Analysis of product designers' creative and cognitive processes.

Recommendations for the development of EsQUIsE to support Product Design.

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Abstract.

The goal of this work is to analyse the product designers' main habits in creation and cognition, to study the sketches' contributions to early stages of design processes (these sketches being one common feature in creation that designers have with architects) in order to evaluate if EsQUIsE could support product design. Several questions sequence this evaluation:

i) What are the main product designers' work's methods? What type of projects do they usually approach? What kind of issues, constraints do they have to confront?
ii) What are the cognitive processes involved during the design phases?
iii) When and how do sketches enter these processes? What are their effectiveness, their main contributions and on the opposite their main limitations?
iv) Assuming that sketches constitute for product designers an effective support for the early creative phases, what are their principal characteristics? What do they content? What are their predominant graphic codes in this particular domain?
v) What are the nowadays Computer-aided design tools' appointed functions in product design? What are their advantages and drawbacks? How could they become better adapted to preliminary design phases?

These interrogations are considered thanks to the following work methodology:

- First an information collecting through a short state of art.

The following subjects are: projects and constraints analysis; technical background; summary of the principal creative and cognitive processes in design; study of sketches potentials; advantages and limitations of actual CAD tools and short listing of the main software used in product design.

- Then a straight contact with designers through interviews in order to collect their points of view on the previous subjects.

- Follow the appreciation of the previous theories and collected information thanks to the pragmatic character of two experiments.

These experiments bring new elements. They afford a better understanding of the general design theories, they confirm the sketches' and 3D representations' contributions to the design processes and furnish the first basis of graphic codes' and sketches contents' analysis.

- Finally, the observation of graphic designers during the modelling of a simple object permits the deeper analyse of the relationship the user maintains toward nowadays CAD tools.

A summary of the multiple aspects EsQUIsE should present to efficiently support the early conception phases in product design concludes this research.

Acknowledgements.

The writing of this thesis wouldn't have been possible without the precious help of many people.

I would like to express my gratitude to my main advisor, Professor Pierre Leclercq, for his patience, his confidence, his English lessons, the numerous advices he gave to me and more than everything else for the opportunity he offered me to introduce my personal interest about the design world within the context of his actual research.

Thanks a lot as well to my jury's members, Mrs. Françoise Decortis, Mrs. Geneviève Martin, Mr. Jean-Claude Cornesse for their listening, pertinent advices and support.

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Preliminary notice.

I decided for several reasons to write this thesis in English. What was initially a personal challenge slowly but surely becomes everything but a sinecure – I must admit I learned a lot and of course improved my level, but I still would like to apologize for the unavoidable mistakes and clumsiness you'll find all along this work. I'll go on with practice to make the following attempts better.

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Chapter one.

1.1 Introduction.

Design tasks are quite similar to architecture's ones. In both disciplines, designers are asked to improve every day life through functional, technical, aesthetic (or so called) solutions. I've always been interested in what could link architecture and design, and the faculty of improvement they could have on each other. Purposes and artefacts are different in several ways as we will see, but one interesting similarity still exists: designers are supported in their creative mission by hand sketches. Therefore I decided to focus my research on this shared characteristic and to study the cognitive inputs and effects drawing has on creative processes. My hope is that this starting point, the better understanding of designers' sketches, will finally help me to better understand this fascinating world, so deeply linked to the architectural task that could be mine someday.

Universally used and worldwide fashion, the "design" phenomenon is pregnant in our XXI century's culture and society. Nowadays a broad effort is trying more and more to define the blur contours of the profession, without satisfying the whole community. In order to stay coherent and to apprehend a more specific domain, I chose to concentrate my analysis on product designers. That means professionals trying to improve our life and modes' styles by modifying objects of our everyday life. I decided to stop my decision on this definition because it is in my opinion the conception category the more linked to what could be done in architecture: humans interactivity, ergonomic, material's behaviour and properties, environmental and economical considerations, ... are some of shared constraints between architecture and product design. This way I avoid to centre my research on too specialized sectors like industrial design, which has in common with building or mechanical engineering optimisation[1], but for whom it miss one pregnant architectural common feature: creativity. This way, my bases in architecture domain can serve my thesis in a more connected way.

This definition will probably reject lot of annexed professions, but just initially. Indeed my hope is that at the end of this thesis there will be no doubt that the main type of observations and experimentations proposed here can be applied to other domains, and also that this thesis, supported by a strong experimental character, can maybe open some doors to further investigations.

1.2 EsQUIsE for Architects – feedback, potentials and perspectives.

Many research have been done about sketches and their potentials. I had the opportunity to take advantage of what had already been observed in architecture by the LuciD Group (University of Liège). Indeed, based on an enormous experimental work about rough sketches' analysis, this laboratory brought into focus an innovating prototype named EsQUIsE. EsQUIsE is founded on an original "Augmented Sketch" concept. This program is able to seize, analyse and interpret creative architecture sketches in order to support the early conception stages [Leclercq, 1999]. At present,

[1] By optimisation here I hear "arriving at a solution by strict calculation". This "mechanical" side of optimisation is not regarded here as designing. However, if optimisation constitutes a concept (in a more "minimalist" signification), a creative step being introduced, this type of design can reinstate my definition.

this software models in real time a 3 dimensional building representation from sketches and offers in a few seconds evaluations of different performances such as thermal loss, energy consumption.

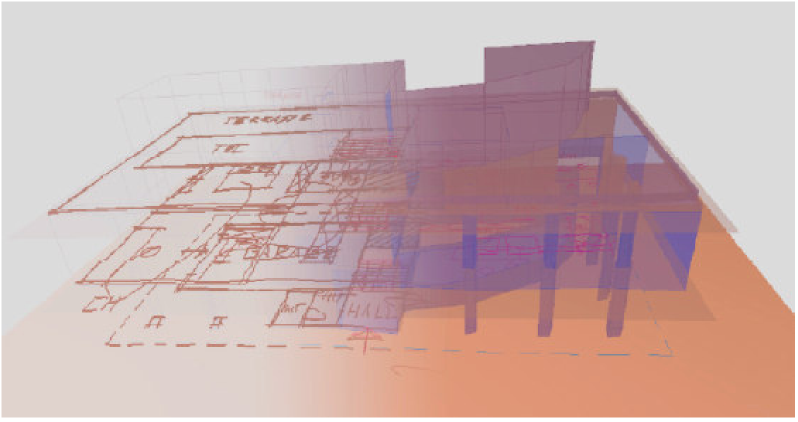


Figure 1 - The EsQUIsE principle: sketch interpretation into its building model. Source: Lucid Group documents.

This software is the consequence of two very simple observations based on the relationship between designers in general (and more particularly architects) and nowadays CAD tools. First, hardware and software are now essential in creation process, should be as easy to use as useful they are. Unfortunately they stay far away from real and spontaneous way to create. They are inadequate to concept or need and human being's natural capacities toward tools. On top of that, the LuciD Group, after observation of architects' cognitive and creative processes, concluded that the very first steps of sketches are fundamentals for the deep characteristics, qualities and defects of the future object. But it seems that so to say no software is able to support and to second the architect in this early design phase. The main used tools are simply pen and paper. Why? Simply because they remain the best and easiest way to express, modify and organise the early creative ideas. Rich of these observations, the LuciD Group decided to prototype one of the new generation tool able to help and support concepts or original ideas and to share with architects an implicit knowledge, grounded on the real sector's habits and uses. This thought process, appointed by the term "focused on user", offers a bright new proposition of human-machine interaction.

In a short future, we can hope that these types of programs will be wide used, affording in this way to connect different computers and users, to share ideas and ease communication. Right now the prototype is constantly adapted to lasts scientific discovering and improve a little bit more every day. I wish to introduce my interests in product design in this adventure, trying to propose ideas to support this sector by the amazing EsQUIsE's faculties. In order not to be already outdated of six months when this work will be achieved, I'll try to disconnect my observations of standard computer tools nowadays used for the Lucid Group works, while staying near of their observation protocols in order to ease the results connections.

1.3 EsQUIsE for Product Designers: Why?

Out of my concerns for product design, will a tool like EsQUIsE be useful for designers and support them in their early design stages? Right now, I'm convinced that the common features between both domains, architecture and product design, will led to a positive answer. But at this point, no certainty does exist. Therefore I hope that my contribution in this sector will accredit this assumption.

A few elements can yet already be pointed out. As previously said, product designers share with architects lots of common habits in creation, one of these being sketching. On top of that, the two skills depend of the same practices: creation, cooperation, communication, compromises are both designer and architect spearheads. Thanks to these characteristics, the designers are likely to use the computer and computer-aided design tools in an intense way. So they represent a new generation of designers well adapted to software and, in the same time, applicant to everything that could ease their job and allowing them to gain time. As adage says "time is money". In this case there is no doubt about it: although the design industry is very young in our countries, the value-added for one designer in Belgium is estimated around 75.000 euros per year, and the 6000 workers in design sectors represent 350 millions euros in Wallonie[2].

But these initial observations have to be sustained by further investigations, which should answer to the following research questions:

i) What are the main product designers' work's methods? What type of projects do they usually approach? What kind of issues, constraints do they have to confront?
ii) What are the cognitive processes involved during the design phases?
iii) When and how do sketches enter these processes? What are their effectiveness, their main contributions and on the opposite their main limitations?
iv) Assuming that sketches constitute for product designers an effective support for the early creative phases, what are their principal characteristics? What do they content? What are their predominant graphic codes in this particular domain?
v) What are the nowadays Computer-aided design tools' appointed functions in product design? What are their advantages and drawbacks? How could they become better adapted to preliminary design phases?

1.4 EsQUIsE for Product Designers: How?

To support this research, I consequently have to collect information about the design world, the common practices, the keys factors in cognition, creative processes, graphic representations and sketches' production. My work methodology grades on 3 main steps: first an information collecting through a short state of art, then a straight contact with designers through interviews and, finally, the confirmation of the previous theories thanks to the pragmatic character of experimentation. I decide to propose my results in the manuscript following the same logical chronology than the one I used during these few months, in order to stay close to the sequence of observations I made and their consequences on my conclusions.

[2] Data coming from "Design innovation" symposium, Liège, October 2006.

Chapter two: collecting information.

2.1 What type of information?

Once the goal is defined, there is time to find the more productive way to obtain results. Far from knowing enough of product design, I'll first need to get used to their way of work, trying to understand problems and tasks they meet in their every day life. After this very first step, I'll analyse their conception habits thanks to what I've already met in architecture. Then I'll use the sketch tool to penetrate more deeply their cognitive and creative processes.

After this stage, I'll look over the computer tools they have at their disposal, trying by this way to list the advantages and gaps they still present.

2.2 Architects vs. Product Designers – implicit knowledge.

Starting with a global point of view, there are already facts that could be mentioned here, called "implicit knowledge". These considerations or principles, which could seem just obvious but important to keep in mind during this work, result from general observations.

First, a fundamental difference exists between both practices: the relationship between the created object and human beings. On one hand, architects design life spaces, playing with envelopes and spaces to offer the place that could suit some predefined activities. They respond to the customers' needs and by respecting technical, functional, environmental, economical rules, they create most of time an unique object, with a certain aesthetic matching their own way of creating and the customers' desires. On the other hand, designers play with matter, texture and icons to set up an object, trying to improve the use of this one, or trying to propose new ideas simply to perfect our life. Their customers aren't limited in quantity: the most the object pleases to the biggest amount of people, the better it is. They have to respect the wishes of selected subjects but also to analyse the market needs to succeed[3]. We can then notice a complete different reference to human beings and production requirements.

Other elements of distinction can be pointed out, for instance the life expectancy (a few years for product design vs. a few decades for architecture), the liability's level or the projects' duration (often longer for architecture) and their extents (the work-spaces, the range of considerations and consequences, the number of domains implicated,…) that present a totally different scale.

Another obvious difference is the details' scale. If architects build a blocks wall, these ones can present some defects: that isn't an issue because we consider the homogeneity and stability of the wall and not the components considered separately. On the contrary, designers watch over mostly the details: each piece has to be perfectly equal to what he designed, and each single component has to be conceived in particular. This scale gap also explains other work's methodologies and tools.

[3] That means that we do an additional distinction between the chosen design, concerning mass production, and a more "arts and craft" way to conceive that won't be analysed here because of its more "artistic" character that leads to further pilosophical choices.

2.3 Product Design: first observations.

2.3.1 Definitions.

The official definition of the design, proposed by the ICSID (International Council of Societies of Industrial Design) is the following one: "Design is a creative activity, which consists in settling formal properties of objects we want to produce in an industrial way. By formal properties we shouldn't just understand external characteristics, but especially structural relations that made from one object or one objects system a coherent unit, as much as producer or consumer point of view".

By "product design", as explained before, I mean the design of objects of every day life, filling in a certain way the gap existing between art, where creativity exists for itself, and engineering, where technique respond to rational constraints. Product design stays nevertheless an ambiguous term, which blurs the boundaries between specialised fields such as lighting, furniture, graphic, …these perceptual and physical boundaries being constantly eroded as global communication improves.

2.3.2 Projects and Constraints

> *" Design has numberless concertations. It is the organisation in a harmonious balance of materials, procedurals and every single elements tending to a certain function. Design is nor a façade or an external appearance. It has rather to penetrate and understand the products' and institutions' essence. Its task is complex and meticulous. It integrates as well technologic, social and economical needs as biological necessities or psychological effects of materials, shapes, colour, volumes, space. The designer must see, at least from a biological point of view, the whole and the detail, the immediate and the outcome. He has to conceive the specificity of his task in regard to the complexity of the system. His training must concern as well the materials' uses and technologies as the knowledge of functions and organic systems."*
>
> L. Moholy Nagy, 1947.

On top of this global complexity, design is bound to a production system either massive or supposed to please the masses. The projects reach almost all levels of creativity. The designer is asked to conceive totally new products responding to new needs, or to re-design a product taking account of the new technologies, as well as developing, enlarge or decline a product range already existing. And that without forgetting the strategic rules of innovation and competition they have to face (especially in product design). Design projects are also multi-functional, concern numerous domains, as we can see on the following array.

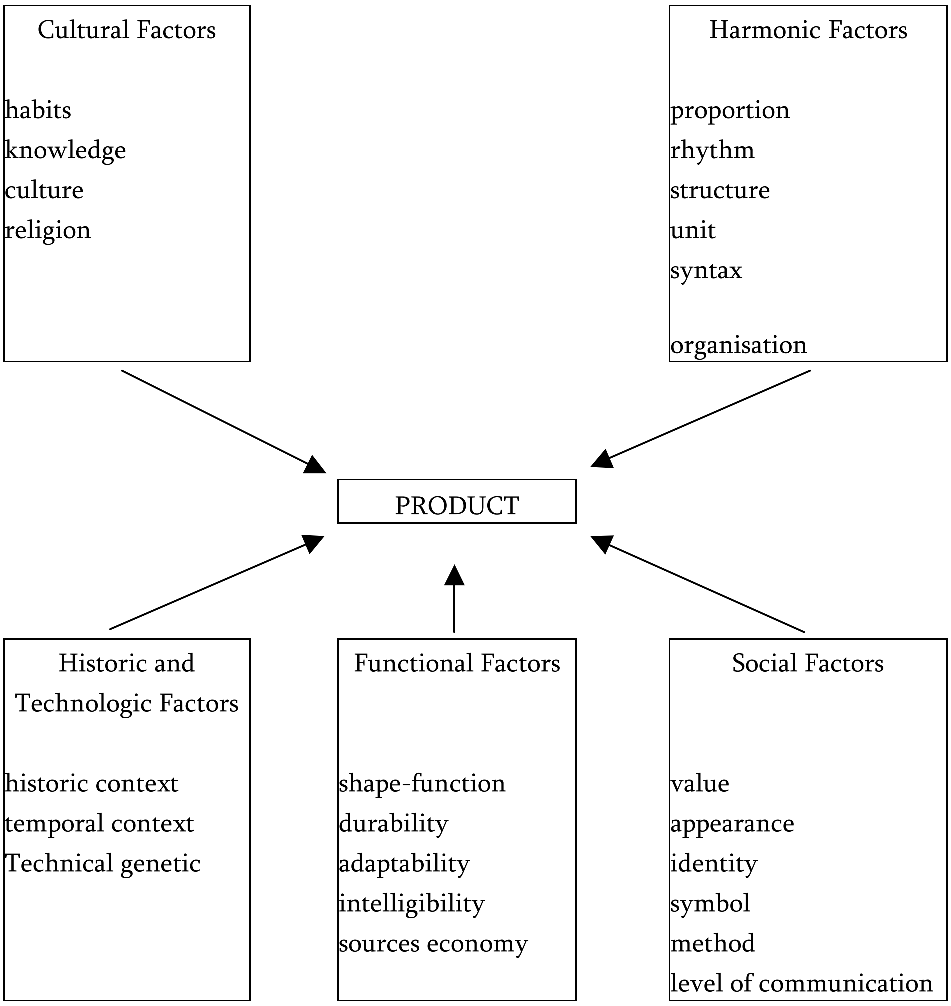
Product design and implied domains														
	Urbanism	Architecture	Sociology	Aesthetic	Pedagogy	Ecology	Psychology	Economy	Marketing	Ergonomy	Technology	Computer	Value analysis	Patent
Product design	○	○	●	●	○	●	●	●	●	●	●	○	●	●
Domains widely involved				●										
Domains involved				○										

Array 1 – "Eléments de design industriel", Danielle Quarante, p 456.

Moreover, each of these domains requires multi-purpose solutions. Indeed, we can list the general design goals as follow:

- Innovation
- Usefulness
- Safety
- Accuracy
- Environmental protection
- Public acceptance: researches showed that more than 80% of products were failures toward public acceptance [Swasy, 1990]
- To fit consumers' expectations trough enough and pertinent semantic pregnancy
- Reliability: performance under varying environmental conditions
- Performance
- Ease of operation: comprehensible and self-explicative
- Durability
- Use of standard parts
- Minimum cost
- Minimum maintenance, ease of maintenance

And a certain "aesthetic sense". Far from being the easiest one, this goal is yet decisive as R. Loewy explained in 1952 by this sentence "*Never leave well alone*". Danielle Quarante [Quarante, 2001] proposed about this subject this well-suited diagram:



Array 2 – "Eléments de design industriel", Danielle Quarante, p. 119.

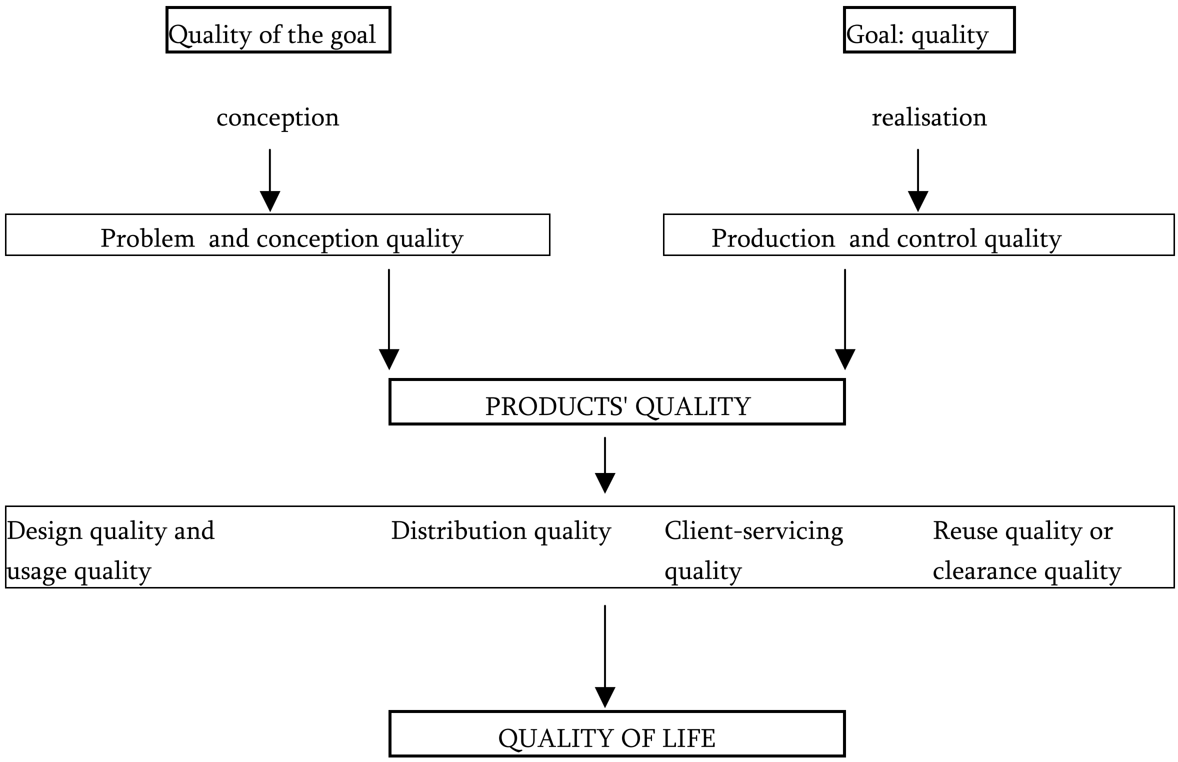
An object fulfilling these goals also has to respect some constraints:

- Physical: space allocation, dimensional requirements, weight limits, material properties, energy, power, …
- Functional and operational: suited dimensions, acceptable vibration ranges for example, or operating times, …
- General cost notion: not only financial cost, but also effort parsimony, temporal cost (waste of time), risk cost…
- Environmental: moisture limits, dust, intensity, temperature ranges, noise limits, …
- Economic: decrease of production costs, depreciation, service or maintenance requirements, …
- Legal: governmental safety requirements, environmental and pollution control codes, …
- Humans factors – Ergonomics: strength, anatomical dimensions, …

By reconsidering an existing object or part of it, the designers also have to juggle with various ways to enhance this one:

- Eliminate: could some components and functions disappear?
- Reduce: could some components or parts be merged or reduced?
- Simplify: do easier alternative, forms, … exist?
- Modify: material or production techniques more satisfying and cheaper?
- Standardization?

To conclude, these few elements assert the fundamental goal of design: to enhance quality of life.



Array 3 – "Eléments de design industriel", Danielle Quarante, p. 556.

2.3.3 <u>Technical background.</u>

Designers, as well as architects, have to consider technical constraints. Here I supposed that these considerations could influence the way of conceiving in the early design phases and therefore there is a need to complete my basic knowledge about design with some technical and production concepts.

One of the most important characteristic in product design sector is the treatment accorded to surfaces' states. The surface state of an object is usually essentially linked to the materials used for the mould or the machine constitution. Indeed, production lines required more and more objects that can be entirely made up by machines, without some necessary finish recoveries that slow the entire system and decrease the production yield before assembling. The numerous existing technologies afford the designer to realize almost all shapes, the principal limitations staying the production costs and the material properties. Production costs won't be approached here because considering their oscillating influences would overstep our principal interests, but the main materials will be listed with their production's characteristics and limitations.

- “Plastics” is the term used by the industry to designate materials (raw materials or finished products) that are based on organic, synthetic polymers capable of flowing and consequently be shaped. On the basis of how they react to heat, plastics are divided into two main types: thermoplastics and thermosetting plastics (or "thermosets"). Thermoplastics are based on linear or branched polymers and are capable of repeated softening by heat and hardening by cooling. Typical of the thermoplastic family are materials based on polyethylene, polypropylene, PVC, polystyrene polymers and copolymers, acrylics, celluloses, nylons and the various fluorocarbons. Thermosetting plastics are materials based on mixing of two polymers that have undergone a chemical reaction that results in a relatively infusible, intractable and insoluble product with a polymeric cross-linked state. Thermosetting plastics thus behave like concrete: once set (or cured) they cannot be melted and shaped again. Typical plastics of the thermosetting family are epoxies, phenolics, alkyds, polyurethanes, melamine- and urea-formaldehydes. Generally, thermoplastics are favourite because their polymerisation time, shorter than the thermosets one, permits a quick moulding injection and only the matter’s cooling time is needed before removal. This moulding technique afford a huge variety of shapes, the main limitations are the impossibility of producing hollow objects and the constraint of pre-defined skins’ angles for easy removal. For object presenting these types of characteristics or other complexities, other techniques exist: blowing injection, extrusion paths, hot-pressing for sheet-like shapes, rotomoulding, soaking…

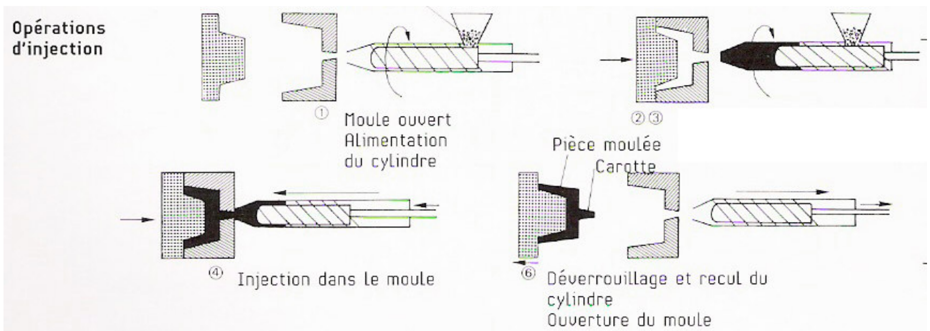


Figure 2 – Moulding injection’s technique.

- Glass: laminated, blown, in moulds or centrifugation, … Glass as well presents several possibilities and sees its structural properties extended thanks to new incorporated agents or high-silicon levels.

- Metals: with foams and plastics, metals are among the most used matters in product design. Various techniques as stamping, cutting, lamination, folding, bending afford multiple profiles (sheets, tube, threads, …).

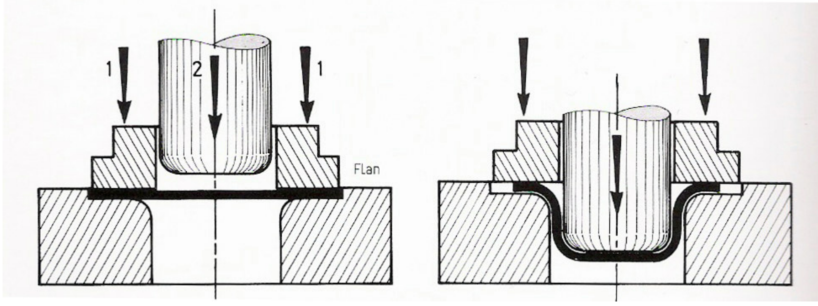


Figure 3 – Stamping technique.

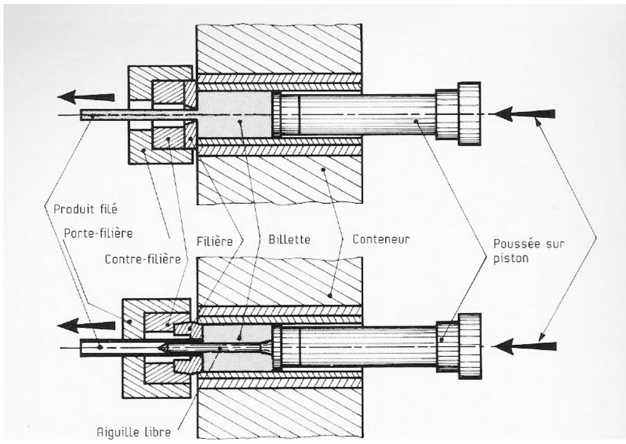


Figure 4 – Extrusion technique. « Design, techniques et matériaux », R. Guidot.

- Aluminium: among all the metallic materials it is the one that lend itself easier to shaping processes, because of its low melting temperature (600°C). It also affords embossing techniques for revolution's volumes.
- Wood: mainly produced in plywood, laths, particle panels, wood presents satisfactory resistances properties and amazing folding dispositions. Thermoforming and thermocompression techniques allow very narrow radius angles without too much deformations and cracks (order of magnitude: some centimetres.)
- Composite materials, generally a matrix drowned in a resin, constitute interesting solutions especially for textile-like materials. They are moulded by contact, by injection or by extrusion (for shaped plates for instance).

Another important influence on production's considerations are the nowadays CAD tools' abilities. Indeed, they theoretically afford to directly and automatically manage a production chain. These high technologies aren't at present profitable enough for such a global fabrication but are spreading out for rapid prototyping techniques. These prototypes stay quite expensive but allow the designer to quickly know if the object corresponds to standards and specifications, and to ensure that the proposed shape pleases the customer. Several techniques exist, for instance Laminated Object Manufacturing, 3D printer, drill with numerical command, stereolithography, … In front of these extremely fast techniques' evolutions, the main limit is generally speaking the designer's creativity and his/her ability to propose original propositions with low cost. Indeed, the most the object will present a complex design the most it will induce a complex and expensive fabrication process. Therefore the object will have to present a real asset or innovating character in order to constitute a good and feasible investment for designers.

This data collection couldn't be exhaustive: listing the whole production's possibilities would go away from the main objectives and they are anyway in constant progress. But it helped us firstly to realize the different relationship the designers generally maintain with matters and details and secondly to prospect the potential influences of these upstream technical considerations. Indeed, the review of these few techniques and their pointed specificities confirm the strong relationship existing in product design between the detail scale, the available techniques and the costs, that have inevitably to influence numerous decision already in the early design phases.

2.4 Product Design: creative and cognitive processes.

2.4.1 Introduction.

This paragraph sums up the information I have collected about the main cognitive theories developed in design. There is again no need to be exhaustive here: there are as much cognitive theories about design as there are authors, because of the innovating character of research in this domain. Therefore I'll summarize Willemien Visser's book [Visser, 2006] that gives me in a very complete way a global view on this wide subject. First the principal models proposed these 40 last years will be presented, and then we'll point up two very different ways to consider the design processes (Symbolic Information Processing vs. Situativity approach) and finally study a new point of view centred on external representations. These selected approaches will help us to understand the major distinctions we can found in this thematic, the advantages and limitations of these ones and the perspectives opened on further investigations.

2.4.2 Creativity.

Creativity is "the ability to produce work that is both novel and appropriate" [Lubart, 1994]. This definition is one among the several propositions we can found in literature about this blur subject. There is nowadays no unified theory, but the most easiest creative process model is the Wallas one [Wallas, 1926]. He described this process using four main stages:

- i) Preparation: formulating the problem[4] and making initial attempts to solve it
- ii) Incubation: leaving the problem while considering other things
- iii) Illumination (also called the "Aha!" moment): achieving insights into the problem
- iv) Verification

This process introduces, as we can see, no emotional considerations. Indeed, this type of cognitive approach is frequently opposed to emotion (referring to affective states, events and life's experiences) and the main cognitive theories do not take emotion into account. This lack is considered nowadays as unacceptable by many authors, and some of them start to insert elements like context's influences, humans' relationships and sharing, discovering and inspiration in their research. I'm entirely convinced about the capital influence these characteristics have on design processes, nevertheless they will be very shortly discussed here because of the lack of relevant

[4] A consensus defines a problem as a gap between an observed state and a desired state, with no known solution, given a set of constraints [Newell & Simon, 1972].

information and also because they stay very difficult to "measure" in an experimentation's context like the one chosen to build this work.

2.4.3 Cognitive theories in design.

Cross, in his book "Developments in Design Methodology" [Cross, 1984] proposed 4 main stages in cognitive theories' progression through time:

i) Prescription of an ideal process (systematic design and design methods), from 1962 to 1967;
ii) Description of the intrinsic nature of design activity: design problems are discovered to be not so systematizable. Authors then try to understand their apparent complexity, attributing it in large part to the "ill structuredness" of design problems[5] (1966 to 1973);
iii) Observation of the reality of design activity (methodical data collection) in the late 70's;
iv) Reflection on the fundamental concepts in design and emergence of a more fundamental and psychological approach to design method (from 1972).

Two principal model's classifications can be done: the first one distinguishes prescriptive and descriptive models and the second one stage and process models.

Prescriptive and Descriptive Models.

Prescriptive models are linear, sequential. The problem solving process follows an abstract axis, generally divided in several parts: a first solution stage (partial and intermediate), followed by its evaluation, which lead to the generation of a better solution, …

Descriptive models on the other hand are seldom global models that cover the entire design process. They generally focus on particular aspects, for instance constraints management [Darses, 1994], reuse in design [Détienne & Burkhardt, 2001 ; Visser & Trousse, 1993].

