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DOES IT MATTER WHERE DESIGN TEAMS COME FROM IN DESIGN STUDIES?

Julie Milovanovic
Virginia Tech,
Blacksburg, VA, USA

John Gero
University of North Carolina at Charlotte,
Charlotte, NC, USA

Kurt Becker
Utah State University
Logan, UT, USA

ABSTRACT

Professionals need to collaborate with multiple stakeholders in product development to stay competitive and to innovate. Through their values and mission, companies develop a specific working environment that can lead to the development of design methods and tools. In this article, we study design team dynamics of professional engineers working in two different organizations. We aim at identifying differences in team behaviors between teams drawn from two different organizations. The goal is twofold. At a theoretical level, we aim at gaining a better understanding of the effect of work culture on design team behaviors. At a methodological level, we explore whether grouping teams from different organizations into a single larger sample to obtain better reliability is relevant. To do this, we compared two cohorts of teams based on which company engineers worked at. Both companies are international organizations employing more than 50,000 collaborators worldwide. Teams of three engineers worked on designing a next-generation personal assistant and entertainment system for the year 2025. We analyzed each team's design interactions and behaviors using quantitative tools (Multiple Factor Analysis and Correspondence Analysis). Results from this exploratory analysis highlight different behaviors between cohorts as well as a common overall approach to team design thinking.

Keywords: Design collaboration, design teams, design cognition, protocol analysis, professional engineers

1. INTRODUCTION

Team design has become the norm of design process as numerous stakeholders participate in design development and user-center design gains popularity. Studies of team design focus on a diversity of characteristics such as team performance, leadership, team collaboration and developing tools to support remote collaboration. We can distinguish several levels of team analysis in co-design: the micro-scale or groups of actions in design (i.e. individual level processes), the meso-scale or groups of tasks (i.e. intra-team level processes) and the macro-scale or groups of activities (i.e. inter-team level processes) [1]. The literature on design teams bridges two main research communities, design cognition research and organizational management research. Both focus on team interactions, but at varying scale, temporality, and levels of details [2,3].

Many factors can impact the performance of a design team such as team composition, organizational culture, conflict or shared cognition within a team [30]. For example, at the individual level, cognitive style diversity positively impacts the design output [31]. At a macro-level, team management aligning with organizational goals tends to increase team satisfaction and efficacity [32]. There seems to be a relation between macro-scale level factors, like organizational culture and micro interactions at the team level.

In this article, we explore differences design team behaviors at the micro-scale level between professional engineers drawn from two different engineering companies. We reflect on the impact of work organization on design collaboration by comparing teams from two different companies. In other words, we explore if where teams come from impacts teams' micro-interactions while designing. We aim at identifying if the source of the companies affects design behaviors.

Companies usually develop a clear work culture and environment to put forward their identity, making them more competitive and innovative. An example of such firm in industrial design is IDEO [4,5], that developed a set of tools for design thinking and innovation used in their own company. Organizational context, such as management process and organizational culture (macro-scale level of teams), have an effect on team effectiveness and processes [6]. In this study, we expect to find differences in design teams' behaviors at the micro-level, depending on the firm that the team is from.

In this experiment, each team of three professional engineers spent one hour designing a next-generation personal assistant and entertainment systems for the year 2025. In total, 57 professionals participated in this study (19 teams of three engineers). Half were working for Company #1, which specializes in proposing solutions for automotive safety and the other half were working for Company #2, a leader in the development of product and systems for the aerospace and defense industries. Both companies are international and count more than 50,000 collaborators worldwide. All engineers were experts, meaning that they had more than 10,000 hours of professional design experience. The work presented here is part of a larger study on design teams. This study did not include an analysis of organizational culture. At first, we intended to consider all 19 teams as a single cohort. This sample size is bigger than most design studies using protocol analysis reporting sample size of no more than 10 protocols [33]. Moreover, participants are professional designers, not design students, which better capture expert design processes. While analyzing our dataset, we reflected on the reliability of considering all teams in a single cohort as engineers were from different work companies. In this article, we explore this train of thought. The research presented here does not provide an analysis of the correlation between organizational culture and design teams behavior. It formulates a hypothesis about the effect of organizational culture on design behaviors, which has methodological consequences in using protocol analysis to explore micro-scale level design team interactions.

Our comparative analysis provides general insights on how teams of professionals co-design. The influence of where teams come from on team behaviors is explored. It provides theoretical information on possible effects of work organizations on design teams behaviors. Moreover, it reflects on research methodology using protocol analysis to study design teams.

