicting individual or team performance and behavior (Cannon-Bowers et al., 1993; Norman, 1983).

2.1 What are mental models?

Mental models can be defined as simplified representations of the world that human beings produce for quickly processing new information, and acting in unfamiliar situations (Badke-Schaub et al., 2007; Badke-Schaub et al., 2011; Smyth et al., 1994). Another important function of mental models is that they can contribute to enhance team communication (Klimoski and Mohammed, 1994), and to guide the behavior of team members when dealing with new situations (Stempfle and Badke-Schaub, 2002). These cognitive mechanisms aid to understand what type of knowledge individuals and teams exchange, how they organize it, and what are their beliefs and perceptions about the problem (Smulders, 2007). Given that designers may possess different knowledge, skills, expertise, and objectives, the way they approach a design problem can vary significantly with respect to other team members. Yet, while they exchange views with others, they develop gradually their own representations and adapt them to build mental models that are shared by the team.

2.2 A framework for studying the development of mental models in teams

In this study we introduce a theoretical approach for analyzing the development of shared mental models that is partially based on the work presented by Badke-Schaub et al., (2011). The model starts from a basic distinction between taskwork, embracing content and process aspects, and teamwork, including cohesion and social atmosphere issues. Accordingly, it distinguishes among four types of mental models dealing with task, process, team cohesion, and team atmosphere.

The task mental model refers to the communication of knowledge related to the problem at hand. It embraces representations related to the framing of the problem, the generation of ideas, the production of explanations, analyzes and evaluations of solutions and decisions. The process mental model is concerned with conjectures associated to the appropriate practices for solving the task. It includes the strategies, rules and procedures that need to be considered in order to attain the goals, and arrive at a satisfactory result. Process mental models are critical for design problem solving, characterized by the absence of routine procedures (Edmondson and Nembhard 2009). Aspects influencing the extent to which process mental model are communicated within the team include information exchange about planning (in what moment to proceed and what to do), procedures (in what way to proceed, as well as planning strategies and methods to use), and reflection (considerations about what the team has already accomplished, and how it should continue in the coming steps).

Finally, team mental models represent how team members work together as a social group. Badke-Schaub et al., (2011) further differentiate between team cohesion and team atmosphere. Team cohesion reflects the consent of team members being part of the team and embraces: appreciation and rejection related to the approval or disapproval of other team members or their contributions; confirmation, a positive assessment supporting communication exchange among team members; and help, the assistance endowed among the team members. Team atmosphere embraces the communication processes that takes part in keeping a harmonic and positive team climate and includes: informal talk, which improves mutual knowledge about individual inclinations and preferences as well as laughter.

3 SHAREDNESS OF MENTAL MODELS IN DESIGN TEAMS

When exchanging information with other team members, an individual mental model can develop into a shared mental model. Various empirical studies have shown that the successful work of a team was largely influenced by the extent to which its members shared their individual mental models (Badke-Schaub et al., 2011; Mathieu et al., 2008). Thus, as information exchange augments, also the knowledge that is shared by the team increases.

3.1 Basic assumptions

In their framework, Badke-Schaub et al. (2011) propose that shared mental models develop over time from explicit information exchange to implicit knowledge about the task, the process, and the team. Explicit communication acts, externalized mainly through verbalizations, gestures, and sketch representations (Nik Ahmad Ariff et al., 2012), enable team members to share their understanding of the design situation. When teams manage to achieve a certain amount of sharedness of their mental models, they are supposed to coordinate their design actions without permanent and explicit information exchange. However, what exactly “a certain amount” might be has never been operationalized. The more sharedness is often believed to lead to better performance (Mesmer-Maguns and De Church, 2009). But for a highly synchronized groupthink (Janis, 1972), it always exists a risk of lack of independent thinking, that may derive into design fixation (Janson & Smith, 1991). According to Badke-Schaub et al. (2011), two different stages characterize the development of shared mental models: (i) an initial phase where the team develops shared mental models in an explicit and coordinated fashion, mainly characterized by verbal communication; (ii) a later phase, in which after some degree of sharedness has been accomplished among members, more implicit than explicit coordination takes place. Consequently, a mutual understanding characterized by the development of a common understanding of norms and rules needs first to be established, before maximal efficiency is achieved (Tuckman, 1965).