Stage and Process Models.

Stages models present the design process as a range of steps that are traversed consecutively, in a particular order (therefore stage models are prescriptive models as well). Once translated into a method, each stage must be finished before the next one begins; once it is finished, one cannot come back to it.

Process models present activities or operations supposed to be carried out by a designer in order to realize a task. [Blesssing, 1994] distinguished 3 main stages:

i) Problem definition resulting in a problem apprehension and a set of requirements;
ii) Conceptual design (concept or solution principle);
iii) Detail and embodiment design, full product description.

Visser summarizes the different stages' models in the following array:

[5] See Appendix A for further explanations about ill-structured problems.

Author/Source	Stage 1	Stage 2	Stage 3
Simon	Structuring and Analysing	Problem solving	
Hamel	Analysis	Synthesis	Moulding
Classical Models	Problem and representation construction	Solution's generation	Solution's evaluation
Schön	Naming / Framing	Moving	Evaluating
De Groot	Perception And observation	Trying	Evaluation
Jones	Analysis	Synthesis	Evaluation
VDI Guideline 2221	Problem analysis Problem definition	System's synthesis	System's analysis Evaluation Decision making

Array 4 – "The cognitive artefacts of designing", Willemien Visser, p. 34.

These models suffer of some drawbacks. Indeed, their sequential organization runs up against the actual designers' activity, which never follows such a sequence, and on top of that the formal separation between problem analysis and decision-making (followed by action) is in contradiction with the opportunistic character of design activity[6].

Nevertheless they constitute a first attempt to discern the different steps a designer usually takes to grow a solution, this final solution being one answer between others that matches the customers' needs and that respects the requisite constraints. *Indeed*, conception is not the research of optimal solution but rather the research of the most satisfactory one.

Examples.

Here are illustrations of what could be a whole prescriptive and stage model resulting in a satisfactory solution [Samuel & Weir, 1999]. Theses examples will help us to better understand the previous theories and the information's sequencing.

[6] Visser [Visser, 1994] qualified the conception's activity as opportunistic. According to her, conceptors don't follow a restricted and predeterminated scheme to create. They take advantage of possibilities offered by their activity, possibilities that they see as opportunities thanks to their cognitive cost. The cognitive cost is defined by "the number of informations units to be processed and the nature of this processing (both the cost of accessing the required informations and the use of it)".

The first graph indicates the cyclic interconnected nature of the process. It is particularly useful for keeping track of all the necessary steps and interconnections when preparing a design review. The second one shows a simplified linear-serial version of the same process. This abstraction draws particular attention to the divergent-convergent nature of problem solving (as we will explain below, cfr. Design trees' theories). Moreover, it identifies the need of separating the idea-generation phase from the evaluative-judgemental phase.

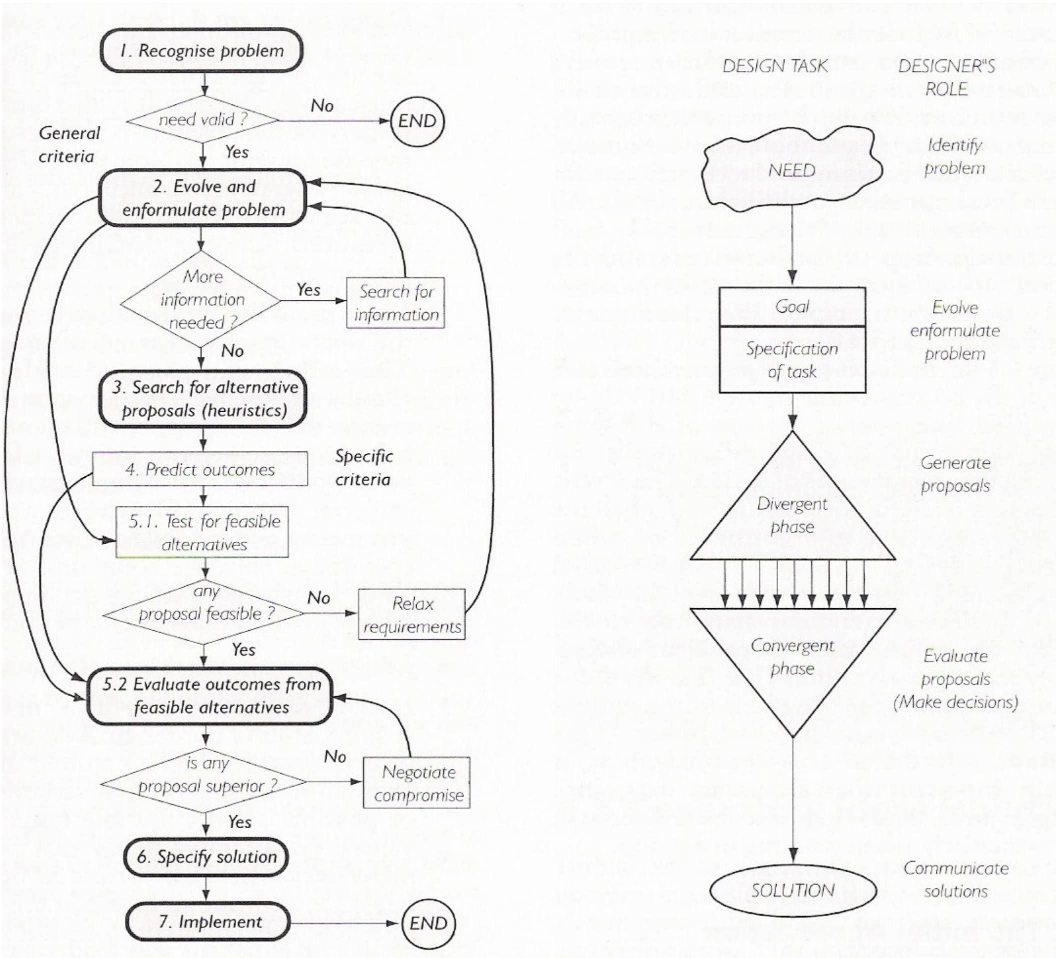


Figure 5 – Extract from "Introducing to engineering design", Andrew Samuel and John Weir, p. 293.

These diagrams are composed of several stages:

1. Problem recognition: very first step of declaring the problem.
2. Problem evolution and reformulation (and task understanding): establishment of the problem boundaries and their nature, according to the incomplete and ill-structured problem characteristic (see above).
3. Solution generation: this is the divergent phase of the problem-solving process, closely coupled with the problem evolution.
4. Predication of outcomes: mathematical modelling and estimation. The outcomes from alternative design proposals need to be predicted in terms of operating parameters (rarely applied).

5. Evaluation of feasible alternatives: selection of those proposals that meet the agreed design objectives and restrictions within the problem boundaries. It constitutes the convergent phase of decision-making.
6. Specification of the solution: this phase communicates in precise detail the elements of the solution that determine successful solution.
7. Implementation: prototype testing and evaluation.

2.4.4 Symbolic Information Processing vs. Situativity approach.

Among the most famous authors trying to reach a global conception's model, I have to present Simon's Symbolic Information Processing (SIP) and Schön's Situativity approach (SIT). Visser chose them because she saw in these two theories' confrontation the main paradoxes existing in cognitive sciences. Here I'll present her conclusions about these theories, the advantages, gaps and limitations of these ones. For a more complete description see Appendix B.

Simon's proposition is the following one: ill-structured problems have to be solved in two consecutive stages, the first one being the problem's structuring and analyse and the second one the solving step. The SIP paradigm, typically a stage and prescriptive model, pays more attention to people's use of knowledge and representations in problem solving than to the construction of representations. On top of that, SIP authors don't analyse activities as they occur in interaction with other people and the broader environment.

On the other hand, Schön considers design as a reflective practice. As [Winograd, 1996] pointed out, design is conscious, keeps humans' concerns in the center, is creative and communicative, is a social activity with social consequences. Therefore a conception understanding has to adopt a "situated" perspective. A "reflective and situated" activity may be defined as the activity by which people take work itself as an object of reflection, in a defined context. For [Schön, 1992], the SIT approach should be contrasted with the familiar image of designing as "search within a problem space" (understand be contrasted with the SIP theories). The designer constructs the design world, he/she sets the dimensions of his/her problem space and invents moves by which he/she attempts to find a solution. These practitioners' moves also produce unintended changes, which give the situation new meanings. "The situation talks back, the practitioner listens, and as he/she appreciates what he/she hears, he/she reframes the situation once again" [Schön, 1983]. Schön named this design process' characteristic the "reflection in action" or "see-transform-see" theory.

Discussion about the SIP :

Visser and her colleagues pointed out some of the main SIP's drawbacks.

- The SIP theory is too systematic, design is not so orderly: Simon overestimates the role of systematic problem decompositions;
- They are not two separate phases in design, because design is more than a linear process;
- Simon considers intuition, insight and inspiration as nothing like "mysterious internal force" but simply as acts of recognition (solving by reminding). Visser however notes that interesting ideas are not always directly evoked by representations constructed by the designer, but often depend on less simple leads (they require leaps between domains);
- The SIP approach disregards the rich and specific other activity's characteristics, that are more considered in the SIT one.

Discussion about the SIT: other limitations can be quoted:

- SIT presents lacks of precision;
- The character of its conclusions is more anecdotal: there are no results likely to be replicable and no conclusions likely to be generalized. This anecdotal side is due to the fact that SIT emphasizes the role of environment, context, social and cultural setting, as well as the situations in which actors find themselves. Indeed such blurred elements are never easy to point out and to systematize in any model.

2.4.5 Design as construction of representations.

Visser, after the listing of all these theories, presents her own view about the subject. She (and her colleagues) starts from elements from both SIP and SIT theories that are considered as pertinent. For instance, she keeps from Simon and other SIP authors the importance they give to people's internal representations. These representations, even if they evolve under the influence of peoples' interaction with their environment, provide designers a basis from which they may act on this environment. She also adheres to the satisfactory theory and to the fact that design is a type of cognitive activity rather than a professional status (see Appendix B).

As far as SIT approach is concerned, she adopts the Schön's definition of problems' setting, framing, reframing as well as the active and constructive problems' understanding aspects (which lead to a continuously evolving problem's representation). For her, decomposition goes together with concretising: there is no hierarchy. Designers do not follow systematic decomposition strategies, but still usually decompose their problem in order to plan their activity. And of course she considers emotional, conceptual, … elements as decisive.

She also starts on a new design's definition in order to define her own model. Indeed, for her: "*design consists in specifying an artefact, given requirements that indicate – generally neither explicitly nor completely – one or more functions to be fulfilled, and needs and goals to be satisfied by the artefact, under certain conditions (expressed by constraints). At a cognitive level, this specification activity consists of constructing (generating, transforming and evaluating) representations of the artefact until they are so precise, concrete and detailed that the resulting representations – the "specifications"- specify explicitly and completely the implementation of the artefact product."*

Consequently, the perspective she adopts, namely to consider design as the construction of representation rather than a problem solving, leads her to consider the 3 main design activities (construction of problem representation, solution's generation and solution's evaluation) as construction of representations, even if they may involve different types of inputs and outputs representations. Indeed, that's the designer who, using her/his knowledge and representational activities has to process the situation (identify and select elements, interpret and transform them). Knowledge is then a central resource in the construction and use of these representations. She asserts that design always consists in representations' transformations (no new elements emerge from other sources), and this information's reuse takes place in at least 5 phases:

i) construction of a target problem representation;
ii) retrieval of one or more sources;
iii) adaptation of the source's material into a target-solution proposal;
iv) evaluation of the target-solution proposal;
v) Integration into memory of the resulting modifications in problem and solutions' representations.

2.4.6 Other conception's aspects.

In front of these global models, several approaches afford us to understand other conception's aspects. Two more sides of cognitive theories have to be explained here to offer us a sufficient vision of conception processes that allows us to go on with our reseach.

1. Heuristic approach.

In a global sense, this approach denies to accredit what is only grounded on analysis. Popper [Popper, 1972] asserted that no decision could be deduced from isolated fact statement. The designer has previous knowledge and uses them by comparison with the proposed problem. He/her applies domain or general rules, or takes advantage of his/her personal experience. This step can be typological [Heath, 1984]: the designer solves the problem in regard to a semantic signification[7], or conceptual [Zeisel, 1981]: the designer quickly chooses an intuitive global image of the product[8].

2. Referential processes.

Also called analogies, these processes can be classified as follows [Lassange, 1995]:

- Devices transfers: finalized devices are reinterpreted in the new project context. An answer scheme is indeed already built and just need to be adapted.
- Processes recovery: "in the style of…"
- Indirect reference [Goodman, 1990]: refers to figurative representations, objects, culture, feelings, ideas, …

These analogies are distinguishable from copy processes by the multiplicity of knowledge domains and the multiplicity of information sources involved.

2.4.7 Work methodologies.

Before closing up these cognitive aspects, let introduce the main tools or methods that designers can use to support their fascinating creative emergence.

The introduction of a work methodology can happen at two levels [Cross, 2000].
First level: the formalisation of design proceedings. This formalisation affords to go straight to the main goal, avoiding redundant reflections and opening the "feasible doors". The second level is the externalisation of design thinking through drawing. Taking out reflections from the brain to the paper enables to ease communication with thirds and to light the process complexity by liberating thought. This last sketches' aspects will be studied more deeply later.

They're two distinguished methodologies. On one hand, the creative methods:

- Brainstorming, helping to generate large number of ideas
- Synergies: collective work toward a particular problem

[7] For example : toward symbolic objects, the designer will appeal to intuiton, and toward more traditional goods the approach is almost an algorithmic one (predefined and routine problem solving).
[8] And the design as itself just begins after the choice of this intuitive mental image.

And on the other hand, the rational methods, like checklists, matrix or design trees[9].

These methodologies suit several work stages. Indeed, they can support the designer in :

1. Clarifying objectives:

The checklist is particularly well adapted in this case. It helps for example to establish a goals list (with clients, collaborators), to discern main and secondary goals and to organize them into a hierarchy.

2. Establishing functions:

This method permits to light the problem by listing the functions the object really has to fulfil.

3. Determining characteristics:

Here is the matrix the more paying. Generally, this one is planned on the following statements. Vertically: customers requirements, horizontally: engineering/design requirements. Each compartment expresses interaction and possible connectivity, weighable with symbols and/or numbers. This method offers information about priority elements and about decisive interactions.

According to Cross, even if all these creative methods can appear as trivial in a first sight or as pure loss of time, they actually put off the designer for a while, affording him or her to come back later to the creating stage with a more rational and structured point of view.

2.4.8 Conclusions.

Among these few models and theories there isn't the right one. None of the two main "traditions" (SIP and SIT) renders the actual design activity: design involves problem solving, but design is not mainly and not only problem solving. Actually, both theories seem to be contradictory but they emphasize different behaviours and methods of study [Norman, 1993]. On top of that, every single project is born of the meeting and interactions between elements belonging to the context and elements out of this one and there will certainly always remain a misunderstood part in creativity and creation processes. Furthermore, the design process evolves in the same way that the conceived object.

The choice of a research or modelling paradigm will then depend on the research goals, objects of study, and, most important, on the kind of design activity studied. This choice will anyway engage a certain form of answer and a certain way to analyse information. As far as my work is concerned, I decide to analyse the problem solving process with a more "SIP" and "construction of representations" point of view: the type of information available, the time factor and the experimental approach aimed in this thesis lead to this choice. Nevertheless, I'll take into account elements quoted in the descriptive SIT approach as well, for instance the environment's influence.

2.5 Sketches' potentials.

2.5.1 Creative and cognitive processes understanding through sketches' analysis.

As pointed out in the previous paragraphs, the design process is first of all a process oriented toward the searching of an unknown result. Consequently, an analysis limited to the investigation

[9] For more explanations about design trees theories, refer to appendix C.

of the final object couldn't reveal its whole complexity. Therefore there is a need of an intermediate artefact supporting us in a better understanding of creative and cognitive processes.

As already proved many times, external representations can fill this role. They are mnemonic help [Scaife & Rogers, 1996], they relieve visual and spatial memory [Bilba & Gero, 2005], they support coordination and communication by proposing information that can be used directly without being explicitly formulated. External representations are widely used in most of the design processes. This intentional process scans the represented object, extracts and deduces new information that underlies a new representation.

This human capacity to visualize and to propose this visualization is especially expressed in product design by models, mock-up and sketches. The domination of realistic 3 dimensional representations, afforded by computer-aided tools, puts mock-up a little bit in a superseded position. Despite this domination, 3D representations (modelled with a CAD tool) often constitute a secondary stage in design processes. Indeed, the early conception's phases are rather supported by paper and pen through rough sketches and remain, as explained above, a link between product design and architecture. Therefore I'll focus my research only on hand drawings.

Sketches can be classified in several ways. Here we point out three main types of sketches, more liable to support the first design steps:

i) The personal sketch, also called the mental sketch: is used to support the project evolution at a personal level. This representation, which often stays very vague and incomplete, is essential for the visual object identity research.

ii) The communication sketch, or synthetic sketch: the sketch becomes a communication tool. The designer points out the elements representing the graphic solution that has to be conserved from all the other underlying attempts [Leclercq, 2007].

iii) Storing sketches afford the designer to put aside some ideas or analogies. They have in common with communication sketches the freezing (for a while) of the creation process instead of keeping it evolving.

2.5.2 Potentials and limitations of sketches.

In this section, I will try to list the well-known sketch advantages and drawbacks and the diverse theories linked to them.

Sketch potentials.

- Sketches ease the process structuring, confer to the simultaneous exploration of problem and solution an harmonious context. They help the designer to identify his/her act's consequences, keeping the problem exploration going on, till the convergence to a satisfactory matching problem-solution pair [Cross, 2000].
- Sketches help to apprehend a too complex system, too large or insufficiently understood.
- Sketches ease the apprehension of semantic meanings.
- Sketches serve as external memory. Based on the Rasmussen predicate [Rasmussen, 1990], which says that the power of creative thought is interrelated with the lighting of mental load, the fact of drawing could relieve the concentration. This way, this relief liberates resources for creativity.
- Sketches provide unexpected discovering and feed the creation process [Suwa & al., 2000]. They support a reinterpretation cycle of individual creative process. Also called by Schön

the “see-transform-see” phenomenon, this approach of “reflexive conversation with the situation” is allowed by the vague and incomplete sketches’ character.

- Designing is not a strictly hierarchical process, although there are some predefined decisions structures. Sketches afford the designer to move freely between these different levels of detail [Cross, 2000].
- Sketches support the creation of common systems of reference and ease the collaborative work [Detienne & al., 2007].

Sketches limitations.

- Sketches are rigid and static: they allow the emergence of one single idea at once and there is no reactivity with the drawing.
- Sketches aren’t standardized and aren’t practical to communicate, especially with the computer based production chain [Leclercq, 2005].
- Sketches require usually a lot of time. But this slowness is seen for many authors as an opportunity, because it imposes a duration needed for idea maturation, their emergence observation and their control.

2.5.3 Sketches’ contents and characteristics.

Sketches are as different and multiple as the designers drawing them[10]. However, some similarities can be observed as far as content is concerned. In term of content precisely, sketches are composed by few elements: huge quantity of lines, more or less vague, more or less distinct but always redundant, as well as points, cross hatches, arrows, symbols, shades through gradation, … Drawings rarely present a common scale’s unity.

Annotations are in general present as well using the form of notes, text, lists, calculations as well as secondary schemes, they contribute in a semantic way to the drawing they refer to.

Among the essential sketches’ characteristics, we can cite the following ones:

- Sketches must follow the fast creative stream, therefore they are based on an economy statement [Leclercq, 2005]: symbols, metaphors, lines belonging to two or more concepts, … Moreover they present a typical lacunar characteristic in parallel with some elements paradoxically redundant.
- They contain a huge implicit level, because of their rather individual aspect.
- The more the mental model is precise, the more the sketch will be precise as well [Lebahar, 1983].
- Before beginning and during a major part of his/her reflection, the designer doesn’t know the result of what he/she’s doing. Therefore sketches are unstable: they evolve all the time without really disappearing (“paper memory”) and present a low structuration level.
- They are virtual in the sense that they are never totally realist.

[10] There is besides no real rules about sketching. One of the most famous attempt, actually more concerning the shapes, has been made with the Gestalt theories, see Appendix D.

2.6 Product Designers and CAD.

Computer tools are nowadays more and more used in every sector linked to design processes. The product design sector is taking advantage as much as it can of these new tools. Therefore I found useful to review the main computer-aided design programs widely used in design, to summarize their main features, advantages and drawbacks. This way, I will approach designers during interviews and experimentations with some basic information about their supposed way of working with CAD tools, information that will better support interactions and analysis of their wishes.

2.6.1 CAD tools in product design: categories and basic instructions.

CAD software in product design can be categorized as follows:

1. Production tools are very powerful to help all stages of production, without exception or almost. They concern the very last step of detailed design, when each part has to be precisely conceived and calculated in dimensions. They also afford the automatic development of prototypes.
2. Rendering and modelling tools propose visual renderings. They show how the object will look like and perform without any kind of technical considerations on the contrary of production software.
3. Visualization software afford 2D and 3D manipulations without modifying the object. They are especially used as communication tools.

Basic instructions are quite similar for most of them. There are possibilities to:

- Draw with several scales on several layers;
- Use standard and predefined codifications and symbols;
- Combine elements (shapes connections, Booleans,…);
- Modify, copy, make symmetries, add, correct, translate, rotate, erase, project surfaces or volumes;
- Transform the topology: removal, intersection, cut, …
- Use some predefined shapes or create new ones (with more or less success) to define an object, using a specified scale and quotation or, on the contrary, escaping from dimensional considerations;
- Communicate easily worldwide and transmit information.

On top of that, every single artefact can be parameterised. A very simple example is the several features a simple line can adopt : continuous or dotted, more or less thin, coloured, infinite, finite or quoted, …

Model-building and picture-generation techniques distinguish several way of proceeding, like “extrude-edge”, “box-modelling”, “surface-modelling», several designations for finally a few methods, explained here.

Geometric modellers.

These modellers build models from predefined volumes[11]. Available shapes are the basic geometrical ones, that can be simply added, combined by Boolean[12] operations or distorted by user to produce other components. These tools are more powerful for instance for mechanical design, but hardly handle the more "freeform shapes".

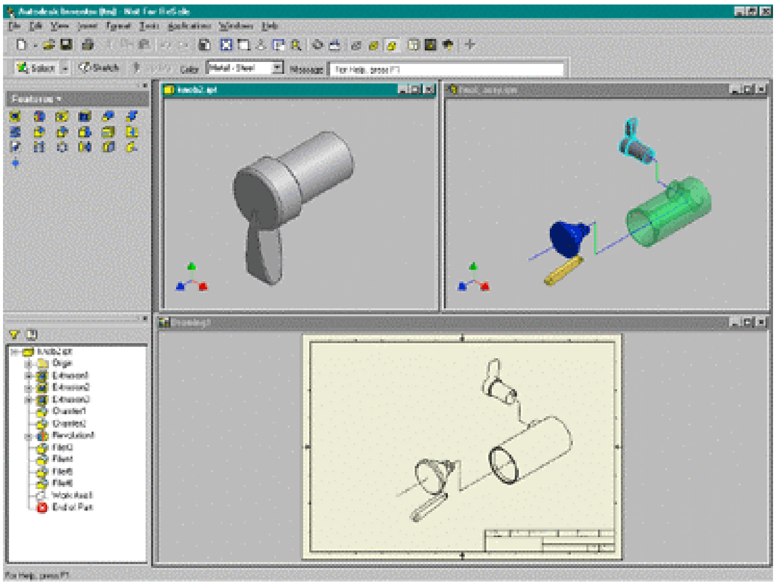


Figure 6 – Geometric modelling.

Meshed surfaces.

The user has here to generate or import a whole of specified points (through calculated, transferred, measured coordinates). The modeller will then generate a 3D meshed surface joining all the specified points, interpolating between these ones.

The meshed surfaces can also be deduced from easier methods. Sweeps for instance: a 2D outline is defined graphically and then lofted or swept by the modeller to give as a result an uniform thickness appearing as the final 3D. Volumes of revolution or ruled surfaces are also widely used. These last ones are the simple extrapolation between two given sections.

[11] …which present mathematical formulaes that exactly define any point in the 3D space occupied by these solids.

[12] Booleans operations afford to produce shapes through three very simple actions : the final object can result from the union of any two 3D shapes or other objects, or from the difference between them, or finally it can result from the common volume of interconnected objects or shapes.

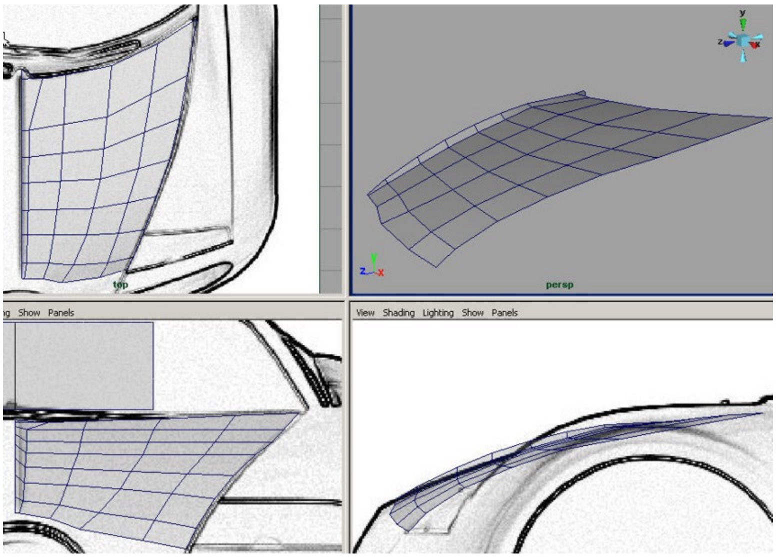


Figure 7 – Meshed modelling.

2.6.2 Main software in the product design domain.

As the previous paragraph shows, the multiplicity of basic instructions generates a lot of manipulations since these instructions are combined. The undeniable power of this software allows to obtain objects with a very high level of detail and proposes quantity of calculations and optimisations to the designer. There are so many possibilities that even the CAD concept is now dispatched in numerous sub-tools with a specific specialization (Production Aided Design, Drawings Aided Design, Manipulations Aided Design…). I'll list here the main types of software used in product design. For each type, the main methodology will be presented as well as the functionalities they offer and the most familiar programs will then be shortly described[13].

Production software.

This tool is very useful for the last stages of conceiving as explained. They enable to calculate every single property from separated components or global object. For example they inform and calculate (check, optimise): weight, constraints, vibratory and mechanical behaviours, material characteristics, hydrodynamics, quotation, and of course optimisation combinations (volume, cost, time)… Because of their accuracy characteristics, they need a quasi-complete declaration of every single action: there is no space here for fuzzy descriptions nor for "free" shapes.

- CATIA

The assets of CATIA are mainly the exactitude of the productions plans and the possibility to create prototypes. This software, very complete but one of the heaviest to apprehend, is matched as well with a line-production support (assembly-dismantling tool) and an application for the rapid creation of injection mould and electronic circuits. A Knowledge Advisor device can be added: this knowledge management tool takes over implicit and explicit rules to constitute an interactive checklist.

[13] Actually a more complete description of each one would present a few interest without even talking about the outdating my descriptions would present after a few months.

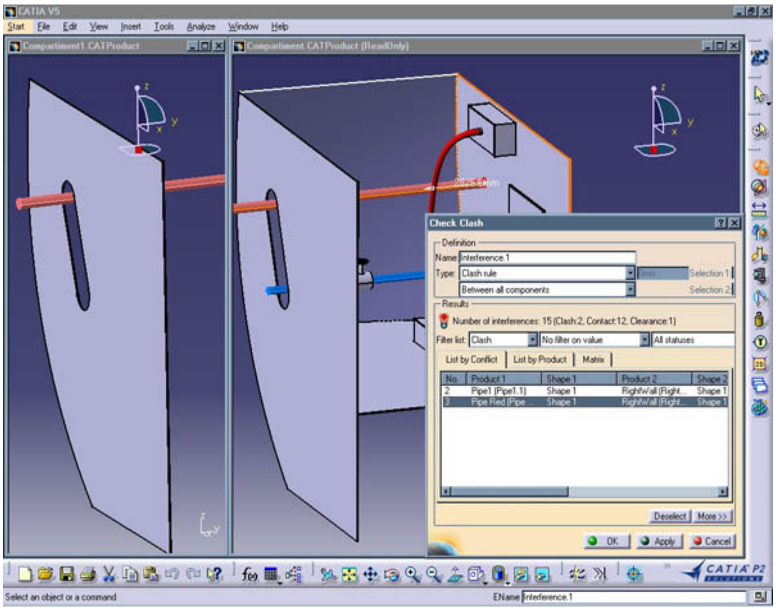


Figure 8– CATIA easiest interface.

- Pro-engineer

Pro-engineer is mostly used in industrial design. It is a great calculator, very heavy to learn but efficient, it provides widely compatible production plans.

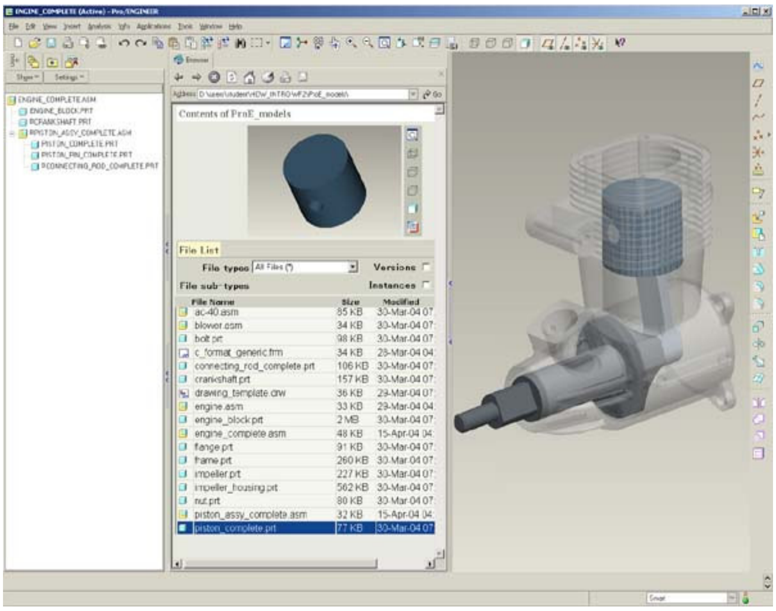


Figure 9 – Pro-Engineer interface in industrial design.

- Rhinoceros

This software presents less calculation and optimisation tools but proposes functions for rapid prototyping, for drills and 3D printers. Able to deform surfaces, it nevertheless requires high-speed processors.

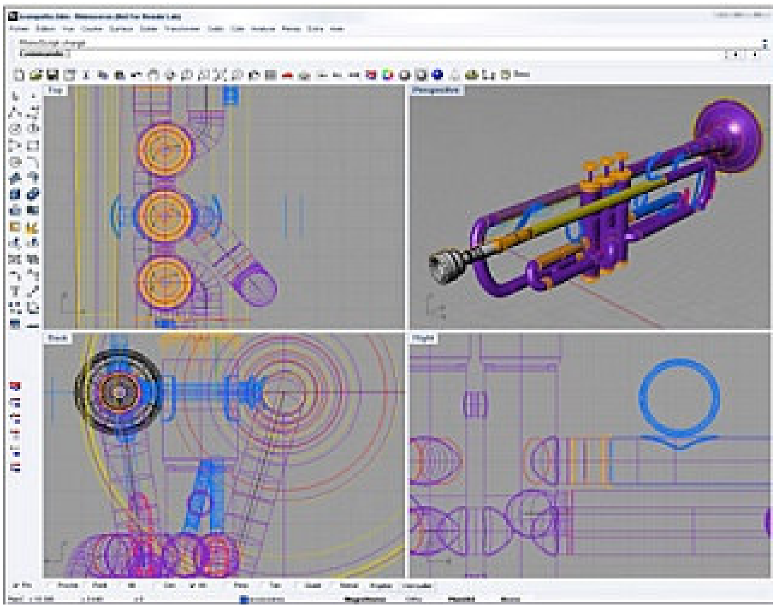


Figure 10 – Rhinoceros typical technical interface.

