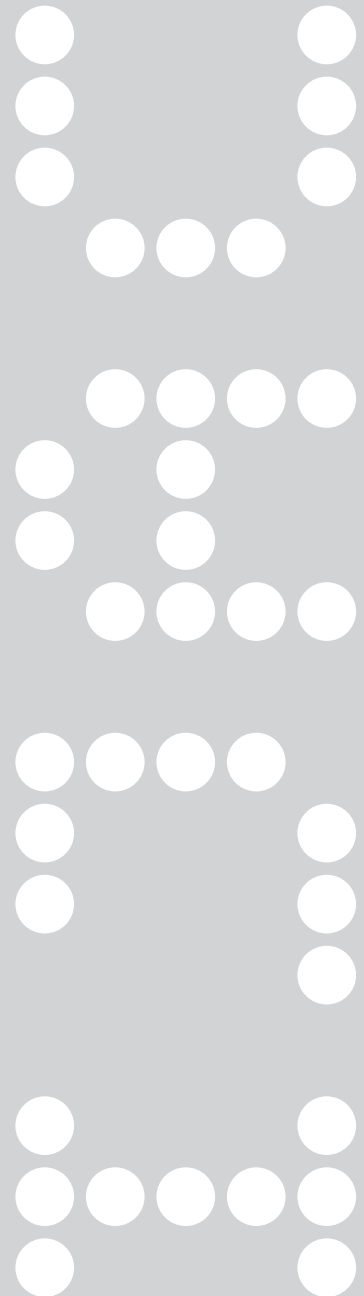


Design Flow and Ideation

Tomás Dorta



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In the last year, we developed the Hybrid Ideation Space (HIS), an innovative immersive sketching and model-making system that augments analog tools with digital capabilities, for continue and direct reflective conversation with the representation. The system enables designers to sketch and make models all around them in real-time and real scale using a digital tablet (sketches), image capture (physical models) and a spherical projection device (immersion). Teams of industrial design students participated in the study working on the initial stages of the design of a car. This is a comparative study putting side by side the HIS, analog tools and hybrid modeling techniques. We developed the notion of Design Flow to assesses the design ideation process. The students reported being in the state of flow more often in the HIS than with digital or physical modeling.

I. INTRODUCTION

Ideation is a complex and important activity in the design process. Usually, we are tempted to evaluate it in terms of performance rather than having a deep look inside the experience of designing itself. This is akin to evaluating a 100-meter race, caring only about who won. To have a better portrait of the activity and of the athletes' experience, we should find out how they felt *during* the race. Furthermore, since each designer's performance is unique, evaluating the experience by looking at the results would put us in a subjective and difficult territory. For both of these reasons, we opted to see ideation as a process, and evaluate it through a new assessment tool: *Design Flow*. We will use the expression *Design Flow* to refer to this concept/notion throughout this paper.

In the early stages of the design process, there is a void of relevant digital support when it comes to generating new ideas. This paper describes the evaluation of an interactive environment space for ideation developed by the author, which is called Hybrid Ideation Space (HIS). It was developed in response to this situation with the intention of augmenting analog tools and, in turn, improving ideation. The HIS maintains the intuitiveness and ambiguity needed to generate ideas. It allows users to sketch and make models all around them in real time and in scale using a digital tablet and an immersive projection device. The HIS adds to traditional sketch and models the advantages of a virtual environment, which provides a sense of immersion and presence.

Current approaches in Human Computer Interaction (HCI) base their evaluation of digital design tools on usability tests concerned with task execution. The notion of flow [1] studied in other fields can become a pertinent notion to evaluate design tools, this time focusing on the implication of the designer as it unfolds during ideation. The theory of flow centers on the autotelic experience, or intrinsically rewarding activity. To achieve this, a balance is required between the challenge faced and the person's skills. If the complexity of the activity increases, the flow can be kept by developing new skills to meet the new challenges.

This paper documents what we observed when the HIS was tested by teams of industrial design students in. The HIS has proved to be well adjusted for idea generation, supporting fluid and ambiguous representations. Furthermore, the notion of Design Flow seems to accurately account for the complex process of ideation and could become a method to evaluate digital and even analog design tools.

2. IDEATION OR REPRESENTATION.

The design process is an evolution of different kinds of representations, as stated by Goel [2]. For each step, a specific type of representation is used for specific tasks. During the ideation stage, the first kind of representation (e.g., freehand sketches and rough physical models) serves designers,

individually or synchronously within a team, to exteriorize and visualize their design intentions, or to communicate them among themselves. Later on during the process, designers employ a second type of representation (e.g., digital 3D models, drawings and images) to better communicate asynchronously (at another time) to colleagues and clients already designed proposals. At the end of the process, a third kind of representation is reached (e.g., detailed technical drawings and rapid prototyping models) to communicate exact and definitive information to build the artifact.