In the following section, we present different approaches to studying teams in research. The materials and method section describes the design task given to participants, provides an overview of the companies, of the engineers' backgrounds, and explains methodological tools used to convey the analysis. The results and discussion sections highlight different trends in team behavior that could be related to company affiliation and/or individual design and social traits. Similarities in team behavior also appear which could define the essence of team co-design processes at the cognitive micro-scale level..

2. BACKGROUND: STUDYING DESIGN TEAMS

2.1 Design teams at a macro-scale

Organizational context of companies tends to have an effect on team efficiency, such as productivity or quality, and on team processes [6]. At a macro-scale level, organizational context integrates management processes (in terms of defining goals and allocating resources), organizational culture (inter-team interactions, integration of the team to the rest of the organization), and organizational systems (team-level feedback, access to technical information, team training). These elements define a company's culture and environment. Authority and credibility in design teams, as well as socially mediated information about the design product define working practices and are related to a company's history and structure [29].

Cash and colleagues' study [7] supports the idea that there is an interdependence of individual team level process (micro-scale level of teams), intra-team level processes (meso-scale level of teams), and inter-team level process (macro-scale level of teams) [8]. In their study, they pointed out the emergence of team process patterns in meso-scale process, influenced by team level process at both taskwork and teamwork scale. This suggests that teams in work organizations function like complex systems integrating multiple scales of interactions.

2.2 Design teams at a micro-scale level

Team research in design cognition has specifically focused on the micro-scale of the design activity. Findings from studies show that individually, a single designer showed a larger range of design behavior patterns than team members [13]. In a team, participants tend to assume specific roles, and mostly relied on their own expertise.

Designers' expertise and leadership tend to impact team organization and performance [34]. Individual diversity in cognitive styles has an effect on the team design output [31]. Other characteristics like gender diversity in teams also affect the team design process [35]. Social relationships also affect the team process as co-design is socially situated [36]. For example, successful teams manage to reduce uncertainty in the design process after having social micro-conflicts, whereas unsuccessful design teams had more design uncertainty after experiencing social micro-conflicts [37].

2.1 Bridging scale of team analysis: teams as systems

While most of design research on teams focused on the micro-scale, some empirical research included two levels of analysis to explore team behavior: micro-scale or action level and meso-scale or task level. For instance, Darses and colleagues [20] developed a two levels coding system for design conversations: design actions like generating, informing and evaluating; and co-operation moves related to the task level such as planning. Similarly, the coding framework developed in Stempfle and Badke-Schaub's work [21] distinguishes content-based activities (goal clarification, solution generation, analysis, evaluation, decision and control) and team-process-oriented activities (planning, analysis, evaluation, decision and control). A limit to those empirical case studies is that the team design activity is considered as a whole, without taking into account the contribution of each designer. Alternatively, taking into consideration individual participation, as well as team members collaboration, provide a more granular description of team behavior while co-designing [22].

Design processes in teams are embedded at multiple scale levels. Macro-scale processes tend to drive and be driven by meso-scale processes but is not directly linked to them [1]. This implies that design processes are not only driven by individuals but across all scales of the design activity integrating intra-team level processes and inter-team level processes.

3. METHODS TO STUDY DESIGN TEAMS

For decades, protocol analysis has provided a methodological framework to analyze designers' thinking processes based on their verbal expressions [9–11]. Using protocol analysis, design actions or moves are associated to a code, usually defined a priori (for example analysis, evaluation, or goal clarification). Based on the coded verbal utterances, cognitive design behavior is analyzed using qualitative or quantitative methods and tools [12]. The conversation transcript of a team of designers' verbalization while co-designing is equivalent to a single designer think-aloud protocol [13]. Considering this allows a straightforward application of individual design cognition analysis tools to co-design situations [14]. Frameworks used to analyze empirical studies of single designer think-aloud protocols, like reflective practice, were mapped onto teams' protocols [15] [16]. Another example is the use of the problem/solution co-evolution paradigm [17, 18] in the analysis of teams in engineering design [19]. Protocol analysis provides an in vitro setting appropriate for quantitative analysis and generalizable findings. But, its limitations are a lack of ecological validity as the design activity is monitored in artificial settings and in a short time period (1 to 2 hours).

On the other hand, ethnographic approaches to studying design teams [1, 29] offers an accurate representation of in situ design processes. It captures social interactions within a work organization over longer time periods (months) that reflect better project development length. This approach provides rich qualitative information about co-design processes but fall short in providing reliable data sample to generalize findings.

GOAL OF PAPER

The methodology used in our wider project is based on protocol analysis study. Although teams were not observed in their work environment on a 'real' design project, we found it relevant to verify the effect of work culture on design team behaviors. We aim at identifying if when designers worked at different companies, they displayed distinct co-design behaviors.

