DESIGN TOOLS AND COLLABORATIVE IDEATION

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ABSTRACT: This paper presents the results of a comparative study between traditional analogue tools (sketches and physical models), a CAD software (digital) and a hybrid tool (digital and analogue) that allows immersive freehand sketching and model making (the Hybrid Ideation Space), in order to assess their respective abilities to support collaborative ideation. By comparing these tools, we were able to better understand the relationship between the activity of collaborative ideation, the tools that support it and the experience of the designer in order to provide principles for the development of collaborative tools in design.

KEYWORDS: Collaborative ideation, design flow, hybrid ideation space

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RÉSUMÉ : *L'article présente une étude comparative entre des outils traditionnels analogues (esquisses et maquettes), un logiciel de CAO (numérique) et un outil hybride (numérique et analogue) qui permet le sketch et le maquettage immersifs (l'Espace hybride d'idéation), pour évaluer leurs habiletés respectives à assister l'idéation collaborative. En comparant ces outils, nous avons été en mesure de comprendre un peu mieux la relation entre l'activité d'idéation collaborative, les outils qui la supportent et l'expérience des designers, dans le but de contribuer aux bases théoriques pour le développement d'outils de collaboration en design.*

MOTS-CLÉS : *Idéation collaborative, flux de design, espace hybride d'idéation*

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1. INTRODUCTION

We couldn't help but notice that designers' discourse change according to the tool they use. During a previous study (Dorta *et al.* 2008b) on ideation in the Hybrid Ideation Space (HIS), it was found that design conversation dominated any other kind of conversation (about the tool, the experiment, etc.). This seemed a significant proportion for digitally supported design collaboration; in our general experience with 3D modelling, we have observed that designers need to face the logic of computers, thinking through menus and commands, before they can really engage the logic of design. From this, we decided to investigate the collaborative potential of different conceptual tools in a comparative study (traditional analogue tools, a hybrid tool—the HIS—and a CAD system). The study was done in a face-to-face (synchronic and co-located) setting, where teams of two industrial design students worked on the ideation phase of the body of a winter rally car.

The assessment of the collaborative ideation was carried out with two methodological tools: Design Flow (Dorta *et al.* 2008a) and the Collaborative Ideation Analysis Grid. Design Flow is an assessment framework that considers the psychological states of the designer and the usability of the conceptual tool, relying on flow and workload measurements. The second tool, an improved version of the Conversation Analysis Grid (Dorta *et al.* 2008b), registers the actions related to collaborative ideation.

In the end, it appeared that the hybrid tool was better at supporting collaborative ideation than traditional or digital design tools; our results also suggest that some digital approaches in CAD should be reviewed.

2. IDEATION AND COLLABORATION

According to Schön (1983) conceptual design is a reflexive conversation with the representation in order to exteriorize verbally and visually (Goldschmidt 1990) a yet unformed concept. Jonson (2005) considers verbal communication to be the first design tool, prior to visual representation. This representation needs to enjoy some degree of ambiguity, imprecision and abstraction (Goel 1995) in order for this process to deliver. Designers work with incomplete information, making assumptions and provisional decisions that need to be revisited and reviewed. Imprecision (flexibility), ambiguity (alternative meanings) and abstraction (simplification) characterize the relationship between the actual and the possible solutions (Stacy and Eckert 2003). In collaborative design, Schön's metaphor of a conversation with the situation takes on new meaning. The design situation now includes other designers in conversation with each other and with the external representations.

Going beyond the cognitive processes, Bucciarelli (1988) considers that designing is a social process involving participants with different capabilities, responsibilities and interests, thus viewing the object of design differently. Key to collaboration is communication, verbal and non verbal, and how to incorporate computers and physical materials in a communication environment (Munkvold 2003). We feel that the apparently conflicting needs of ideation (ambiguity, imprecision and abstraction) and collaboration (clear communication) can both be honoured as long as the tools used to mediate the collaborative ideation offer enough subtlety to support them.