3.2 Measuring the development of mental models in design teams: coding scheme

Mohammed et al. (2000) defined shared mental models as the degree of superposition among team members regarding the content of known elements, and the structure between elements. However,

most of these studies do not offer any indication about how is possible to measure mental model components and their possible connections over time. Despite the existence of research how designers think and act in real settings (Badke-Schaub and Frankenberger, 1999), and in artificial environments (Badke-Schaub, et al., 2007; Bierhals et al., 2007) the process of how mental models develop is not well understood. However, analyzing the development of mental models can contribute to enhance our understanding about team coordination (Klimoski and Mohammed, 1994; Schaub, 2007).
Therefore, in the present study we propose a method for measuring the development and sharedeness of mental models that is based on the analysis of explicit verbal communication of team members. The uninterrupted observation of design team behavior by means of the analysis of verbal communications produced during the problem solving sessions, affords a convenient method for measuring the development of shared mental models. In this work, verbal utterances are coded in terms of the categories and sub-categories that are partially based on the model proposed by Badke-Schaub et al (2011). The categorization consists of the four types of team mental models that are detailed in Table 1: task, process, team cohesion, and team atmosphere, and the corresponding subcategories. These subcategories, however, are not assumed to be completely independent from each other. When statements contained more than one topic, they were parsed in such a way that each part could be classified into a single category. Verbal activities were coded by the two researchers that authored this paper, and Fleiss' kappa (Fleiss, 1971) was found to be 0.72 on the level of the subcategories, denoting substantial agreement.

Table 1. Categorization system for verbal activities (explicit coordination) in teams

Task	PD	Problem definition	Definitions that are mentioned in order to define the problem
	SI	New solution idea or new solution aspect	Stating a new idea or a new solution for a problem or sub-problem, or new aspects of an earlier solution idea
	SA	Solution analysis	Analysis of characteristics and potential application of a solution idea
	SAE	Solution evaluation	Evaluation of a solution idea by assessing its value and feasibility
	SAX	Explanation	Clarification of aspects and questions related to design issues, i.e., user, technical, budget.
	SD	Solution decision	A final and definitive decision
Process	PL	Planning	Aspects related to when to proceed and what to do
	PR	Procedure	How to proceed to approach the task, strategies and which methods may be used
	RF	Reflection	What the team has been doing so far and what variables have shown influence
Team cohesion	AP	Appreciation	Approval of other team members supporting an idea, an explanation or a problem definition
	C	Confirmation	Positive statements confirming other team members' statements
	RJ	Rejection	Disapproval of other team members about an idea, an explanation or a problem definition
	H	Help	Aid or assistance provided to other team members
Team atmosphere	IT	Informal communication	Statements not directly related to the task at hand
	L	Laugh	Laugh spontaneously expressed

4 METHODOLOGICAL APPROACH

To exemplify the use of our methodological approach, we analyze two case studies from the Design Thinking and Research Symposium, DTRS 2007 in London (see McDonnell and Lloyd, 2009). Videos and verbal transcripts of design team meetings were available to the participants of the symposium for its analysis. One data set involved two meetings by an engineering design team, and another two meetings by an architectural team. In this paper we analyze the first meeting of each group, which is the most rich one in terms of communications. In each meeting, designers were requested to generate ideas and solutions for a new design product. Transcriptions from the videotapes were parsed into utterances, and coded with regard to a categorization system. The analysis inspected the manner that communication among team members developed through time. Design meetings were divided into two parts containing an equal number of lines as supplied in the transcripts. Categories were classified into task, process, team cohesion, and team atmosphere. Mangold InterAct (version 9.3.5 http://www.mangold.de) software was applied for information coding. This software program supports the coding and rendering of behavioral data per time unit, and statistical calculations of the coded results in an easy way.