In this paper, our analysis metrics focus primarily on the micro-scale, while considering the organizational context of companies where teams are from. The aim of this paper is to explore whether design teams from different companies exhibit a similar design cognition when carrying out the same design task. This has significance for design research methodology since, if they are similar, participants can be randomly drawn from different companies. However, if they are not, care needs to be taken in selecting participants when studying design cognition in industry before generalizing findings. The richness of this study is to explore design teams' behaviors with expert professionals, while conserving a semi-naturalistic environment since team members are used to working as teams in their professional environment.

4. MATERIALS AND METHODS

5.1 Experiment

Engineers from two companies participated in the study. The first company (Company #1) specializes in developing solutions for automotive safety whereas the second (Company #2) is a leader in providing systems and products for the aerospace and defense industry. In Company #1, twenty-seven professional engineers participated in this study. Nine teams of three engineers were formed randomly. All engineers were used to working together as the company use a lean manufacturing and production process in their product development and production that requires them to engage on projects together. Engineers from this company were all males, and come from different background ranging from mechanical engineering, quality engineering to manufacturing.

Thirty engineers from Company #2 participated in the study, forming ten teams of three engineers formed randomly (5 females and 25 males). Most engineers from this group were electrical engineers, and others had backgrounds in mechanical engineering, computer science, and physics. All engineers were used to working together as the company uses agile manufacturing and creates the processes, tools, and training to enable it to respond quickly to customer needs and market changes while still controlling costs and quality.

Each team was given the same task, to design a next-generation personal assistant and entertainment systems for the year 2025 (see Appendix). They were invited to focus on what this system would be, how this system works and interacts with people, and what the personal assistant and entertainment system would provide to end users. The team had 60 minutes to propose a concept description and sketches on a white board. All team members were collocated and a research assistant stayed in the room as participants developed their design. The companies requested the experiment to be done outside of the work environment for privacy reasons. Each design session was video recorded to be analyzed. No incentives were given to participants.

5.2 Describing design processes and collaboration

A general way to describe design knowledge is given by the Function Behavior Structure (FBS) ontology [23]. The FBS framework represents six design issues:

- Requirement (R) includes the design brief and is outside of the designer
- Function (F) is what the design object is for
- Expected Behavior (Be) represents an expected behavior of the design object
- Structure (S) represents elements and their relationships that go to make up the design object
- Structure Behavior (Bs) is behavior derived from a structure
- Description (D) is an external representation of the design object.

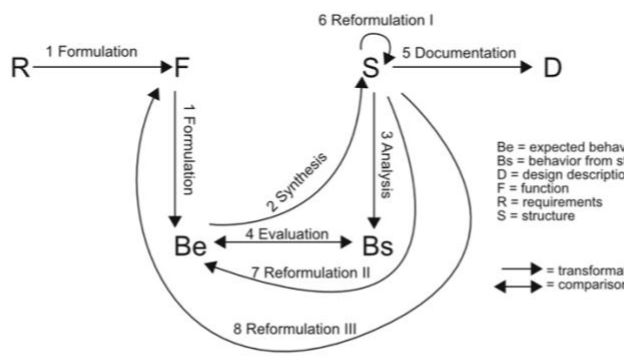

FIGURE 1: FBS FRAMEWORK (SOURCE: [23, 24]).

The FBS framework accounts for a total of eight cognitive design processes as a consequence of transitions between the six design issues, as shown in Figure 1 [23, 24]:

- Formulation, a transition from a requirement (R) to a function (F), or from a function (F) to an expected behavior (Be)
- Synthesis, a transition from an expected Behavior (Be) to a design structure (S)
- Analysis, a transition from a design structure (S) to a behavior from structure (Bs)
- Evaluation, a transition from an expected behavior (Be) to a behavior from structure (Bs) and inversely
- Documentation, a transition from a design structure (S) to a description (D)
- Reformulation 1, a transition from a design structure (S) to a different design structure (S)
- Reformulation 2, a transition from a design structure (S) to an expected behavior (Be)
- Reformulation 3, a transition from a design structure (S) to a function F

5.3 Coding the design protocols

The protocol analysis methodology was applied to analyze each design session. Video protocols were transcribed, segmented and coded using the Function Behavior Structure framework represented in Figure 1. In this study, we also analyzed collaborative interactions between each teammate. Therefore, each segment was coded with the speaker's name. In order to aggregate the design protocols, in each team, designers were labeled as A, B or C based on their participation in the design session. Designer A verbalized the most design issues, followed by designers B and C.