Achten (2002) suggests that collaborative design is a process in which participants work together in a meaningful way, their interaction adding to more than just efficient work, instead stimulating each other to contribute to the design task, sharing information in an environment that supports communication. But even with these criteria there is no definitive guidelines on how to create collaborative design environments; designers adapt to the environment in which they collaborate (synchronous or asynchronous, co-located or remote) by having multiple ways of producing representations and of communicating (Achten 2002; Maher *et al.* 2006).

3. COLLABORATIVE IDEATION WITH DESIGN TOOLS

Designers should be able to retrieve more information from their representations (sketches) than what they put in (Schön 1983). In a collaborative setting this information is shared by both the sender (the one who makes the representations) and the recipient (the one who construct meaning from these). CAD models offer precision about the design, which is good for people outside the ideation process, but they narrow the perception that designers can get from them (Stacey and Eckert 2003). For this reason, Henderson (1999) considers it expectable that CAD models be supported with sketches as alternative representations.

Most CAD tools are designed to be used on a Personal Computer (PC) therefore for individual use during conceptual design. Sharing information in a distributed design setting works, but simultaneous access by multiple participants in face-to-face setting is still limited. In order to change current CAD systems into a face-to-face collaborative tool, it would require supporting the complexity of collaborative design activities (Achten 2002).

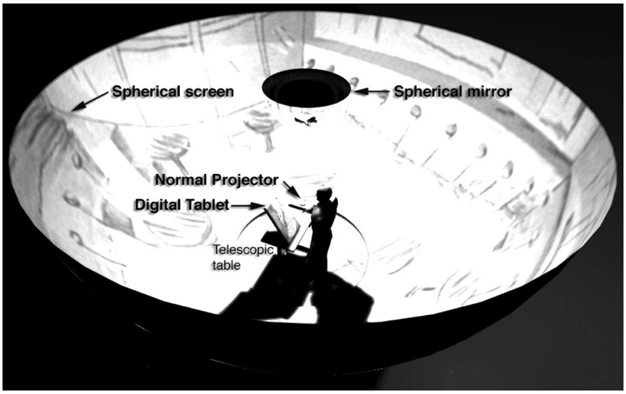
Rough physical models are used during conceptual design to get quick feedback on proportions and form. Freehand sketches and physical models offer tangibility and manipulability. They are key steps towards the final design (Kvan and Thilakaratne 2003). Arjun and Plume (2006) distinguish two levels of conversation: between the designer and the representation, and then between the members of the design team. Physical models allow collaborative design by providing a common starting point for designers with different backgrounds allowing them to identify and explore the differences in their understanding. Fischer and Ostwald (2005) refer to these as boundary objects. Fan *et al.* (2004)

suggest that sketches have the advantage of providing a sense of shared design space suitable for collaborative design. But these authors also express disappointment at our inability to go beyond sketches as preferred conceptual tool, the same tool used by architects since the Renaissance.

3.1. Hybrid Ideation Space (HIS)

The HIS was developed in response to this disappointment, tapping into the advantages of traditional tools and augmenting them with the advantages of a virtual environment. As explained in a previous paper (Dorta 2007), we have developed the HIS to support the needs of conceptual design for intuitiveness and ambiguity when generating ideas. The HIS allows the designers to sketch and make models all around them in real-time and in life-size scale providing a sense of immersion and presence (see Figure 1).

FIGURE 1. *THE HYBRID IDEATION SPACE.*



The HIS supports two different techniques: Immersive Sketching and Immersive Model Making. Immersive sketching allows sketches made with a digital pen and tablet to be displayed through an immersive projection device onto a semi-spherical screen, as the designer draws them. This immersive projection device is based on Courchesne's Panoscope 360° (Courchesne 2000). Immersive model making captures scaled physical objects (easily manipulated and serving as symbolic models) and displays them life-size in real time, through the same immersive device. The two techniques are often used in combination, designers drawing over the image of the physical model.