4.1 Sample

Seven designers from a technology development company formed the engineering team. It was composed of a business consultant in the role of a group moderator, a person from the business development, one expert in electronics and another in ergonomics and usability issues, three mechanical engineers, and an industrial design student. The architectural team consisted of a municipal architect, the manager of the existing facility, and an officer from the local government on behalf of the municipality.

4.2 Design tasks and procedure

The architectural task consisted in the design of a municipal crematorium to be situated nearby an existent one. The brief contained a series of facilities that included a cremation room, waiting rooms, a vestry, a chapel for 100 people, as well as parking zones. The engineering task dealt with the design of an original print head mounting for a thermal printing pen. The pen had to be produced as a kind of artist's instrument, or as a toy. Designers were informed about the various aspects to be considered along the meeting, and were advised to employ brainstorming techniques, and to imagine possible analogies that could aid to solve the problem.

4.3 Hypotheses

Based on the theoretical framework illustrated above, we present hypotheses concerned with the development from unshared to shared mental models.

H1. Task. At the outset of the meeting, verbal utterances need to be related to problem definition, idea generation, explanations, analysis, and evaluation. Since members in both teams are not very familiar with each other, their shared understanding about the task would be low, and thus a high number of communication activities is expected. While the work evolves, their knowledge about the task and potential solutions is believed to increase, and therefore fewer utterances should occur, mainly for problem definition and idea generation. Nevertheless, the team is supposed to continue generating explanations, analyses and evaluations of solutions, so these task-related utterances will not decrease along the process. On the other hand, decisions about solutions will be taken at the end of the process, and thus will increase significantly over time. When considering all task-related utterances together, it is hypothesized that they will be higher in the first phase of the meeting.

H2. Process. Knowledge exchanges related to the process are supposed to develop by an increase in planning aspects in the first part of the process, and should decrease after a shared understanding has been achieved. While procedural and reflection aspects may serve to remind the team on what is doing and how is proceeding throughout the whole design meeting, a possible increase in these process-related utterances can be also expected at the end of the first meeting to arrange certain planning activities for the next session. When considering all process-related utterances together, no differences are expected along the whole process.

H3. Team cohesion. Taking into account that members in both teams have different knowledge and skills, they are believed to strive for attaining a shared understanding among each other. Therefore, team cohesion utterances are expected to develop all over the whole design meeting.

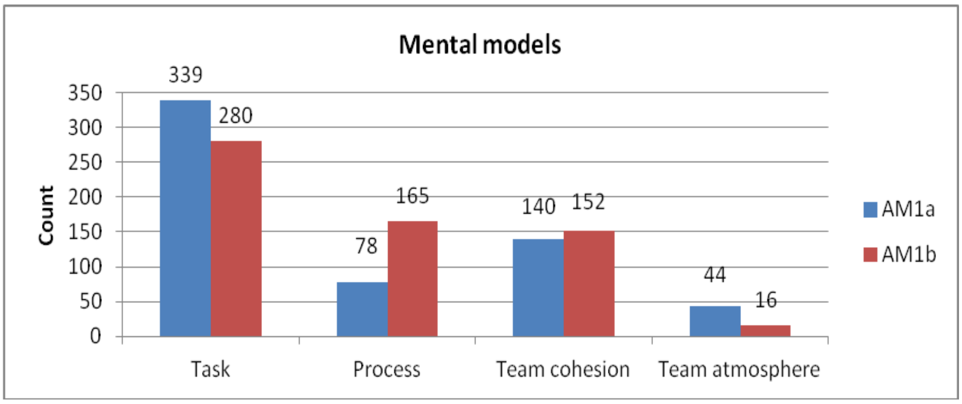
H4. Team atmosphere. Since team members are not familiar with each other, team atmosphere utterances are expected to be higher in the first phase, when team members attempt to gain mutual acceptance and build trust among each other.