The problem here is that ideation is still done as it has been since the Renaissance, by traditional analog manual tools, like sketches and physical models, without real support from current digital tools. During the Renaissance, Brunelleschi and Alberti proposed perspective as a design and representation tool to capture form. Not until the XXth century has it become an exploration device and a mean to present projects [3]. On the other hand, building scale models was a way to communicate with clients and construction crew [4]. The tandem of physical models and two-dimensional drawings (plans and perspectives) as tools for representation, has defined architecture as a profession.

Ideation often happens not on a computer but rather through sketches on paper or mock-ups using malleable materials, steering away from the exactness of digital representations and the inconsistencies of interfaces. Therefore, computers are limited to represent anew already designed ideas.

To allow the designer to exteriorize and visualize internal mental images, external representations must be fluid, abstract, ambiguous and imprecise [2]. However, studies opposed to ambiguity and imprecision argue that designers need to communicate with colleagues exactly what they mean, as clearly as possible [5]. For asynchronous communication, computers have revealed their capacities to communicate using the above-mentioned second kind of representation. Abstraction and imprecision are important during ideation, while the ideas are emerging, whether working alone or in synchronous (same time) collaborative settings. This process is set in a specific context, with plenty of gestures and verbal expressions, allowing for good communication of intentions and permitting a reflective conversation with the representation.

For each observer, a sketch has a *perceptual interpretation space* [5]. The main problem of current digital ideation tools is that digital wire-frame or shaded models appear exact, so their perceptual interpretation space is very narrow [5]. Furthermore, even with generative parametric solutions (e.g. [6]), designers are not expressing their actual intentions but are inspired by digital propositions that always require computer savvy users to drive them.

3. IDEATION PROCESS

A designer needs qualitative and imprecise mental images and external visualizations, in a continuous interaction between the two types of

representations [7]. Making sketches and physical models is an interaction, a conversation. Designers see more in these representations than they put in when they make them [8]. This means that when the representation is finished, it communicates more information than expected. 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 [5].

In these reflective representational conversations, designers frame and reframe problems. In such conversations, designers' effort to solve and reframe problem produce new discoveries which call for new reflection-in-action. The process goes through appreciation, action, and re-appreciation. In addition, designers' actions also produce unexpected consequences bringing new meanings. During these *back-talks*, designers perceive and reframe the situation once again [8].

Buxton [9] explains the conversation with sketches as being able to "write" or "read" (produce or perceive) sketches for the designer her/himself or to others. In this situation the inability to read (perceive) or to write (produce) a sketch can compromise ideation. However, the significance of the sketch quality itself is debatable, as the meaning of design intentions is well understood by the designer's mind, even if there are some problems representing them. Likewise in synchronic collaborative work, the sketch, however ambiguous, will be completed by its accompanying commentary, which allows it to remain approximate and still be fully meaningful, in spite of what others have claimed against sketch ambiguity [5].

4. DESIGN FLOW AS ASSESSMENT TOOL FOR IDEATION

Cognitive science and design theory have made attempts to study ideation, the former with highly controlled lab experiments concerning task execution, and the later through direct experiments using idea generation methods. These two types of studies are needed to develop holistic models of design ideation [10]. Several experimental methods have been used to study the design process associated to cognitive activities: case studies [11], [12], protocol studies [13] and controlled tests. In order to evaluate the effectiveness of ideation there are two approaches: a *process-based* approach that measures the process of ideation, and the *outcome-based* approach related to the ideas generated or results [10]. For the first approach data collection comes from protocol analysis using ideation cognitive models (including classification of cognitive process, attributes to recognize them, etc.). However, this approach has not been mastered yet, and the cognitive processes described by psychologists such as the *Geneptore Model* [14], the *Roadmap Theory* [15] and others are based on simple problems or tasks

[10]. As for the second outcome-based approach, it is questionable because it is based on the designer's performance, including *idea-count*, *sum-of-quality*, *average-quality*, and *good-idea-count*, the last being the most recommended [16]. As we said before, evaluating the results of the process of ideation is difficult because it depends on the designers experience and capabilities, which brings us on a subjective territory.

In this work we are not proposing a new idea generation method, but a new system to support it. Therefore we opted for a process-based approach but through a new perspective of cognition based on the experience of the interaction the user has with the digital design tool. In other words: how does the user feel when ideating with it. Hence, if the digital tools are well adapted for this process, we expect the results will also be.

Ideation is, as previously stated, a reflective representational conversation therefore we regard the relation between the designer and the tool as synergetic. This perspective highlights a gap in the evaluation of design tools. As we looked for an instrument that can provide better insight on how designers experience ideation and that can address creativity, we came upon Csikszentmihalyi's concept of flow, which we have expanded into *Design Flow*.