4. ASSESSING COLLABORATIVE IDEATION

The Design Flow framework (Dorta *et al.* 2008a) was developed to assess the ideation activity through the experience of the designer as well as the performance of the design tool. Because ideation is a reflective conversation with the representation, the conversational synergy requires evaluating the tool and the user in the context of the task. This user experience assessment is based on Csikszentmihalyi's concept of *flow* (Csikszentmihalyi and Csikszentmihalyi 1988) allowing the capture of the varying psychological states of the user in a systematic, measurable way throughout the ideation process. Csikszentmihalyi's concept of flow is a complex psychological state that describes a perceived optimal experience characterized by engagement in an activity with high involvement, concentration, enjoyment and intrinsic motivation. Flow state is determined by the balance between challenges and skills (Csikszentmihalyi and Larson 1987). The relation between perceived skills and challenges gives rise to eight possible dimensions (Massimini and Carli 1986): apathy, worry, anxiety, arousal, flow, control, boredom, and relaxation. Design Flow also includes the evaluation of the tool by a workload assessment.

We have observed (in Dorta *et al.* 2008a) that during the ideation process, the designer proceeds through a predictable pattern of psychological states. At the beginning, the designer experiences the stressful states of worry, anxiety and arousal. We attribute this to the process of giving form to ambiguous ideas. Once this process is well engaged and the concepts are starting to form, the designer's experience alternates from arousal to flow, falling into flow with every satisfying result. Once a concept is identified and the designer is working at stabilizing it, the states experienced will alternate from flow to control, on the less stressful spectrum of the flow wheel. If being in the flow is a sign of good performance, on its own it doesn't account for the whole process. This progression from more stressful to less stressful states transiting through flow is what we regard as the typical Design Flow pattern.

To evaluate collaborative ideation, we improved a previously developed methodological instrument: the Conversation Analysis Grid (Dorta *et al.* 2008b). In this previous study, this grid was used to gain insight into the relationship between the conversation, the ideation activity and the tool while sieving out participants' personal differences. It identifies different types of "actions" found in the verbal conversation and (non-verbal) gestures, and in the creation of representations accompanying collaborative ideation. The collaborative ideation analysis grid is grounded in Bucciarelli's design as social process (1988), complemented by Schön's reflective conversation concept (1983) and Goldschmidt's (1990) graphical representation of concepts and actions. Every action will be registered as design related or non-design related. Design related actions are based on design conversation (naming, constraining, negotiating, decision making) and design moves (action of changing de design and pointing gestures). Actions not related or having no impact on design are preparation work, technical issues and cleaning up representations.

Design moves are characterized by a physical action; it is a step, an act, or an operation, which transforms the design situation (Valkenburg and Dorst 1998; Goldschmidt 1990). The gestures (pointing with hand or laser pointer, making an arm or body movement) are accounted as moves, as opposed to the verbal exchanges, because they also participate to the representation.

5. THE EXPERIMENT

20 minutes per team for each of the three ideation tools was videotaped, meeting each team in their first two hours of work.

5.1. Sketches and physical models

These traditional tools served as benchmark because they are the most familiar to designers and they remain the most widely used conceptual tools. First, the teams produced freehand sketches (pencil on paper) and foam models. They had 4 hours to hand-in a completed physical model (scale 1:25) on the first day of the project. They were free to use any documentation or images for inspiration or references (e.g. the 2D plans of the chassis).

5.2. Hybrid Ideation Space

Next, each team had access to the HIS for 20 minutes in which time, they learned how to use it (the first 5 minutes) and they furthered their concept. We filmed the students as they worked from their physical model. The life-size projection countered the "Gulliver effect" of the hand-size model, allowing them to correct proportion mistakes. In the HIS, one student would draw with the interactive pen while the other engaged in the design using the laser pointer. Designers work standing up in the HIS, moving and gesturing freely. The life-size representation supports an intuitive, physical relationship between the designer and the representation, allowing teammates to communicate verbally as well as through gestures (pointing and sketching with the digital pen or the laser pointer). Some gestures left permanent traces (those of the digital pen) and some were ephemeral (hand drawing in the air, or laser pointer gestures over the representation). From the sketches made in the HIS, they corrected their physical models that were then scanned and handed back to them on the next class.