5 RESULTS: THE DEVELOPMENT OF SHAREDNESS IN THE ARCHITECTURAL AND ENGINEERING TEAM

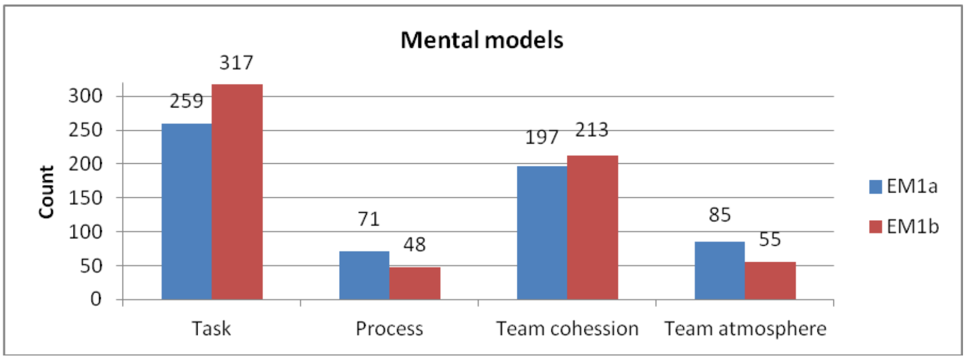
Results from the case studies are presented and discussed according to the proposed hypotheses. Figures 1a-b depicts the cumulative activity counts per design team, according to the first and second phases of the sessions, related to the main categories task, process, team cohesion, and team atmosphere**.**

5.1 Extent of sharedness with regard to mental model categories

In the architectural team, there were a total of 1214 utterances in the first phase, where 51% corresponded to the *Task* activities, a 20% to *Process*, 24% to *Team cohesion*, and 5% to *Team atmosphere*. In the engineering team, there were a total of 1389 utterances, 52% of which corresponded to the *Task* activities, a 13% to *Process*, 27% to *Team cohesion*, and 8% to *Team atmosphere*. These results indicate that the *Task* mental model plays a key role in both teams, followed by *Team cohesion*.



(a)

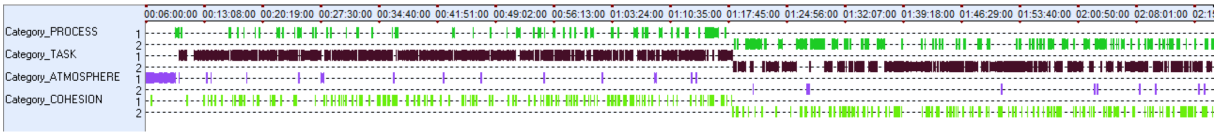


(b)

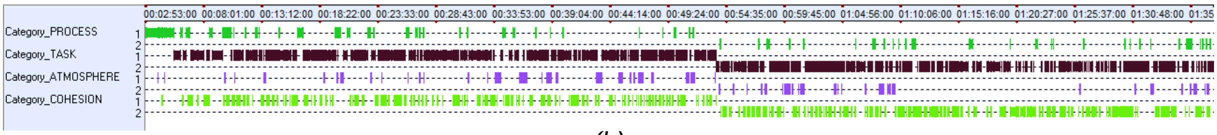
Figure 1: Mental model categories cumulative counts per design team - (a) architectural team; (b) engineering team

A chi-squared test of independence between the first and second phases of the meeting revealed that the frequency of the observed utterances for the four mental model categories in both groups were significantly different than the expected utterance counts overall. Whereas in the architectural team x^2 (3, 1214) = 50, p<0.001, two tailed), in the engineering team, x^2 (3, 1389) = 13, p<0.01, two tailed).