Csikszentmihalyi's [17] 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. It is a state of mind that has been observed in other activities such as web navigation, surgery, composing, and painting, but not yet in design. It is characterized by clear goals and quick feedback, focused attention, loss of self-consciousness, altered sense of time, a sense of control, a merging of action and awareness, a match between participants skills and the activity's challenges, leading to an experience which is autotelic. To reach the flow state requires a balance between the challenges perceived in a given situation and the person's skills. The relation between perceived skills and challenges gives rise to eight possible dimensions [18]: apathy, worry, anxiety, arousal, flow, control, boredom, and relaxation.

Current approaches of human computer interfaces evaluating digital design tools are based on usability tests of task execution. However, the flow of creativity and inspiration during the design process, especially during ideation, has not been considered as a relevant cognitive aspect in this evaluation. The activity of design, in particular during the ideation process, may be evaluated using this notion of flow that we call the *Design Flow*.

5. THE HYBRID IDEATION SPACE (HIS)

Most of the solutions proposed until now to integrate the sketch in the digital design process seem to take a particular path in imitating or simulating the real sketch [19]. It is used as a trigger to execute commands because of its intuitive characteristics [20]. Also, filters automatically

translate accurate shapes to *sketch-like* representations during the rendering process, suggesting that it preserves the advantages of freehand drawings. Moreover, the sketch is used in virtual reality, but in 3D, floating in space [21], [22] or in the computer screen using instrumented gloves [23], a kind of sketching never used before, and without the psychomotor perception [24] provided by a solid support, normally paper or a graphic tablet. Using the sketch to enter information into the system which is later translated into accurate shapes [25], [26], [27] is to go against the features of the real sketch.

The HIS allows the designer to use traditional techniques augmented by the advantages of a virtual environment. It is intended as a cognitive artifact for ideation [28] and stemming from hybrid techniques we developed earlier [29], [30] in order to put the user inside real sketches, and mix manual actions with digital ones using rapid prototyping and 3D modeling.

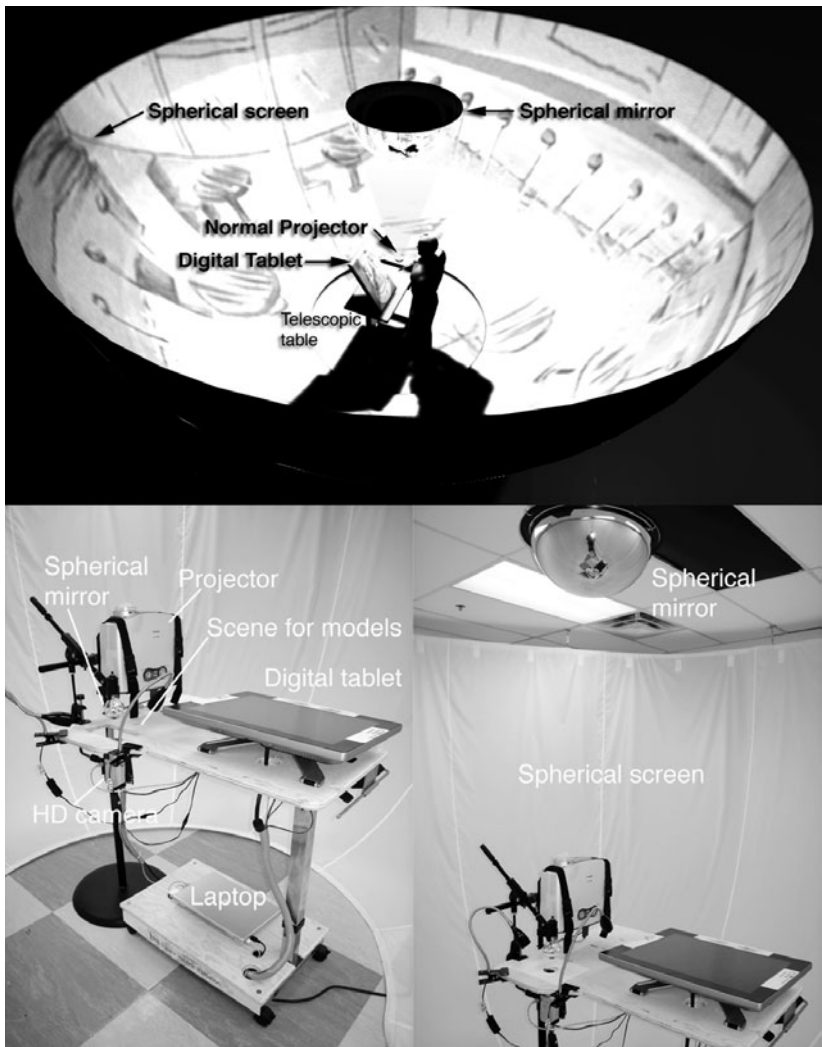
Technology is an invaluable partner to the designer, mostly in the tasks of representing already identified concepts. There is a discrepancy between current computer systems and the designers' needs for uninterrupted reflective conversation with the representation in order to exteriorize mental images [8]. In the early phase of design, where ideas are still not clear, traditional pen-and-paper sketches and physical models remain the tools of choice to do ideation because they are intuitive, direct and they allow ambiguous, abstract and imprecise representations.

