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THE SKETCH POWER TO SUPPORT PRODUCT DESIGN.

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Keywords: product design sketches, 3D representations, sketch based interface.

1. Introduction.

This paper is interested in the extent to which sketches and 3D representations are important in today's design process, and more particularly during the preliminary creative phases of product design. We question the relevance of sketches within systems of external representations and amongst the infinite possibilities offered by the actual Computer Aided Design (CAD) tools. This exploratory research is conducted through to 3 main steps: first an information gathering step where we assess the current state of art, then a direct contact with designers through interviews and, finally, the testing of the existing theories thanks to the pragmatic character of two experimentations. The project's goal is to objectivize a Human Machine Interaction that could effectively and efficiently support the product designers in their preliminary creative phases.

2. Augmented Sketch.

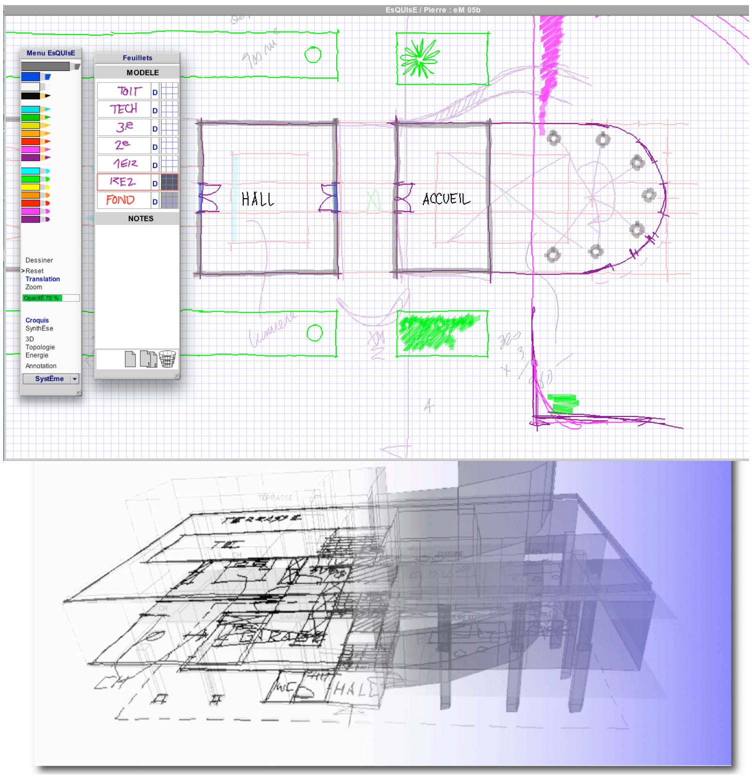
The design activity has been supported for two decades by CAD systems. By offering architects, engineers and designers new possibilities of modeling, these tools undeniably add value to their work. CAD tools, while extremely efficient in various domains as post-production, rapid prototyping, 3D realistic of even photo-realistic renderings, still present a limited ability to support designers in their early creative steps. This limitation is explained by (i) the necessity to encode entirely predefined models, opposed to the vague and implicit representations generated during the creative activity, and (ii) by the recourse to declarative WIMP operating methods (Window, Icon, Menu, Pointing Device interaction), imposed by interfaces that don't match the designers' spontaneous ways of expression [McCall & al, 2001]. These tools might even deform the mechanism of thought, to the extent of negatively affect the inventiveness of their propositions [Van der Lugt, 2005].
On the other hand, according to a number of authors, sketches play a major role during the preliminary phases of designing. For instance, they allow the designer to assess some of the blurred mental images s/he makes of the artifact to produce [Visser, 2006]. Bilba and Gero [quoted in Gero & Bonnardel, 2005] explained that sketches lighten the visual and spatial memory load, freeing up cognitive resources better used in maintaining a dynamic exchange with the drawing, proper to go on with the problem space exploration, till the convergence to a problem-solution pair which could be considered as satisfactory [Cross, 2000].
Consequently, despite the computing power available today, the "paper-pen" combination seems to remain the main tool of creation in the early stages. It is this paradox that our project aims to analyze and surpass, by proposing a new supporting concept for the early design stages, named "augmented sketch".