According to predictions, task and atmosphere-related utterances in the architectural team were higher in the first phase of the meeting (both residuals p<0.001, two tailed), whereas no differences in cohesion-related utterances were found when compared across the two phases of the meeting. However, in contrast to our expectations, process-related utterances were higher in the second phase (p<0.001, two tailed). As expected, in the engineering team atmosphere-related utterances were higher in the first phase of the meeting (p<0.01, two tailed), and no differences were found for cohesion utterances. However, the frequencies for task and process utterances failed to confirm our hypotheses. As predicted, results showed that the architectural team behaved like the engineering team in terms of cohesion and atmosphere-related aspects, but differed with regard to task and process. Findings suggest that the architectural team dedicated its initial efforts to create a positive climate among team members to exchange knowledge communication related to the design task. Differences in background are believed to be a main factor for this (Bradshaw, 1989), considering that the architect and the clients may have struggled for reaching a shared understanding on cohesion-related issues all over the whole design session. Figure 2a shows at the beginning of the session the existence of a remarkable intensity of communication acts related to team atmosphere. The prediction that process-related utterances increased towards the end indicate that sharedness among team members was not completely attained (See Fig. 2a). A reason could be also attributed to differences in knowledge and skills in the architectural team that might have caused a need in communication reinforcement for either discussing or corroborating some procedures necessary for the successful attainment of the design goal. Also in the engineering team first efforts were set to generate a positive climate at the end of the first phase, although relatively more attention was dedicated to reach a mutual understanding in procedural issues (See Fig. 2b). The fact that members of this group were not familiar with each other may explain why no significant differences in the frequency of communications related to task and cohesion aspects were found over time. It is suggested, that the group did their best to reach a shared understanding along the meeting.



(a)



(b)

Figure 2: Activity focus according to main design activities belonging to the mental model categories developed over the course of design – (a) architectural team; (b) engineering team

5.2 Extent of sharedness with regard to mental model sub-categories

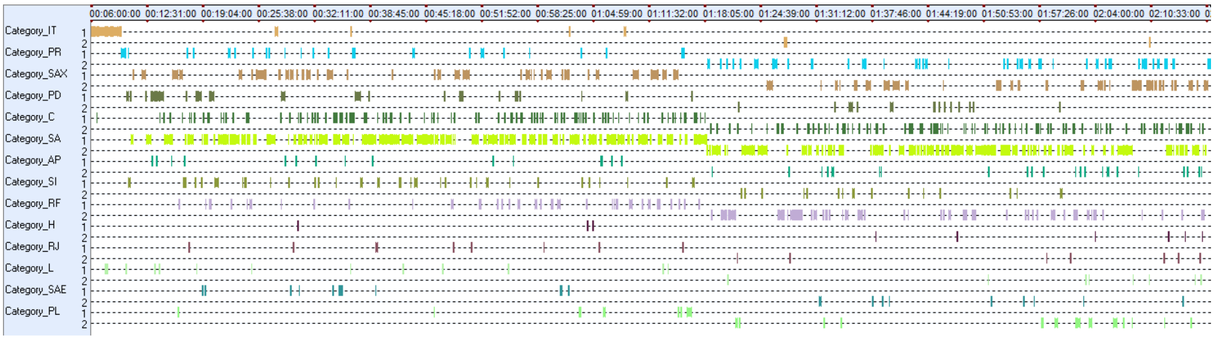
We further differentiated the results in terms of the design activities related to sub-categories within each mental model that was described.

A chi-squared test of independence between the first and second phases of the meeting showed that the observed utterance counts for the different mental model sub-categories in both groups were significantly different than the expected utterance counts overall. Whereas in the architectural team, x^2 (13, 1214) = 68, $p<0.001$, two tailed), in the engineering team, x^2 (3, 1389) = 80, $p<0.001$, two tailed).