- AutoCAD 3D

This last one allows only the formulation of production plans (line by line), but offers interesting properties of rapid quotation and exchange of information between several orthonormal views and cuts.

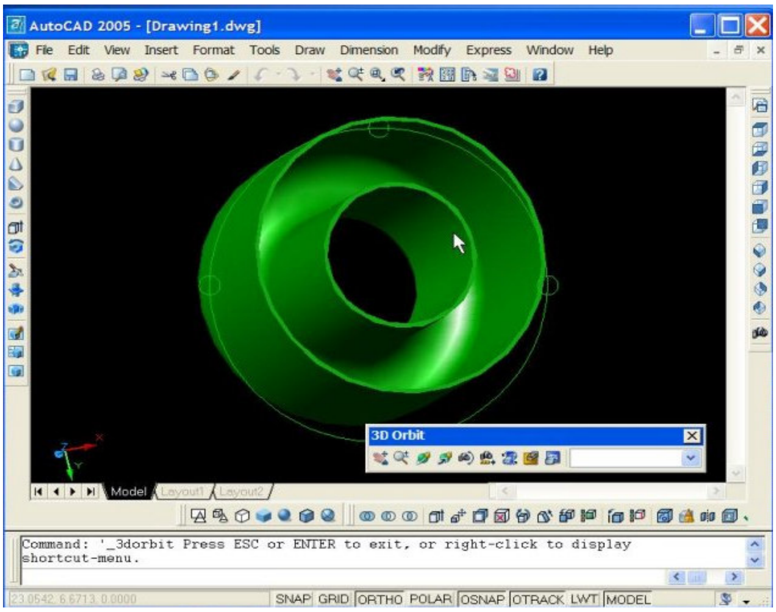


Figure 11 – AutoCAD 3D interface.

Rendering software.

Principally based on objects' visualization and conceptualisation, this type of software is very popular in product design because it assists in a considerable way the objects' appeal. Although they are very performing, modelling are high time consuming processes. Lighting, shadows, textures and materials, background scenery can be added as well as animations to totalise an undeniable visual impact. Once finished, the products can be rotated through 360 degrees to present their global appearance, according to the customer's desires. Objects often look so realistic that these types of simulations may be enough to demonstrate the object's values, reducing this way the need of expensive rapid-prototyping.

- AutoDesk Alias Studio

One of the best contextualization software, Alias affords almost all shapes but is also one of the heaviest one, considering the multiplicity of menus, sub-menus and parameters. It is also very powerful with meshed surfaces' manipulations and proposes a good level of coherence for these ones[14].

This software also integrates the work with tactile screens.

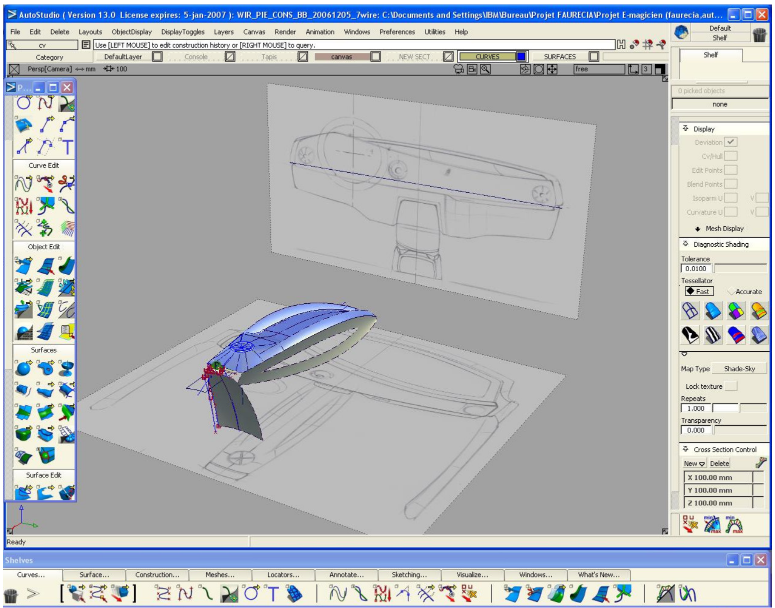


Figure 12 – ISD Students designing a car central island by using a meshed surface method.

[14] See chapter 4.11 « Graphic designer at work ».

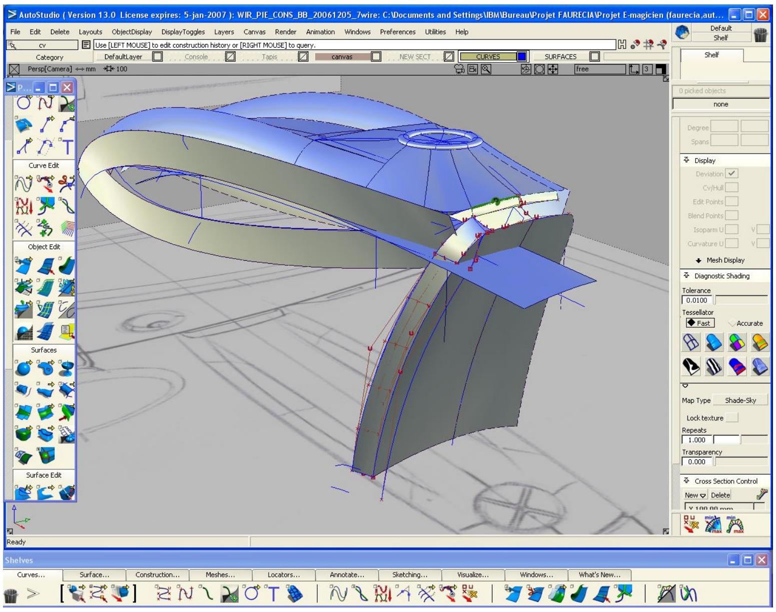


Figure 13 – Detail – meshed surfaces and point positioning.

- 3D studio Max

3D Max is one of the modelling programs that have speeded up the entire CAD process. It allows designers to quite quickly render a 3D image that afford a rapid visual evaluation of their work. However, behind this apparent facility hides a large drawback: plans cannot be produced through this software and the exportation function to other production software isn't satisfactory. Consequently, the only way to obtain some required technical plans is to stard again the modelling thanks to a production software.

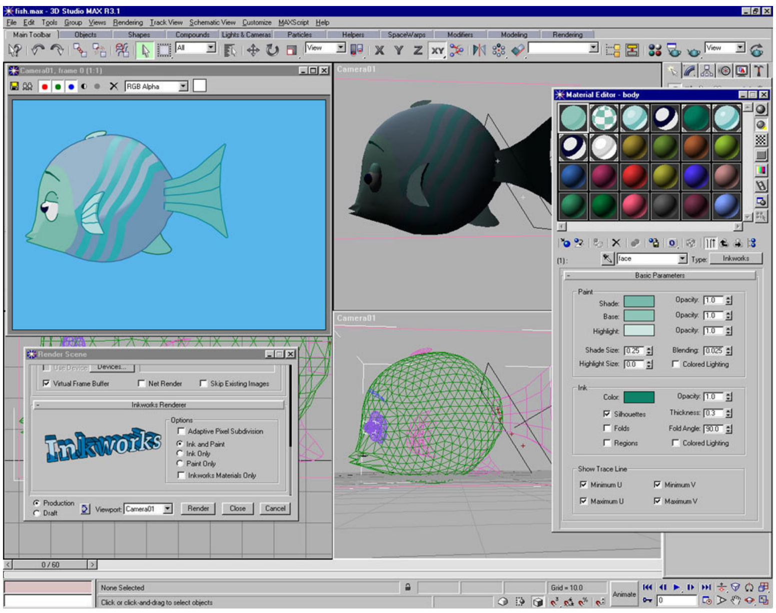


Figure 14 – 3D Studio Max Interface and Form modelling.

- Cinema 4D

Comparable to 3D Max but more expensive, Cinema 4D finds its power in texturization and renderings. It allows sweeps and blobs[15], but as 3D Max it will never propose a production plan.

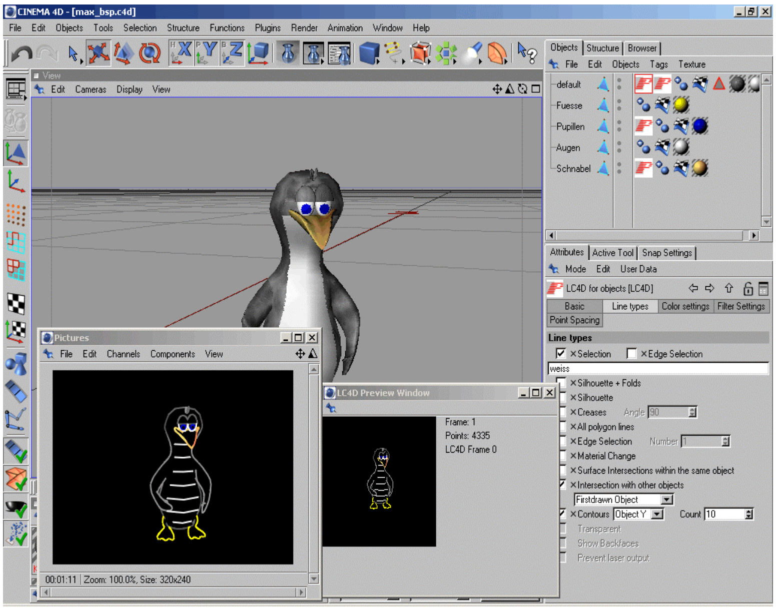


Figure 15 – Cinema 4D Interface and textures.

<u>Visualization software.</u>

A good example of visualization software is E-drawing. Almost compatible with all the previously mentioned software, it just proposes dynamic visualisations of the loaded object. It allows a certain protection level (a little bit like a PDF reader) and eases the communication and transfer through emails for instance.

[15] Litteraly « Binary Large OBject », it is an uncontrollable 3D volume obtained by the mutual deformation of two supposed spheres.

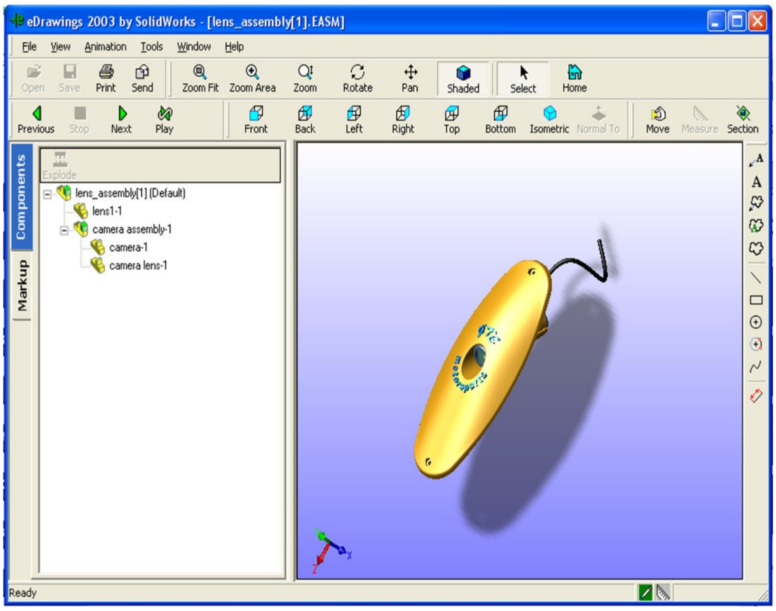


Figure 16 – E-drawing Interface, moving functions.

2.6.3 CAD in design: contributions and gaps.

Beside all these rational functions and possibilities stays the question mark of adaptation toward conception's processes. A lot of researches have been done about this subject, especially centered on new human-machine interactions. I'll try here to resume the main conclusions, classifying the CAD's contributions and gaps as far as cognition and natural design behaviours are concerned.

Contributions.

There is here no denying about the CAD power and possibilities. They ease and speed up in an extraordinary way calculation, optimisations and verifications, renderings and contextualization. On top of that:

- The main CAD contribution, and not the smaller, is the complexity level they help designers to reach. The created objects can present very complex shapes and spatial configuration, surpassing all the conventional geometric elements reachable by drawings and in the mean time computer tools can support their technical study [Lynn & Rashid, 2002]. CAD tools therefore open doors for new ways of conceiving.
- CAD systems shear with users some unified codes that can support and ease design communication.
- Once a designer is used to a specific tool, a faster 3 dimensional exteriorisation can helps him/her to apprehend a global shape maybe better than a deformed drawn perspective.

Gaps.

As we saw before, CAD software is able to support some of the designers' tasks. There is no point here to question CAD tools utility or to doubt about their future, but rather to examine the blanks they still represent for the users, especially during the early design stages.

- CAD tools are so complex that designers are shackled in their creative process by concentrating on the software's interface and functionalities rather than on the design task [Norman, 1998; McCullough, 1996].
- CAD tools are "declarative»: each single part of the object must be dissected in primary orders. These declarations are predefined and limited, therefore they create a wide constraints field for the designer [Leclercq, 2005].
- As far as production software is concerned, some authors observed that the necessary accuracy needed to define shapes – to define the fleeting mental image designers have of the solution – ask designers to have a realistic and rapid perception about functions and aesthetic. This geometrical perception, if occurring too prematurely in the design process, constraints the creative intention and the mind's freedom [Lebahar, 1983]. It is unfortunately often the case because the financial return depends on designer's ability to speed the whole process. The modelling stage lasting a non-negligible time, the designer generally cuts of the first conception stages (the idea gestation) and is forced to take premature decisions, inappropriate in comparison with other external representations (mock-ups, drawings) [Cross & al., 1996].
- The potentialities of 3 dimensional visualizations are weakened by the parameters' multiplicity (textures, lighting, rendering times, …).
- CAD tools are built on the same fundamental univocity principle: for each user's declaration must correspond one and only one predefined and intern computer representation [Leclercq, 2005]. This rational coherence refuses too abstract or implicit semantic contents.
- Although the given possibility to copy and use several layers, the main observed work methodology is a corrective approach. The "delete" instruction doesn't afford to keep in mind the previous works' states and to create some unexpected discoveries as sketch is able to (see 2.5.2 paragraph).
- Once a designer is used to a specific way to work with CAD tools, the "habit phenomenon" appears: instead of going on with learning new tools, a certain "laziness" annihilates further efforts even if the managed interface is not proper at all. At a society scale, it leds to global passivity and faithfulness to monopolizing programs[16].
- The direct manipulation of computer tool decreases the quality of problem solving process [Golightly D., Gilmore D & al., 1996]. This theory asserts that when a designer can succeed in a profitable time by a concrete action, he/she will be less prone to expend as much efforts to mentally solve the same problem. And even if the problem is set in the interface itself, users will probably pass a lot of time – even more – trying to solve it instead using a more efficient "hand" method[17].

Conclusion.

The effectiveness of CAD in product design is depending on the global conception's organisation, on the object's complexity and the users' abilities. The tools are not fitting the early stages of conception, but stay very performant mostly when projects involve a broad survey in material, products, production and geometry domains.

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[16] A funny example of these society effect is the Canadian rail norms, see Appendix E.

[17] An interface allowing a direct manipulation could then decrease the necessary time to solve the problem. This fact linked to the WIMP (Windows-Icon-Mouse-Pointing) issue is also an handicap for designers but won't be detailed here.

Chapter three: meeting the profession.

3.1 Introduction.

Now that the necessary information has been collected about cognition in design, sketches or CAD, I can take advantage of pragmatic points of view by meeting and observing designers at work. I chose to contact six Belgian product designers, young and more experienced, coming from different design schools or reaching the design sphere by other ways, to observe a global panel of personalities.

3.2 Interviewing a few designers: goals and questions' grid.

In expectation of these interviews, we've first prepared a question grid that helped me to structure in the answers gathered at the mercy of conversations. My principal goal was to obtain designers' point of view about the subjects introduced in the previous state of art: creative processes, sketches, CAD in general, as well as other general information testifying the global range of characters I tried to meet.

This question grid, built with the help of a skilled psychologist (Lucid Group collaborator), has to respect some basic rules to make the interviews more rich. Consequently, some questions are deliberately open to cause different reactions and deduce a way to apprehend design in general, some other are more focused in order to provoke more detailed and reflexive answers. Globally speaking, the questions follow a certain chronology in order not to restrain designer freedom toward different subjects, especially the CAD one. I met them without specifying too much the finalities of this work, to avoid any kind of "formatting" their way of answering. The main results are given below.

General information

1 How long do you work as a designer?
2 Through which training/middle did you join the design world?
3 What type of designer are you?
4 Do you always work in design or do you have other business?
5 How much projects do you have per year in the design sector?
6 Do you prefer to work alone or in team?

Creation process

7 What's happening in the very first stages of a project?
8 What type of information do you have to begin a project?
What information do you search in general afterwards?
9 What is your main work methodology?

Sketches/object's representations

10 From what stage do you estimate having a sufficient image of the object to conceive?
11 What do you do of this image?
12 What type of representation do you use?
13 Which place has sketching throughout your process?

Exterior interventions

14 At which level do your customers step in your process?
How is this collaboration working?
15 On which support do you collaborate?
16 Do you agree with sketches modifications?
17 How many times do you interact with collaborators and when does this interaction stop?
18 What are your main collaborators' functions?

The CAD tools in your job

19 What are the main tools you use in design (pencil, computer, …)?
20 When does the CAD step in your process, if it does?
21 What type of CAD tools do you use?
22 What do you think about these ones? Do they match your needs?
23 What easiness do they bring to your work? Or on the contrary, what difficulties?
24 What do you think about current human-machines relationship?
What would you consider as a "technical improvement" in this domain?

Array 5 – Question grid for interviews.

3.3 Designers concerned.

I met 6 persons for these interviews, mainly on their workplaces, each interview lasting an average of one hour and being recorded. All of these designers can be seen as experts, so I “classified” them thanks to their sentant in the design world. Four of them then belong to the “10 years experimentation or more”, the two others to the “5 years experimentation or less”. I decided not to meet novices because on the lack of experience they have toward practices, production and collaborative work. I’m aware this could be seen as a rigid choice but I also have the feeling that, much more than in architecture, these rational characteristics will be pregnant in sketches and first design steps[18].

Among the first group, one designer is industrial designer for more than 30 years and studied industrial and engineering design in St Luc Liège. The second one is teacher in St Luc Liège and teaches the primary approach of design, formal structures, to first year students. The third one presents an unusual route: coming from cabinet making to interior architecture and finally design, which he also studied in St Luc Liège. The last of this group also had several formations, from plastic arts to monumental painting, architecture, the whole journey bringing him naturally to product design.

The second group is composed of two young designers, beginning in the profession and both coming from St Luc Liège as well.

I have to notice here that, although I tried to collect information coming from diverse horizons (by selecting designers with different design visions, sentant level and professional ways), a coincidence nevertheless made that they almost all studied in St Luc Liège. This information collection, that I already have to be considered with precaution because of the small samples, has also to take this fact into account to stay as much as possible objective.

3.4 Analysis of these interviews.

Here are the more remarkable facts I keep back from these interviews.

<u>Question 6:</u> *Do you prefer to work alone or in team?*

Generally speaking they prefer to work alone. But currently the design activity is so time consuming – delay, break-event points, quantity of factors to manage – that they need collaborators especially for edition and modelling.

<u>Question 8:</u> *What type of information do you have to begin a project? What information do you search in general afterwards?*

Clients have mostly functional, aesthetic, costs and delay requirements. Ergonomics considerations for instance are available in bibliography, or through training, but there is often a “feeling” (an intuitive way to create) that reveals to match these constraints in a correct way. More pointed issues, for example about materials or productions techniques, are dispatched to engineers or more simply obtained through discussions with factories.

[18] Actually it is the case but, in further investigations, it could be interesting to observe novices as well in order to compare the crucial stages in conception through an « essay-error » analysis.

<u>Question 9:</u> *What is your main work methodology?*

For most of them, the problem being quite quickly understood, there is a need of incubation. Very short, sometimes a few hours, this step induces a more or less defined mental object's image. Then there is a necessary drawing stage to support design in a more complex level, or simply to keep the idea "in mind", understand in sketchbooks. After a potential new creative time is the introduction of CAD step inevitable. The final object will be defined after verifying dimensional requirements, constraints' respect and client's acceptation and sent to the production line. This final object represents several stages of modifications and compromises in comparison to the first pen shot.

Only one, among the youngest, considered the sketch step more as an external memory, and said to go the faster to a CAD representation. For him, the drawing step is a pure loss of time, regarding to the possibilities offered by nowadays computers and because of the quite precise mental image he's able to built of the object. This assertion, that could be debated, is nevertheless interesting because it brings the CAD tools' potentials to light, especially the rapidity and efficacy that could be regarded as the main sketches' drawbacks.

Another designer accorded to mock-ups in a first step and prototypes in a second one a definitive importance: the material behaviour, the human feelings and interactions toward the object being determinant in his way to conceive. These mock-up steps take place in parallel to his sketch stage.

<u>Questions 10 & 11:</u> *From what stage do you estimate having a sufficient image of the object to conceive? What do you do of this image?*

The object mental image quickly needs an external support to be developed. After the CAD step, the object can be considered as finished in different ways depending on the work's habits. Some designers will regard the client satisfaction as sufficient, letting them (or collaborators) the care to bring the idea to a final state. Other projects will require a prototype, and then the production software insures the last steps. The sketch is never considered as a final representation, excepting for project that will never born.

<u>Question 12:</u> *What type of representation do you use?*

Essentially drawings, cheap mock-ups and CAD representations.

<u>Question 13:</u> *Which place has sketching throughout your process?*

A lot and paradoxically a few. Indeed, designers using sketches in a consistent way will draw on quite everything, as soon as ideas emerge. Through a "personal" project, sketch has a real artistic and creative meaning: drawings reflect abstract ideas that could become a potential object. It can be said that in this option sketches are "time consuming" in the sense that designers authorize themselves to take this time. However for an order, as explained before, they can't afford to have a wide interval for sketching, fact that they generally regret.

They can draw orthometric views or perspectives. Sketches, as personal they are, go straight to the main goals and are more often abstract drawings than masterpieces. As far as content is concerned, sketches are usually more an aesthetic research, communicative and technical tool than an end in itself. The research of the most pragmatic and efficient fabrication methodology is also already pregnant in drawings.

Questions 14, 15 & 16: *At which level do your customers step in your process? How is this collaboration working? On which support do you collaborate? Do you agree with sketches modifications?*

As well as designing the object is the design activity a relational business. The customer is always present through the projects assignment of course, but the relationships during the creation stage are rare. Indeed, personal sketches are never modified by peer intervention. They remain the individual expression of an unique idea. The repetitive collaborations, and the objects' modifications, will rather often occur around 3 dimensional pictures or print-screens because they constitute a perfect vulgarisation and serve objects appeal, till the satisfactory point.

Question 17 & 18: *How many times do you interact with collaborators and when does this interaction stop? What are your main collaborators' functions?*

The collaborators, from 2 or 3 of them till 20 for the biggest projects, are essentially engineers and graphic designers. The engineers invest the project once the first "final" object image is ready. They call it the "first final" image because production constraints, if not already introduced in the earlier conception stages, can considerably modify this one. Graphic designers' aim is to propose an object representation, in a rendering goal or in a technical one, depending on their abilities. They analyse designers' sketches (orthonormal views and sometimes a light 3D one) to model the object. The interaction is intense as we will see below, and last almost till the production line[19]. All of them have temporary collaborators, this number increasing with experience level.

Questions 19, 21 & 22: *What are the main tools you use in design (pencil, computer,…)? What type of CAD tools do you use? What do you think about these ones? Do they match your need?*

They usually use pencil and sketchbooks or everything that could support a drawing, as well as computer of course. The main CAD tools used are the ones described before (see 2.6.2 paragraph). Generally speaking, as far as production software is concerned, they regret their heaviness and complexity as well as the lack of compatibility, as well as the high graphic design competence needed to produce rational production plans. However, they remain inescapable tools for rapid prototyping and fabrication. Among rendering software, the most famous in their area is 3D Studio Max (simply because it is the taught one). Designers regret its rendering times, its inadequacy to create precise plans but applaud the added value it can bring to their objects appearance (as far as the modelling is satisfactory which is a real challenge). Sometimes the heaviness of model even leads to an incapability to present a dynamic 3D representation, designers having to print static views!

On top of that, CAD programs are expensive (from 8 to 20.000 euros), high time consuming and the average necessary time to apprehend them in a satisfactory level is 3 years.

Question 20: *When does the CAD step in your process, if it does?*

Generally speaking the faster they can because of the delays. There are no more designers working without these powerful tools (as expected). The first CAD step depends on the project, the

[19] Indeed some factories propose to model themselves a technical representation fitting their machines in a better way.

way to conceive and the complexity. Indeed, some works are more conceptual or abstract and can be fast modelled because there is no more aesthetic research to do once the concept has emerged. On the other hand, more functional or shaped projects will require an incubation and drawing time as explained, the 3 Dimensional views helping then to apprehend the entire volume[20]. The orthonormal views are also computer designed, but more in a technical and practical goal.

Questions 23 & 24: *What easiness do they bring to your work? Or on the contrary, what difficulties? What do you think about current human-machines relationships? What would you consider as a "technical improvement" in this domain?*

The two main CAD contributions in their work are the 3D visualisation effects and the rapidity brought for technical considerations. These images help the designers to apprehend the project difficulties, to fix the real proportions and the hidden sides. Rendering software are also very helpful for texturizing and shadows, both elements quite difficult to represent in a satisfactory way through other artefacts. Among youngest designers there is also sometimes a certain creativity in playing with distortions and software' functionalities.

The main quoted dissatisfactions are the time-consuming character as well as the high degree of qualification needed to use CAD tools in an attractive way. Indeed, modelling becomes slowly but surely a profession in its integrity. Schools are developing bachelor trainings for rendering CAD tools because designers need more and more these specific collaborators, having no time/no desire to learn these programs themselves.

Consequently appear other main issues as communication lacks and hazardous reinterpretations. In fact, designers will propose communication sketches to graphic designers who have to understand the drawing and to model it, but generally the implicit character of sketches lead to false interpretations. Depending on the level of complexity, the modelling quality and the finished degree of detail in designers' minds, there are several "go and return" to find the right compromise. And this even more when technical plans are required because of the designer's responsibility toward the design efficiency and quality. Because of the software inertia, each of these modifications consist almost in a new modelling, costing a lot for both parts. So these communications issues lead to a huge loss of time and money as we see and, in the worse cases, to projects' abandonment.

Some designers, especially among the first group (10 years experimentation or more), also regret the rigid and superficial look of 3D representations. That could depend on the modelling quality, but it also comes from the lack of interaction created by models' heaviness. On top of that, the creative support of sketches and the surprising discoveries they're able to cause disappear with these too detailed and crystallized images.

There is also sometimes too much "image" design instead of "real" design. Users then lose their capacity to apprehend material and technical realities toward endless CAD visual effects.

Finally we can notice other problems linked to programs compatibilities and property failures linked to security problems.

According to our subjects, the main CAD tool technical improvement would be a more intuitive interface. The combination of both rendering and production software would be an utopia because of the program complexity and heaviness, but at least a total and efficient compatibility could speed up the process (mainly from production to rendering software even if they usually begin with a 3D

[20] One of the interviewed designer make this subject explicit by saying « Design is not an image but a 3 dimensional reality ».

visualisation before according the last technical details). To conclude: "*the CAD tool must remain a tool and never become a finality*".

3.5 First conclusions.

The first conclusions emerging of these interviews are

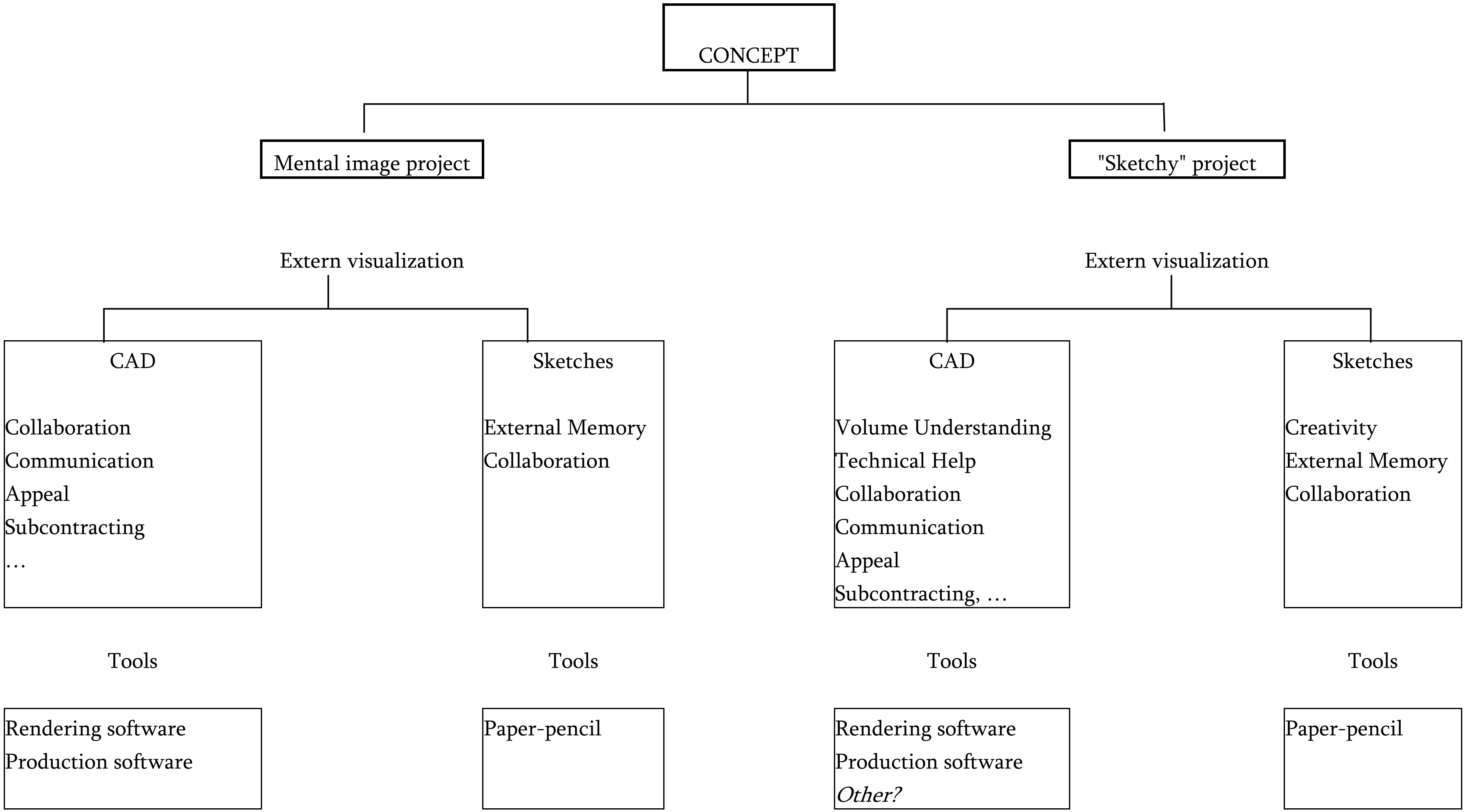
- The role and contributions of sketches;
- The pregnancy of particular elements as: material behaviour, detailed fabrication solutions' and production feasibility's influences since the drawing step, much more than in architecture. That's due to the typical different relationship product design maintains between objects and large-scale production[21];
- The need of a CAD stage;
- The 3D contributions and technical helps attributable to CAD software;
- The emergence of new graphic designers;
- The multiple loss of time;
- The communication issues;
- The yield and time restrictions associated to design activities;
- A new interest toward computer possibilities especially from youngest designers.

Another proposed conclusion is the projects' classification showed in the following diagram. Even if the small quantity of information necessitates a certain standing back, this diagram presents the deductions made on external visualizations' importance inside the design process, the usual tools used in product design and the potentials the studied domain could present for new generation's human-machine interactions.