This concept, that wants to transpose the paper-pen metaphor into the digital environment and to exploit it directly for 3D modeling, tends to specify a new generation of design system, supplied with:

- a multimodal interface : freehand sketches, annotations and dimensions are interpreted as synthetic expression of a 2D sketch in order to generate a 3D model.
- an interpretative interface : able to overstep nowadays CAD binding declarative proceedings to allow the designer to focus on his/her creative task.

2.1. EsQUIsE : a 3D interpreter of architectural sketches.

The Augmented Sketch concept first finds an application in architecture through the EsQUIsE software [Leclercq & Juchmes, 2002; Leclercq & Elsen, 2007]. This software, combined with a “disappearing computer” concept [Safin & al., 2005], is able to track, analyze and interpret architects’ freehand sketches in real time. EsQUIsE can be shortly described by 3 modules [Safin & al., 2005]. Firstly, the entry module : it consists in analyzing sketches in order to construct the geometrical model of the drawing, in other words, the internal representation of the structure of the drawing. Because of the sketches lack of precision, a “fuzzy graphic” model approach has been developed to take into account the considerable margin of error in the identification of the drawing geometry. Secondly, the interpretation module translates this geometrical information into a functional model of the planned architectural object (analysis of the semantic content of the drawing) : annotations and implicit information allow the system to compose in real time a complete model of the building designed. Thirdly, the evaluation module offers to the users non intrusive feedbacks about the artifact, like for instance (and at the present time) 3D visualizations, thermal consumptions, topological organization or energetic needs (in heating or air-conditioned).
So, EsQUIsE aims at helping designers in the early stages of their creative processes, lend itself to the natural and intuitive way to conceive: the user is allowed to draw and annotate whatever s/he wants without any kind of pre-defined declarative steps, in a total freedom of action and/or in time.



Figures 1 & 2. EsQUIsE interface and 3D interpretation of sketches

2.1. Innovation as context.

EsQUIsE, as sketches' support tool, has already been evaluated : several experimentations have been conducted [Safin & al, 2005; Decortis & al, 2005; Darses & al, 2008], one of them bringing together 7 practicing architects. This research presents two main results [Darses & al, 2008]. First, the usability of the digital environment for sketching has been assessed. The principle on which the sketching device works is well suited to the architects' needs, and these ones do not limit themselves to a narrow exploration of the solution space (some of them don't hesitate to generate up to 9 design solutions).
Then the production of "3D sketches" (understand drawn perspectives from various points of views) as well as the use of 3D visualizations for generating and exploring alternative solutions have been investigated. The study highlights that architects in fact do not produce a large volume of 3D sketches and neither make extensive use of 3D views. Some authors explain this preference for a 2D media in generating an architectural artifact by the inadequacy of the 3D representations (drawn by the architect or shaped through a CAD tool) to support the early creative phases. Indeed, some relevant reports notice that the supposed 3D predominance in design processes is based on the predicate that the object's initial mental image would be so limpid that this object could be right away designed by an unique and complete 3 dimensional representation [Estevez, 2001]. Yet, studies show that architects need plans, sections and elevations to nurture the design process: these representations are multiple, partial and autonomous though linked in their essence. This fragmentation doesn't reject the integration notion but never imposes it, this individual progress allows architects to create incoherences that offer a creativity freedom. This theory, explaining the observations gathered on EsQUIsE as far as 3D sketches are considered, is also validated by architects' practices observations, which show that, indeed, the perspective drawings and 3D views concern only 5% of sketches [Leclercq, 1996]. These are mainly used for control and evaluation purposes and rarely participate in hand sketching design, the terrestrial gravity inciting architects to work in plan.
On the other hand, the second result (the small appeal of 3D visualizations) could be explained by the prototype's poor adjustment to the architects' external representations and their level of abstraction. Architects certainly conduct a lot of spatial reasoning, but these thoughts aren't entertained through this prototype's functionality because the model proposed is mainly form-driven, since the architects' internal volumetric representations are mostly concept-driven.
Starting from these results and observations about architecture, we decided to open a new field of investigations and we chose product design as another goal of research. Indeed, in comparison with what have been already observed with architects, product designers are hoped to bring complementary and interesting information about the early relationship held, in primary conception stages, between freehand sketches and 3D representations. Is the 3D "world" at this point maladjusted to all categories of design, for instance product design? If not, is there something to do to support these kind of representations at the early phases of sketching? The ability of product designers to conceive everyday objects has been chosen amongst more specific professions, like for instance mechanical designers, hospital or sport equipments designers: product designers are indeed more likely to propose free-shaped artifacts, proceeding from a more creative throw rather than an optimization one, and are well suited to quite short design processes, involving less technical considerations and external interventions at the very first stages of design. We required this specific spontaneous innovation context to go on with the first steps of our exploratory and clinic researches on sketches and 3D representations.