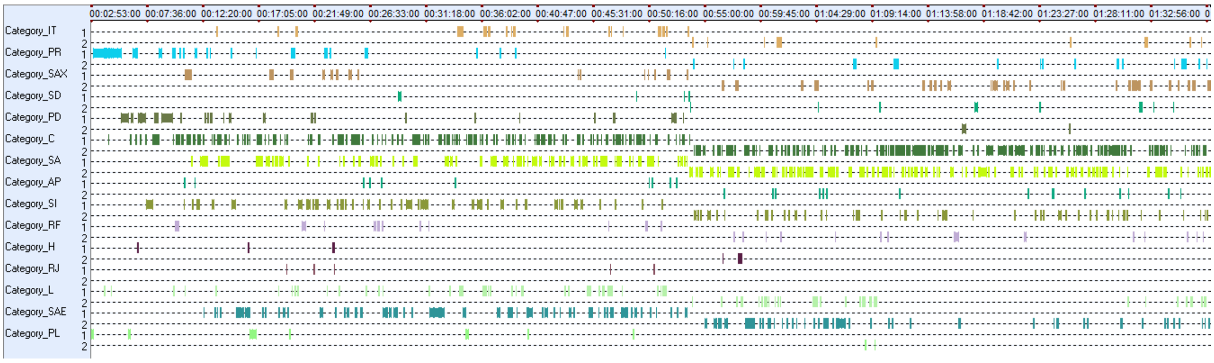
Task. As predicted, results in the architectural group showed that the frequencies of new ideas and analysis of solution utterances decreased significantly from the first to the second phase of the meeting (both residuals, $p<0.01$). Explanations and solution evaluations remained stable throughout the whole meeting, as expected. However, in contrast to our hypothesis the group continued defining problems, despite no solution decisions were taken at any time. In the engineering group, results showed that according to what was hypothesized, the frequencies corresponding to problem definition and solution evaluation utterances decreased significantly from the first to the second phase of the meeting ($p<0.001$ and $p<0.05$), and solution decisions increased in the second phase ($p<0.05$). Yet, against our predictions, whereas no differences were found in the generation of new ideas, solution analysis and explanations were higher at the end of the process ($p<0.01$ and $p<0.05$).

The decrease in regard to the frequencies of new ideas and analysis of solutions indicates that the architectural team managed to develop sharedness for these topics from the outset. Possibly, an increase of problem definition observed in the second phase of the meeting did not lead to the generation of new ideas, but instead created the need to produce additional explanations and solution evaluations. It is probable that since no sharedness was attained for problem definition, the team was unable to produce final design decisions (See Fig. 3a, PD, SI, SA, SAX, SAE). In contrast, in the engineering group sharedness for problem definition and solution evaluation was reached from the beginning of the session, and thus most solution decisions were taken at the end. However, in the second phase the team still felt the need to produce further new ideas, analyze solutions and produce additional explanations, which might suggest that sharedness was not developed to a sufficient extent till that stage. These results also show that when an unshared issue was raised by the group, more explicit communication about this topic was demanded (See Fig. 3b, PD, SI, SA, SAX, SAE, SD).

Process. According to our expectations, procedural and reflection aspects showed to be higher in the second phase of the architectural meeting (both residuals, $p < 0.001$). But in contrast, planning was developed throughout the whole design process, and therefore no differences were found between the first and second phases. On the other hand, all the hypotheses were met for the engineering team. Results showed no differences for procedural and reflection aspects along the process, whereas planning aspects become more frequent at the beginning ($p < 0.05$).
As expected, following a phase of explicit coordination with regard to planning, the engineering team managed to develop a shared understanding. Such increase in sharedness led to more implicit coordination and consequently, the frequency of this type of process utterances decreased towards the end of the meeting (See Fig. 3b, PL, RF, PR). On the other hand, the total number of procedures and reflections stayed the same in the first and second phases of the meeting, enabling to gain a good overview about what the team was doing, how they proceeded, and what procedures were used during the entire process. This behavior was also characteristic in the second half of the architectural session, suggesting that some commonalities could be identified between the process of both groups or in the design process in general (See Fig. 3a, PL, RF, PR).



(a)



(b)

Figure 3: Activity focus according to main design acts belonging to the mental model sub-categories developed over the course of design. (a) architectural team; (b) engineering team. IT: Informal Talk; PR: Procedure; SAX: Explanation; PD: Problem definition; C: Confirmation; SA: Solution analysis; AP: Appreciation; SI: New Idea; SD: Solution decision; RF: Reflection; H: Help; RJ: Rejection; L: Laugh; SAE: Evaluation; PL: Planning

Team cohesion. The expectation that team members will strive for attaining a shared understanding among each other throughout the whole design meeting was met in both teams. As a result, no differences regarding the frequencies of appreciations, confirmations, rejections, and help aspects were found between the initial and final phases of the design work. Members of cohesive teams more frequently take on fluent and active communication (Owen, 1985), and it is highly probable that cohesion utterances play an important role in the development of team mental models till the end of the session. Our findings suggest that both design teams felt in the need of receiving continuous feedback for supporting their ideas and personal views as a way of attaining sharedness (See Figs. 3a-b, AP, C, RJ, H).