To address this void between the current technology and the designer's needs, we have developed the Hybrid Ideation Space (HIS). The HIS is an immersive environment where designers sketch and make models all around them in real-time and life-size scale using a digital tablet (sketches), image capture (physical models) and a spherical projection device for immersion. It dwells on traditional analog manual tools and augments them with digital capabilities. Two techniques are used in the HIS: Immersive sketching and immersive model making (Figure 1).

5.1. Immersive Sketching

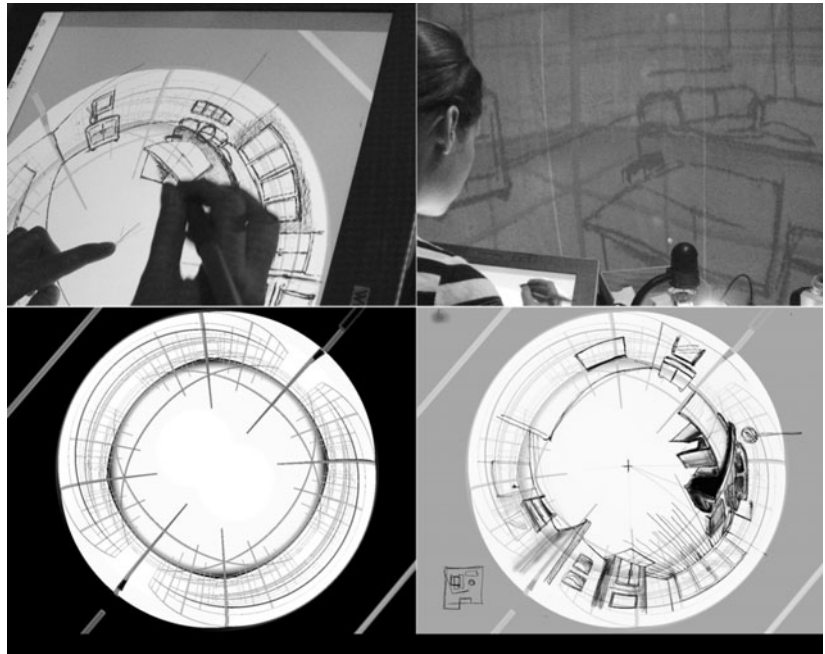
This technique is based on an anamorphic spherical panoramic perspective. The anamorphosis technique produces distorted projections that look normal when viewed from a particular position, projected on a cylindrical or spherical surface, or using a specific mirror or lens. In order to help the designer getting used to this kind of representations, a spherical graphical template is constructed using a ray-trace render of a reflective sphere in a basic 3D model containing elementary shapes or primitives. This sets proportions, which become graphical guides for sketching. This template can be used with any image editing software (Corel Painter™ or Adobe Photoshop™) via a digital tablet (Wacom Interactive Pen Display™) as an input device connected to any powerful laptop. The computer has two displays/graphic outputs, one for the digital table and another for a

conventional projector. These two display devices are mounted on different supports in order to avoid shaking the projected image by the manual actions. The digital tablet is supported by a telescopic table permitting work seated or standing, the latter being better for immersion because the user's eye level is aligned to the projected perspective. The projector, placed at table level so as not to disturb the user's gaze and supported by an individual tripod, points upwards (Figure 2).



◀ Figure 1: The Hybrid Ideation Space.