2.2. Prospected themes.

Consequently to these global considerations, several questions structure this first phase of our project :

- Which relationships do contemporary product designers maintain with sketches and 3D external representations? What are their real efficacy, contributions to design process and on the opposite their main limitations ?
- How could we efficiently adapt the proposed augmented sketch concept to their early design phases ?

3. Methodology.

These interrogations have been conducted through the following work methodology : first a short assessment of the current state of art, then a direct contact with designers through interviews in order to collect their points of views about the different subjects concerned. Afterwards, the existing theories and the information gathered are evaluated through to the pragmatic character of two experiments including post interviews. Finally, the observation of graphic designers at work, modeling the artifacts produced by the product designers during these experimentations, permitted the deeper analysis of the user's relationship to modern CAD tools.

We have to warn the reader that a certain category of designers aren't included in those results. Indeed, some of the designers who were interviewed made use exclusively of CAD tools. Their projects, simple translation of a fleeting mental image onto the PC screen, never required the use of freehand sketch to be developed. These subjects' data isn't included in our results because their workflow pattern doesn't fit our specific research scope, namely the design supported by interpreted sketches.

3.1. Interviews.

The interviews of 6 professional product designers, experts or beginners, teachers, freelancers or employees, teach us about the genuine usefulness of freehand sketches in an everyday or business context as well as it's shortcomings. Specifically, this first qualitative collection of information shows us that sketches' lack of a flexible and adaptable structure still require the dynamic digital 3D representation to quickly apprehend the global artifact's complexity, to communicate with industries and colleagues or to seduce the customer. This visualization is most of the time executed in parallel by graphic designers, leading to unavoidable interpretation mistakes, back and forth information exchange between designers and drawers and, as a consequence, loss of time, money and credibility in the context of a competitive market.

On the other hand, as expected, the multiple benefits of freehand drawing, already documented extensively in architecture, have been validated as well in this domain : freehand sketches still constitute a powerful and unavoidable design tool, just as it is in architecture.

3.2. Experimentations.

The goal of these experimentations is to better understand the relationship the designers maintain with 3D representations in general and to evaluate to what extent the observations gained for architects are also true for the product design domain.

3.2.1. Subjects.

Once the designers' profiles had been clearly defined through the interview process, we decided to solicit two of them more particularly for a real time design experience, under video-camera recording and in presence of an observer. The exploratory character of this research lead us to a clinic procedure instead of a statistic one, with a small number of created objects, observed subjects and a thin granulometry level analysis. These two designers selection was based on their confessed attraction to hand sketches, not only for the sheer pleasure of drawing but above all for the necessity to construct a first whole solution through a paper and pen stage. We also chose them for their different sentant level, methods and design contrast highlighted by the interviews: they both are considered as experts and successful designers [Ehrlenspiel, 1995], the first designer is quite young (3 years of design business), in contrast to the second one (more than 30 years experience).

3.2.2. Statement.

The designers were asked to produce a multi-functional remote control. This statement was the result of a deep and long analysis, first validated by another professional designer, external to the exploratory process devised here. The object had to be "easy" to conceive, without the need of external intervention which is impossible to provide in this experimental setup. This remote control has been chosen for its potential to lead to sketches with a rich user relationship (ergonomic, aesthetic, functional, economic considerations) as well as the freedom it offers in terms of shape, allowing for bright and complex 3D exteriorization.