Indeed, once the concept has emerged, it can be exteriorised through sketches and CAD tools. On one hand, takes place the "mental image project" : the project is almost entirely mentally defined and doesn't need an intense drawing stage to be achieved. The CAD tools are sufficient to fix the last details and to begin the following design phases (communication, advertising, subcontracting, production). In this case, sketches can ensure roles like external memory (sketchbook) or collaborative tool (when the modelling is delegated to graphic designers for instance). On the other hand, we found what I called the "sketchy project". These projects on the contrary need paper and pen as an early design phase's support, the designer using them for "real" creative purposes. Again, CAD tools will facilitate the succeeding design steps but will also, in collaboration with sketches, ease the volume apprehension and definition.

In this second scenario, certainly more frequent, there is an open door for a new generation of CAD tool. These tools, like EsQUIsE for instance, should be able to support in an adequate way this sketch phase and should propose to designers, in an intuituve way, this required relationship with volumetry.

[21] See paragraph 2.3.3.



Array 6 - Interviews' deductions about extern visualization and usual tools.

3.6 Question marks.

These previous interviews present interesting new information about the product design world and the relationship designers maintain with sketches and first design stages. This step helps me to learn more about designers' projects, habits and their expectations toward CAD tools as well.

It also defines the components and facts to take into consideration to grow up my experimentations protocol and the elements that stay worth to be extended. Indeed, even if I had the opportunity to discover some sketchbooks during the meetings, there were some aspects I wanted to deepen. For example, are all the theoretical assertions about sketches realistic? Designers admit that they have in finality very few space left for drawing in their business, fact already acknowledged and "measured" by some authors, as the following figure shows.

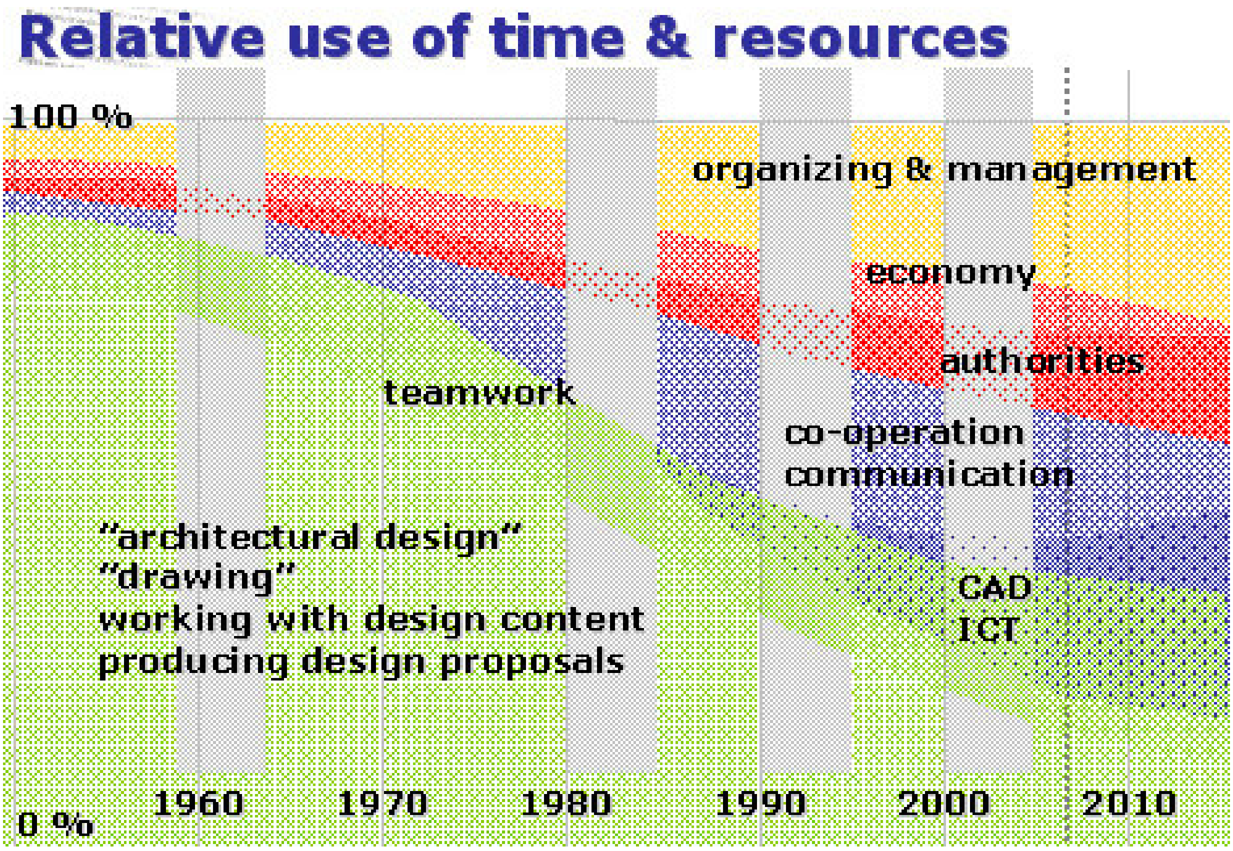


Figure 17 – Hypothetical sketches and fundamental design's future – Hannu Pennttilä, Helsinki University of Technology.

So, in product design, does the sketch stay the powerful conception support it is said to be? And if it's the case, what type of "cognitive" signification and contents could we observe? And in which proportion could the "Augmented Sketch" concept [Leclercq, 1999] support these previous observations in order to ease designers' work?

Chapter four: the experimental side.

4.1 Experimentations' goals.

These experimentations have three main goals to fill. Firstly they will help me to consider the previous theories and assumptions in light of a practical exercise managed with product designers. The hope is to conclude if yes or no these theories could help us to build with EsQUIsE a global work methodology fitting the designers needs. Secondly, they will provide a new range of information that I'll call "implicit data". This information is so deeply linked to designers' usual way of conceiving that there is a possibility not to have noticed them thanks to interviews. They could concern sketches as well as cognitive processes or every day life practices. Thirdly they should provide the last main missing information, especially about sketch contents and signification in practical applications.

Through sketches observations (results and proceedings), I plan to pursue two analyses. On one hand, I propose to observe creative processes, affording to identify the work methodologies, the strategies, the different tasks and stages, as well as the concept's evolution and its external representations. Ideally this part will lead to the building of an activity model that we could compare to the ones presented before[22]. On the second hand, the analysis of graphical representations will contribute to set up a graphic code of product design drawings and will confirm or invalidate the sketches' properties[23].

4.2 Questions' and Analysis' Grids.

The following question grid lists all the questionings left in view of the previous objectives' definition.

The analysis grid[24] is built on the same framework and presents global descriptions of the "object" created during the experiment. These descriptions proceed from the instantaneous and post-experimental observations (see below, paragraph 4.6 "Experimentation modalities").

[22] See paragraph 2.4.3.

[23] See paragraph 2.5.

[24] See Appendixes F and G.

Processes

1 What is he doing? Does he:
Analyse? (Interpret, negotiate, organize, calculate, reason)
Search? (Read, listen, observe)
Propose? (Creative phase: new information, ideas, concepts, …)
Evaluate? (Controls or judgements)
2 What's the data type? Aesthetic, functional, technical, ergonomic? …
3 What's the abstraction level? Is it a unlabelled concept, a named object (labelled), 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?

Array 7 – Question grid.

4.3 Object definition.

I decided to propose to the subjects a fictive program, defining in a quite accurate way an object to conceive and to draw in front of me. It was necessary to fix common bases for both experiments, in order to build a similar scheme that could be compared and perfectly reproducible.

The object to design has to match several requirements. It has to:

- Be easy to conceive: one of the main constraints to make designers, who come voluntarily without any kind of advantage, coming and offering their experience, is the time factor. The experiment has to last a few hours maximum. Therefore I preferred to propose an existing realistic object to redesign, feasible in the available time, avoiding this way too complex creative load that could induce less complete cognitive process or more drawings' hesitations.
- Imply sufficient components to consider, not being on the contrary to fast to apprehend. The object has to present aesthetic, functional, ergonomic and technical characteristics.
- Present by essence the potentiality of being curved and composed by multiple shapes. I hoped this potentiality would incite the designer to draw the object from several point of views (also a perspective why not), an object that should be more "sketchy" than "mental image"[25].
- Present also a certain relationship with matter, light and texture to help us better understand how the designer represents these types of interactions.
- Be fundamentally accepted in our every day life but still presenting huge improvements' potentials, a certain challenge. Consumers have to be satisfied with the object current qualities, defects and ordinary aspect so far that a renewal could probably provoke astonishment and contentment.
- Avoid too much technical complexity. None designers own complete knowledge about mechanic, kinematics, dynamic, electric components etc. Usually they appeal to specialists for these types of elements. We unfortunately have no time enough to build a complete scientific team supposed to support the designer with these aspects. On top of that, the easiness to solve more pointed and technical details also depends on the sentant level and the feeling toward one or another discipline, and to stay far away from everything that could bring too much disparity between the results we will simplify this technical complexity.

I finally defined a remote control conception's program. This object with its impersonal but multiple appearances was well suited to previous objectives. Each domestic appliances need one of them, they stay usually regular (or even monotonous) in their aesthetic and are worth to be improved. This object seems interesting because it also appeal to several concepts: ergonomic, 3D shape, simplified and predefined electric components, implicit social recognition and also an hypothetic storage system.

[25] See 3.5 paragraph.

4.4 Program definition and validation.

The program[26] has then to propose a remote control project in a fictive but realistic context. It has to match the previous requirements. On top of that, this briefing has to inform about the fictive study goals, the project position within the context of the company's strategy, its expectations toward market competition, the expected contributions, potential costs, study limits and planning. Indeed, even if these constraints could be considered as obstructing designers' freedom and thus their creativity, they constitute an useful tool to narrow down a space of possibilities that can otherwise be too large for searching the most satisfactory solution.

A few more elements are added, in order to analyse other designers' reactions. For instance:

- the "pick me" contest label could support in a more effective way the ergonomic side of the project, or in another way lead to an original graphic proposition;
- the discussion about keys (understand buttons) aimed to make them draw thick and round elements that could result in interesting 3D representations;
- the technical and fabrication criteria are managed to observe the relation they have toward these constraints since de sketch step;
- finally the Internet link is evoked to check whether they would use or not another information source.

<u>Assignment validation.</u>

This program has been previously sent to another confirmed designer for validation. Used to this type of assignment this reference designer was liable to tell me if its fictive character was near enough to reality and if this program could offer me the information I needed. According to him it was the case.

4.5 Designers concerned.

The thin granulometry level required by the projected analysis and the time factor of this thesis leads to a clinic procedure instead of a statistic one. This procedure takes place in a deep analysis of individual cases' perspective, allowing sharp observations but delivering results that have to be considered with caution. Consequently I proposed the entire experimentation to two designers I already met for the interviews.

These two designers, given what I knew about them, were the most prone to propose a "sketchy" way to design. This characteristic was major because it would lead to "full" sketches with a high implicit content as well as a complex cognitive process, itself conducted by an intense exteriorisation. I also choose them thanks to their experience, sentant level, methods and design contrasts. Indeed, on one hand, the first designer (Experiment 0) is quite young, with more or less 2 years sentant and a totally different relationship toward computers and CAD (actually he really likes the modelling stage). He asserts a really lovely curved design and considers projects with a "graphic" point of view as well. On the other hand, the second subject (Experiment 1) is a 30 years' sentant designer, with a high domain knowledge and his own design company. He counts graphic designers among his collaborators, never models himself his projects, which usually present a refined and innovative character.

They are both considered as successful designers, this property being defined by [Ehrlenspiel, 1995] as designers that:

[26] See Appendix H.

- Produce better quality solutions;
- Spend more time with the analysis and formulation of product requirements;
- Have a larger solution space;
- Prioritise the tasks of their work;
- Generate more variants but never exceed some limits;
- Analyse the generated solutions in a more accurately way and thus spend less time at this activity;
- Tend to operate opportunistic strategies, i.e. can follow sub-problem oriented procedures with success instead of applying a systematic approach at all design steps;
- Have good spatial representation skills;
- Have a good process control;

And who keep an overview by periodically assessing and evaluating their work in order to reduce the number of mistakes/possible variants. We can for now put forward the assumption that this definition is valid.

4.6 Experimentation modalities.

The whole experimentation is video recorded (one front camera and one up camera), in order to allow a post analysis. For a first attempt with designers we decided not to make them draw directly on a digital interface. Mainly because anyway the prototype wouldn't have been already able to analyse and interpret a product designer's sketch in 3 dimensions. Consequently the only advantage compared to a classical paper interface would have been lost and, on the contrary, I should have taken in consideration the interfaces' differences to build a coherent analysis. Therefore the designer is asked to conceive by drawings only, using any kind of papers and pencils he wants.

The experiment shouldn't last more than 2 hours and a half and the designer is allowed to stop and take a break at any moment he wishes.

On top of the previous program, the designer receives the experimentation's objectives and a short description, with very few explanations to take out the maximum potential data (priority to spontaneity without any kind of predefined yoke).

You are asked, on base of a fictive program, to draw a new remote control concept.

This experiment will spread out into two phases :

- First, a maximal period of 1h30 is planned for the conceptual sketches. The drawing is totally free.
- The second phase is a reconditioning one. You're asked to propose a production drawing, the more detailed the better, affording graphic designers to realize a faithful 3D model on any software.

In order to help us better understand the successive stages of your work and the conceptions' processes, please « think aloud » during the whole experiment (speak aloud about everything you're thinking about).

These last statements aimed a double exteriorisation (production of a personal sketch and a communication one) as well as a spontaneous process explanation during the whole experiment. It could have been possible to ask the designers to explain their work after all, on base of the video analysis for instance. But it would have led to an unavoidable argued speech, much more structured, sometimes predefined but anyway always more warped than the usual way to speak.

An Internet connection was at the designers' disposal for any kind of search.

<u>Experiments limitations.</u>

- The think aloud method: contributions and limitations.

We have to notice that this "think aloud" method has detractors that advance arguments we couldn't deny. Indeed, some authors like [Ericsson & Simon, 1993] argue that the designer, expected to say what he's doing (not what he plans to do and not to reflect on what he did), performs more slowly. This bias would be the only one because just verbalizations like explanations or judgments could influence the performance. On the other hand, [Davies, 1995] criticized the fact that the protocol analysis method has been developed for well-defined problems and short tasks (equations resolutions for instance) and may not be adaptable for design problems. Davies doubts that the verbal protocol alone gives a realistic picture of the design process, therefore an additional sketch analysis is recommended.

- Experimentation context.

The subject is put in an emotionally loaded situation (his competences and skills are considered, analysed, …). Although everything is done to produce the most adequate work atmosphere[27], we have to consider that the designer doesn't work in his usual practical environment. This "lab" environment restricts the number of external influences and thus the variables in a study. This is an advantage especially for comparative research, but it also implies that this environment's lack is less suitable for a realistic analysis of how design actually takes place. For Davies, it is also possible that the designer does not act in a natural way even if everything is done to reach this goal. He could try to justify more his choices and reflect over his actions.

- The creative steps.

The usual creative steps may suffer of this environment. The "incubation" state is indeed usually deleted in such contexts of short experiments, which could lead to a project presenting inferior performances.

These limitations aren't negligible, but until now the think aloud method stay the better way to track the reasoning and the post-video analysis is unavoidable to depict the design' characteristics.

In addition to these drawings and speech analysis, I also observe gesture as an interesting element. This purposeful body movement can indeed communicate information such as references to existing objects in the workspace, relationship between the created object and a defined part of the human body or simulations enacted by the designer.

[27] Especially through preliminary declarations that certify that their work won't be judged in a qualitative way, or used afterall for any kind of purposes out of the limits of this research.

4.7 Experiment 0.

The experiments will be presented on a common scheme. First of all I'll describe the object produced and the main design steps observed (general actions' analysis). Secondly I'll consider the main sketches characteristics: contents, exteriorisation's methods, detail level. Then the design processes will be analysed.

The chosen analysis methodology is the following one. Thanks to video analysis I cut the whole film in about one hundred and fifty actions. This cut-out is corresponding to the main steps I observed during the session:

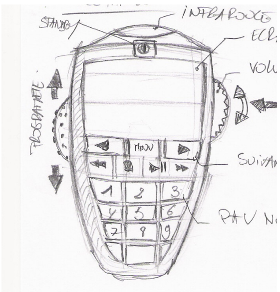
- data consultation;
- concept emergence (through speech, drawing or gestures);
- beginning of a new sketch, detailed drawing of a new defined zone or of a group of similar elements (combined thanks to their identical semantic signification, their identical graphic exteriorisation or identical abstraction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

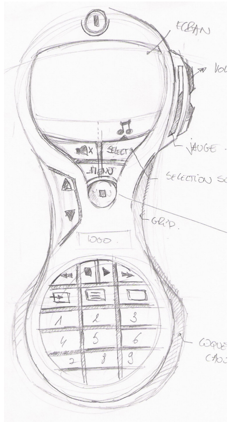
For each action I obtain a starting and an ending time, affording me to deduce the duration of actions. Once the actions defined, I can distinguish for each of them some characteristics[28], which are coupled with duration information and give me the opportunity to gain two types of results: a proportional and a chronological one. The proportional results are simply the percentage of one selected criterion (thanks the number of actions concerned or the time spent on this criterion) in comparison to the actions' sum or to the global duration. The chronological results are the reconstruction of global criteria evolution during the whole session. The amount of links and combinations able to furnish any type of information about the results were infinite. Therefore I chose some of them liable to provide the most interesting information.

4.7.1 Description.

The first designer, the youngest one, proposed two solutions. The projects' print screens can be seen in real size in Appendix I.

[28] See Array 7 – Questions grid and Appendixes F & G.





Figures 18 and 19 – First designer's work: solution 1 on the left, solution 2 on the right.

He began with a program reading and asked me some questions, negotiated about program elements that seemed to hail him. He quickly started to search information on the Internet (a computer was at his disposal). He looked at a few remote-control pictures, negotiate again about the possibility of combining a tactile screen with the main buttons (keys that would be disposed on both remote control's sides, see the sketch below, underlying the checklist).

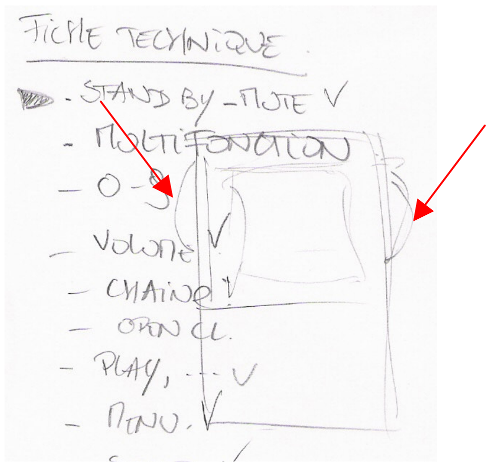


Figure 20 and 21 – analogy with an Internet search result; buttons on both sides.

After finding a compromise between buttons and tactile screen, he built a checklist, summarizing all the information and constraints he had to consider during the conception work.

Then he conceived the first solution, beginning with the plan, followed by the profile, for about half an hour. The consideration of the storage system's constraint made him draw a perspective, trying to define the best way to introduce a potential storage box. After a quarter, he began to evaluate this first project mainly with aesthetic and ergonomic points of view. He suddenly decided to propose another solution, on a new page.

The second project stood out this time without any references' search and seemed to constitute a more personal way to create. Much more round in its shapes and including ergonomics considerations as the starting point, this object kept from the first throw some elements such as the tactile screen, the sides buttons and the curved profile. Here again he drew a front elevation to begin and then the referent profile, but none perspective view has been proposed. In conclusion of this one hour and a half work he seemed to be much more satisfied with this second solution and explained me that in an usual context he would have begun from this point[29] a CAD modelling, in order to better apprehend the hidden sides and 3D aspect's of the object. Accordingly to the type of information I needed and his own way to consider the process continuation, the experiment ended.

4.7.2 Analysis of graphic representations.

The criteria exploitation first brings me data concerning drawing representations. In figure 22, we observe the used representation mode. The designer drew in plan, elevation and "3D" (understand: perspective). The distribution percentage between these three exteriorisations considers, on one hand, the number of actions and, on the other hand, the time spent on these types of representations.

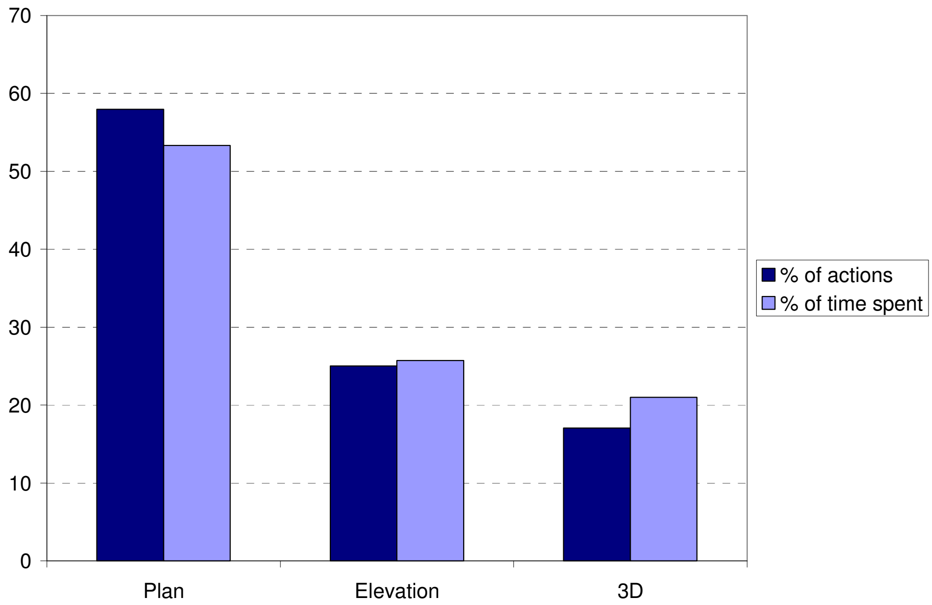


Figure 22 – Proportion (percentage of actions and time spent) of the three types of representations.

We see an outright dominance of plan drawings (58 % of actions or 53 % of time spent) compared to elevations or perspectives. This fact has already been observed during other experimentations, especially for architects [Leclercq, 1996] but here it seems that other conclusions have to be drawn as far as 3D usefulness is considered.This point of view will maybe be better supported by the second experiment, and in this case it will be deepened later.

We can also notice that the actions' durations are proportional to their respective importance.

Figure 23 shows the chronological distribution of the various representations during the hour and the half experiment.

[29] Understand : from the point where the object requires a 3 dimensional view to be completely apprehended.

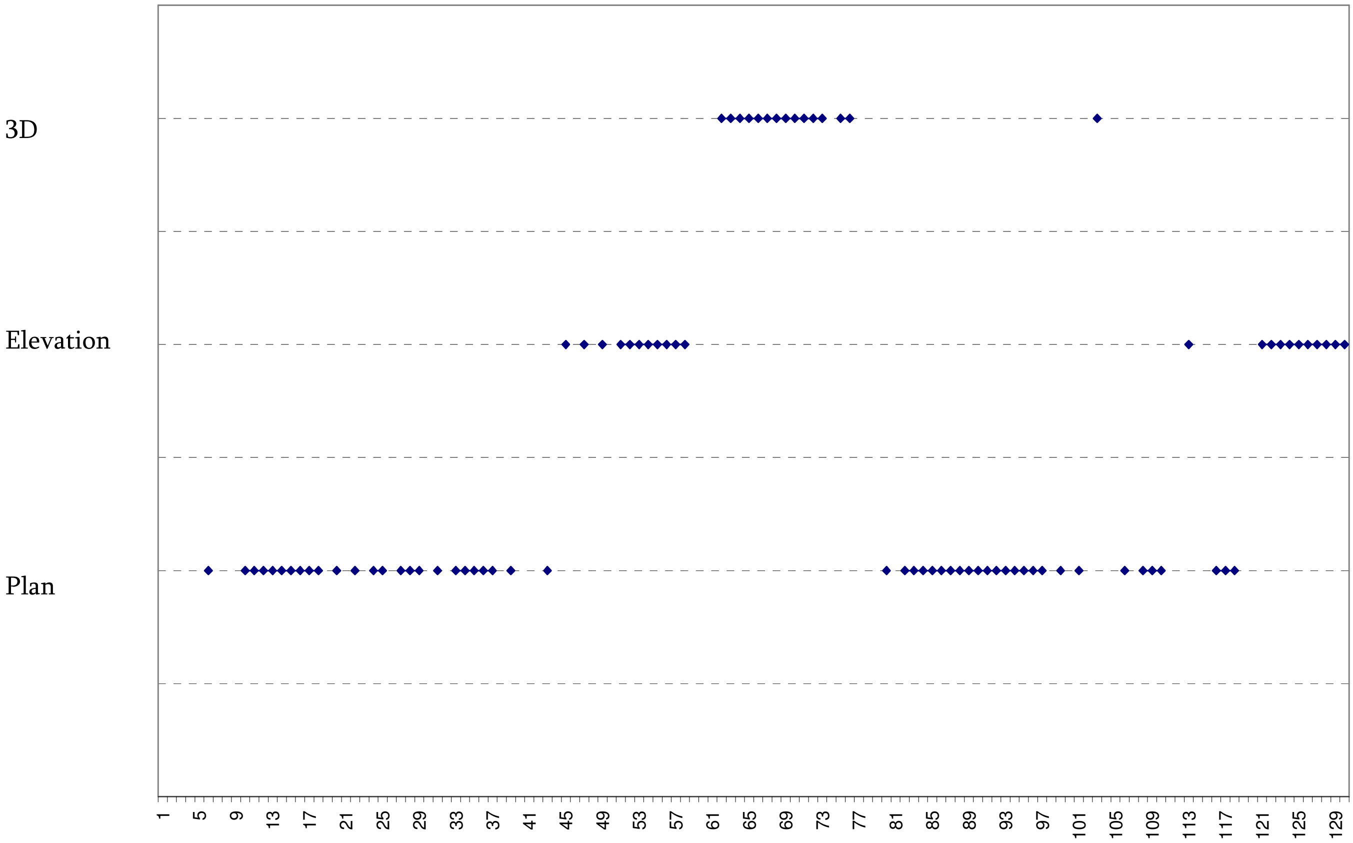


Figure 23 – Chronological evolution of the three types of representations.

The designer had no time to produce a perspective representation for his second project, but we can clearly detect a cycle, going from the plan to elevation for achieving by a 3D sketch.

Each step corresponds to a new sheet and we observe no turning back to previous drawings.

The following graph, figure 24, represents the abstraction levels (from global shape to aspect characteristics) reached by each action, in percentage of time:

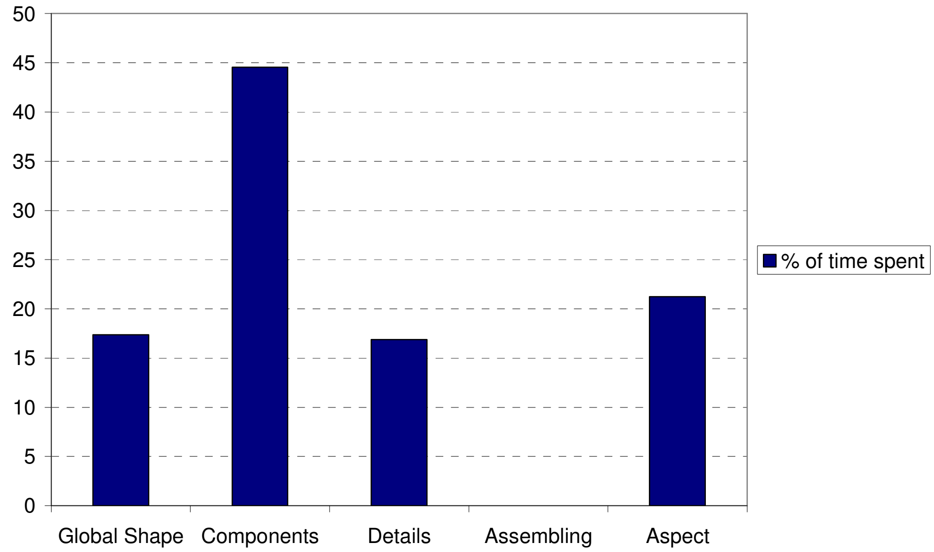


Figure 24 - Proportion (percentage of time spent) of the different abstraction levels.

We observe 45% of time spent on components (each part of the object considered separately). The global shape reaches a lower value (17%), this value could seem strange in a first sight but actually the object being quite small and full of components to insert, we can understand that the designer preferred to concentrate on the repartition of functions instead of on the global appearance. The detail criterion is referring to lines that present a lower abstraction level than components. Assembling techniques' criterion is not considered at all, while aspect (texture, matter, shadows, …) takes 21% of time. This last value can maybe be reduced for a "real" personal work. Indeed designers were asked to work in the most realistic conditions, simply as they act in their sketchbook, but we cannot deny that they certainly (and maybe unconsciously) draw in a more communicative or even "advertising" way, which could lead to different aspect's artefacts (see experiments limitations on point 4.6).

The next graph (figure 25) shows the distribution of actions between different drawing codes.

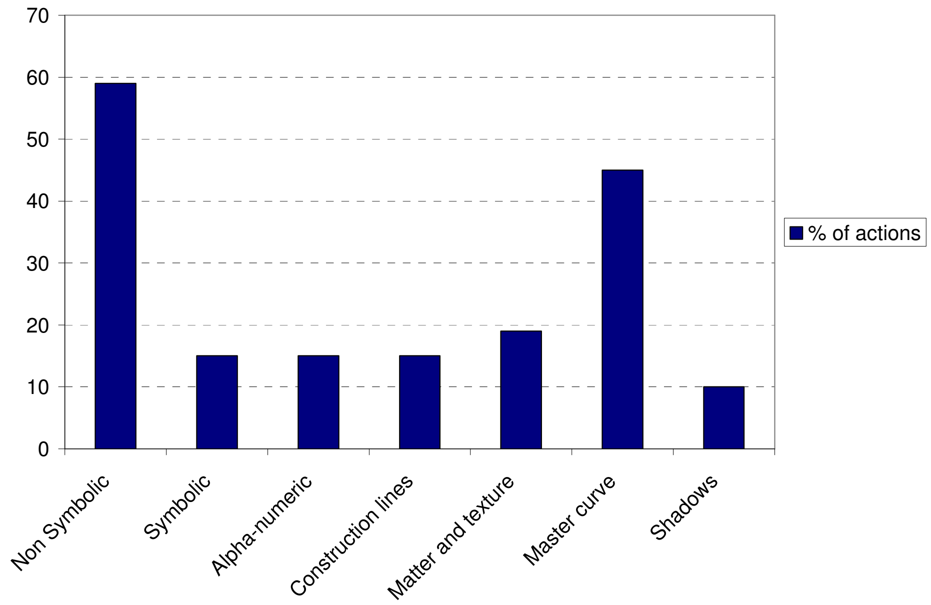


Figure 25 - Proportion (percentage of actions) of the different drawing codes.

Not surprisingly come the non-symbolic lines in first position, these one being differentiated from master curves for the need of the following result.