5.3. CAD System

The CAD package used in this study was Cinema 4D™. To initiate the CAD representation, the students were introduced to the intuitive technique of Hybrid Modelling (Dorta and Pérez 2006). They had to acquire the digital dexterity to handle complex shapes with double curvatures found in car design. This technique starts from the digitalized 3D scan delivered by the previous steps. The scanned model served as a template on which the participants used the HyperNURBS command, interactively deforming a shape with a subdivision surface algorithm. The 3D model of the chassis was used to validate tolerances and scale. The participants also referred to their (old) physical model to step back from the PC and engage in design negotiations. Although there were no instructions to this effect, each team chose to work together on a single PC. The second PC was at times used to look up information. The students had a full week to finish the CAD work.

5.4. Sampling

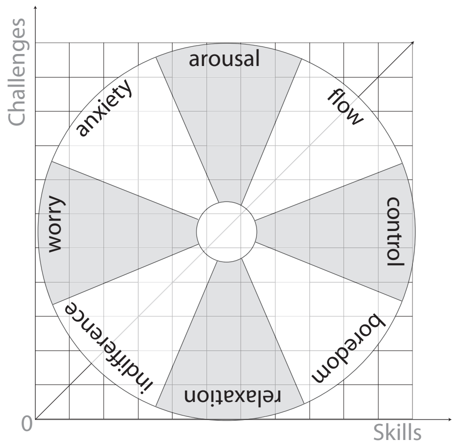
The 38, 2nd year industrial design students were paired in 19 teams of two, and had to work collaboratively. They were all skilled in 3D modelling (intermediate to advanced), the car body competition being the last project of a 3D modelling class. The behaviour witnessed with sketches and physical models was used to establish the team types. Teams spontaneously elected two distinct ways of working together: half the teams chose to do every task together (some even sketching on the same paper as they discussed their concept), and the other half choose to split the work between each other, touching base regularly and sharing the results of their individual actions. The latter behaviour is a *cooperation* pattern (Achten 2002), where as the teams sharing everything are referred here as working in *co-design*.

But some teams were better matched than others. Beside the well-matched teams (co-designing and cooperating teams) we added a third category: the *unevenly* matched teams, composed of student of markedly different skill levels, the stronger designer typically dominating the design actions while the less skilled one held a more passive role. The 19 teams fell in three groups: 7 teams were identified as working in co-design, 7 in cooperation, and 5 as unevenly matched.

5.5. Evaluation methods

Design Flow is made operational through a combination of two evaluation instruments: the Flow wheel (Figure 2) and the Flow questionnaire (Dorta *et al.* 2008a).

FIGURE 2. *THE FLOW WHEEL WITH ITS EIGHT DIMENSIONS.*



The Flow wheel was adapted from Massimini and Carli's (1986) eight dimensions diagram. In this study, after each 20 minutes of observation the participants individually identified their psychological states at the beginning, middle and end of this session. Compiling the 38 sets of flow wheels according to their team-type revealed a pattern showing the designers' experience.

The Flow questionnaire, based on the Experience Sampling Method (Csikszentmihalyi and Larson 1987), consists of 12 questions covering the conditions and outcomes associated to the flow experience: clear goals, direct and immediate feedback, high degree of concentration and focus, above-average challenges matched by the user's skills, a sense of control, an altered sense of time, a loss of self-consciousness, and a merging of action and awareness.

The workload is assessed with NASA Task Load Index (NASA TLX) (Hart and Staveland 1988), a multi-dimensional rating procedure based on six dimensions: three on the user (mental, physical and temporal demands), and three on the tool (frustration, effort and performance). If the frustration, effort and mental demand are high, the workload is high and negative, i.e. the task is difficult or needlessly complicated. The optimal rating is a low workload (i.e. low frustration, effort, physical, temporal and mental demands and a high performance) in combination with a high flow.