3.2.3. Modalities.

The designers had to propose, through sketches, a feasible solution of the remote control, in a "think aloud" context, without any kind of time constraint. They could take a rest at any time they wanted. The whole experimentation was video-recorded (one front camera and one up camera), in order to allow post analysis. We decided, for this first attempt with the designers, not to make them draw directly onto a digital interface. Indeed, the less the design process was disturbed and the more the sketches were natural, the closer we were to ecological conditions of work (EsQUIsE wouldn't of course be able to interpret non-architects sketches at this point of the research process). For both designers, the whole object was conducted to an end in about 1 hour and a half.

4. Data analysis.

The post video analysis allowed us to observe the drawings, to analyse the speech as well as the gestures. This last purposeful body movement could indeed communicate information such as references to existing or imagined objects in the workspace, relationship between the created object and a defined part of the human body or simulations enacted by the designer. The variety of elements to observe lead us to define a cut-out of actions. This cut-out has been defined thanks to the natural transition from one activity to another, pointed out for example by:

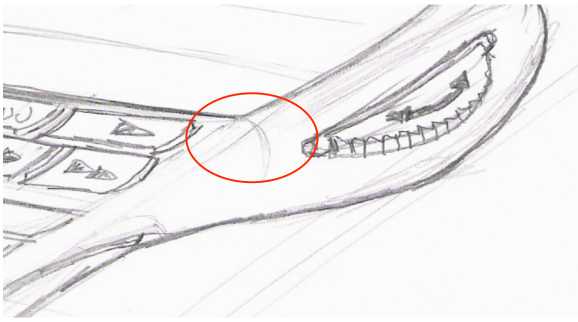
- data consultation;
- concept emergence (detected through speech, drawing or gestures);
- beginning of a new sketch, detailed drawing of a new defined zone or of a group of similar elements (combined thanks to their identical semantic signification, their identical graphic exteriorisation or identical abstraction level);
- introduction of new elements on the sheet, for instance annotations or sketch details;
- return to a previous sketch (and drawing on this sketch or just a visual inspection, comment);
- concept evolution detected through designer speech, gesture or sketches;
- problem emergence detected in the same way;
- drawing deletion by gumming or erasure;
- evaluation (through main curves emphasis or verbal observations for instance) or controls ("*did I forget something ?*")

For each action type, we obtained a starting and ending time, affording to deduce durations and chronological evolution. On top of that, an analysis grid, previously built with the help of a cognitive ergonomist, structured the understanding of each of these activities, their characteristics and the link existing between them. At each action consequently corresponds a range of characteristics, listed in the grid below.

Table 1. Analysis Grid

	Processes
1	What is he doing? Does he: Analyze? (Interpret, negotiate, organize, calculate, reason) Search? (Read, listen, observe) Propose? (Creative phase: new information, ideas, concepts, …) Evaluate? (Controls or judgments)
2	What's the data type? Aesthetic, functional, technical, ergonomic? …
3	What's the abstraction level? Is it a unlabeled concept, a named object (labeled), an association, a qualitative or quantitative data?
	Sources of income
4	Where are the ideas coming from? General heuristics? (General rules) Product design heuristics? (Product design rules) Meta-knowledge? (Operator's characteristics and own way to consider the design activity) Statement? Analogy? Running project?
	Sketches
5	Are the sketches global drawings? Details? Concepts? Linked to environment (external frame, annotations, shadows, …)?
6	Do they act on global shape, or details, or assembling, or components, or aspect?
7	Are the sketches non-symbolic? (Lines, scribbles, strokes …without other purposes than the simple creative gesture)
8	Symbolic? (a specific task underlie the strokes : emphasis, link, move, …)
9	Alphanumeric? (Number, character, abbreviations)
10	What are the external representations used? (Plan, elevation, 3D, …)
11	Is it a construction line? (Symmetry, frame, axis, …)
12	Does it figure matter or texture?
13	Is it a master curve/line?
14	Does it figure shadow?
	Zoom
15	Is the pencil stroke belonging to a line, a point, a hatching, An arrow, a symbol?

At each characteristic consequently corresponds a number of actions (with their durations). These information allow us to calculate ratios of the several characteristics' occurrence and their chronological evolution, and the analysis of the produced sketches (semantic and graphic contents) as well as the simultaneous product designers' comments and gestures provide us with fruitful results.