FBS design processes are transitions from a specific design issue to another specific design issue (Figure 1). Therefore, a process formulated by a single designer, implies that both design issues forming a design process are verbalized by the same designer. Three types of individual processes occurred in our dataset: designer A individual process (A>A), designer B individual process (B>B) and designer C individual process (C>C).

We consider a co-design process as a FBS design process where a first designer formulates the first design issue, and the second designer verbalizes the following one. For example, designer A formulates the following expectation "*what if you took the virtual reality and interacted it with something…*" and designer B responds with a design structure "*Like smart TVs, you connect your system to a smart TV*". In our framework, such interaction is defined as a collaborative synthesis (Be>S) process between designer A and B (A>B). Six collaborative interactions appeared in the dataset: a co-design process between designer A and B (A>B), or inversely (B>A); a co-design process between designer A and C (A>C), or inversely (C>A); and a co-design process between designer B and C (B>C), or inversely (C>B) (see [14] for more details on using the FBS co-design model).

Segments of the coded protocols account for a single design issue, which provides an analysis of design cognitive processes at the micro-scale level. Processes and interactions are based on a syntactic model, looking at the activity in a linear manner, not on semantic associations or turn taking (see Table 1 for an example of protocol coding).

TABLE 1: EXAMPLE OF A CODED PROTOCOL WITH DESIGN PROCESSES AND INTERACTIONS

Utterance	FBS code	Design process	Designer	Interaction
It's got to be able to connect to	Be	-	A	-
all the in-home, you know.	S	Synthesis	A	A>A
So, if you have a Wi-Fi. The Wi-Fi stuff…	S	Reformulation 1	B	A>B
or Bluetooth	S	Reformulation 1	B	B>B
or whatever features	S	Reformulation 1	B	B>B
and be able to network with all of them.	Be	Reformulation 2	B	B>B

And then you got to have, you know, with the TVs	S	Synthesis	C	B>C
and then connecting	Bs	Analysis	C	C>C
to your entertainment things.	S	Synthesis	C	C>C

Each session was coded by two different trained coders. When a disagreement occurred, coders arbitrated each segment together, and relied on an external coder's input if they could not reach an agreement. In total, three coders worked in pairs to code the data (19 one-hour long protocols). The average coder agreement for all 19 sessions is 80%, which ensures the reliability of the data analyzed.

5.4 Analyzing design teams' behaviors

Our analysis of design teams' behavior focused on comparing two cohorts of teams based on work organization affiliation. We looked at quantitative distribution of design interactions and design processes for each cohort to explore the effect of company environment. We also explored qualitative relationships between teams, interactions and, design processes using tools Principal Component Analysis methods with the FactoMineR package in R [25,26].

To explore if there were differences between teams' collaborative behaviors based on their work affiliations, we analyzed the dataset with Multiple Factor Analysis (MFA). MFA is useful to study datasets where variables are grouped. In this dataset, the two groups of variables were individual design processes (A>A, B>B, C>C) and collaborative design processes (A>B, B>A, B>C, C>B, A>C, C>A). MFA provides a graphic representation of relative relationships between all the teams on a 2D plan. Company affiliations was used as a supplementary variable, meaning that it did not influence the relative relationships between teams, but companies are still represented on the 2D graph.

Using Correspondence Analysis (CA) provides a mean to represent the relationship between design interactions (collaborative and individual) and design process for each cohort. Here, we explore whether a specific type of interaction relates to a specific design process. Using CA gives insights on each cohort design collaboration 'signature'.

5. RESULTS

6.1 Design collaboration in teams

Looking at team members' participation in the design activity, we observe a large dominance of individual design process at a micro-level (Figure 2). On average, individual FBS design processes represent more than 70% of the design activity. In Company #1, there is a large dominance of the leader (A). Team member C in Company #1 individually engaged in 10% of the design activity, significantly less ($t(17)= -2.33$, $p=0.03$) than its counterpart in Company #2 ($M=16.2$, $SD=5.4$). Team member B's average participation in the design activity is similar for both cohorts, and represent around 23% of the entire design processes for a session.