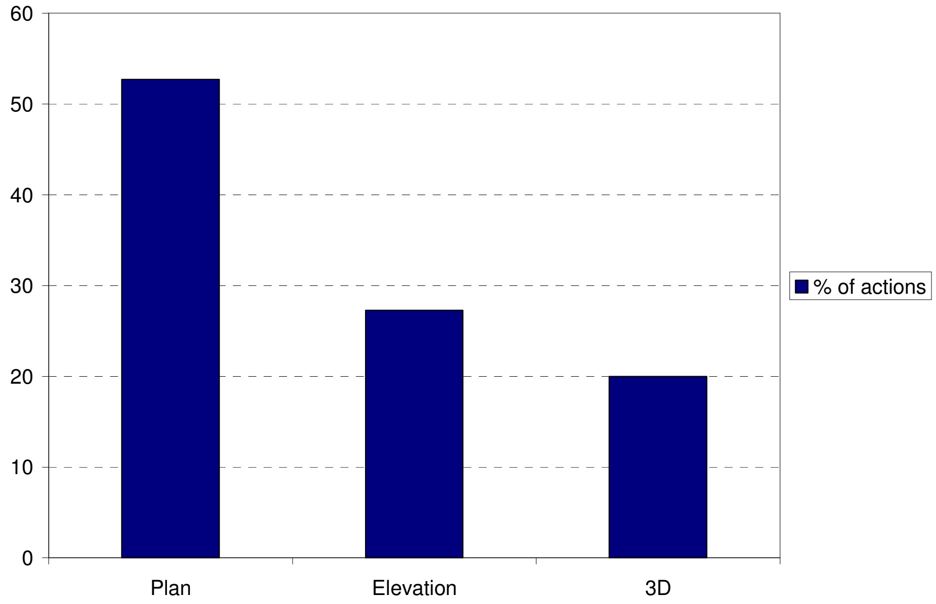
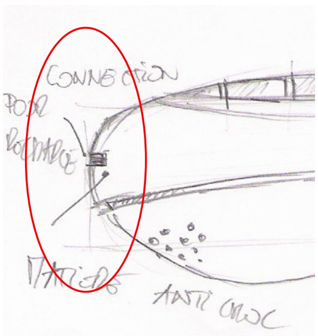
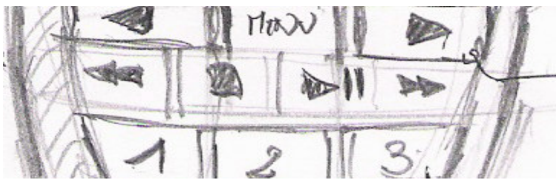
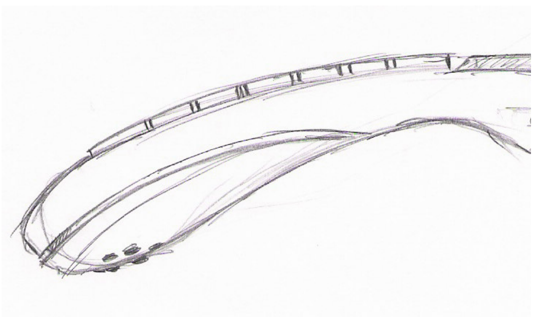


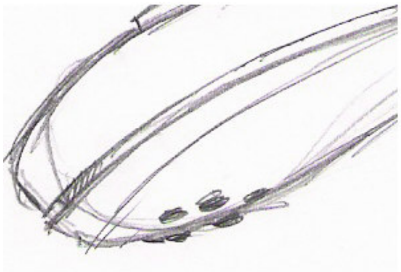
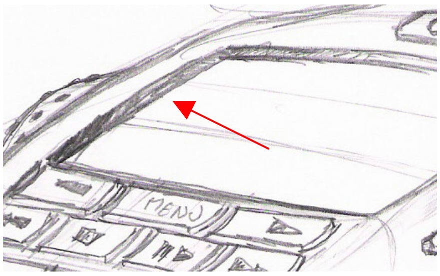
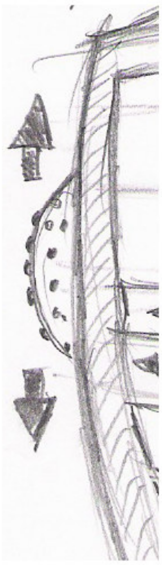
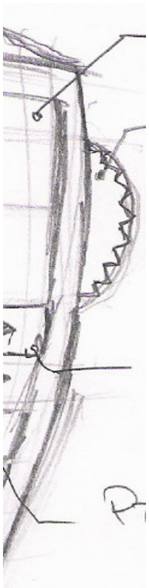
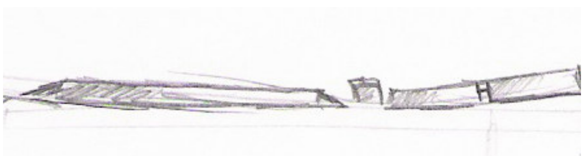
Figure 26 - Proportion (percentage of actions) of master curves drawn in each of the three types of representations.

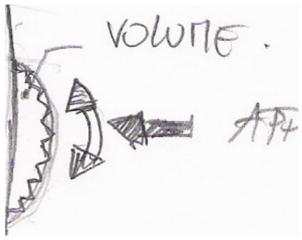
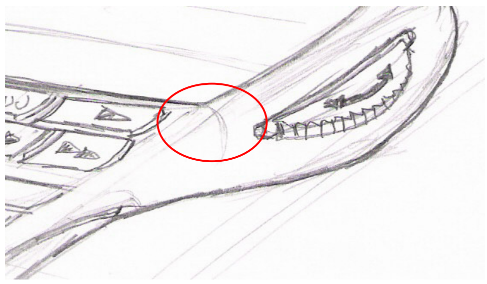
Indeed, this last graph (figure 26) shows the percentage of master curves drawn in each representation (theses curves then being considered separately from other lines for this counting). The master curves are defined as primal lines that define the global shape. I didn't take in consideration short lines that delimit secondary parts or components. We can observe that the majority of actions defining a master curve owns to the plane representation (57% of actions). Indeed the global shapes have mainly been conceived in this first step and the different attempts to reach a satisfactory level happened there. Very few innovator curves are born in elevation and 3 dimensional representations (drawn later), the designer simply trying to redraw the ones he brought into focus before.

Graphic codes.

Here I sum up the main graphic habits observed in the drawings.

	Constructions lines helps the designer to define proportions, to structure his drawing in order to make the design process evolve or just to report plan's information on a profile view. These lines can be outside or inside the object limits and are always very light, usually not split.
	Here we have an example of an intern construction line, very light as well, the designer subdividing the digits keys' location. We can also observe that the used symbols are the usual ones for these types of applications.
	The curves were very pregnant in his work as we can see here. Usually these ones are in a first step roughed out with very light lines, which reach after several essay-error tests the required shape. These attempts aren't erased but simply superposed, and to distinguish the final and fixed trace the designer uses a bold line.

	Here we see very well the several layers of work and the bold line achieving the shape definition. Hatchings are also used to represent the depth of the batteries box's cover and the dark points represent the grip texture facilitating the opening of this box.
	What's interesting here is the grey gradation used to figure the rubber joint between the screen and the plastic box (matter), the depth of this joint and the light withdrawal of the screen compared to the profile plane. Another point to notice is the double short line used to represent button' thickness.
 	Here we see that the button allowing to switch the stations is texturized: the little dots are used to figure the grip sensation, when the two arrows indicate the functioning: one click up or down to change tracks or channels. In comparison, the right button for the sound system presents a grooved aspect, given by a zigzag line, and a simple rotation allows to change the level. The asymmetrical buttons' positions, first whished to make the design more dynamic, was the starting point of ergonomical considerations that lead to the start of a new concept. Indeed, if the right key could easily be handled with the thumb, the left one could quickly cause fingers cramps.
	The main fact to observe here on this profile's detail is the spatial continuation of the curve created to align the different button surfaces. Only the joystick extremity departs from this master profile.

	The annotations lie everywhere on the sketch, bound to the referential object by a single line ended with a small dot. Arrows were also often used to explain functioning.
	The short and light curve that could be seen on this perspective representation is bringing information on the curvature radius the designer defines for his object. This quite unnoticed mark allows us to understand the shape's relationship existing between the profile and the plan.

Array 8 – Graphic codes analysis.

4.7.3 Process Analysis.

Let begin with a global consideration. The figure 27 is presenting the percentage of actions, coupled with the corresponding percentage of time spent for each « modality », namely oral, drawing or gesture actions. 72% of actions are dedicated to sketch, for only 55% of time, and 4% of gesture actions correspond to 17% of time spent. Actually, the considered gestures are mainly data search and ergonomics test (through hand gesture), these actions being more time consumer than oral descriptions.

The think aloud method unfortunately didn't really work for this first experiment as the designer often forgot to speak. I regularly tried to remind him this constraint, but the designer was easily disturbed by exterior interventions and therefore I quickly decided to stop my attempts, preferring this way to lose some information instead of messing up constantly the design process.

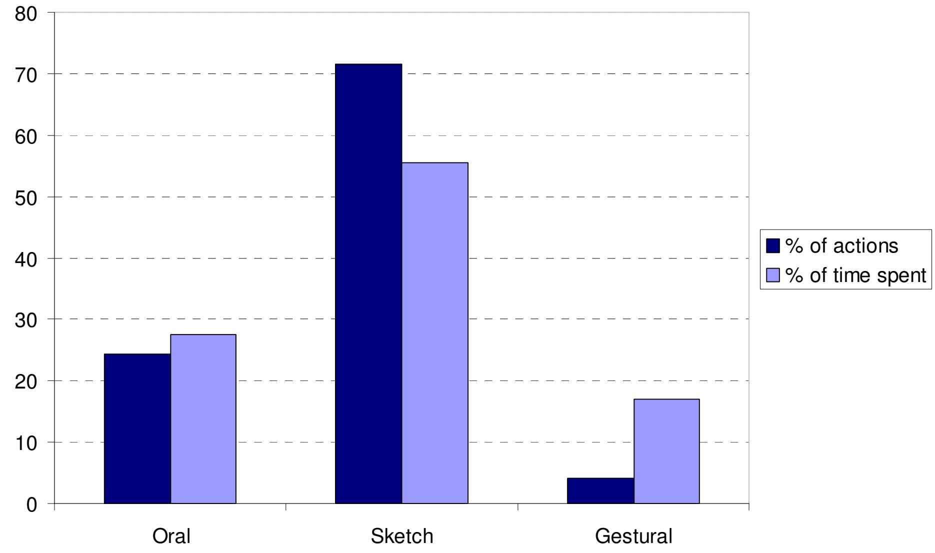


Figure 27 - Proportion (percentage of actions and time spent) of the three types of modality.

The next graph (figure 28) represents the proportion of actions and time spent for each of the four main types of actions. We observe that the search step is concerning 15 % of actions for a non negligible 29 % of time (the internet research took quite a lot of time) and is on parity with the evaluation time as far as numbers of actions are considered. The propositions concern 40% of the observed actions. These actions have been quickly formalized, because of a precedent analysing phase (interpretation, negotiating, organizing, calculating, reasoning) that took much more time.

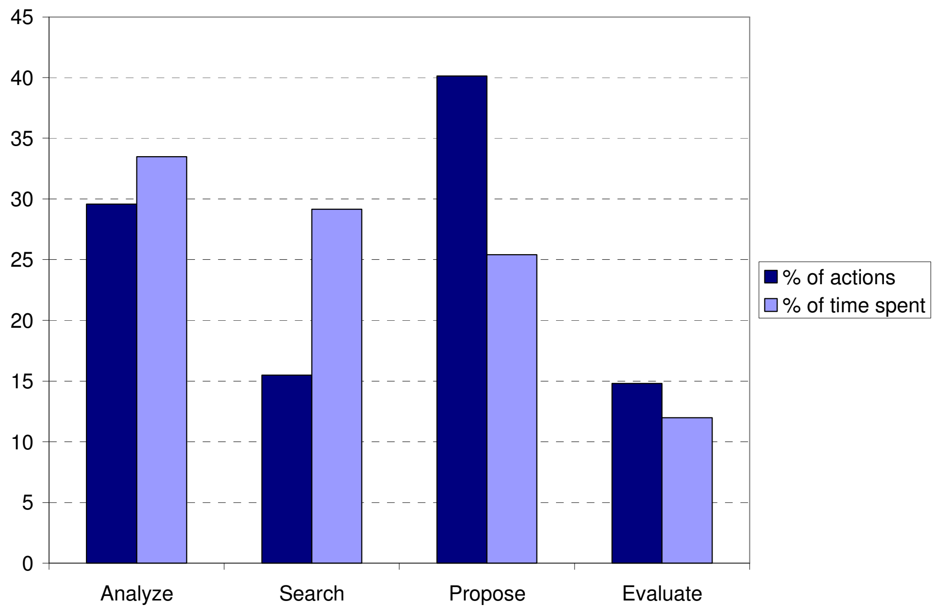


Figure 28 - Proportion (percentage of actions and time spent) of the four types of actions.

As far as chronology is concerned, we can observe on the figure 29 the following phases:

- Phase 1 (action 1 to 47): a searching phase is followed by information's analyse and everything is formalized in a tangible proposition. Evaluations (controls of project quality, of statement constraints) regularly step in the process.
- Phase 2 (action 48 to 71): analysing precedes a proposal: the concept seems to be apprehended and the designer tends to organize the object respecting this procedure.
- Phase 3 (action 71 to 76): a long evaluation period precedes the first project's end.
- Phase 4 (action 77 to 96): beginning of the second project. The whole information being already studied, the searching phase almost disappears. The first project crystallized the global nature of elements to consider, helps the designer to apprehend all the explicit constraints and hidden difficulties, and consequently the second solution is more « liberated », the proposal can emerge faster.
- Phase 5 (action 97 to the end): after this high productive phase, the designer reads the checklist he built before, in a control purpose (« did I forget something? ») and the few more constraints, which remain to be introduced, are taken into consideration in a new creative phase (analysing-proposals). The project is then one more time evaluated.

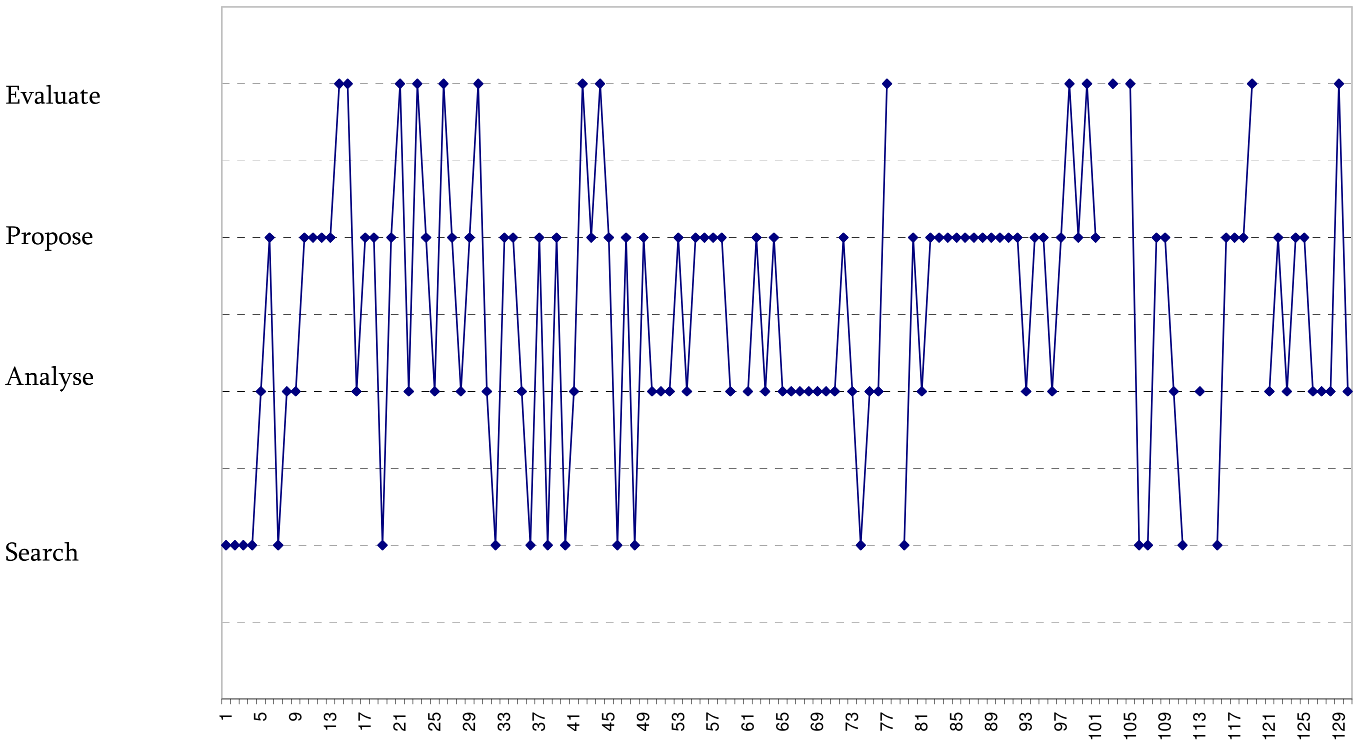


Figure 29 – Chronological evolution of the four types of actions.

The following chronological graph shows the evolution of abstraction level.

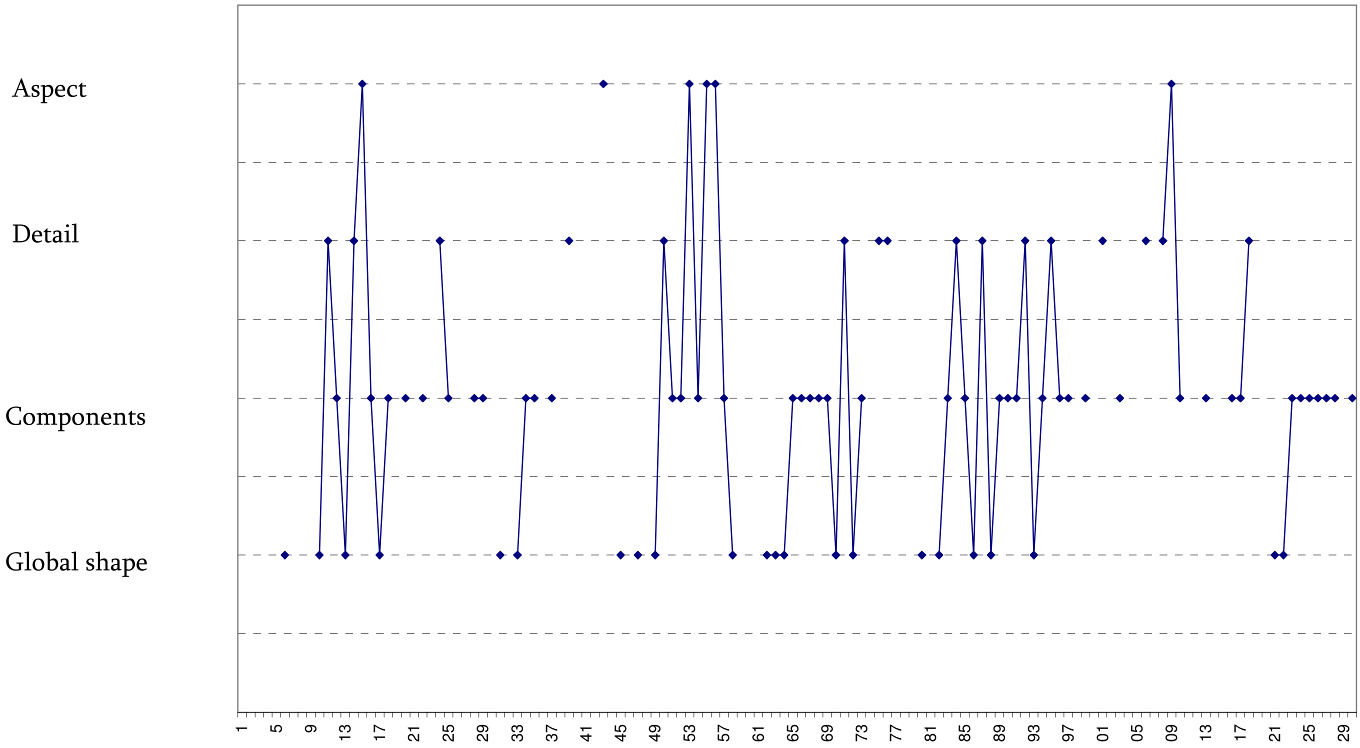


Figure 30 – Chronological evolution of the abstraction level.

We can observe a certain connection between this graph (figure 30) and the precedent one. The searching and analysing criteria are of course situated at a high abstraction level (global shape when sketches are proposed or simple concepts orally expressed). But the propositions and evaluations steps, when exteriorised by a drawing, correspond to well define levels as well. For instance, the first « aspect » consideration (action 21) corresponds to the first evaluation phase of the process. This stage is formalized through a drawing, and shadows are in this case proposed. The second « aspect » phase doesn't correspond to an evaluation phase but a proposition one, and if we analyse the actions contents we can see that this one is concerning texture or matters, and no more shadows. The last aspect action (number 109) also corresponds to a proposition and a texture is drawn again. No certainty exists, but we can for now notice that on one hand, a project proposition, concerning appearance, is often represented through matters and textures and on the other hand, an evaluation is often gone with a shadows proposition, just as if the relationship between the object and the light could support a qualitative judgement. I have to add that the emphasis steps, corresponding to a come back on the main master curves with a bold stroke, has obviously been classified in evaluation's stages as well.

The very last evaluation phase, preceding the second solution, isn't transcribed with aspects drawings: the designer attempts to redraw non-finalized parts of his project instead of considering the global proposition. Details always correspond to a proposition.

Globally, there are go and return movements between general drawings to particular ones, this evolution being limited for a long time to the detail level, the designer being more focused on components organisation and program constraints. In general the designer began with a global shape, drew for example the up part (screen and lateral keys), came back to a general view, before starting propositions for the down part (buttons).

Another information available is the type of semantic content supported by the drawing. The figure 31 shows that aesthetic and functional considerations were much more pregnant in the sketch than technical or ergonomics ones.

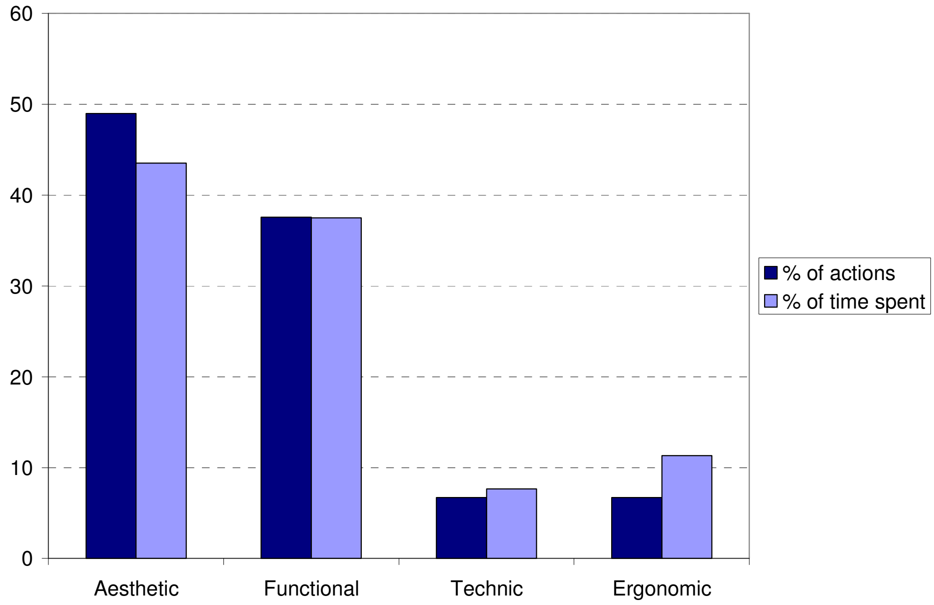


Figure 31 - Proportion (percentage of actions and time spent) of the different semantic contents.

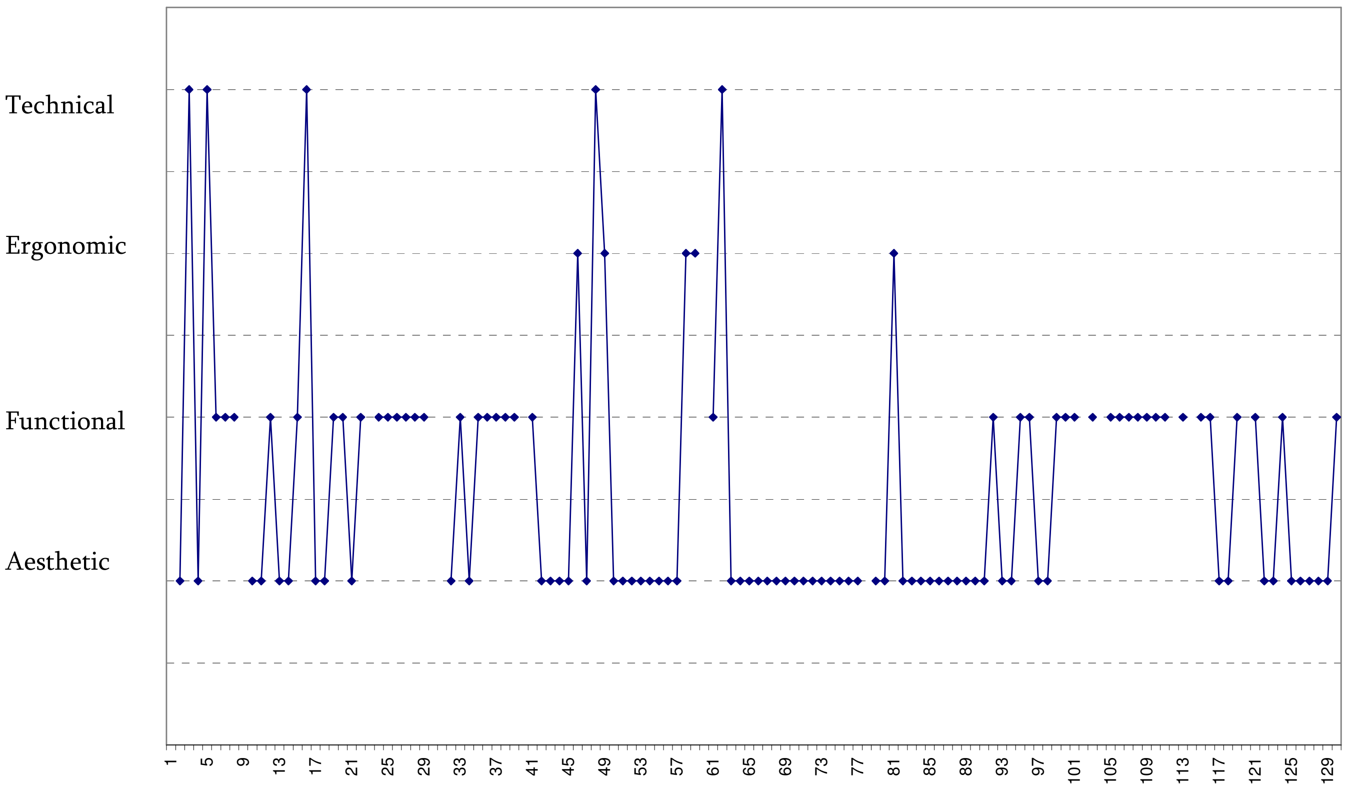


Figure 32 – Chronological evolution of semantic content.

Again the chronological graph (figure 32) presents several elements:

- The first technical considerations correspond more to components operating (very few explicit fabrication constraints took part in the design process here, even if we can assert that elements such as thickness, curvature radius are defined thanks basic knowledge of production);
- Functional and aesthetic contents are mainly considered, all along the process;
- The first ergonomic considerations enter the process at the end of the first project conception. This ergonomic constraint leads to the start of the second solution as explained above (see 81th action).
- We can see that the beginning of the second solution, once the prehension issue is resolved, is mainly constituted by aesthetic contents, the functionality coming back after a while to introduce again all the assignment points.

4.7.4 Post-experimental interview.

I had the possibility to make a short post experimental interview with this designer. Two questions were left after this experiment. First I observed that, once the designer analysed in a qualitative way his first project and once he decided to restart a new proposition by taking a new sheet, there had been nearly no reflection time to take a stand and begin to draw. I asked him how it was possible to find a new concept and start the sketch so quickly (just 1 minute and 6 sec. after finishing the previous one). He said that the ergonomics issue he confronted and the difficulty he had to draw a satisfactory perspective of his first object lead to the instantaneous image emergence of the human grabbing a big bone. Indeed, the second object's primal lines were two circles joined by two tangential curves. He added that this profile was chosen because there was no need of so much matter in the central remote control part.

Secondly I asked him if his object was technically feasible without too much post adaptations imposed by production's constraints/costs. According to him, everything was perfectly feasible, the single question mark left concerning the grip rubber assembling (this rubber used as a shock-resistant matter).

We have to notice that the post experimental discussions aren't considered as "think aloud" part anymore. Actually, there is an unavoidable argumentation and reflect over phase on the created object, therefore we have to consider this information as addition but not as accreditation.

4.8 Experiment 1.

4.8.1 Program modifications.

The first experiment's observations lead to the program revision[30]. I decided to reduce the number of components (the LED transmission diodes and the USB key disappeared), decreasing this way the number of constraints to take into consideration. My hope was to ease the cognitive granting statements' specifications, this load could then be used for other goals. On top of that I erased the storage system constraint. Indeed, this element incited the first designer to draw a perspective view of his object, and I wanted to see if this representation's artefact would disappear with the storage box's removal.

4.8.2 Description.

The second designer's work can be seen in real size in Appendix J.

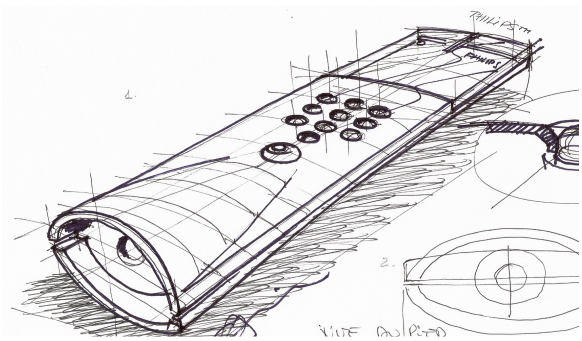


Figure 33: second designer proposition.

He proposed a totally different work's methodology. First through the use of sketches as multi-purpose tool. Indeed, after the program's reading, his first act was to list on a sheet[31] all the constraints he considered as decisive. But this listing, contrary to the first designer who used a checklist, was here mainly composed by schemes. These schemes or diagrams, graphically simple,

[30] See Appendix H : the italic sentences have been erased for the second experiment.

[31] See Sheet A, Appendix J.

investigated the several functionalities and goals the remote control had to fulfil. For instance, we can observe sketches that aim to analyse different numerical interfaces, as well as ways to select functions or navigate in the menus. After these first constraints' considerations, he took a second sheet and proposes several shapes matching the human relationship's requirements (see sheet B, appendix J). Actually he began with a human hand's drawing, then proposed a cylindrical-like shape, a more flat one and finally a glove.

On the third sheet[32] appeared the concept as such. After explaining orally he wanted a "simple shape" corresponding to his usual way of working (a multi-shape concept is decomposed in basic geometrical shapes, that are finally connected together and maybe later deformed), he began to draw a flat parallelepiped. A new idea then raised (a remote-control combined with a miniature TV-screen, in order to see what is proposed on the other channels before zapping), immediately followed by the first technical consideration: the batteries' dimensions and their storage system. This constraint leads him to add to the flat profile a conic basis, these two basic shapes intersecting more and more.

From this point, after less than 25 minutes of work, we can say that the final shape was already defined. The following sketches reflect the buttons' definition, ergonomics considerations, the design of a storage system (coupled with batteries' loading) as well as production's details. After around one hour he ended the experiment by evaluating his work, through master curves' emphasis (in the purpose of communicating his idea to potential collaborators).

4.8.3 Analysis of graphic representations.

I analysed the collected information just as I made for the previous experiment. Consequently, the first data to be considered will be the distribution's percentage (in actions and time spent) between the three main sketches' categories (figure 34). We see this time another relation toward perspective representations. Indeed, the designer composed the global object's image mainly through 3 dimensional drawings, this method explaining the 56% of actions devoted to this type of exteriorisation[33]. Plans (21%) and elevations (23%) have in comparison with the first experiment totally different purposes: the global shape being already conceived, they just support the object's comprehension and fix proportions and details (the perspective representation formalizing optical effects that involve distorted dimensions and appearance).

[32] See Sheet C, Appendix J.

[33] I have to warn the reader here that the graphic analysis based on proportions are only concerning the sketches directly linked to the object's definition (none of the « program's reformulation » schemes or diagrams are involved in these results).