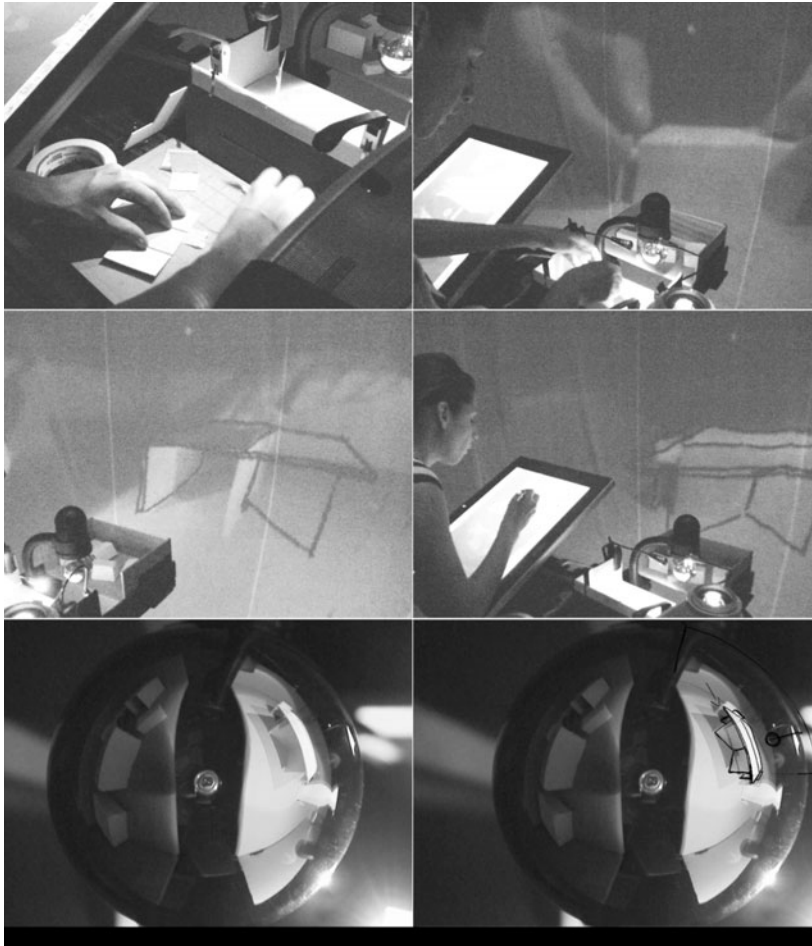
► Figure 2: Immersive sketching in action - Spherical graphical template - Spherical sketch.



5.2. Hybrid Modeling and Immersive Model Making

In earlier studies, we proposed the Hybrid Modeling (HM) technique to work with physical models [29]. This technique lets the user go back and forth between manual and digital models using Rapid Prototyping (RP) and a 3D scanner. Starting from rough hand-made physical models, the designer can create shapes quickly using malleable materials. Then, the model is digitalized and used as a template for 3D modeling. Later, this digital model is printed using RP, becoming a matrix used to continue design explorations manually.

In order to improve this technique combined with sketches during ideation, we use a small high definition camera (1080i) and a small mirror-ball as a spherical panoramic lens. The camera is attached vertically to the table's edge and the mirror-ball is centered in front of its lens. As simple as the immersive projection system discussed earlier, this apparatus is used as an input device. The camera captures a deformed spherical panoramic image reflected by the mirror-ball placed at eye level of the small physical model. The real-time HD image is then displayed by the same laptop to the immersive projection system. In this way, as users move and modify the scale model, they can see a life-size immersive projection of the model all around them. In order to solve contrast problems, the model is sometimes placed in a small scene placed on the table, controlling color background and lighting (Figure 3).



◀ Figure 3: Immersive model making in action - Captured image - Spherical sketch over the image.

Immersive model can be combined with sketches to explore graphically the physical modifications to be made, or with annotations over the image for oneself or for collaborative ideation. The monitored HD image is captured by the system and used as a background layer in the painter software. The user can thus sketch over a graphical spherical panoramic template easily produced by the scale model and the mirror-ball.

6. METHODOLOGY

In order to assess the HIS and compare it with HM and traditional model-making, an experiment with student was carried out. Data was collected on design flow, back-talks and workload using four basic methods of protocol analysis: by observing and recording the work sessions, encouraging participants to think-aloud; by asking participants to periodically identify their state on the flow graphs; by having them fill questionnaires.

Twenty pairs of second year Industrial Design students participated in this study during the ideation stage of the design of a car (exterior and interior) as an exercise for a Computer Graphics class. They started with the HM technique making an initial rough model (up to 3 hours). Then, the models were digitalized and the digital geometry was given to assist the 3D digital modeling process (1 week). Next, these models were printed with RP and used on the HIS during 20 minutes for each team, because of schedule limitations. After that, a spherical graphical template was built from the interior of each digital geometry using the exterior shape and some basic forms as references to the seats and steering wheel. Then the teams returned to the HIS to design the interior of the car (20 minutes).

The student's projects are hypothetical having few real-life constraints and being driven by novices. This kind of setting allows more freedom for the design conversation. Although using students as study subjects is criticized because they are not representative or experts as designers [31], we, in fact, consider them relevant when it comes to the use of the technology; expert practitioners have adopted tools and techniques that are personal to them and may be considered as "latent defects" in their practice.