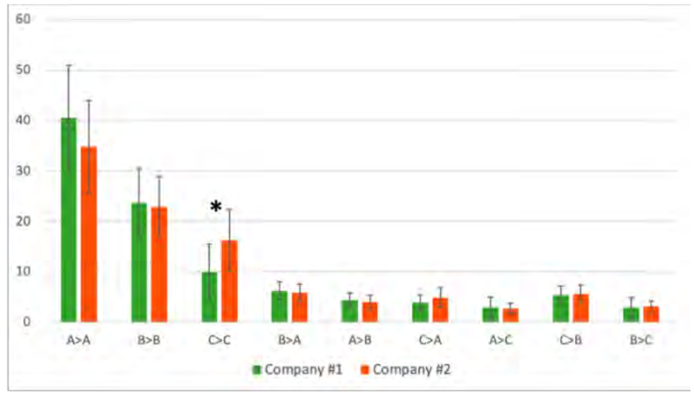

FIGURE 2: AVERAGE DISTRIBUTION OF TEAM MEBERS INTERACTIONS FOR TEAMS IN EACH COMPANY (* INDICATES STATISTICAL DIFFERENCES BETWEEN COHORTS)

Using Multiple Factor Analysis (MFA), we explored the correlation between individual teams based on two groups of factors: individual FBS design processes (A>A, B>B, C>C) and collaborative FBS design processes (A>B, B>A, B>C, C>B, A>C, C>A). MFA provides a representation of relative relationship between all the teams on a 2D plan. Teams are situated in relation to each other on the 2D map with 2 dimensions based on the distribution of team members' interactions (individual and collaborative).

Figure 3 represents the correlation between the qualitative variables (individual and collaborative FBS design processes) for all 19 teams. Arrows indicate associations between teams represented on the 2D graph in Figure 4 and FBS design processes (yellow for individual FBS design processes and blue for collaborative FBS design processes). For instance, the yellow arrow C>C in the lower right quadrant of the correlation circle in Figure 3, indicates that teams situated in this quadrant on Figure 4 (Team 1 from Company #1 and Teams 2, 6 and 9 from Company #2) are relatively correlated to the team member C generation of individual FBS design processes. An interpretation of this is: compared to the other teams, in Team 1 from Company #1 and Teams 2, 6 and 9 from Company #2, designer C tends to engage more in the design activity than in other teams.

When looking at each quadrant of the graph (Figure 3), clear trends appear: the top left quadrant is dominated by designer A's individual design processes, the left bottom quadrant is dominated by designer B's individual design processes, the right top quadrant is dominated by collaborative individual design processes, and the right bottom quadrant is dominated by designer C's individual design processes. In this MFA, the company is considered as a supplementary variable, meaning that it did not influence the definition of the dimensions. Therefore, teams are positioned on the graph regardless of the company they are from. The supplementary information (here

Company #1 or Company#2) is simply projected on the 2D graph. Doing so, we aim at analyzing to what extent teams from the same company tend to display similar behavior in terms of interactions while designing.

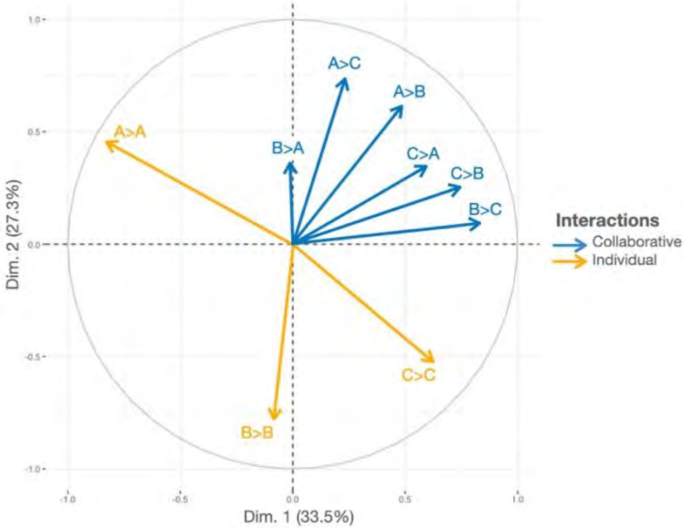

FIGURE 3: MULTIPLE FACTOR ANALYSIS CORRELATION CIRCLE OF QUATITATIVE VARIABLES: COLLABORATIVE FBS DESIGN PROCESSES (A>B, B>A, B>C, C>B, A>C, C>A) AND INDIVIDUAL FBS DESIGN PROCESSES (A>A, B>B, C>C)