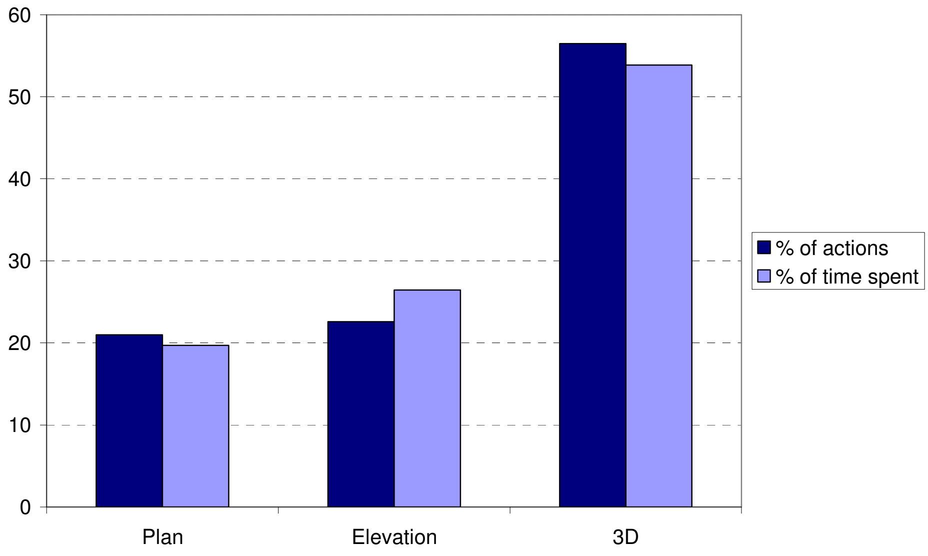


Figure 34 – Proportion (percentage of actions and time spent) of the three types of representations.

The chronological graph that follows (figure 35) presents the evolution of these previous exteriorisations through time.

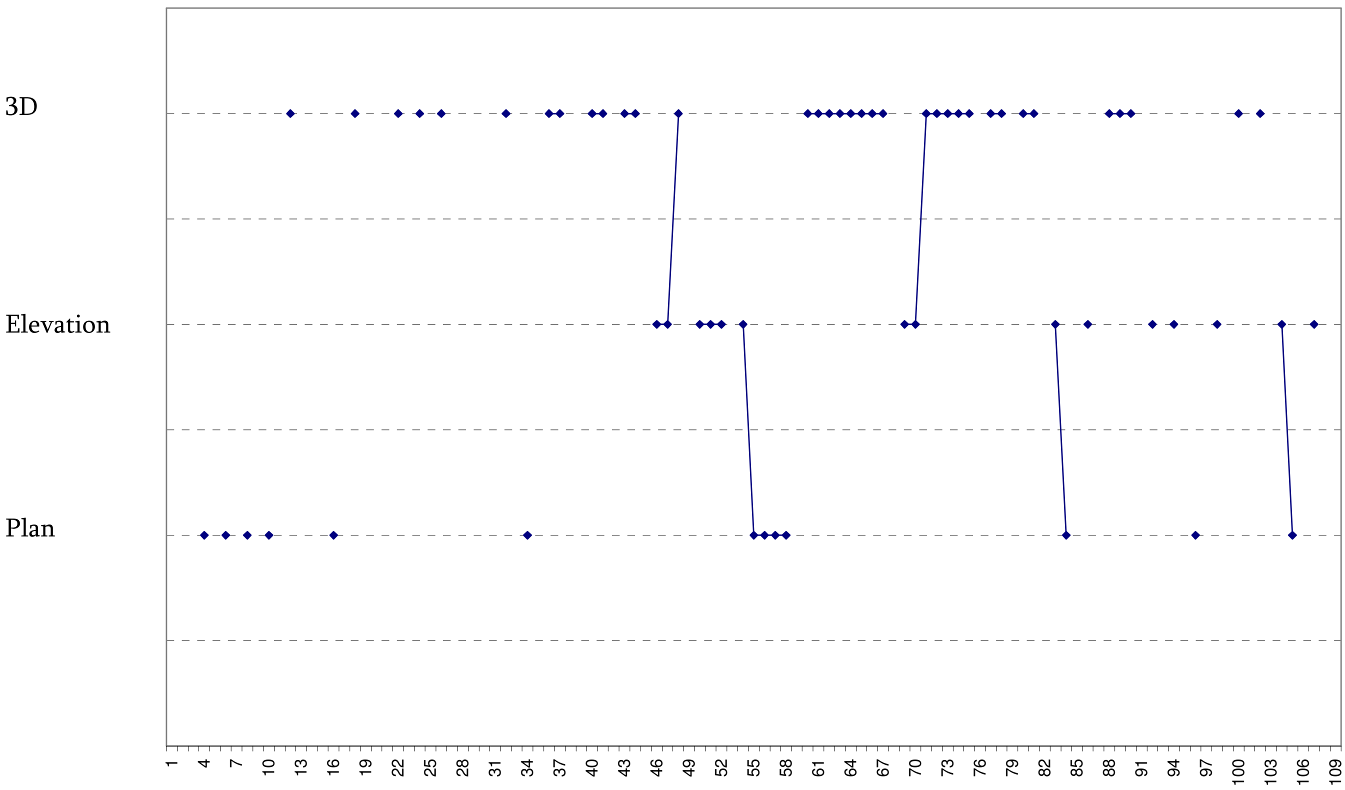


Figure 35 – Chronological evolution of the three types of representations.

The analysis of this previous graph reveals an interesting cycle. If we don't consider the 30 first actions, dedicated to what I'll call the "program reformulation" (see sheets A & B, appendix J), the general methodology that can be pointed out is the following one:

- In a first phase, the designer is proposing a perspective of the nascent project.
- Some technical constraints lead him to draw elevations. These ones help him to define proportions, thickness and to organise his project symmetrically.
- A plan view is drawn for the same purposes.
- From this point the project is defined in its global nature. The designer then begins a perspective representation, more "pictorial" than the first one (he integrates shadows, textures and bold lines in this sketch).
- The more this perspective evolves, the more details' points have to be resolved. Consequently the designer will turn back to his previous sketches, or begin new ones. Again, these plans and elevations make use of more "rational" considerations and support the designer in his technical and functional decisions. Once these sub problems solved, he turns back to his perspective to translate them in a more "rendering" and aesthetic way.

To conclude, we can say that the actions' distribution through time doesn't follow a sequential scheme. The designer regularly comes back to previous drawing to support his idea's evolution. The 3D representation steps an evaluation phase that raises interrogations, these ones are answered thanks elevations or plans' modification (or creation of new ones). These propositions are related on the 3D view that hails again the designer. Sketches, and especially perspective drawings, are the support and the actor of a real and rich "see-transform-see" cooperation (see paragraph 2.4.4).

On the figure 36, we see the percentage on time spent on the different abstraction's levels. We observe a distinct dominance of work on a global shape (46%), followed by components (25%). Assembling' questions are here considered, contrary to the first experiment, and aspect just occupies 5% of the work time (their purpose being simply to differentiate the screen's and body's material). This work seems to less consider appearance and rendering than the one proposed during the experimentation 0. That could be due to the fact that this designer drew faster, had less time to offer and is used to propose this type of more "technical" drawings to his collaborators (for whom no aspects details are necessary and even better to avoid in order to ease the comprehension).

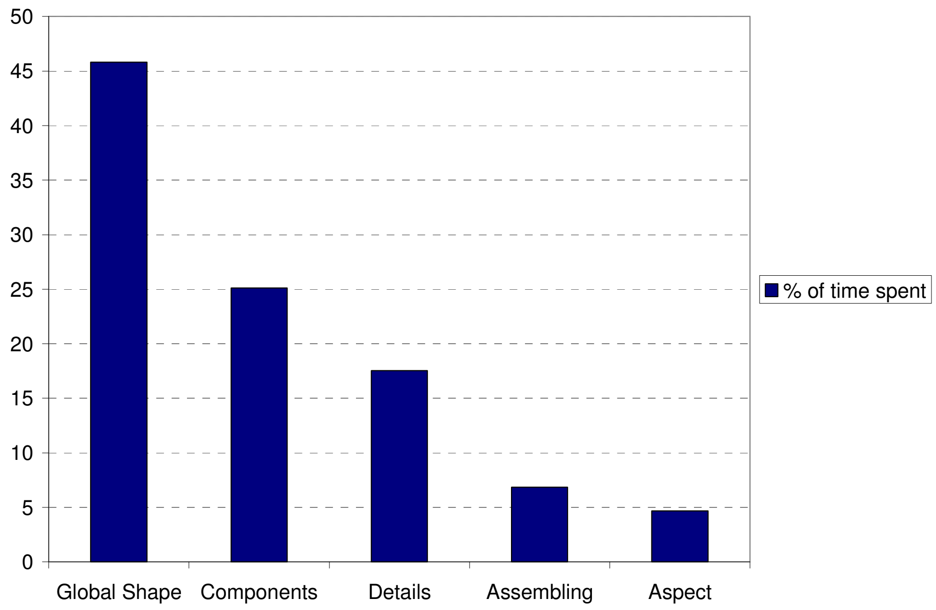


Figure 36 - Proportion (percentage of time spent) of the different abstraction levels.

Below stand the proportions of the different type of graphic codes observed (figure 37).

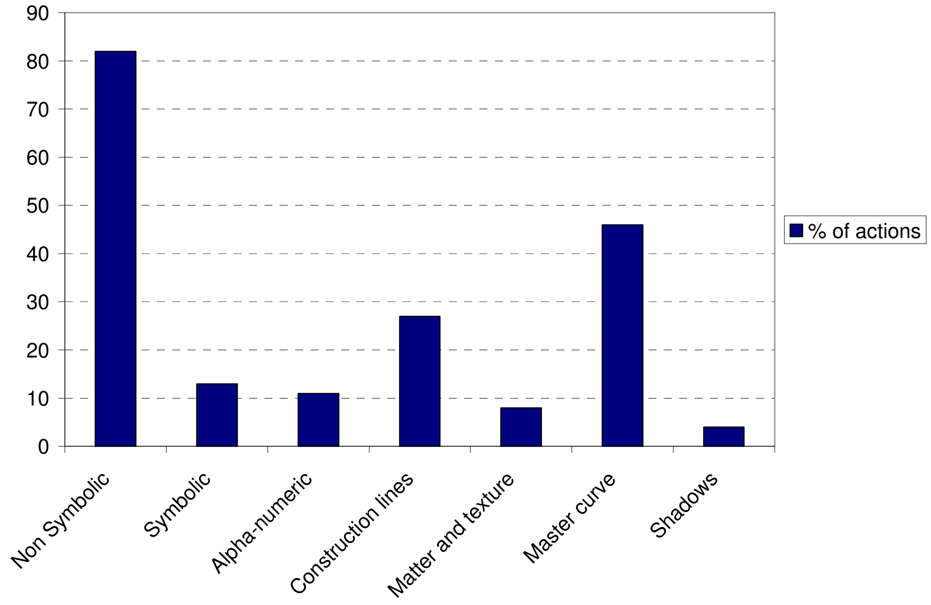


Figure 37 - Proportion (percentage of actions) of the different drawing codes.

On top of the logical dominance of non-symbolic lines (82%), we observe that 46% of actions serve the master curves and 27 % are construction lines. Indeed, in comparison with the previous experiment (59% of non symbolic lines, 15% of master curves), we can directly note that these drawings are more constructed, frames and predefined axes supporting almost all lines. Shadows, matter and textures being used with parsimony. The sketches are consequently more purified (this is also obvious by simple observation).

To conclude with this part, we can observe that the percentage of master curves drawn in each type of representation (figure 38) is totally opposed to what we saw for the first experiment (figure 26). Here 62% of master curves are defined in the 3 dimensional representations, 38% in the elevations, and none of them in plan, these figures confirming the different relation kept with the perspectives (see above).

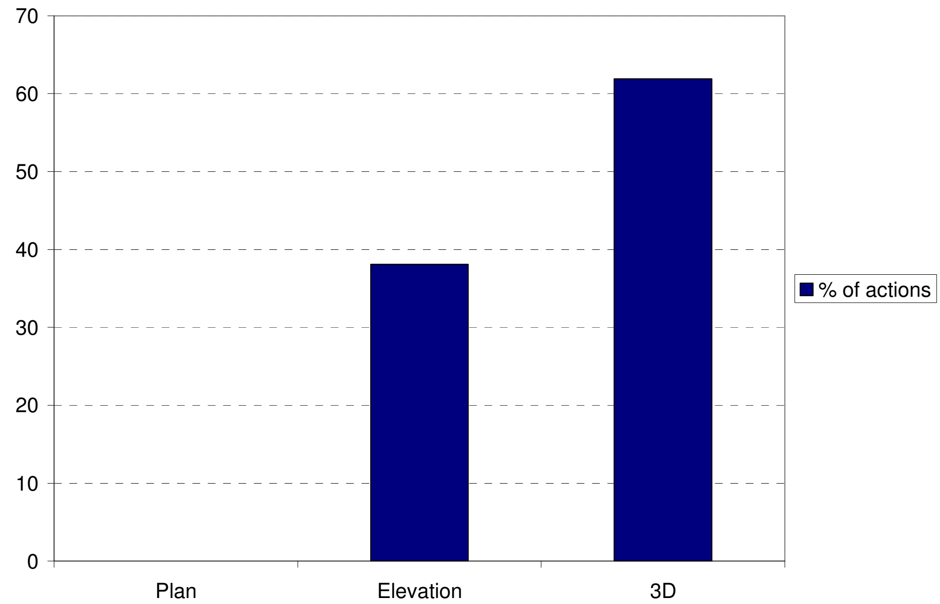
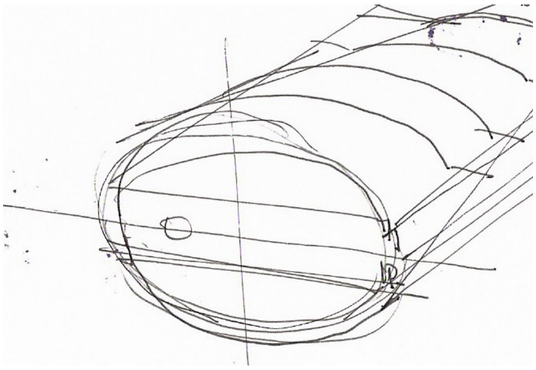
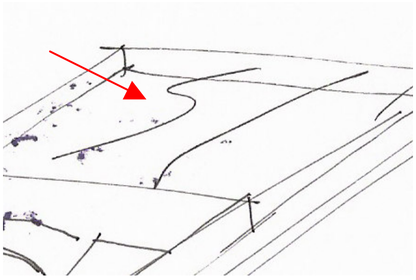
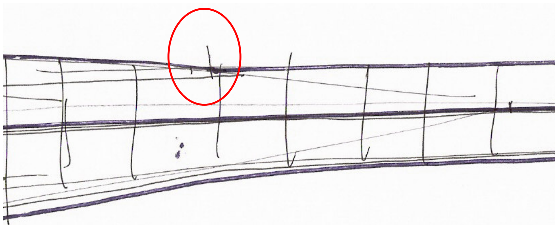
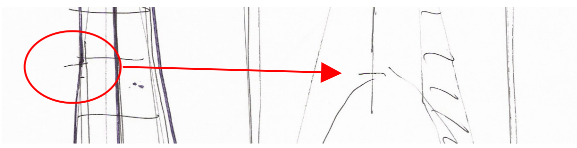
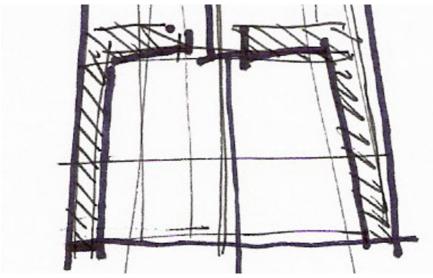
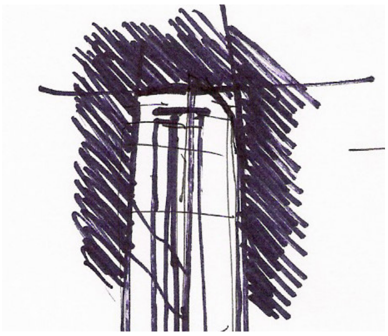
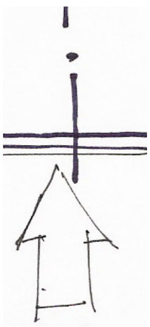
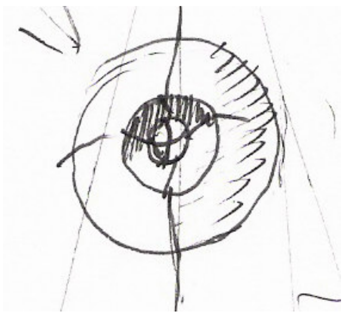
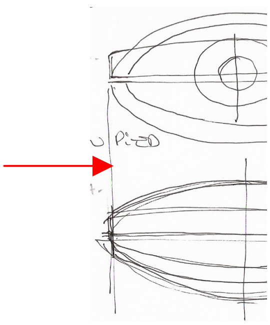


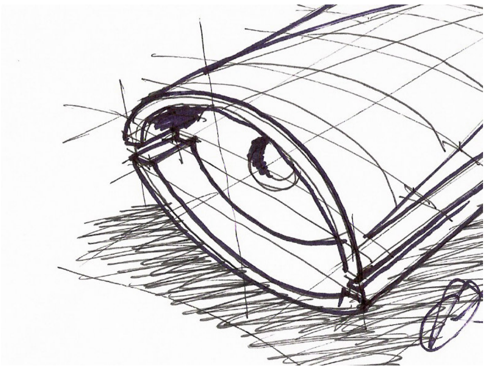
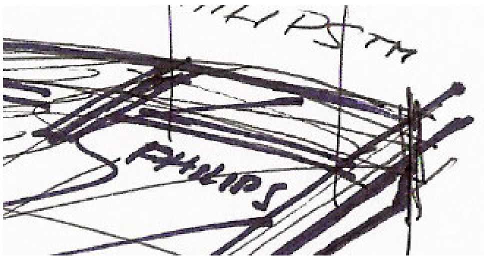
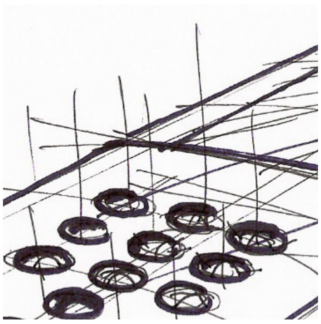
Figure 38 - Proportion (percentage of actions) of master curves drawn in each of the three types of representations.

<u>Graphic codes.</u>

The "program's reformulation" sketches won't be considered here, their graphical content being not representative of how the designer draws. A very first fact to notice is the difference of tool chosen here for the drawings: no pencil anymore but a ball-point pen to begin, which afford less different shades and makes the hierarchy between lines decreasing, and a marker pen then to finalize and emphasize the main curves.

	Here is the first rough sketch proposed. The lines are multiples, especially for the conic basis (and other curved parts), this cone is centred on two perpendicular construction lines. Straight lines are drawn with more assurance and are defined in a clear way. The lines' curvature is decreasing on the top of this zoom, this gradation expressing that the cone becomes more and more flat with the parallelepiped's interpenetration.
	Already on the rough we found the only texture that differentiates matters, here in particular the screen's glass (or transparent matter) from the body's plastic.
	This profile shows different interesting things. First the interpenetration of two basic geometrical shapes (the light lines shows the cone's top penetrating the flat parallelepiped, and the short vertical line indicates the intersection's point), secondly the vertical lines that express the thickness' evolution, and finally the bold central line defining the technical junction between the two plastic hulls.
	The previous short intersection's line helps the designer to take back on the plan view the penetration's point between the cone and the parallelepiped, this point being consequently the up extremity of the curved intersection.

	Here is the bottom part of the profile. The designer draws the hidden hollow that will receive the batteries' loading system (constituting also the base and storage system). The hidden parts are represented with their thickness through a hatching process and are fixed in their shapes through bold lines.
	Here bold lines drawn with the marker pen are used in a corrective purpose. Indeed, the initial and more curved extremity can still be discerned, but the 3 bold construction lines and the hatching fix a more squared profile.
	Very few symbols, annotations or links are used in these drawings. Here is one of the two arrows we can find, this one expressing the fitting's direction of the loading basis into the remote control. We also observe a line-dot-line axis framing the profile on a symmetrical structure.
	Paradoxically this 3D-like drawing can be found on the plan view. So we see that the designer tries to express the bulged aspect of the button-case using two methods: first the shadows through very short and bold lines and secondly two construction lines whose central deformation represent the little cavity.
	Light construction axis and construction lines are pregnant in this work. Here on top of that we can see catch lines that structure and bind the two up and bottom elevations.

	This zoom is part of the main sketch, presenting the object in the more qualitative and communicative way. Several things can be pointed out: - First the several construction lines, expressing either the symmetry or the curves' development. - Secondly the black marker pen that fixes the final shape and expresses thickness through shadows - Thirdly the close hatching representing a context on which the created object stands out.
	The light lines are much more distinct than the pencil drawings of course, and the bold lines defining the final shape are also sometimes extending their boundaries. We found the same zigzag stroke representing the screen's transparency and the "Philips" annotation is bent to the Philips logo with two light vertical lines.
	Here again a good example of structural lines: these vertical strokes define the buttons' locations, previously fixed on the plan thanks to a symmetrical frame.

Array 9 – Graphic codes analysis.

4.8.4 <u>Process Analysis.</u>

Considering the same type of information than for the first experimentation, the following graphs can be elaborated to better understand the conception's process used.

First the figure 39 (proportion of actions and time spent for each of the three modalities considered) shows that sketches concern 90% of actions (for 70% of time consumed) and that gestures (in direct relationship with the project's evolution or object's interactions) are absent of the proceedings.

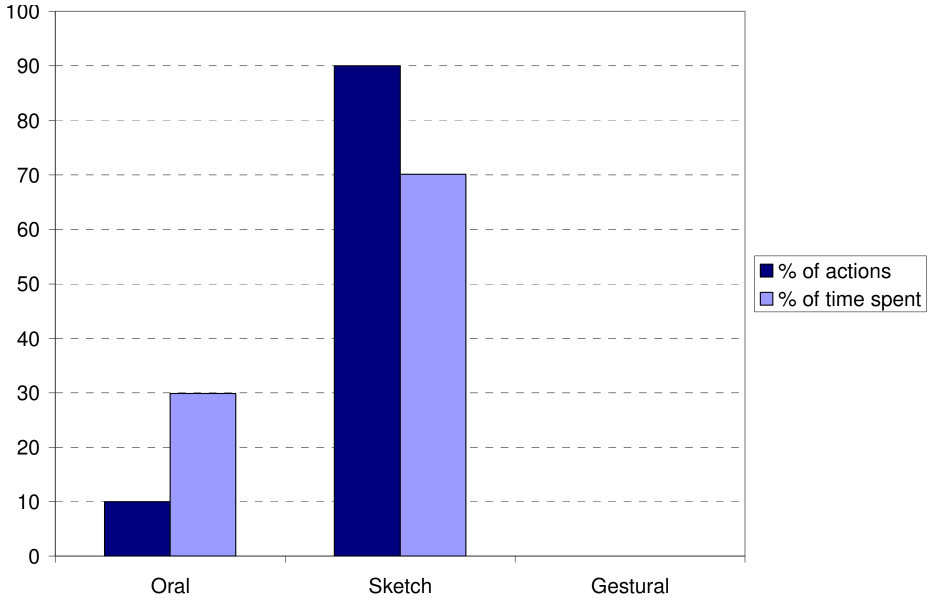


Figure 39 - Proportion (percentage of actions and time spent) of the three types of mediums.

As far as oral operations are considered, we have 10% of actions for three times as much assigned time. In this case, the “think aloud” method was more efficiently applied, the designer speaking as well about the way he draws or the emerging ideas he had.

Other elements of comparison can be drawn from the four types of actions’ distribution (figure 40). Indeed, we see that analysing took the second designer the same time as the first one, but concerns 11% actions more (this raising due to the fact that the analysis was here also supported by sketches and schemes). The searching step concerns a very small amount of actions and took less time (this designer didn’t use the internet connection at all but still talked a lot about what he was doing) and the proposal’s percentages increase but keep the same proportions in actions and time spent.

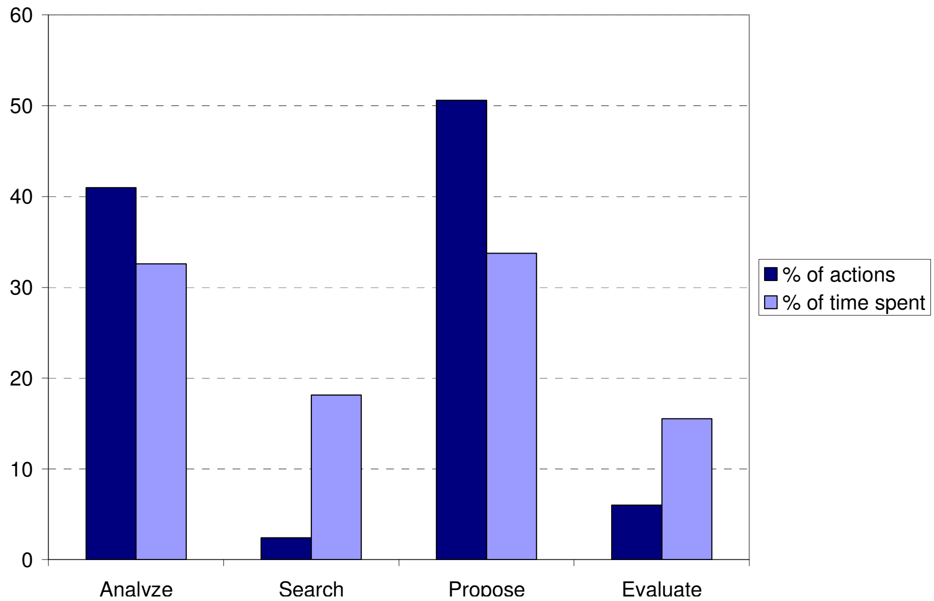


Figure 40 - Proportion (percentage of actions and time spent) of the four types of actions.

Finally, the evaluating stage concerns fewer actions but takes more time. This last observation could be explained thanks to the “think aloud” method’s efficiency: the designer spoke more, also about the satisfaction’s level he had toward his project, the time consequently raising. Paradoxically fewer actions are dedicated to evaluation, and that can also be explained through the following graph’s observation (figure 41).

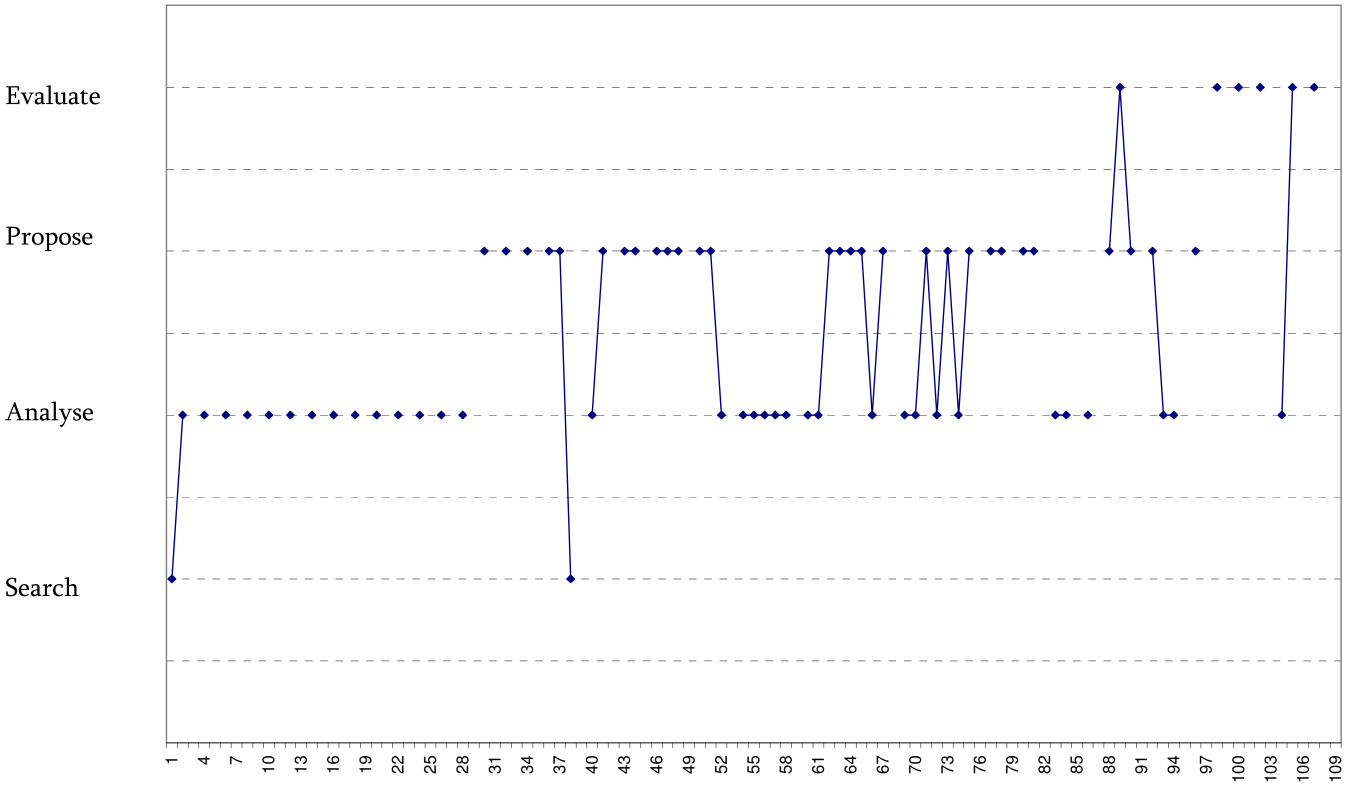


Figure 41 – Chronological evolution of the four types of actions.

Indeed we observe here (figure 41) a much more sequenced evolution through time. 5 phases can be discerned.

- The very first searching action is the program's reading.
- Follows an intense analysing phase, where the program is decomposed and reinterpreted through rough sketches (what I called "program's reformulation"). These elements could have been classified as proposition as well. Actually, even if the designer didn't sketch any realistic object at this point, he still schematised what could be considered as first ideas. Nevertheless I preferred to put these attempts in the analysing stage because these ideas would anyway be reintroduced later in the object's drawings and then considered as propositions.
- The first proposition sequence then happens and is directly followed by an oral questioning about the battery loading system (action 39), that leads to the conic structure's consideration (constituting the loading system as well as a storage basis).
- Then the main conception's phase begins, composed by analysis's actions alternately with proposals (actions 39 to 89), the sketch constantly involving new ideas and reactions.
- The 90th action is the first evaluation one, all the evaluations being formalized by sketches' accentuation through marker pen's use.

This chronological and sequential way to work, very different from the first designer's methodology, could be linked to the program's complexity level. Indeed, even if both subjects can be considered as experts, this designer in particular seems to develop the whole project with an easiness and quickness that can be due to his high expertise level in the product design world (more than 30 years sentant). The design process he developed could therefore be considered as a "routine-problem solving"[34] that leads to a predefined and well-structured sequenced scheme.

This chronological graph (figure 42) shows the abstraction's level evolution. An added level appears, concerning the assembling systems the designers considered during the conception.