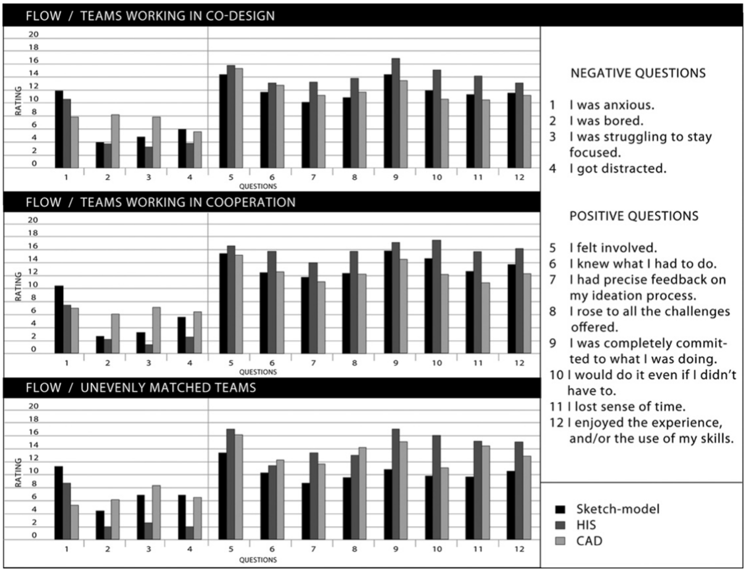
The data from all videotaped sessions were processed with the Collaborative Ideation Analysis Grid, registering actions every 10 seconds.

6. RESULTS

6.1. Results from the Flow questionnaire

In the positively oriented questions of the Flow questionnaire (Figure 3, questions 5-12), the HIS scored generally higher for all three types of teams. Teams working in cooperation showed the strongest flow across all tools. The only departure from this trend is seen in the unevenly matched teams as they gave CAD slightly higher flow rating than they did the other two tools. In the negatively oriented questions of the Flow questionnaire (Figure 3, questions 1-4), there is a visible difference between the ratings for the HIS (very low) and those of the other two tools. CAD received the highest negative ratings overall.

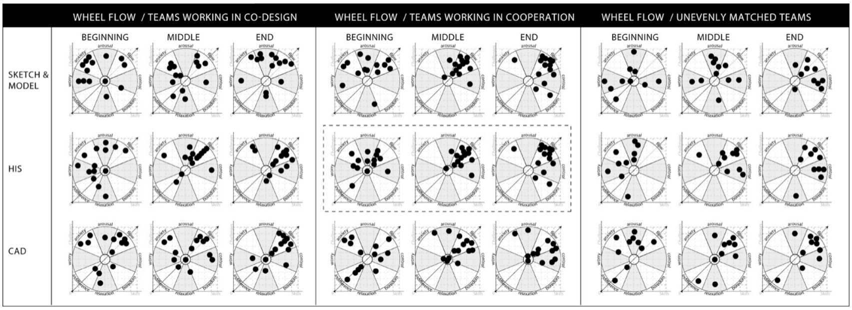
FIGURE 3. *RESULTS OF THE FLOW QUESTIONNAIRE.*



6.2. Results from the Flow wheel compilation

All teams display a Design Flow pattern in the HIS, the cooperating teams showing the most typical Design Flow pattern (Figure 4).