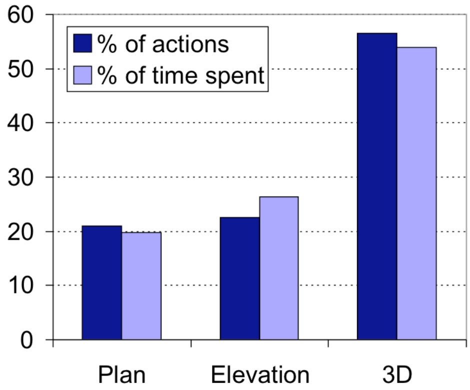


Figure 3.
Analysis of the produced sketches

Figure 4.
Ratios (percentage of actions and time spent) of actions characteristics (here the three types of representations)

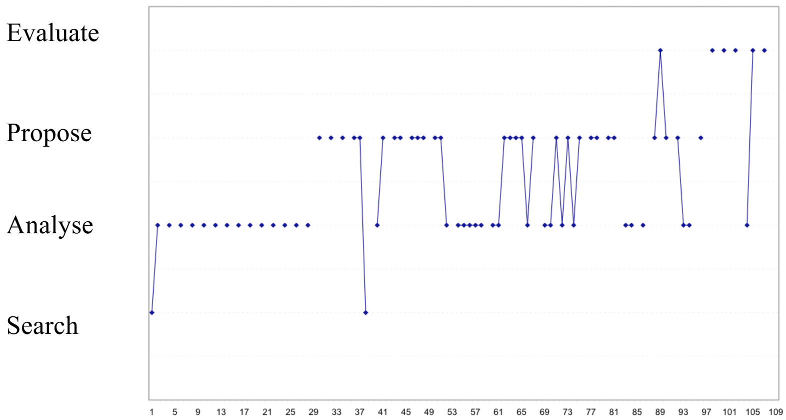


Figure 5. Chronological evolution of actions characteristics (here the processes)

4.1. Designer 1 : methods and progress.

The designer 1 explained that he mainly uses the CAD tool as a rendering and production tool. He doesn't like to draw, so as soon as his idea is sufficiently defined after a few sketches, he goes on with the exploration of the problem-solution space through the construction of a 3D digital model. He recognized that, although these tools are very powerful, he has to regret that once the model is constructed, he's loath to consider a new solution as the model construction takes too much time to afford other attempts.

During the experimentation, he proposed two solutions presenting the same sequential evolution of drawings : after some reflection time, he began to draw an elevation view, followed by a profile one, and finally a perspective drawing. The main decisions were take on the elevation (58% of actions devoted to it, 57% of master curves defined), but numerous comments and gestures (evoking invisible shapes) show us that the designer was actually thinking and designing in 3D. After reporting his choices on the profile view and, afterwards, on the perspective sketch, considered here as the exteriorization he would have made with CAD tools, he decided to go on with another solution and his final comment was: "*Ok here would be the step where I really need my computer to embrace the whole complexity of my work*". During the post experimental interview, he explained us that the second solution (see below), that seemed closer to his usual design style, was the result of a precise image in his brain: the prehistoric men grabbing a bone.

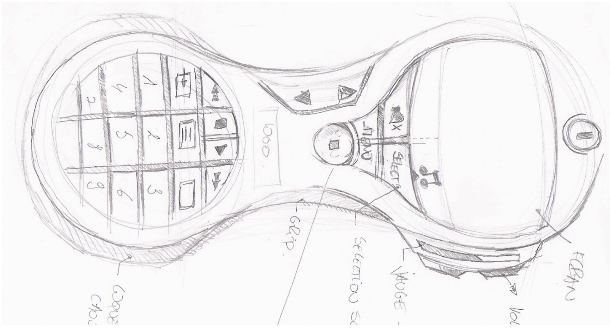


Figure 6. Designer 1 Work – Second solution

4.2. Designer 2 : methods and progress.

The designer 2 entertains with CAD a totally different relationship : he never models himself the objects and conceives exclusively in sketch-books. He regrets the lack of time caused inevitably by the multiple exchange of information he has to do with graphic designers working in his company.
He proposed only one solution. His methodology was much more structured, although he made a lot more “go and return” between the proposed drawings. What could seem at a first sight disorganization was in fact an intense relationship with the proposed sketches.
The designer 2 began with a long program reformulation, through checklists, conceptual drawings and comments. Then he proposed simultaneously an elevation, a profile and a perspective view, all these drawings evolving in parallel at each new constraint considered. He mainly developed his idea on the perspective drawing, 56% of actions being devoted to it (against 21% for the elevation and 23% for the profile), and 62% of master curves have been defined on this representation.