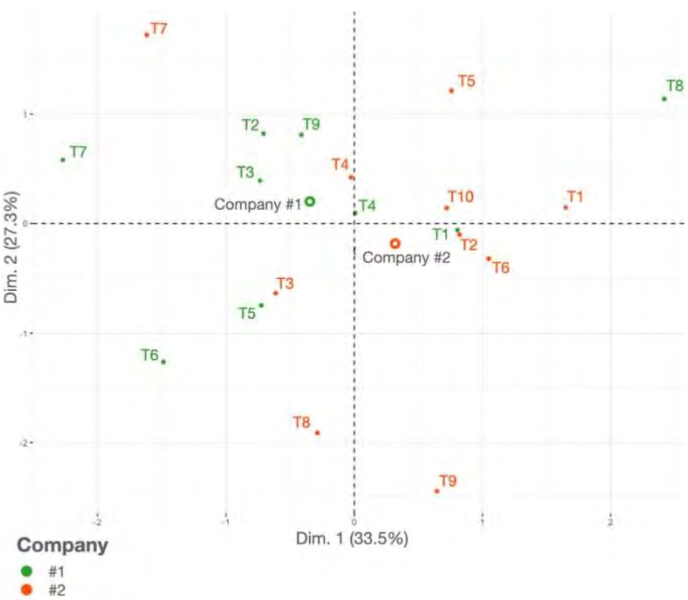

FIGURE 4: MULTIPLE FACTOR ANALYSIS REPRESENTATING CLOSENESS OF TEAM BEAHIVORS BASED ON INDIVIDUAL AND COLLABORATIVE DESIGN PROCESSES DISTRIBUTION (GREEN DOTS REPRESENT TEAMS FROM COMPANY #1 AND ORANGE DOTS REPRESENT TEAMS FROM COMPANY #2)

Both companies appear on opposite quadrants of the graph in Figure 4, revealing differences between cohorts. Company #1 (green points in Figure 4) appears on the left top quadrant of the graph, which highlights a correlation with leaders' A individual design processes (see Figure 3). Company #2 is situated on the right bottom quadrant (red points in Figure 4), which show a correlation with team members' C individual design process. These results align with the distribution of interactions discussed above as designer C is significantly more engaged in the design session in teams from Company #2 (see Figure 2).

The MFA results highlight similarities between teams from the same company as more than half of Company #1 regroup on the left of the graph, and more than half of Company #2 appear on the right side on the graph (Figure 4). Nonetheless, we observe cross-overs between teams from these two companies. For example, Team 1 from Company #1 (in green) and Team 2 from Company #2 nearly overlap on the graph, which indicates a similar behavior in terms of interactions.

These first results highlight differences in team behaviors that could relate to their organization affiliation. Our findings suggest that teams from Company #2 adopt a more horizontal hierarchy between designers as 1) the distribution of individual design processes between team members is more balanced, and 2) teams from that company tend to associate relatively more to collaborative design processes. Although there is a trend showing a distinction in micro-level design team behavior depending on work affiliation, some teams have very similar behavior regardless of where they work. Differences could come from individualities within the teams, not specifically from macro-level factors.

6.2 Dominant design processes in teams

To gain a better understanding of teams' behaviors, we analyzed the distribution of different type of design processes per cohort. At a micro-level, the dominance of design processes is similar between the two cohorts (Figure 5). Design teams put their cognitive effort on Reformulation 1 and Analysis. Those processes represent between 20 and 35% of the design activity. Both processes are focused on the design solution which highlights a common design cognition style for all the design teams. The third dominant process for all teams is Evaluation, which accounts for a transition of the teams' cognitive effort between expected behaviors and behaviors of the current design solution. Synthesis and Reformulation 2 represent between 5 and 15% of the design activity for each team. During those processes, team members either redefine elements of the design solution (Synthesis), or adjust parts of design proposal based on expected behaviors (Reformulation 2).

There are significant difference in the teams' behaviors when compared grouped by their company affiliation for some of the dominant processes like Synthesis ($t(17)=2.85$, $p=0.01$), Analysis ($t(17)=-2.24$, $p=0.04$) and Reformulation 2 ($t(17)=2.40$, $p=0.04$). Teams from Company #2 tend to put significantly more effort on solution-focused processes (Analysis and Reformulation 1) compared to teams in Company #1 (see * in Figure 5). Indeed, those design processess are either a redefinition of the solution or an analysis of it. On the other hand, teams from Company #1 tend to put significantly more effort on design processes indicated by transitions between the problem space and the solution space (Synthesis and Reformulation 2), compared to teams from Company #2 (see * in Figure 5). Both those design processes account for transitions between design solution structures (S) and expectations (Be) emerging in the problem space. These findings could account for companies' design styles and professional practices.