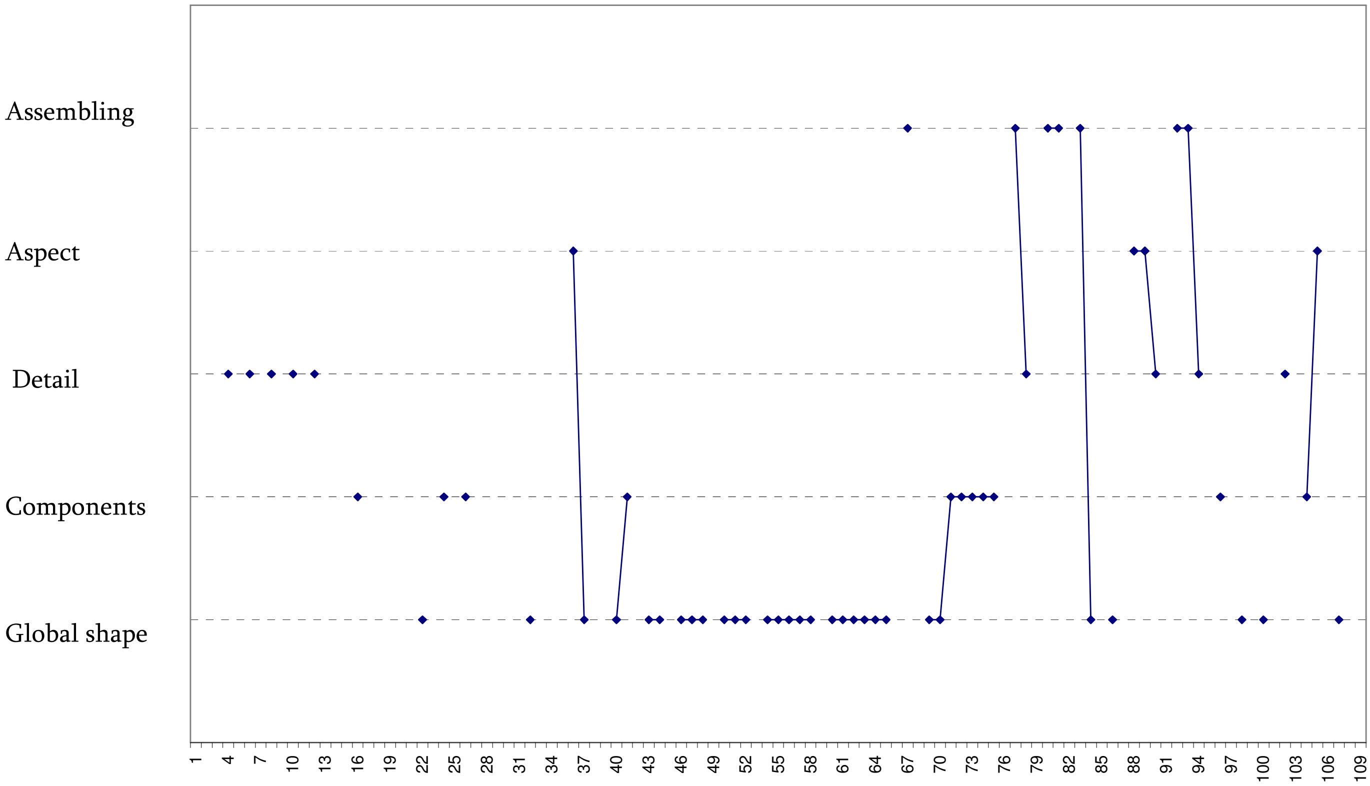


Figure 42 – Chronological evolution of the abstraction level.

Previously a link between the graphic codes and the abstraction level was proposed. Let see if similar facts can be observed here.

The 30 first actions, the "problem reformulation", concern different abstraction's levels that aren't considered in this analysis because of their global nature that doesn't really fit a graphic codes' observation.

Globally speaking, global shape, components and detail always correspond to analysing and proposition phases. The analysis of the current project indeed often involves the drawing of a new elevation's or plan's view: the designer wants to analyse and to fix how the object "behaves" on the

[34] See Appendix A.

other sides after having considered the respective parts on the 3D view. Proposition as already said principally occur on the perspectives.

Aspect considerations are often transcribed through master curves' emphasis (therefore they correspond to evaluation's phases). But the few matters, textures and shadows support the previous observations. The best example is the following one:

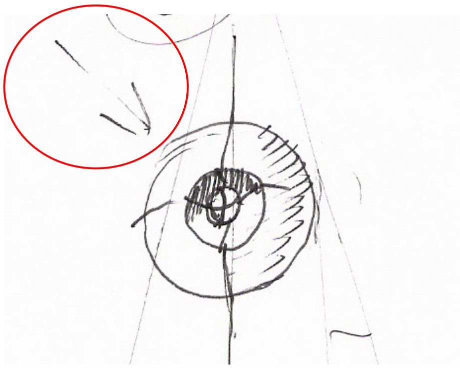


Figure 43 – Example of the light's introduction as an evaluation tool.

This button's alcove with its plumpy appearance was already defined before the designer decided to introduce a light's effect, the incidence angle being represented by the light arrow. The shadow helped him to estimate this initial proposition (considered as a success). We can consequently say that textures and matters always concerns propositions (are then never used as an evaluation's tool), on the contrary of the few shadows proposed that are every time linked to a qualitative judgement and never consist in an accomplished fact.

In general, the chronological evolution seems to be more structured, less go and return movements between the different abstraction's levels are observed.

The graphics' semantic contents(figure 44) show similar proportions than the precedent experimentation (figure 31). Aesthetic and functional elements are dominating, technical is a little bit more pregnant here (also because of assembling details that didn't appeared in the first designer's work), on the contrary of ergonomics that concern less actions here (the designer being maybe more used to these types of issues).

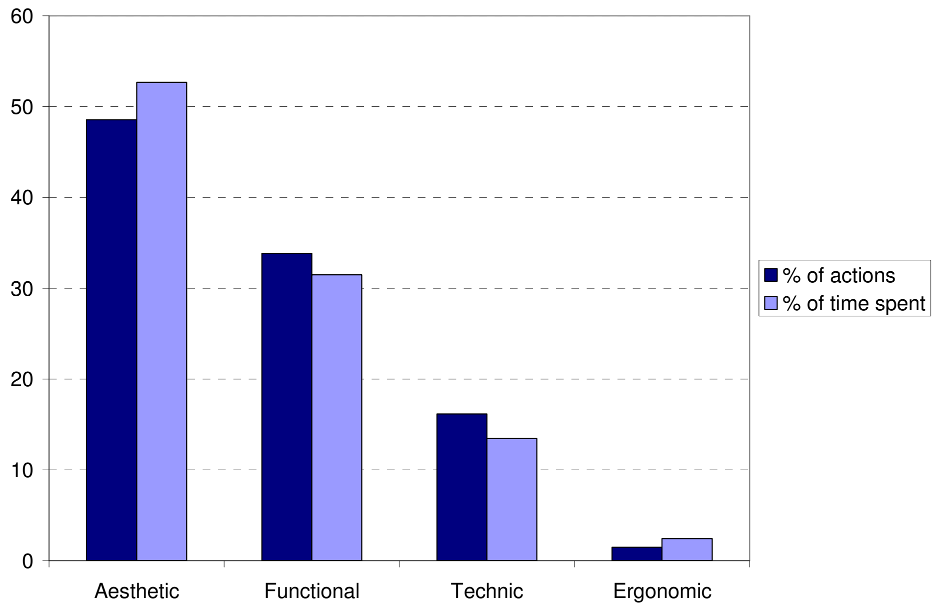


Figure 44 - Proportion (percentage of actions and time spent) of the different semantic contents.

And from a chronological point of view:

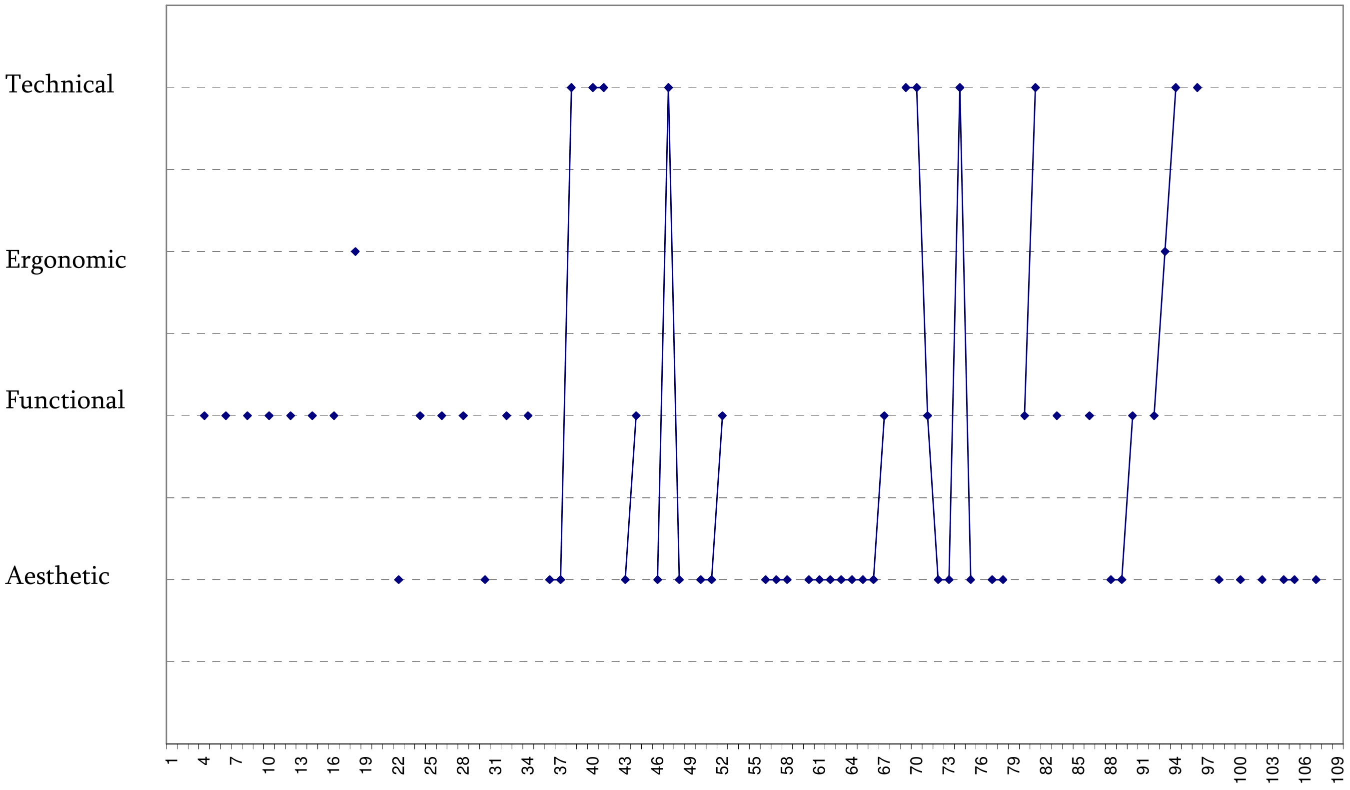


Figure 45 – Chronological evolution of semantic content.

Here again the 30 first actions won't be regarded as representative. We observe (figure 45) that the designer made several movements between the different types of contents. The way he apprehends the multiple project's sides seems to be less structured, the elements being examined at any time of the project. However, a certain cycle can be noticed: each time an aesthetic and functional decision is taken, a technical consequence to resolve appears. This can be observed directly on the sketches through the constructions lines and axis, which structure the object in response to a proposition (made most of the time on the perspective view). To illustrate this point, let consider this following part concerning the buttons technical, aesthetic and functional definition:

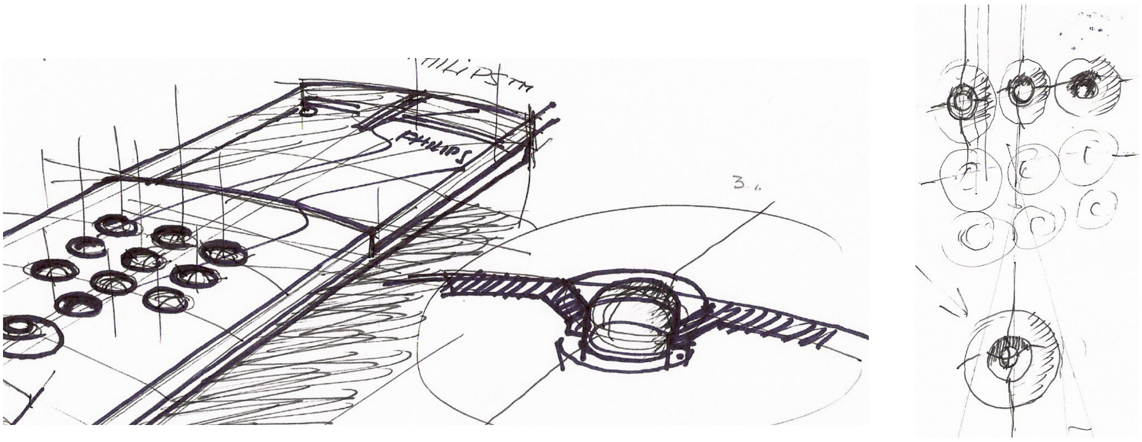


Figure 46 – Example of a technical problem's emergence.

The corresponding process was the following one: by sketching his perspective the designer decided to introduce the keys through "simple" buttons. He organized these buttons thanks to vertical construction lines. Functional and technical considerations appear, on one hand the symmetrical repartition being fixed through the plan view (see the drawing on the right with the symmetry axis) and on the other hand technical and production detail being resolved through the 3D button's "zoom".[35]

4.9 Comparison of the two experiments.

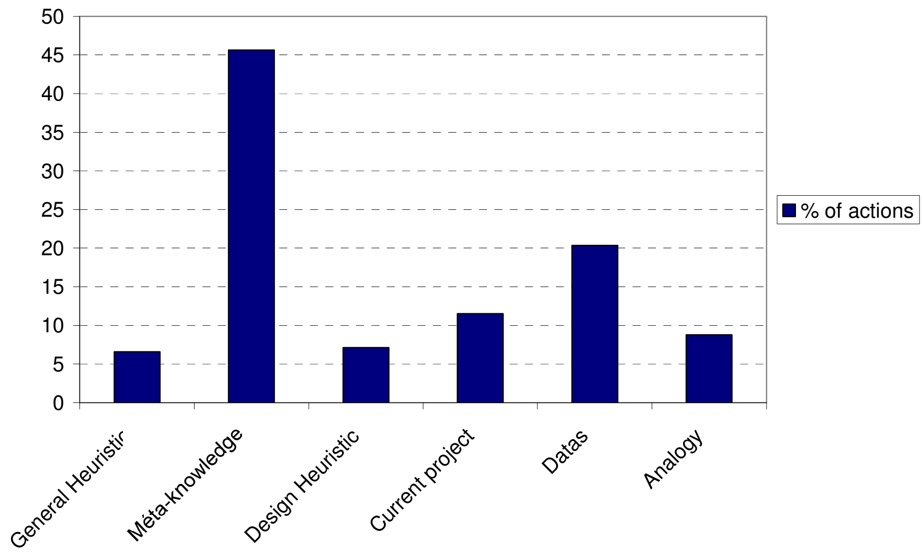
I have to insist on the fact that there is here no wish at all to discern the two experimentations in a qualitative way. First because I have no valuation enough in this domain and secondly because, as already explained before, I chose not to work with students especially to benefit from experts' knowledge and experience. And they are both considered as such. The only difference that could be pointed out here is the sentant level, that brings to the second designer maybe a certain easiness and structure in his work and that affords the first designer to keep a "new" view on projects he's less used to be confronted to.

During the video analysis I also tried to keep an eye on the information source the designers referred to, either in a explicit way or in an implicit one (distinguished thanks to gestures or the glances they cast at documents for instance). Many sources were used:

[35] Another funny observation made is the following one : drawing a circle around this « button detail », in order to link this related sketch to the main perspective, induced the idea of designing the pumpy area around each key.

- General Heuristic: concerns all the general rules we socially consider as natural (example: a car has four wheels);
- Meta-knowledge are the knowledge the designers have thanks to their personal experiences (life, business experiences, …);
- Design Heuristic are the general rules more especially linked to the design world (what they learned during their training, production's constraints, …);
- Current project: expresses an information's search concerning directly what has been previously designed of this current object (reference to precedent sketches for instance);
- Data concerns all the information contained in the statement or information gained through questions they asked me;
- Analogy (see paragraph 2.4.6, "Referential processes").

Here below are the percentages of actions concerning each of these 6 types of sources for respectively the first and the second designer.



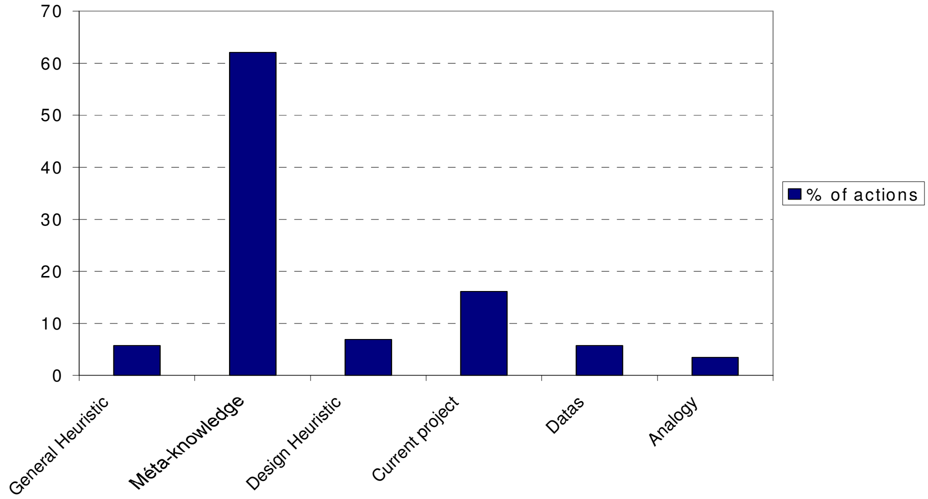


Figure 47 – Proportion (percentage of actions) of the six types of sources. First designer above, second designer below.

We observe (figure 47) that at first sight the proportions seem to be more or less identical. However, some differences can be noticed. First, Meta-knowledge concern logically 61 % of actions more for the second designer, this one having also 30 years' experience more. The multiplicity of drawings this designer proposed, as well as the constant go and return movements between these sketches involve 4 % more of current project's references. The youngest designer made use of more data information, as well as anlogies (the internet search leading to an explicit one).

The other criteria observed during the experimentations have for most of them already been compared during the analysis and these comparisons are summarized in the array below.

Element considered:	Experiment 0	Experiment 1
Global proceedings	- 2 objects proposed - more curved design - more searching time and negotiation - few sketches, analysis through check list - less perspective views (does prefer to use directly CAD tools), almost every elements are defined on plans or elevations	- 1 object proposed - design based on the sum up of several basic geometrical shapes - no internet use - a lot of multi-purpose sketches, problem reformulation through schemes and rough sketches - immediately the project begins with a perspective view. The relationship toward 3D representation is totally different (creative processes on 3D view, detail and technical considerations on other representations)
Graphic analysis	- no turning back to previous sketches, very sequential evolution - a lot of decisions concern components - more "communicative" way of drawing - most of the master curves are defined in the plan	- constant go and return between the several sketches - global shape is the most considered, assembling appear - sketches stay more constructive and technical, and the few communication's artefacts come in the process later - most of the master curves are defined in the perspective - intense "see-transform-see" interaction with the drawing
Graphic codes	- construction lines disappear behind a more "furnished" drawing, that corresponds to another way to design the object as well (more detailed, use of material properties and surfaces' states, …) - a lot of textures, matters, shadows, annotations are added - bold lines fix the final curve and fit the double statement's requirement: personal sketch and communicative sketch	- construction lines really frame and structure the drawing - very few "rendering" elements, the sketch is purified - the master curves' emphasis through bold marker pen strokes has mainly a communicative purpose

Process analysis	- think aloud method didn't work really well - chronological graph of the four main type of actions: global phases can be noticed but it is less sequenced - chronological graph of abstraction level : more confused, frequent go and return between the different levels, aspect coupled with evaluation that seems to be formalized through light interaction - aesthetic and functional elements rank first - ergonomic steps in the process later, at the end of the first project	- the designer had no difficulty to express his ideas - searching time shorter, evaluation time longer - … much more sequenced (routine-problem solving ?) - … much more structured and the same conclusion can be drawn as far as light interaction is concerned - idem, with a little bit more technical considerations (and ergonomics ones enter the process in a different way) - chronologically: much more frequent go and return between the several semantic contents, each aesthetic and functional decision involves a technical problem to solve

Array 10 – Summary of the analysis' comparisons.

4.10 Conclusions.

These experimentations had initially three main goals: firstly to consider cognitive and sketches' theories in a « realistic » context, with the assistance of experienced product designers; secondly to gain information implicitly contained in their everyday-life practices and thirdly to learn more about sketches (contents, significations, uses).

As already said, none of the previous cognitive theories considered hold the perfectly suited answer. Each proposition presents gaps and interesting aspects, stays maybe far from what would be needed to build a CAD tool able to support the designers in the upstream conception's phases, but still helped me to better understand the multiple facets of product design and their main actors. The goal wasn't to query these theories' pertinence: I have no valuation or setback enough to allow me this type of conclusion. Nevertheless, I yet could position some of these assumptions as better adapted to support EsQUIsE's recommendations' development:

- The opportunistic vision of conception's processes seems to be well suited to product design cognitive approach. As we saw on the several chronological graphs for instance, there isn't a real predefined conception scheme. The designers consider the problem in a logical way, attempting to understand the whole program, to structure their thought with check-list or sketches, to propose an initial concept and to build the global solution by adding more and various constraints and ideas that enter the process at the mercy of the choice they've already made.

- The cognitive theory that considers design as a construction of representations matches quite well the observations made before: a fleeting « mental image » initialises and formalizes the very first choices, and in the same time referential proceedings, meta-knowledge and heuristics help the designer to feed the creative process. Moreover, there is a real conversation with the several drawings, just as explained in the « see-transform-see » Schön theory.

- There is no doubt left about the sketches' potentials. The designers drew in such a natural and easy way that we can be sure that sketches still constitute, with the CAD tools, an unavoidable exteriorisation's method in the product design world. We should rather consider their limitations as carrier of solutions. Among these limitations, their static, communicative and time-consumer characteristics could especially involve improvements.

Among all the other information gained about sketches or product design's practices, I would like to point out again the few that could support further recommendations.

First the real goal of 3 dimensional representations in the product design world has to be discussed. Indeed, I could assert that these ones are totally unavoidable for the design processes we observed. But it would neglect the numerous observations made by many authors, especially in architecture, about the overrated seat of honour reserved to 3D representations. On the contrary, I would like to consider these opinions that bring an interesting point of view about the subject. Indeed, these relevant reports noticed that the 3D predominance in computer representation was overvalued. This predominance is based on the predicate that initial object's mental image would be so limpid that this object could be right away modelled by an unique and complete 3 dimensional representation [Estevez, 2001]. Nevertheless, studies showed that architects (here in particular) need plans, sections and elevations to grow up the conception's process: these representations are multiple, partial and autonomous though linked in their essence. This fragmentation doesn't reject the integration's notion but never imposes it, this individual progress affording the architect to create incoherences that offer a certain freedom. This theory is validated by architects' practices' observations, which show that indeed the perspective drawings concern only 5 % of sketches [Leclercq, 1994]. These ones are mainly used in controls and evaluation purposes[36] and rarely participates to *hand sketching* conception.

This work, because of its clinic character, doesn't bring enough substance to radically confirm or invalidate these conclusions. Yet, my personal observations would incite to adopt a more flexible judgement since 3 dimensional representations are considered in product design. What I learned about the subject in the CAD tools' study, interviews and what I observed during the experimentations indeed present the perspective drawings and CAD 3 dimensional representations as much more as simple control's or evaluation's tools. We saw that the designers consider them as an unavoidable stage in their design process, that enters this process very fast and constantly support the project's evolution. 3D representations integrate reflections concerning ergonomics, techniques, aesthetics or even practicality: there are not only communication tools, rapid-prototyping step or selling practices but really enter the conception's process and fill init a full job. That doesn't mean that the other types of representation are less decisive: they fulfil exactly the same goals than in architecture and support the conception's processes as well. Let say that the tasks are in this case just more shared.

If we adopt for a while the previous assumptions, I could here sum up the main 3D representations' contributions that haven't been yet listed. Thus, we can remember that:

- Perspective drawings incited sometimes to bring technical solutions to previous aesthetic or functional choices;
- Master curves' definitions took place as well in plan, elevation representation as in 3D ones;
- Perspective representations were the tool mainly used by designers to formalize matters, textures or structural choices while plans and elevations rather fix dimensions, frames or details;
- These representations also lead to a new type of interaction with light that have been classified as a qualitative evaluation tool;
- Perspectives bring information about the link existing between plans and elevations. This link is often more complex that what we can see in « standard » architecture because of the different shapes and works' scales.

Another relationship toward production's costs and techniques also have to be mentionned for product design. This fact was already pointed out above but I didn't gather a lot more information about this subject, mainly I think because these considerations are so deeply linked to designers' everyday-day way to conceive that they maybe didn't regard them as pregnant in their work. Nevertheless I assess here another important distinction with architecture. Technical and production constraints of course also enter the architecture upstream conception's phases but in a more passive way and that's principally due to the scales' differences. For instance: an architect, by

[36] On top of this control purpose there is of course the 3D tools' use as a powerful communication's support which won't be queried here.

designing a building, will consider the maximal range the structure is able to cross as an important constraint but not as a fundamental one. He/she knows that columns, materials with high properties or new techniques he/she doesn't usually use will help him/her to surpass this technical constraint and to reach the goal defined in the first conception's phases. That will inevitably lead to additional costs, but if this « architectural coquetry » is supported by a strong concept the architect can assert that there is somewhere a solution that will succour the project.

On the contrary, if we consider designers that have to struggle a ruthless rivalry, that have to match the customers' needs and propose at low cost a product that should be adopted by the biggest amount of people, we enter another sphere where production and techniques are success' keys. That's not arts and crafts anymore but line production and the resulting details' concern have to be taken in consideration as soon as possible. That's why so many details were already observed in rough sketches where they inhabit a strategic place.

To put an end to this conclusion, here is the summary of the essential observations about sketches:

- The strokes stay blurred and redundant until an emphasis stroke fixes the final line;
- Constructions' lines and frame as well as symmetry form a global structure. These lines are light and most of the time out of the drawings' boundaries;
- The scale introduces new representations' potentialities already in the initial sketches' levels. For instance textures, matters and shadows emerge.
- Missing information can be added by the superposition of two types of representations or by schematic secondary sketches.
- The relationship with « essay sketch » is also different. Indeed, architects will use several sheets of paper to create several variant of solution, and will prefer to restart a new trial instead of drawing on top of previous sketches. This need is materialized in most CAD tools by the multi layers' option. These new drawings help them to light the other sketches' contents, ease the cognitive process, consider the preferment stage or simply starting a new solution's research. Of course the experimentation's context didn't afford the designers to multiply the attempts. But I observed that the designers prefer to draw again on the previous shape, creating several layers of lines *on the same drawing*, just as if the first line make the born of the following one easier. In finality an evaluation of the final shape is nevertheless required, and as explained they use bold lines to crystallize their ideas.

4.11 Graphic Designers at work.

4.11.1 Introducing graphic designers in the process.

At this point, if we assume that the 3 dimensional representations constitute for design processes a founding element, there is still a design step that is worth being studied. As a matter of fact, we know that CAD tools play an intense role in 3D representations' modelling. Some designers, as the one that contributes to the first experiment, prefer to sketch very quickly a plan and maybe an elevation on a sheet of paper and then model directly the perspective, usually with rendering software, to consider the third dimension.

Consequently, it was interesting to observe how an usual object, for instance the second remote control designed during the first experimentation, could be modelled. This second project was chosen because it showed the biggest shape's complexity as well as a lot of curves and couldn't this way be "simply" deduced from basic geometrical instructions. We didn't ask product designers but professional graphic designers to realize the 3D model, knowing that the software's complexity wouldn't allow a lot of designers to model such a project in an effective way.

Two graphic designers accepted to model it in front of a camera and observers, using a rendering software (3D Studio Max). Their task was very simply to develop the 3D representation in the most adequate way just as if the designer had asked them to. Again the think aloud method was adopted.

4.11.2 Observations.

The whole process is deciphered in Appendix K and the views of the final 3D object are in Appendix L. Here are the general principles I observed during the modelling.

The graphic designers proposed a first work's methodology, named "extrude-edge", to model the remote control. This method isn't the easiest one but stay the faster one and was well suited to model this type of shapes. Very simply, it consists to build a global shape by creating a networking of edges and points. Each edge is limited by a couple of points and a threesome of spatial coordinates defines each point. This way, the surfaces composing the shape are built by extrapolations between each point. Basic instructions allow the designer to modify at will edges' and points' position. The possibilities of moving points, extruding and combining edges, creating or deleting points make the model approaching more and more the final shape. Nevertheless some rules have to be respected to reach a certain effectiveness.

- The less the model presents edges the less the rendering view risks to present defects. Indeed, the computer will extrapolate the tangential surface between at least 3 edges, which means that the more the edges are close the more the resulting surface will be sharp. This sharpness can be sometimes needed for a more stringent curve's definition but usually a more continuous profile is initially designed. Therefore, if basic geometrical shapes are used to build the global object, they have to present a low polygonal definition (a minimal quantity of initial surfaces) and generally speaking the networking have to stay continuous, coherent and simple.
- Moreover, the graphic designers have to be careful with points' and edges' modifications. Firstly because these modifications, if not operated in a defined projective view and if not limited in movements in the two considered orthonormal directions, can act on the third dimension and deform the whole object in an unverifiable way. And secondly because these moves can modify the global edges' distribution and create nodes and edges' concentrations that will lead to a shape's discontinuity. Consequently, the graphic designers generally worked on the orthonormal views, the 3D view being used for evaluations' purposes.
- The drawings' interpretation must be carefully considered, the feeling and the sentant level introducing certain fineness in the sketches' understanding. Master curves and lines are here fundamental for the global object's apprehension. It happened that during the process, graphic designers modified some sketches' aspects, for instance to ease the production feasibility and model a realistic object (example: a joint's line was added on the profile view to take production's techniques into account, the remote control being certainly composed of two separate cockles).

Among this global methodology, other functions made the process easier.

- The graphic designers made an intense use of symmetry. Plans were defined around which mirror reproductions facilitated the work by decreasing it by half.
- The networking's coherence was evaluated thanks to a smoothing function. This one makes the polygons disappear to reveal the global and final surfaces' aspect. These smoothing functions coupled with a predefined contextual light allow the graphic designer to judge qualitatively his work. Indeed, the strongest curves grasp the light and this property immediately shows discontinuities and defects that are pointed out thanks to shades' areas. This use of shadows and light's effects as a qualitative tool reminds us that similar observations were made during the sketches' analysis.

After around 45 minutes' work the global shape was defined (see Appendix L), some details were added such as the screen and the keyboard. The graphic designers then decided to test a second method, called "box modelling". This method consists in adding basic geometrical volumes that can be deformed, connected or interconnected to approach the final shape. The remote control was this way modelled on the basis of two crushed spheres and a narrow lying cylinder. The previous rules were also adopted but actually the basic volumes being very simple in their polygonal definition, almost no edges' and points' modifications were needed. This second step took the graphic designers 14 minutes to reach a satisfactory rendering level, the global shape being to all appearance identical to the first one.

4.11.3 Analysis and conclusions.

The process' analysis allowed me to consider the two methods' specificities. The number of mouse's clicks was more particularly counted[37] and it leads to a few more observations. On one hand, 896 clicks and a 47 minutes' duration were necessary to build the first model. It corresponds to an average of one click every three seconds. On the other hand, the second method, much more faster, was achieved in 14 minutes and the 90 corresponding clicks lead to an average of one click every 9 seconds. We see that even if this second method seems to be more easy than the first one, in reality another reflection's level is required (3 times more time is needed between two successive actions). The first method can be consequently considered as a more routine-minded one in comparison to the second, that was more complex (as far as the cognitive cost is considered) but more efficient. A last element can be pointed out: the second methodology indeed better corresponds to the initial concept[38] the product designer set on foot for this second remote control. No generality can be deduced, but in this specific case the fact of adapting the modelling methodology to the basic concept involved a higher modelling productiveness.

As already listed in the CAD tools' limitations (see 2.6.3 pparagraph), the software's use proved to be slow and complex, with several haggling phases on detail points, errors, defects and hazardous interpretations despite the graphic designers' high professionalism level. On top of that, the ulterior product designer's opinion about the model confirmed that a lot more work would be necessary to obtain a satisfactory rendering level. Although their powerful capacities, rendering (and by extension production) software therefore stays far away to efficiently match the designers' needs.

[37] I didn't take in account the clicks corresponding to hesitations, errors, zooms or simple moves to consider the object with another point of view (in the same projective's window).