The students were encouraged to exteriorize their thoughts through the think-aloud method in order to expose their inner-speech and to fuel the design conversations between the team (external-speech).

We applied the Design Flow based on eight dimensions (apathy, worry, anxiety, arousal, flow, control, boredom, and relaxation) [32]. We also used a questionnaire with twelve questions related to how they experienced the ideation working with the physical mock-up (the Model), HM technique and the HIS (Immersive Sketching "IS" and Immersive Model Making "IMM"). The last part consisted of ranking eight components that can start or sustain the flow. A final question was related to the back-talks of these representations and the development of concepts.

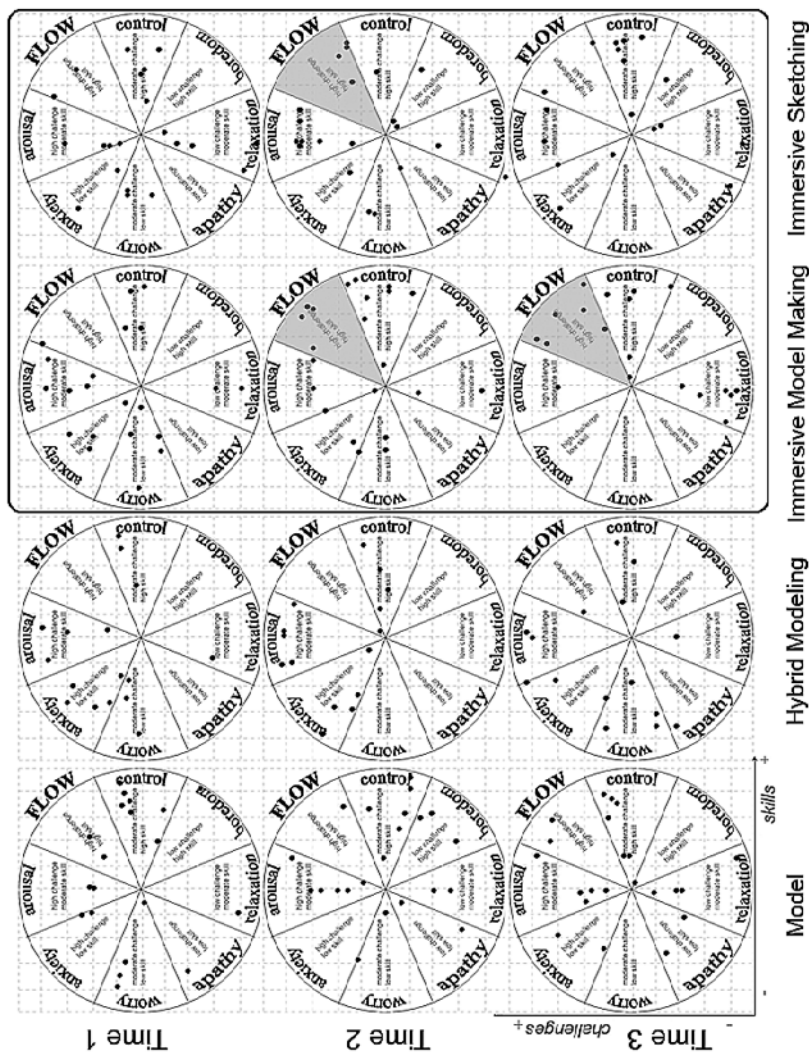
In order to evaluate the cognitive aspects of the HIS as an interface, we also used the NASA Task Load Index (TLX) [33]. TLX is a multi-dimensional rating procedure that provides an overall workload score based on a weighted average of ratings on six subscales: three dimensions relate to the demands imposed on the subject (mental, temporal, and physical demands) and three to the interactions of the subject with the task (performance, effort and frustration).

7. RESULTS

7.1. Design Flow

For the evaluation of the Design Flow students put a dot in a circle divided in eight dimensions (Figure 4). These dots were placed according to how they felt at the beginning (time 1), the middle (time 2) and the end (time 3) of the task. For the Model, which was not demanding or laborious, students went from *worry* and *control* at the beginning to *control*, *arousal* and *relaxation*

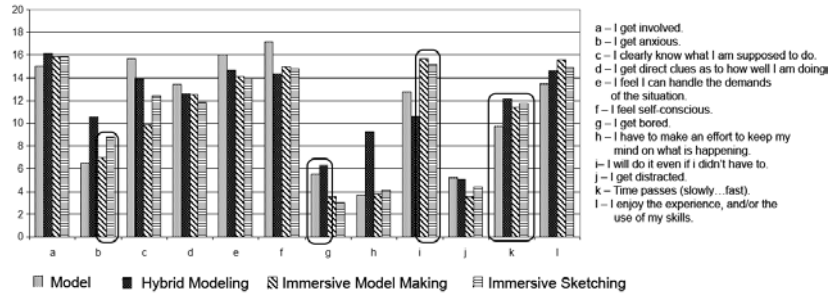
at the end. Some students finished the model in less than one hour. HM was more precise and complex, and the performance of the students depended on how well they knew the technique. Values were constant for the worry, anxiety, arousal and control dimensions. The task was less demanding and most forgiving in the HIS. Students went from worry, anxiety, arousal and control to relaxation, control and finally flow. Students felt more comfortable with the interface. Even with the time pressure and being first-time users, students reported being in the state of flow more often in the HIS (IS and IMM).