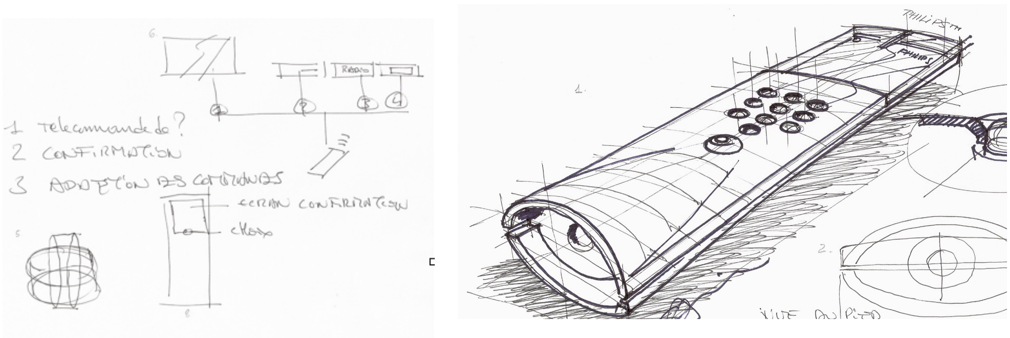


Figure 7. Designer 2 Work – program reformulation and perspective view

5. Discussion.

Amongst all these results, the analysis of processes and sources of income for the artifact construction show us which propositions, between all the cognitive theories listed, seem to be the most adapted to product design domain. So, the opportunistic vision of the design schema [Visser, 2006] fits quite well this situation, with a solution-problem solving couple emerging as the constraints are progressively taken into account, without a real pre-established design process. Moreover, the theory that presents the design process as construction of representations [Visser, 2006] would clearly explain the intense

relationship the designer maintains with the drawing, some of these aspects being already defined by Schön [quoted in Visser, 2006] as “see-transform-see” theory.
Then, an interested link has been observed from the sketches, comments and gestures analysis about the relationship existing between designers and the 3D freehand representation, in comparison with architects. In architecture, as explained above, the seat of honour offered to 3D externalisations is nowadays considered by many authors as overvalued.

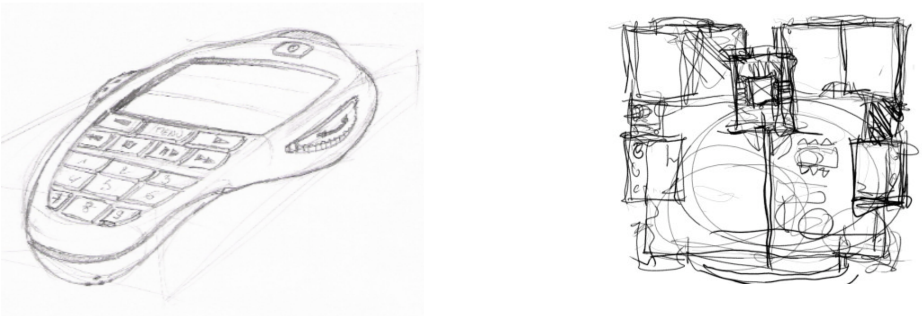


Figure 8. Designer 3D sketch on the left, architect plan sketch on the right

This research, although presenting a clinical character, would incite us to adopt a more flexible judgement since 3 dimensional representations are considered in product design more particularly. As a matter of fact, the results gained through interviews and experimentations show that 3D is here more than a “simple” evaluation or communication tool. Designers consider this representation type as an unavoidable step of their design process, introduced very early in the creative throw, not to say immediately from the initial instant. Of course they also use orthonormal views, but 3D here really helps them to integrate ergonomic, technical and aesthetic considerations. Most of the master curves of the final artifact are crystallized on the perspective drawing, although defined simultaneously on the different views through an intense go and return between drawings.
We also observed that the perspective is used to formalize textures, rendering or interactions with the supposed environment. Experiments showed us moreover that precise formalizations correspond to defined types of actions : for instance, textures or renderings artifacts correspond most of the time to a proposition phase, contrary to shadows and light interaction that generally fit with an evaluation step.