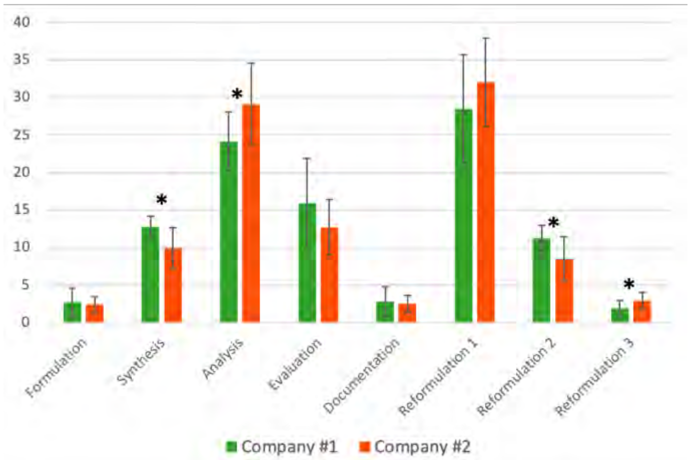

FIGURE 5: AVERAGE DISTRIBUTION OF DESIGN PROCESSES FOR TEAMS IN EACH COMPANY (* INDICATES STATISTICAL DIFFERENCES BETWEEN COHORTS)

To better understand the specificity of teams' behaviors, we analyzed the correlation between design processes and designer's interactions for each cohort of teams using CA (Correspondence Analysis). Doing so, we aim at exploring if some interactions between designers support specific type of processes. CA provides a 2D representation of relative qualitative relationships between two categories: interactions and design processes. On the graphs in Figure 6 (Company #1) and Figure 7 (Company #2), when two categories appear close to each other, it suggests a correlation between categories.

In both cohorts, the type of dominant individual design processes is different than collaborative ones. We see that in both CA results, individual interactions (A>A, B>B and C>C) appear on the left side of the graph, whereas collaborative interactions appear on the right side of the graph (Figure 6 and 7). For all teams, collaborative processes are associated to a design cognitive effort put on analysis and synthesis, as those processes also appear on the right side of the graphs.

Concerning individual interactions, for teams in Company #1 the individual interactions A>A and C>C appear in the same top left quadrant of the graph (Figure 6). It means that for teams from this company, designers A and C tend to have a similar design behavior in terms of design process distribution. Two type of design processes appear in that same quadrant, Evaluation and Reformulation 2. This indicates the types of design behavior prevailing for those two designers. An interpretation is that designers A and C in Company #1 tend to support design evaluation and redefining design expectation based on current design solutions. Unlike teams from Company #1, in teams from the other cohort, designer C's behavior is more similar to designer B's behavior as they appear in the same top left quadrant in Figure 7. Both designers from those teams tend to engage in Reformulation 1 processes, that redefines parts of the design solutions. Designer A tends to be more involved in evaluation in this cohort.

FIGURE 6: CORRESPONDANCE ANALYSIS ILLUSTRATING QUALITATIVE RELATIONSHIP BETWEEN INTERACTIONS AND FBS DESIGN PROCESSES FOR COMPANY #1

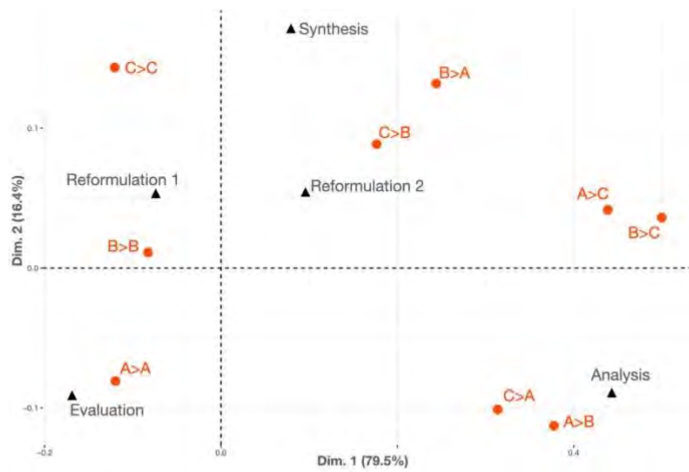

FIGURE 7: CORRESPONDANCE ANALYSIS ILLUSTRATING QUALITATIVE RELATIONSHIP BETWEEN INTERACTIONS AND FBS DESIGN PROCESSES FOR COMPANY #2

6. DISCUSSION AND LIMITATIONS

Most studies in design research focus on the micro-scale level of analysis and put a lesser interest in studying design processes at the intra-team design task (meso-scale level) or the inter-team design activity (macro-scale level) [1]. This study is no exception as our analysis explores design teams micro-level interactions. But, we considered teams' macro-level environment (workplace) in our analysis, as a covariate to alleviate this limitation. Doing so, we aimed at verifying if we could aggregate all teams to convey analysis on a bigger sample of team.