◀ Figure 4: Design Flow I (circle).

In another questionnaire on the Design Flow, students indicated that there was *anxiety* in the HIS due to first-time use, yet at a lower rate than the *anxiety* reported in the HM, a technique they already knew (3D modeling). The level of *boredom* was higher when working with the Model and in the HM. The complexity of the task and interface in the HM required more concentration from the students. They lost track of time similarly in the HIS and the HM, even if the HIS was used only for 20 minutes and HM for one week. Also there was a clear preference for re-doing the experience for its own sake in the HIS (Figure 5).

► Figure 5: Design Flow 2 (questionnaire).



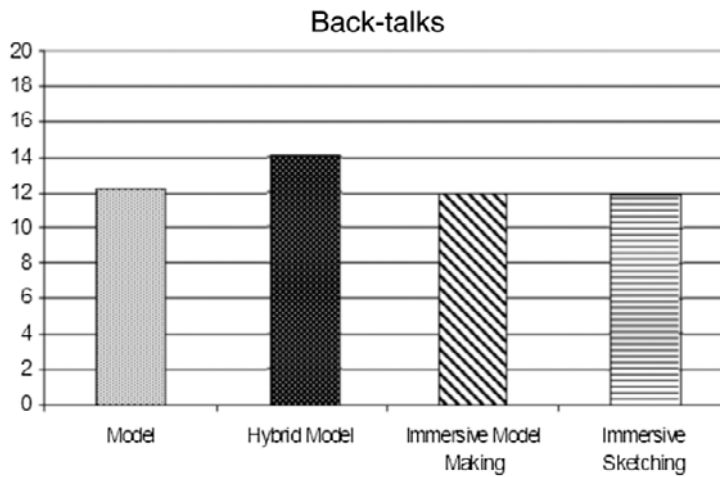
Students considered eight components that can start the *flow* or support it during the ideation. They ranked these components in order of importance. When the students felt more comfortable with the HIS, they were able to perform without any problem. The performance in the HM depended on how the students knew the technique, and the intrinsic motivation was more important in the Model and in the HM. In the HIS, their attention was focused on the activity (ideation) and on the environment surrounding them.

In order to sustain the experience in the HM and Model, the skills are still more important compared to the HIS.

7.2. Back-talks

Students ranked the representations according to the feedback they got from them. These representations helped students develop their concept in different ways. It seems that the traditional techniques such as the Model and the HIS provided enough information for the ideation process without the need of complicated interfaces options and special commands or special training. Also HM technique was used longer (one week) (Figure 6). This longer use was needed because of the complexity of the design task using digital 3D modeling techniques inside the HM approach. As explained in the following sections, a consequence of that is reflected on students' perception of temporal demand using the HIS and HM.

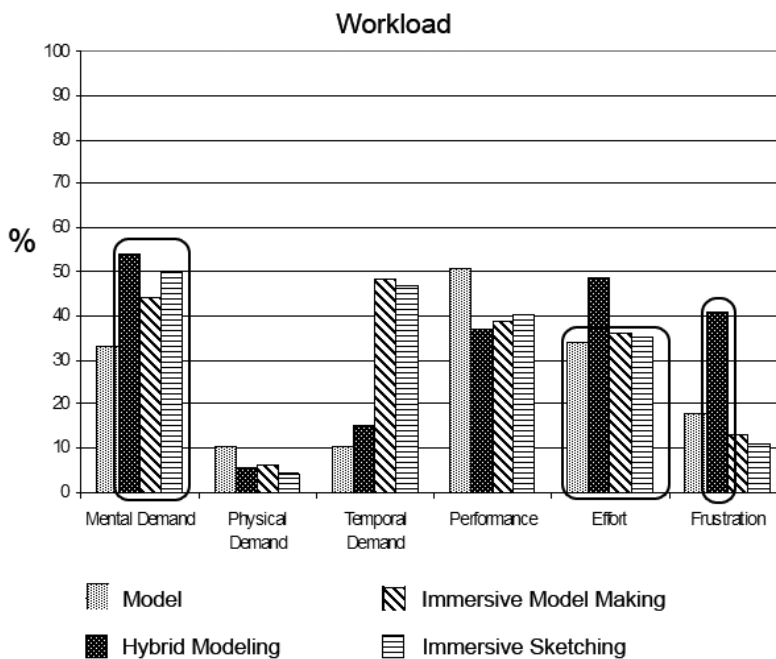
◀ Figure 6: Back-talks.