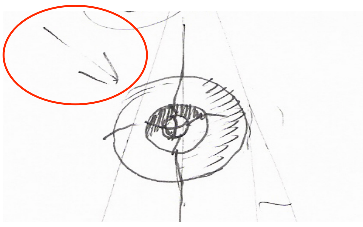


Figure 9. Example of the light’s introduction as an evaluation tool

As far as sketch contents are considered, we observed that light lines are used to construct the global structure (axis, frame, construction boxes), when bold ones define the finalized structure of the drawing, this way underlined and easy to be later reconsidered or communicated.
Sketches observations also teach us that product designers entertain with draft drawings - or more generally speaking with “essay-error” constructions - a totally different interaction than architects. On the one hand, architects will prefer to realize several attempts on several sheets (or layers) to reach the satisfactory solution, each floor being constructed at the same time, with most of the constraints considered on the ground floor plan and, once solved, applied on the other levels [Safin & al., under review]. On the other hand, product designers will produce also the different views on separate sheets, but once started, a proposition will grow in parallel on the same drawing, creating this way several layers of lines on the same externalisation, just as if the first lines make the born of the following one easier.

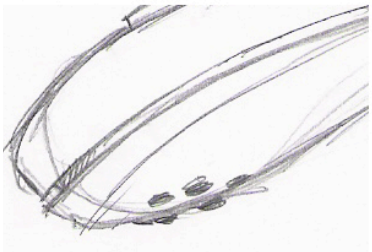


Figure 10. The several layers of work and the bold line achieving the shape definition

Finally, graphic designers model one of the artifacts produced during our experimentations and the observation of this three hours task completed the list of actual CAD tools limitations. Moreover, the regular issues encountered by the graphic designers to understand and apprehend correctly the proposed sketches comfort us about the necessity to develop a design support tool especially for this particular step of the creative process.

6. Future prospects.

As shown here, freehand sketches constitute powerful design tools for product designers as well as 3D representations (drawings or models). Sketches could therefore be analysed and interpreted globally in the way proposed by EsQUIsE right now : the analysis of free-form shapes through lines recognition, semantic contents and graphic characteristics indeed seems to be the more adapted solution to support the early and blurred artifact construction.
The augmented sketch concept nevertheless has to be adapted to the product design specificities: indeed, thanks to what interviews and experimentations analysis already showed us, the software able to support this concept should interpret orthonormal views as well as perspective drawings, these 3D views being of course deeply linked in their essence with the previous ones (at this stage, systems like EsQUIsE are able to interpret sketches in a 2,5 dimensional way, the 3D being in fact a temporary extruded construction). Far from competing with prototypes like Teddy [Takeo Igarashi, 1999], which propose a "blob" reconstruction of sketches, the interest would be here to propose to designers a more "structural" way to consider their sketches and design process. Creative lines, construction lines, formal research and rendering would be differently interpreted and represented, everything being subjected to the user's validation. The drawing could consequently be interpreted little by little, offering a growing view of the artifact, faithful to the level of abstraction the designer really reaches at each step of the design process.
This pointed interpretation of lines characteristics could, in a short future, become true with TraGeRe, a prototype developed in our laboratory. TraGeRe (French acronym for realistic generic drawings) purpose is to render, in real time, digital sketches in a more realistic way. Classic screen strokes always have the same characteristics : same thickness, same blackness,… TraGeRe's new mathematical model enables digital stroke rendering through modeling of real interaction between graphite pencil and various drawings paper types. These strokes characteristics will bring the new kind of interpretation we need to scan the designers intention in a more accurate way.

The ultimate goal is, through numerous experimentations and on-site observations, to set on foot a real virtual and "intelligent" design sketch book, that would be able to make the "bridge" between the creative throw and the unavoidable modeling stage. Surpassing this way the nowadays limitations of both freehand drawings and CAD tools considered separately, we could add their advantages for a great potential human-machine interaction.

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