Team atmosphere. The prediction that team atmosphere utterances will be more frequent in the first part of the meeting was partially met. In both teams, informal talk utterances were as predicted significantly higher in the first phase (both groups, $p<0.001$), However, in contrast to our hypothesis no differences were observed in each group for laugh utterances along the process.

Building trust and friendly relationships among team members is very likely to be a prerequisite for developing sharedness of team mental models. The lack of familiarity in both teams is supposed to be a major reason due to which informal talk was higher at the beginning. However, the finding that laugh stay the same along the process may indicate that sharedness was not completely reached (See Figs. 3a-b, IT, L).

8 CONCLUSIONS

This study dealt with the measurement of sharedness in different design teams from the architectural and engineering domain, based on the categorization of observed data, and how the models develops over time. Data was coded in terms of mental models, which were categorized according to task, process, team cohesion, and team atmosphere aspects. Considering the theoretical notion of the role of shared mental models in the transition from explicit to implicit coordination, hypotheses were tested. Although a restrictions of this study is the few number of cases deal with, it should be stated that a quantitative study would not had allowed to analyze the phenomena into depth. Based on the proposed methodology, the frequency of certain verbal utterances in each study sample were expected to initially increase for the sake of attaining sharedness and then turn down over the course of the design session once sharedness increased. Other verbal utterances were expected to stay the same over time.

Both similarities and differences were observed between the engineering and architectural groups when comparing mental models developed in the first and second phases of the meetings. While differences can be attributed to the specific background and composition of each group, similarities between the groups may be considered as an indication supporting possible generalizations for certain behaviors across the different design disciplines.

On the whole, the main contribution of this study is that the methodology for assessing the development of team mental models by means of two main design phases showed to be suitable for addressing the temporal, and dynamic characteristics of sharedness. In many cases, results supported the view that the team is in the need of exchanging more information in the first phase of the design activity, and through this behavior to eventually develop shared mental models. In other cases, it was found that some communication acts are necessary to take place over time in a same proportion.

One limitation of this study is related to the composition of the design teams (e.g., background and expertise), over which we had no control. Regarding size, background and skills of the group, the engineering team had a larger number of members and can be considered to be more homogeneous than the architectural team. It is possible that any of these aspects could have affected to some extent the dynamics of the design activity, as well as the content and frequencies of information exchange among team members with regard to the different mental models. Another limitation of the approach is that the content of the mental models can be only assumed from the transference of communication acts. Therefore, it is not possible to differentiate between situations where low transference of communication is due to implicit understanding and good sharedness among team members, or from circumstances where a decrease in utterances is related to a wrong assumption that they are sharing a similar mental model (Badke-Schaub et al., 2011). Despite these limitations, the contribution of the present study is lying in its methodology that combines both, qualitative and quantitative data for both visualizing and measuring cognitive and social aspects of the design activity from the perspective of mental models.

REFERENCES

Badke-Schaub, P. and Buerschaper, C. (2001) 'Creativity and complex problem solving in the social context', in Allwood C. M. and Selart M. (eds.), *Decision Making: Social and Creative Dimensions*. Dordrecht: Kluwer, pp. 177-196.