Organizational context of companies tends to have an effect on team efficiency, such as productivity or quality, and on team processes [6], therefore we expected to find differences in our two cohorts of teams. Our findings point out several differences between the teams:

- Teams in Company #2 adopt a more horizontal hierarchy between designers as the distribution of individual design processes between team members is more balanced, and teams from that company tend to engage more in collaborative design processes.
- Teams in Company #2 put more effort on solution-focus design processes (significantly more analysis processes) whereas teams in Company #1 tend to rely more on the navigation between problem and solution (significantly more Synthesis and Reformulation 2 design process – both processes represent a transition between expectations (Be) and current solutions (S), or inversely).
- In teams from Company #1, Reformulation 2 design processes tend to predominate in individual design processes whereas in teams from Company #2, those design processes are associated to collaborative design processes.

These differences could be a consequence of teams' work environment at the meso and macro level. If so, such characteristics in team behavior reveal each company's 'signature' in terms of design approach. Those difference could also stem from individual design traits based on designers' intuition and past experiences [28].

Although our results show some difference in micro-level design team behavior when compared based on work affiliation, some teams have very similar behavior regardless of where they work. Indeed, our findings also show similar behavior between teams that captures the essence of designing in teams. Based on our results, teams design at a micro-level seemed to be defined by the following statements:

- Team design is based on individual processes more than collaborative design processes as more than 70% of syntactic design processes are associated to individual interactions.
- Team design is similar to individual design process. The distribution of design process in these team cohorts follow a similar distribution than individual designer [12]. Analysis and Reformulation 1 design processes tend to dominate representing more than half of the cognitive effort of the teams, followed by Synthesis, Evaluation and Reformulation 2 design processes that each account for around 10% of the cognitive effort of the teams.

The implication of our results at a methodological level is that when designing experiments with professional engineers, special care should be taken in considering the work organizational context of participants as the design thinking culture and management in companies tend to influence the micro-scale interactions in a design team [1, 28]. In our sample, we still see common general team behavior that could represent the essence of designing in teams. In our in vitro setting, teams were uprooted from their work environment and engage in a new design task. Since they were not observed in situ, the management culture might have had a lesser effect on teams' micro-scale level design interactions. Another explanation for the commonality between design team behavior could be related to a similar organizational design thinking culture. Based on the information we have from those companies, we can only hypothesize on the impact macro-scale level work culture on micro-scale level design team behavior.

7. LIMITAITIONS

Two main limitations appear in this study. The first one relates to the lack of information measured on teams' company organizational context at the macro-scale level such as inter-team interactions and the integration of the team to the rest of the organization. To get a better qualitative and quantitative measure of such characteristics, our future work will include surveys [6]. The second limitation in our study is that we did not analyze the effect of team interactions on design performance, for instance creativity, quality, or efficiency [27]. The work presented here is part of a larger project, which will explore correlation between team micro-level interaction and team performance in future work.

8. CONCLUSION

In this study, we explored differences of team design behaviors at the micro-level (individual level of design actions). We compared two cohorts of professional engineer design teams based on their affiliation to a work organization. Our findings reveal that teams show different behavior depending on where they are from, which could be a sign of the company's design culture, but we also observed commonalities across design team behavior that accounts for characteristics of team design. Differences in design teams behavior could stem from individual interaction more than macro-scale level organizational culture.

Our result suggest that care should be taken in considering the work organizational context of participants in design studies when using protocol analysis. In this paper, we shared our methodological concerns about grouping teams from different work organization in order to increase the sample of design protocols. While bigger sample size provides more reliable results, attention need to be put to maintain validity in our analysis.

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APPENDIX

Personal Entertainment Systems (PES) is one of the most comprehensive entertainment companies in the world. In order to keep its leading position in the industry of entertainment, PES cooperates with many agents to explore the possibilities of new types of entertainment. Your design team has been invited to help in designing the next generation of a personal assistant and entertainment system suitable for family use in the year 2025.

Concept Design

In the context of engineering, a characteristic feature of the product design-related function is the description of products. Concept design includes a thorough roadmap from concept generation to production to product launch. See figure below:

The aim of concept design is to prepare for concurrent engineering by specifying the fundamental solution to the design problem.

Task

Your team is tasked with producing concept designs of a personal assistant and entertainment system suitable for family use for the year 2025.

For this project, your team should focus on:

- what this system would be,
- how this system works and interacts with people, and
- what the personal assistant and entertainment system would provide.

Your goal is to produce a number of concepts and then develop one of those concepts into a detailed design. At the completion of the session, please present sketches (using the whiteboard) and a verbal description of your solution. Your team will have 60 minutes to complete this task.