FIGURE 4. *FLOW WHEEL COMPILATION, WITH TYPICAL DESIGN FLOW PATTERN IN DOTTED LINE.*

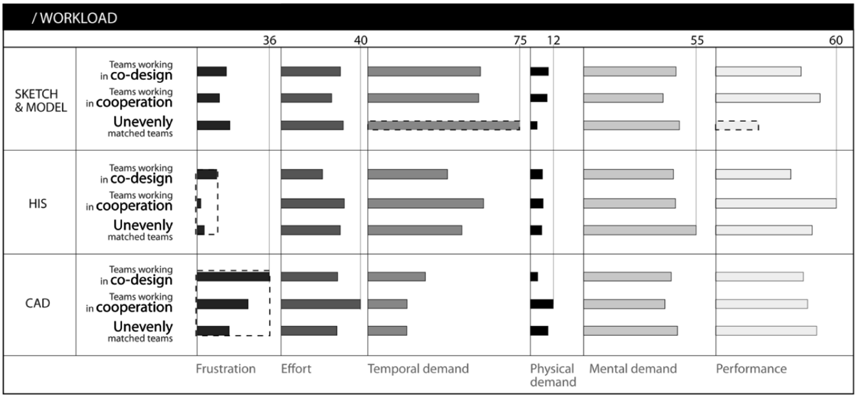


In CAD, each team type has a different Design Flow pattern depending on how they dealt with the inability of the PC to engage more than one person at a time. Teams working in cooperation and unevenly matched teams show a clear Design Flow pattern, meaning that these teams made the CAD work for them (cooperating teams developed an adaptive strategy to by-pass the narrowness of the PC, and unevenly matched teams were dominated by one active member).

6.3. Results from the Workload assessment

CAD registered the highest frustration ratings and slightly higher effort of all tools (Figure 5). On the other hand the HIS received the lowest frustration ratings. The unevenly matched teams doubled their performance ratings from the sketch models to the HIS, which we feel is significant.

FIGURE 5. *RESULTS FROM WORKLOAD QUESTIONNAIRE.*

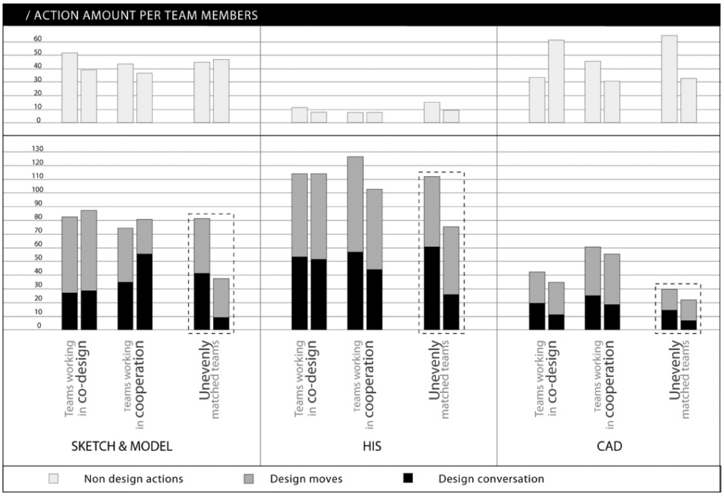


We attribute the overall high mental demand to the ideation task and not to the interfaces. The temporal demand registered here is related to two factors: the stage, early or late, in the ideation process and the timeframe imposed on the participants.

6.4. Results from the Collaborative Ideation Analysis Grid

There is twice to three times more design related actions (design conversation and design moves) in the HIS than in CAD systems (Figure 6).

FIGURE 6. *IT SHOWS THE ACCOUNT OF 3 TYPES OF ACTIONS OBSERVED DURING THE 20 MINUTES OBSERVATION SESSION: DESIGN CONVERSATIONS, DESIGN MOVES AND NON-DESIGN ACTIONS.*



All participants have increased their design-related actions (conversation and moves) by almost half as much in the HIS from the sketch and model phase, with one exception: the less skilled members of the uneven teams have doubled their amount of design actions. There are far fewer non-design related actions in the HIS than in the other tools.

The total amount of actions in all categories is smaller in the CAD than in the other tools. The teams working in collaboration have the highest amount of overall and design related actions in CAD tools, which is correlated by their Design Flow pattern in CAD (see Figure 4).

7. DISCUSSION

In collaborative ideation with sketches and models, the two student-designers worked side by side on their individual drawings, exchanging verbally about the merits of either propositions, co-design teams often pooling their efforts on a single drawing. Cooperating teams had silent, focused periods when both participants worked individually on a few sketches followed by moments of shared evaluation and exchange. The unevenly matched teams worked like either of the other types of team, the dominant partner assuming most of work.