Badke-Schaub, P. and Frankenberger, E. (1999) Analysis of design projects. *Design Studies*, Vol. 20,

465-480.
Badke-Schaub, P., Neumann, A., Lauche K. and Mohammed, S. (2007) Mental models in design teams: a valid approach to performance in design collaboration? *CoDesign*, Vol. 3, 5–20.
Badke-Schaub, P., Neumann, A. and Lauche, K. (2011) An observation-based method for measuring the sharedness of mental models in teams. In Boos, M., Kolbe, M., Kappeler, M. P. M. and Ellwart, T. (eds.), *Coordination in human and primate groups*, Springer-Verlag, Berlin, pp. 177-197.
Bierhals, R., Schuster, I., Kohler, P. and Badke-Schaub, P. (2007) Shared mental models – Linking team cognition and performance. *CoDesign*, Vol. 3, 75–94.
Byme, R. (2002) Mental models and counterfactual thoughts about what might have been. *Trends in Cognitive Sciences*, Vol. 10, 426-431.
Cannon-Bowers, J. A., Salas, E. and Converse, S. (1993) Shared mental models in expert team decision making. In Castellan Jr., N.J. (ed.). *Individual and group decision making: current issues*, Lawrence Erlbaum, Hillsdale, NJ, pp. 221–246.
Craik, K. J. W. (1943). *The nature of explanation*. Cambridge University Press, Cambridge.
Denton, H. G. (1997). 'Multidisciplinary team-based project work: planning factors'. *Design Studies*, Vol. 18, 155-170.
Eccles, D. W. and Tenenbaum, G. (2004) Why an expert team is more than a team of experts: a social-cognitive conceptualization of team coordination and communication in sport. *Journal of Sport Exercise Psychology*, Vol. 26, 542 – 560.
Edmondson A. C. and Nembhard I. M. (2009) Product development and learning in project teams: the challenges are the benefits. *Journal of Product Innovation Management*, Vol. 26, 123–138.
Fleiss, J. L. (1971) Measuring nominal scale agreement among many raters. *Psychological Bulletin*, Vol. 76, 378–382.
Goldschmidt, G. (2007) To see eye to eye: the role of visual representations in building shared mental models in design teams. *CoDesign*, Vol. 3, 43-50.
Gentner, D. A., and Stevens, A. L. (1983). *Mental models*. Lawrence Erlbaum, Hillsdale, NJ.
Jansson, D. G., and Smith, S. M. (1991). Design fixation. *Design Studies*, Vol. 12, 3-11.
Janis, I. L. (1972). *Victims of Groupthink.* Houghton Mifflin, New York.
Klimoski, R. and Mohammed, S. (1994) Team mental model – Construct or metaphor? *Journal of Management*, Vol. 20, 403–437.
Mathieu J., Maynard, M. T., Rapp, T. and Gilson, L. (2008) Team effectiveness 1997–2007: a review of recent advancements and a glimpse into the future. *Journal of Management*, Vol. 34, 410–476.
McDonnell, J. and Lloyd, P. (eds.) (2009) *About: designing – analysing design meetings*. London: Taylor and Francis.
Mesmer-Magnus J. R. and DeChurch, L. A. (2009) Information sharing and team performance: a metaanalysis. *Journal of Applied Psychol*ogy, Vol. 94, 535–546.
Nik Ahmad Ariff, N. S., Badke-Schaub, P. and Eris, O. (2012) Conversations around design sketches: Use of communication channels for sharing mental models during concept generation. *Journal of Design & Technology Education*, Vol. 17, 1-10.
Norman, D. A. (1983) Some observations on mental models. In Gentner, D. A. and Stevens, A. L. (eds.), *Mental models*. Hillsdale, NJ: Erlbaum.
Schaub, H. (2007) The importance of the characteristics of the task to understand team mental models. *CoDesign*, Vol. 3, 37-42.
Smulders, F. (2007) Team mental models in innovation: means and ends. *CoDesign*, 3, 51-58.
Smyth, M. M., Collins, A. F., Morris, P. E., and Levy, P. (1994) *Cognition in action* (2nd ed.). East Sussex, UK: Psychology Press.
Stempfle, J. and Badke-Schaub P. (2002) Thinking in design teams – an analysis of team communication. *Design Studies*, Vol. 23, 473–496
Tuckman, B. W. (1965) Developmental sequence in small groups. *Psychological Bulletin*, Vol. 63, 384–99.