7.3. Workload

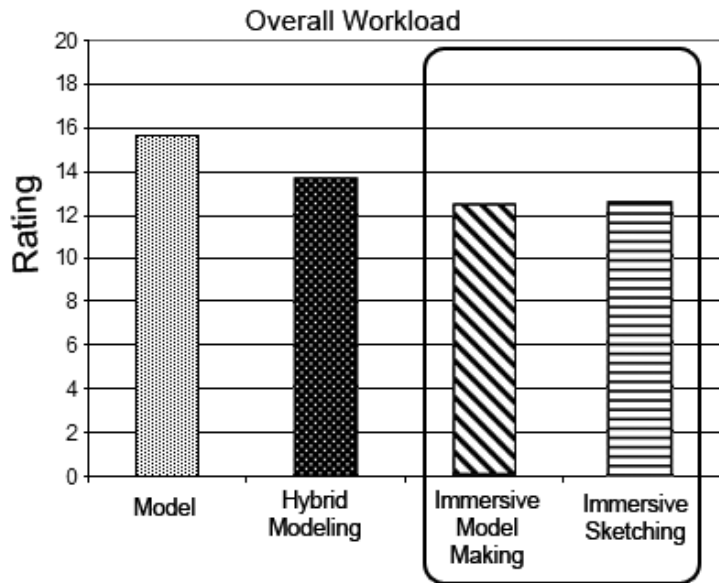
Even with the time limitation in the HIS, students were able to achieve most of their design goals. The mental demand was similar in the HM and the HIS but since the *frustration* was greater for the HM, this technique proved more demanding, stressful and complex. The *effort* was low when intuitive interfaces were used (Model and HIS) (Figure 7).

◀ Figure 7: Workload.



The overall workload shows that for the Model the students achieved more design goals but it required additional effort. In the case of the HM the overall workload was lower but the main source of workload came from the effort, *frustration* and *performance*. The design goals that the students achieved with the HM required more *effort*, which caused *frustration*. For the HIS, the workload came from the *effort*, *performance* and *temporal demand*. Even with the *temporal demand* and *effort* from the new interface, the students achieved their design goals.

► Figure 8: Overall Workload.



8. CONCLUSIONS

As observed here and better understood in a subsequent study [34], although Csikszentmihalyi's flow is often an indicator that the ideation delivered positive results, Design Flow accounts for the full measure of the ideation process, which involves episodes of anxiety, arousal and control as well as flow. There is anxiety and arousal because the act of formulating new concepts is similar to a walk towards the unknown, and there is control because designers give form to new ideas with tools they master. The ideation is often an uncomfortable, yet most productive time. Furthermore, the notion of Design Flow includes considerations for workload (usability) as well as Schön's back-talking (representational conversation).

Some students needed to adapt to the hand-eye coordination to work in the HIS (5 to 10 minutes), while for others was immediate; Immersive Sketching was easier as soon as they felt more comfortable. All the students were able to finish their concept during the 20 minutes that they had. The

real scale in the HIS allowed the students to understand their concept and see errors more easily, triggering a better feedback loop.

Students improved communication by using a laser pointer, one moving it over the projected sketch, the other following it with the pen, as if they were sketching at the same time. The students made observations about their design and the feedback between them was constant and efficient. Sketching and talking at the same time was significant in the HIS. The design decisions improved in quality as the sketch evolved. Once again, the use of the laser pointer helped to improve the communication between the students. Sometimes the students took a little time to reflect on their design and sometimes they just kept going with the sketching until they agreed on it. In the beginning the student's discussion was about the general shape and at the end they talked about details of color and texture, all of this based only on the sketch that they were doing.

The use of intuitive interfaces with physical Models and the HIS allowed the students to ideate more easily, based on factors such as time spent, concepts produced and success rate. The design collaboration among students was very important in the HIS. The students with high intrinsic motivation often outperformed students with low motivation. When students worked together they enhanced the ideation process, particularly in an environment like the HIS where the main focus is active design.

9. FUTURE WORKS

Our future works will be structured comparative studies on collaborative conceptual design with digital and analog tools (paper and physical models) as well as in the HIS. For these studies we want to be exploring all types of collaboration (co-located and remote, synchronic and asynchronic) in the wider design process (involving designers, clients and others actors in the design process).

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