The sketches and models, which were our benchmarks, generally ranked the lowest in the Flow questionnaire (Figure 3), displaying the weakest Design Flow pattern in the Flow wheel compilation (Figure 4). They also rated in second position for the workload as well as on the collaborative ideation analysis grid (Figure 5-6). The physical setting, drawing on a small piece of paper or carving a hand-size physical model, supported individual work. This was compensated by gestures and verbal exchanges, and by the mobility of paper that can easily move from one designer to the other.

The low number of actions in CAD (see Figure 6) may be related to two different processes, either to the design evaluation or to a struggle in the learning curve of the Hybrid Modelling technique. Periodically, the mouse-wielding designer entered long silent moments when s/he rotated the 3D model, apparently assessing the modelling strategy to be followed. This mental work seemed to monopolize all their resources, leaving collaborative communication a distant priority. Figure 6 also shows CAD systems to have the smallest amount of design-related conversation, therefore the lowest amount of collaborative exchanges along with the highest ratio of non-design to design-related actions.

In face-to-face setting, the CAD has left one of the participants of the co-design teams to hold a passive role. This is no surprise considering that CAD packages run on PCs, and that PCs are designed for individual use, tools and commands operated by one mouse-holder; furthermore the Hybrid Modelling technique was new to them and requires some digital dexterity. This situation is akin to the unique role of the surgeon among the operating team: The issue here being how does this necessarily unique role mesh up with the rest of the team? Or how does the mouse-wielding designer collaborate with the other teammate? This was not an issue in unevenly matched teams, since the dominant member took charge of the tool, leaving the less skilled one to interact occasionally, which was apparently acceptable according to their flow evaluations (see Figures 3 and 4) and their low frustration ratings (see Figure 5).

Using a different strategy, the teams working cooperatively brought other tools, and therefore other exteriorization channels, to counterbalance the uneven distribution of the work. This fuelled verbal and visual exchanges between team members, augmenting the amount of design actions (conversations, moving and gesturing). Cooperative behaviour (splitting the work, adding channels as needed and sharing in the conversation) seems to be a good adaptation strategy when working with tools that do not support collaboration directly.

In the HIS, all three types of teams showed clear Design Flow pattern in their Flow wheel compilations as well as high ratings in the Flow questionnaire and low workload ratings. It also received the highest amount of design related actions (conversation and moves); in average 40 such actions above the sketch and model and 80 above CAD, for the same timeframe (see Figure 6). We attribute this to the qualities of the tool, namely that it offers a common immersive representation, two active intuitive tools catering to verbal and to visual exteriorization, as well as supporting ambiguous, imprecise and abstract representations. Interestingly, in the HIS, both co-design and cooperation teams produced the same amount of actions (moving, general design and overall actions), and the same Design Flow patterns. In the HIS, both team-members were actively taking advantage of the dual access to the representation (laser pointer / digital pen). We conclude that the HIS support a hybridization of co-design and collaborative approaches in that it offers simultaneous work on a common representation while giving partners different channels and keeping them actively engaged in different tasks (i.e. drawing and analysing).

8. CONCLUSION AND FUTURE WORKS

Taking in account that the sampling was a class of design students still acquiring 3D modelling skills while doing a design competition, this study points out the strengths of hybrid systems for collaborative ideation. Both participants can work on its shared representation, blurring the ownership of the representation, thus empowering both team members into action. The scale of the representation and the fact that designers work standing up adds another channel of communication through body gestures, pointing, drawing in the air with hands or with the laser pointer. The multiple exteriorisation channels (through permanent and ephemeral representation, through verbal and non-verbal communications) aimed at a single representation apparently accommodate both co-design and cooperation approaches to collaboration.

With CAD systems, participants who added other communication channels (e.g. sketch or physical model) were able to share and communicate better, sustained a greater exchange of ideas, thus a better collaboration. This adaptation strategy made CAD package more efficient but highlights the difference between what the tool offers on its own and what creative users will do to compensate for its shortcomings. Although current CAD systems lack support for ideation, the results of this study could guide the development of new digital or hybrid tools that address these characteristics without forgetting that ideation is more often than not a collaborative process.

Further work will examine the way in which different tools for collaborative ideation in distributed and asynchronic settings support all actors and needs involved in the process.

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