[38] See 4.7.4 paragraph, « Post experimental interview », where the designer explain the bones' ideas.

Chapter five: recommendations.

5.1 Recommendations: what should we found in EsQUIsE to support Product Design?

5.1.1 Introduction.

Now that the principal questions are asked and that the basic information needed to ground some answers have been gathered, there is time to interpret the results and make some recommendations in order to make EsQUIsE support product design in the most efficient way.

The chapter three taught us there is a real opportunity for new generation's CAD tools in the product design world. The designers consider sketches as a powerful conception's support, need a 3 dimensional representation of the project to apprehend it in its global nature and to make the design processes going ahead, but paradoxically have no time to grant to the drawings stages and less more to learn a complex and heavy CAD program.

This new EsQUIsE version should be focused on users just as the initial EsQUIsE is for architects. But what are the other EsQUIsE effective potentials?

5.1.2 Operative EsQUIsE functionalities.

I based this entire work on global considerations, staying far away from any data's computerization. Indeed, I announced since the introduction that I wanted to disconnect my observations of standard computer tools, in order not to be outdated and in order to keep a whole sight on the subject. Nevertheless, some of the EsQUIsE functionalities are worth to be shortly described here, because they constitute a real philosophy of work. These characteristics, which consider a new way of human-machine interaction, have anyhow to be part of the future renewals to make them simply worthy of their successors:

- EsQUIsE proposes to users the more natural and easy way to interact with computer-aided design tools. The environment, named "virtual desk", is defined to "disappear". This "absent interface" [Leclercq & Juchmes, 2002] proposes to the designer to draw on a simple "sheet" with a few pencils and markers, materialized by a digital tablet-screen and an electronic pen. Pointed studies, ergonomic and graphical ones, aim to ease this human-machine relationship more and more.
- The program, very intuitive in its functioning, necessitates no pre-required faculties in computer science. Everything is done to disturb the least possible the designer during his/her design process and to offer him/her the CAD potentials (real time sketches' interpretations and 3D representations, thermal loss and energy consumption calculations in the case of EsQUIsE Architecture). This interface is adaptative [Juchmes, Leclercq & Azar, 2005]: it requires no formal dialogue, i.e. the system is capable of adapting to users, is able to support their imprecise and incomplete behaviours and inputs and allows the users to work in a complete freedom in regard of actions and time.
- The intelligent interface ensures the consistency of its own underlying model, based on a multi agent approach (see appendix M). This interface assigns roles and inter-relations to its multiple components and is capable of completing the model by adding implicit relevant information.

5.1.3 Other actual attempts.

There are a few other CAD tools that attempt to take advantage of the sketches' potential with a view to support the early design stages. Some authors [Cherlin, Samavati & al, 2006] tried to classify these "new generation's" CAD tools as follow:

- Extrusion-based systems (for instance Sketch, GiDeS, Quick-Sketch), that are not suited for editing free-from objects;
- Blob editing systems (for instance Teddy), that allow users to create soft blobby surfaces, but aren't very good to create blade-like or sharp shapes;
- Reconstruction based systems that are better suited for creating 3D solids from wire-frame drawings and thus better at creating mechanical engineering parts, but not free-form objects.

In this particular case, the program should be able to recognize free-form shapes through the analysis of simple strokes, in order to provide more efficient results and be more intuitive.

There is no use here to depict the whole possibilities and trials in this domain. I'll just summarize the different elements, sometimes very vague, proposed in several prototypes and liable to support the type of application we're interested in.

- Computational tools must integrate domain knowledge into the design decision-making process and embody expertise in managing the design process (retrieval of relevant precedents, memorizing of relevant symbols and codes, generation and evaluation of alternatives, consulting experts, …) [Gross & Do, 2004]. In this particular product design application, we could imagine pilots able to offer to the user information like ergonomic values, material properties or optimums, production constraints (for instance minimal thickness or maximal curvature radius);
- They have to support variation: they must be flexible enough to support the application of both sudden and drastic variation of sketched objects [Cherlin, Samavati & al, 2006];
- They could provide the designer <u>non-intrusive</u> feedback when errors or seemingly impossible actions or manipulations are detected [Meniru, 2004];
- Refinement possibilities: if the information delivered by the user isn't sufficient, the system is able to ask him/her to complete it (collaborative system);
- The algorithms must tolerate errors and irregularities in order to respect the approximate character of sketches;
- Programs should keep a certain "history" of the designing, so that the designer can return to previous states and proceed to design from anterior sketches;

5.1.4 Recommendations.

EsQUIsE Product Design would find its real utility, in the early stages of design processes, by introducing itself as a Computer-Aided Design tool able to support, on one hand, personal sketches, and on the other hand, communicative sketches. As explained in the first conclusions drawn from the interviews (see paragraph 3.5), the product design sector principally suffers from lack of time, nowadays CAD tools' limitations and the communication issues that exist between the several collaborators. EsQUIsE, thanks to its capacities of interpreting the sketches, could remedy to these drawbacks.

General operating.

There is no wish at all to supplant the existing CAD tools, nor to suppress the graphic designers' jobs. As explained in the paragraph 2.6.3, CAD tools nowadays constitute indispensable work tools for designers, their numerous powerful functionalities even affording new challenges like creating extraordinary shapes or propose to customers virtual immersions in their future object's context. Moreover, graphic designers will be more and more solicited to support designers in their task. This collaborative way of working being the future of every kind of conception business, there is no point here to ask product designers to deal alone with the complexity of 3D modelling[39].

The goals would be on the contrary to:

> i) fill the gaps these same CAD tools still leave in the product design processes, especially in the early sketching stages;
> ii) build a bridge between the hand drawing conception, the 3D representations and production plans;
> iii) take advantage of the main drawings drawbacks (their statical and slow sides, personal characteristic);

in order to entertain the EsQUIsE Product Design construction. Consequently, in a first step, EsQUIsE could constitute for designers a virtual sketchbook where sketches would be drawn as natural and free as on a regular sheet: they could be loaded, saved, reopened and worked again, ... Afterwards, the program would be able to deliver to the order of the user a communicative interpretation of these drawings, in order to support the succeeding design phases, to avoid the collaborators' hazardous interpretations and time-consuming modifications. This communicative interpretation, materialized by a dynamic 3D representation of the sketched object, induces many consequences on sketches' analysis.

The following operating propositions are far from being near enough to realistic computational considerations. This naïve functionalities' enumeration nevertheless constitutes a first attempt to figure how EsQUIsE Product Design could support these sketches interpretations.

Thus, the idea would be to propose to designers a work sequenced in several stages, corresponding more or less to the design processes I observed during the experiments.

- First the designer would draw absolutely what he/she wants, the program staying passive.

The clinic character of the research doesn't afford to conclude if there is a prevailing representation view in the product design processes. We saw that the first designer preferred to conceive using elevations and plans, the drawn perspective having a secondary role in his design process, while the second one used them in real design purposes. Therefore, 3D representations cannot consist here, as it is the case for EsQUIsE Architecture, in a simple evaluation or control tool. We must consequently admit that designers could start the conception with a perspective view and consider that perspective representations fill the same role than plans or elevations views. This

[39] On top of that, as already pointed out by one interviewed designer, it would be totally utopian to believe that a single program could support rendering and production tools. The only way to ease the communion of these two stages is to ease the data transfer from one to another, but it is out of our concerns in this case.

way, we stay near to the designer's main cognitive and design processes. The respect of this initial drawing choice may hopefully lead to better performances and high quality project, the fundamental way of designing being not shackled[40].

- Once the concept more or less approached, the designer could require the program's main feature: the 3 dimensional and dynamic representation of the drawn object.

Knowing nothing about what the designer has already sketched and, on top of that, nothing about the exteriorisation artefact he/she has chosen, the program should then ask the user to fix the strokes that can be considered as the master lines/curves. This declaration must not be compared to the nowadays-declarative way of operating of the WIMP[41] programs. Indeed, this master curves' fixation could occur thanks to a stroke's emphasis through the use of a bold marker, just as it is the case now in EsQUIsE Architecture. The only difference with the previous version is that this emphasis doesn't have to be applied on a plan view but can here be used on different views.

- The program could then start to analyse and interpret the different strokes that compose the drawing in order to respond to the designer's wish.

At this point, different scenarii have to be considered. On one hand, the designer decides to start the conception with plan and elevation views. We can assert that at least these two views, analysed *together*, are required to consider a concept as sufficiently constructed that lead to the need of a 3D representation. Another assumption I make is that these views correspond to orthonormal ones[42]. The designer could in a first step emphasize the master curves on the plan (respectively the elevation), then check if the program selects in a correct way the corresponding curves on the elevation (respectively the plan). This collaboration, that could simply be materialized through curves adopting a certain matching colour on both representations, is needed in order to ease the 3D representation's refining by the use of these few strokes.

On the other hand, the designer could begin the project by proposing a perspective view. This case, more complex, implies that the program, with a limited quantity of strokes that define a fixed image of the object (observed with a certain point of view), should be able to interpret the drawing in 3D and propose a solution for the hidden sides. This can seem very difficult to imagine, even impossible. Nevertheless, if we want EsQUIsE to respect in the better way the early design processes, it should be feasible for the designer to start the project from a simple perspective without defining and fixing the others views. Once again, the only possibility foreseen is based on a collaborative human-machine interaction. Indeed, we could imagine the following process: the designer fixes the master curves on the static perspective view by emphasis. Then, thanks to the implicit knowledge the program would have about hand sketching perspectives and their spatial deformations, a first more or less "flat" 3D representation would be proposed. This "flat" characteristic would avoid too strong deformations of the initial designed object (strong deformations that could interfere with the initial attempts). The main feature of this first and rough 3D representation wouldn't consequently be the faithfulness toward the shapes but rather the dynamic possibility of observing the hidden sides. The designer should from this point help the

[40] Indeed, [Zhai & Milgram, 1998) showed that the designers' performances were higher when the data's capture tallied with the CAD tool's proposed view.

[41] Windows-Icon-Mouse-Poiting.

[42] This type of representation having indeed been naturally adopted by the designers during the experiments, this general propensity being confirmed by the two graphic designers as well.

program and bring the missing information, by drawing more and more. The hidden sides would appear, the object could then be more and more shaped before the designer's very eyes. This instantaneous interpretation would this time be conducted without any kind of emphasis stage. Indeed, once the global 3D representation built, there will certainly remain some interpretations' mistakes. The designer then has to consider the whole object (always in a dynamic way), and oversketch it to redefine the parts he/she considers as non-satisfactory. This oversketch would lead to the respective 3D modifications, without deleting the previous strokes (to stay near the "essay sketches" characteristic, see paragraph 4.10). Finally, the final stage would be to emphasize the final master lines/curves, the interest of this emphasis being then to activate the "automatic" possibility of getting, out of this 3D representation, all the orthonormal views (and why not cuts) he/she wishes.

Finally, other scenarii could be considered, for instance the fact of drawing a perspective view quickly supported by plans and elevations that the designer wishes to sketch himself because they are part of the design process. In this case, the previous scenarii just get connected and mixed: the same system of exchanging information between the different views and communicating with the program affords the user to start the whole design just as he/she wants in respect of the opportunistic theory assumptions.

- At this point, the program proposes several representations of the designed object.

These representations shouldn't be perfectly precise and defined in details. Indeed, the aim is not to substitute the rendering programs and their amazing 3D features as already said, but just to offer to the designers the possibility to apprehend the third dimension of their objects without too much difficulties. Moreover, such a qualitative image is not desired here, because this type of exteriorisation could interfere with some fundamental sketches' characteristics, like the unexpected discoveries for instance (see paragraph 2.5.2, Potentials and limitations of sketches). Indeed, there is no point to propose a finalized model or image of the object since this one is likely to be modified. The model and the views should be recognizable as consequences of hand sketching drawings and have to stay distinct one from the other all along the process (in order to keep in mind the designer first way to conceive and the fragmentation potentials, see paragraph 4.10). Therefore, multiple drawing tools should be proposed (different pens, pencils, markers, …) in order to stay near the realistic aspect of a "real" drawing, and a "smoothing surfaces" functionality should be proposed in order to ease the 3D representations' apprehension and understanding. This functionality would simply extrapolate global strokes among the whole information while keeping the "rough" aspect of the initial sketch.

- Let's imagine the designer wishes to change some elements by redraw on existing emphasized model and views, without starting a new sketch.

Of course this possibility has to be considered. Here again, the collaborative interaction seems to match in the better way this required property. Indeed, if we consider that the designer oversketches some parts of his/her project, the program has to understand which strokes stay the master ones, and which anterior master lines/curves are modified. I can just imagine that once the new stroke is considered as satisfactory, the program asks the designer (maybe through a coloured code again?) which stroke has to be considered as the new emphasis and introduced in the interpretation process.

- And what about the other strokes?

The strokes that aren't coupled with the modified one keep their previous state: emphasized curves/lines that help to construct the global shape or simple secondary strokes that add some information but aren't interpreted by the 3D simulation tool. If there is a potential misunderstood about the number of strokes concerned by the modification, the designer may be asked to emphasize again the final curves (entirely or parts of it). As far as the modified strokes are concerned, and as far these modified strokes belong to representations that help to construct other elements[43], the modification could be automatically adapted to the other views. The conditional form here is used to express that this functionality shouldn't be applied without the designer's acceptance. Indeed, some modifications can be temporary attempts, can be emphasized on a defined representation in order to apprehend the potential modifications but in the same time could be not adapted to the other views. Just as it works with typical hand sketching tests, the previous states of the drawing should at least be preserved in case of turning back to previous attempts.

<u>Other functionalities.</u>

Out of this attempts to define a global operating system, other elements should be part of EsQUIsE Product Design in order to support the several observations I made during this work.

- The interface could propose several and simultaneous views of the same sketch. We could imagine a 3D view, coupled with a plan and some elevations views. The potential modifications, if automatically taken back, could this way occur in parallel and in the same time on the several matching entities. Of course, out of this structure, the whole virtual desk should be able to welcome any kind of sketch. The object whished to be "3D interpreting" could for instance be pointed out from the other drawings thanks to a natural designation gesture (a simple circle around the chosen sketch for instance).
- The possibility of introducing a frame could be considered. Indeed, structuring the whole drawing area with a predefined matrix stays one of the most elementary way to apprehend an entity scale and the relations existing between several objects.
- Just one "rendering" tool should be introduced in this early design stage (on top of the "smoothing surfaces" functionality) : the light effects. Indeed, we observed[44] that light is used as an evaluation tool that help the designer to apprehend the way the object interacts with its environment and the way certain shapes stands out comparing to others that stay in the shadow. So, instead of asking the designer to draw these shadows (although there will always be the possibility to draw them and to make them understand as shadows by some skilled agents), the program could offer a functionality that makes the interpreted 3D object interact with light. It has already been proposed by [Jung, 2003]. Named light pen, this expert advisor has been indeed developed for architectural lighting. The designer uses a light pen tool to sketch desired lighting patterns on the surfaces of a 3D model. The program analyses the position, size and intensity of these drawings marks and delivers this input to a rule based system for selecting lighting fixtures. The system proposes lighting fixtures and locations to produce the desired illumination. This type of application could be interesting for EsQUIsE.

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[43] For instance, the stroke is part of the first scenario's elevation view that conducted to the 3D construction, or is part of the 3D object that influences the construction of the orthonormal views.

[44] See paragraph 4.10.

- To answer the scale differences that exist between architecture and design, the more powerful tools that remain are the zoom and the oversketching tools. The designer could this way draw details, that wouldn't be emphasized (and consequently wouldn't be interpreted in 3D) but that still constitutes necessary information for the collaborators.
- Only one work methodology has been observed during the first experiment. This checklist feature could easily be supported by "character recognition agent" that would retranscribe the whole list and propose an efficient way to "check" it.
- As already said, domain knowledge should be introduced in the whole process. On top of that, the designer should be able to import any kind of external information liable to support his/her creative process (heuristic or analogical devices for instance).
- The unexpected discoveries, already supported by a voluntarily fuzzy way of interpreting sketches, could also emerge thanks to the total freedom of considering the virtual sheet with any kind of orientation.
- The pre-eminent sketches contents (see paragraph 4.10) can serve the building of a global analysis code, which would lead to several differentiations according to the skilled agents supposed to recognize the items. This way, construction lines, symbols, annotations, hatching… could directly be differentiated from potential master lines/curves.
- A symmetry functionality could afford the definition of axis that support perfectly identical 3D post interpretations.
- If nowadays fictive "non intrusive feedbacks" (see above) can one day support the CAD, the faculty of being "non intrusive", which is decisive in sight of respecting the cognitive and creative processes, could be introduced thanks to a simple timer that would afford the program to analyse if an evaluation phase has begun (the designer being less likely to be disturbed by such interventions during this phase).

These few recommendations could make EsQUIsE support the early design phases of product design in quite satisfactory way. Once the main EsQUIsE functionalities are exploited, a simple data exportation to any type of rendering, production or even visualization software could achieve the global goal this program tends to: ease product designers' every-day work by supporting their first design stages, modify communication issues into a real productive philosophy of work and afford them to gain time.

5.2 Conclusions: thesis limitations, contributions and potentials.

This thesis presents several limitations. Among the most important, the number of designers interviewed and observed during experiments lead to an unavoidable clinic analysis instead of a statistic one. On top of that, this clinic analysis has to be considered with caution because of the unavoidable subjective part my analysis presents as well as the unavoidable committed choices I had to do in order to make the work going on. My inexperienced position toward the product design domain also certainly lead to clumsiness, hoped not to interfere too much with my conclusions.

This thesis main contribution has been to make me approach the complex cognitive and creative processes a designer has to develop during a project. Out of the limited product design domain, this work can be adapted to several other sectors but above all it affords me to consider also architectural conception with another point of view.

The strong exploratory character this thesis presents – all along the months I worked on it, I collected information without really knowing if it could support any kind of recommendation – helped me to refine my synthetic and critic way to consider information.

Finally, my hope is that the few observations I made, the few recommendations I drew, could maybe modestly support the global understanding of product designers processes as well as making the proposal of a new generation CAD tool a little bit progress.

Other points, not considered as limitations but rather as potentials for future improved works, have to be listed here. For instance, the collaborative conception, keystone of numerous design processes, hasn't been considered here because of the time factor that always goes with this type of work. Yet, it could bring a lot of very interesting information especially about the relationship the designers maintain with the communicative side of their creativity. Another fact, already pointed out, is the potential the study of novices in comparison to experts' work could have on errors' detection or non-intrusive feedbacks. The deeper analysis of graphic codes and sketches contents could also constitute one other thesis subject among the several possibilities, as well as the ergonomic and intuitive relationship the designer will maintain with the EsQUIsE interface and environment.

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Appendix A: "ill-structured" or "ill-defined" problems.

A characteristic of design problems, nowadays considered as one of their main specificities, is their ill-defined or ill-structured character. Simon [1984] was the first to discuss that point and to propose a list of characteristics that made a problem ill-structured. He spots "the lacking criteria a problem must satisfy in order to be regarded as well structured" as follows:

- A definite criterion for testing any proposed solution, not to speak of a mechanizable process for applying the eventual criterion;
- One or more problem spaces[45] in which one may represent the initial problem state, the goal state and all other intermediate ones that may be reached in the course of attempting a solution to the problem;
- One or more problem spaces in which one may represent any knowledge that the problem solver can acquire about the problem;
- A possibility to define with complete accuracy the changes in the world that the design may bring about.

Formally it is possible in most cases to transform an ill-defined problem into a well-defined one by closing all open constraints that are often conflicting. Such transformations correspond, however, to a form of premature commitment.

[Gero, 1998; Logan & Smithers, 1995] also differentiate routine and non-routine problems.

Routine Design:

- Involves a well understood sequence of steps where all decision points and outcomes are known a-priori;
- Both the available decisions and computational processes used to take those decisions are known prior to the process' beginning.

Non-routine Design:

- Goals are ill-specified;
- The available decisions are not all known before;
- One has neither fixed strategies nor preestablished decompositions and design plans for sub problems.

Finally, innovative design (solve a known or new problem in a different way from other known designs) can be distinguished in a problem-solving process from creative design (use new variables producing new solutions).

[45] Newell and Simon analyze problems in terms of « states » and « operators ». A problem consists on an « initial state », a « goal state », and of a set of « operators » that are « legal », in the sense they may be used for transforming the initial state into the goal state. Operators have constraints that must be satisfied before being applied. Problem solving takes place in a « problem space » that contains these states, operators and constraints. « The search of a solution is an odyssey through the problem space, from one knowledge state to another, until the current knowledge state includes the problem solution » [Simon, 1978]. Many authors forget that a « problem » is not an entity that exists « out there », « given » to a person in order to be solved : a problem is a particular representation that an individual person constructs of a task (whose presentation is open to multiple interpretations). So a « problem space » is not a simple problem's decomposition into components because objectives never exist independently of a particular person who is confronted to a particular task.

Appendix B: Symbolic information processing and Situativity approach.

[Visser, 2006] notes as follow the main characteristics of the SIP and SIT theories.

The SIP approach is one of the most famous theories in cognitive science. Herbert A. Simon said about design that "*it means synthesis. It means conceiving objects, processes, ideas for accomplishing goals, and showing how these objects, processes or ideas can be realized. Design is the complement of analysis – analysis means understanding the properties and implications of an object, process or idea that has already been conceived".*

The main characteristics of this theory can be listed as follow:

- Design problems require search in a space, which, in the case of design, is a space that contains many possible arrangements of the problem, among which only one or a few satisfy the problem criterion. This view of design activity as *problem solving* in the standard information-processing sense of *search* in a problem space is one of the characteristics of Simon's approach that is going to be the more discussed;
- Design is a type of cognitive activity rather than a professional status;
- Design is the search of the more satisfying solution instead of the search of the optimal one. Indeed, identifying the set of possibilities would be too heavy as task.
- Design as regular problem-solving activity: Simon was studying neither design nor any other real-life activity. The task he studied was short, moderately difficult (algebra-like puzzles, chess or symbolic logic problems). When he started to tackle design problem, he maintained that no unknown concepts or techniques were necessary in comparison to what he did before. It is known as the "nothing special" Simon's position.
- Design problems are ill-structured problems. But for Simon, these typically ill-structured problems quickly acquire structure, due to the designer's strategies and memory's evocation of well-structured sub-problems.

These assumptions support the theory's construction, the process being described through two main stages (problem structuration/analyze and solving step), followed by a third one (solution evaluation).

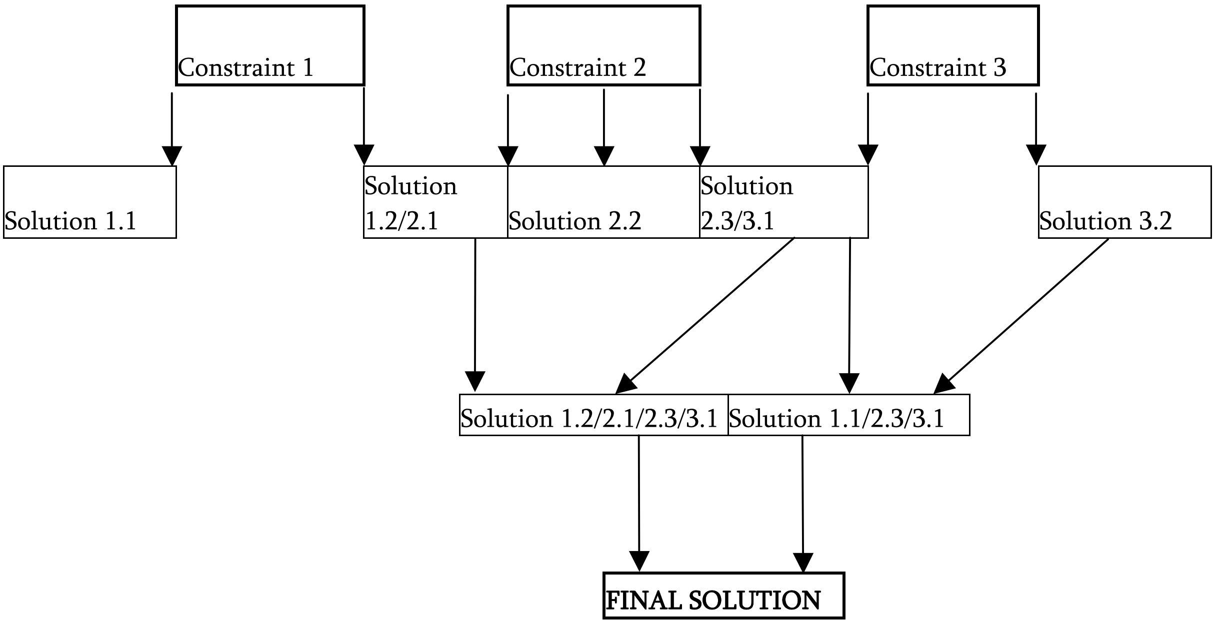
The SIT approach is based on four central reflective-practice activities:

vi) Naming the relevant factors in the situation;
vii) Framing a problem in a certain way;
viii) Moving: making moves toward a certain solution
ix) Reflecting: evaluating these moves.

These iterative cycles progressively load from the abstract, globally specified problem to its concrete, detailed and implementable solution. This theory is right now more appropriated for conceptual design than for detail design, where it could probably "lose some of its descriptive power" [Dorst, 1997]. We have to note that this approach is still current, and it is possible that the nowadays missing structures, rules or techniques, needed to conduct the process in a more efficient way, will be grounded in a few years.

Appendix C: the decision or design tree.

The design tree provides a medium for forward chaining from technical objective to embodiment. It is particularly useful when there are many alternative forms to be considered.



Array A1 – The design tree – Strategies for Product Design, Nigel Cross.

Whether a list of constraints and a few solutions to these ones. In a first step, the designer opts up stream for the solution that seems to be the best one. Once this solution chosen, he/she can consider the news problems for which he/she finds the most appropriate solution (sometimes there is no solution at all), etc… This way he/she goes more and more in detail through the design tree.

The decision tree perhaps implies that the result is the best possible design, but only if the best options are chosen at each level. Indeed, a decision at any particular level may turn out to be sub-optional in the light of subsequent options at other levels. Therefore there are frequent backs tracking up and down in the hierarchy of the design tree, to find the more adequate solution.

Appendix D: The Gestalt Theories.

The Gestalt theories are born during the 19th and beginning of the 20th century in Germany and Austria. The founders, Ernst Mach, Christian Ehrenfels, Max Wertheimer to cite some of them, were opposed to associationnism and argued that shapes were more than poor additions of their separate parts.

They state 5 rules, connecting the mind, the drawings and the represented shapes.

4. The transposition law: when the structure isn't altered by modifications, the shape stays recognizable.
5. The figure (what offer boundaries) and background law: the more the figure is regular, simple and contrasted comparing to the background, the more it stay pregnant.
6. Units segregation law: some groups/units can be spontaneously recognised, thanks to their orientation, distance, similarities, …
7. Pregnancy concept: among all the possible structures there is always one dominating the others. This structure is visually speaking more strong because of its unity, regularity, simplicity, symmetry or structure.
8. Hierarchical organisation law: the eye distinguishes the main from the secondary. The exploration of an image is in a first attempt deformed by the preliminary perception of universal shapes. By "universal" shapes they heard the shapes corresponding to our culture habits that require the minimal cognitive effort.

They are also at the source of well-known observations like the "empty-full" balances and the reversible images perceptions, or also the dichotomy phenomenon.

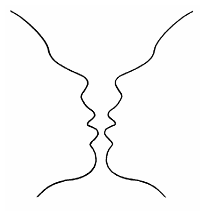


Figure A1 – Dichotomy phenomenon: two faces or a vase? Our brain chooses to see one or the other.

Another interesting observation is the role of previous experience, which explains the magnitude of memory and conditioning. These habits to understand and read the pictures in a certain way rather than another modify our reaction toward this one.

Example: if we show to numerous observants a picture with a high zoom effect (a few pixels for instance), the picture will appear as unintelligible, till the zoom function disappear to show the whole picture. Only at this point will the picture becomes significant. If we begin with other observants the opposite experiment – first the whole picture is shown and than the zoom begins till the single pixel – the signification of each step will be understood. This way, the memory played its role and projected on the none significant zoom a remembered cognitive sense.

Appendix E: the Canadians rail norms.

The standard distance between two rails in Canada is 4 foots and 8 inches and a half. This quite bizarre unity has a long story. Canadians railways have been built on the same model ad the US ones, to ease the products' transportations from one country to the other. The US ones has themselves been built in the same way than the British ones: this way the British engines could take the US market. The British railways presented this dimension because they were designed by the same engineers that conceived then trams, engineers who used the same methods and tools.

This tramways' rail gauge were of 4 foots and 8 inches and a half, simply because the very first tramways' workmen also did the horses' trucks and they used the same methods and tools!

The trucks' gauges were defined this way because roads, everywhere through Europe, were in a very bad state and presented a lot of regularly spaced ruts. Using others gauges would have caused too much axles ruptures. But why were the ruts already spaced out? The first large roads were indeed constructed in Europe by the Romans, to speed up the legions' deployments. The legions always moved using war tracks, pulled by two horses. These two horses had to gallop side by side without annoying each other, and the track had to stay stabilized: the wells couldn't be in the continuity of hoofs imprint. Therefore the further trucks respected this wide.

The 4 foot and 8 inches and a half Canadian rails' gauge are due to the wide of two medium dimensioned horses' hindquarters.

This story has an interesting continuation. When we observe the spatial NAVY shuttle on its rocket base, we can see the two additional tanks, bounded to the principal tank. The company building these tanks is located in Utah and trains always make the transportations. The railway between the factory and Cap Canaveral borrows a tunnel under the Rock Mountains. This tunnel, a little wider than the railway, constrained the tanks engineers to design the tanks with a maximum wide, corresponding more or less to the rails' gauge.

Conclusion: to design the NAVY spatial shuttle, one of the most sophisticated means of conveyance, the engineers had to respect the wide of two medium dimensioned horses' hindquarters because no one in 2000 years decided to change the way of designing, the methods or the tools used.

Appendix F and G: Experiments' analysis grids.

Legend relative to the analysis grids :

Medium : O – D – G

Oral, Dessin, Gestuelle

Donnée de type : esth – fonct – erg – tech

Esthétique, fonctionnel, ergonomique, technique

Niveau d'abstraction : C – O – QUAL – QUANT – ASS

Concept, Objet nommé, qualitatif, quantitatif, associatif

Ressources : HG – M – HD – D – A – PR

Heuristique Générale, Méta connaissance, Heuristique Design, Données, Analogie, PRojet en cours

Dessins : G – D – C – E

Généraux, de Détail, Conceptuels, d'Environnement (grille, trame extérieure à l'objet, ombres, annotations, …)?

Action sur : FG – D – Ass – C – A

Forme Globale, Détails, Assemblages, Composant, Aspect

Appendix F and G: quotas' results.

Here are the arrays in which you'll find all the values that afford the quotas graphs' construction.

Experiment 0.

% of actions	Number of actions	Time spent		% of time spent
58	51	0:28:45	Plan	53
25	22	0:13:52	Elevation	26
17	15	0:11:20	3D	21
100	88	0:53:57	TOTAL	100

% of time spent	Time spent	
17	0:11:31	Global Shape
45	0:29:34	Components
17	0:11:12	Details
0	0:00:00	Assembling
21	0:14:05	Aspect
100	**1:06:22**	TOTAL

59 %	Non Symbolic
15 %	Symbolic
15 %	Alpha-numeric
15 %	Construction lines
19 %	Matter and texture
45 %	Master curve
10 %	Shadows

% of actions	Number of actions	
53	29	Plan
27	15	Elevation
20	11	3D
100	**55**	TOTAL

% of actions	Number of actions	Time spent		% of time spent
24	30	0:26:00	Oral	27
72	88	0:52:26	Sketch	55
4	5	0:16:08	Gesture	17
100	123	1:34:34	TOTAL	100

% of actions		% of time spent
30	Analyse	33
15	Search	29
40	Propose	25
15	Evaluate	12
100	TOTAL	100

% of actions		% of time spent
49	Aesthetic	44
38	Functional	38
7	Technical	8
7	Ergonomic	11
100	TOTAL	100

TOTAL in percentage	Number of actions	
7	12	General Heuristic
46	83	Meta-knowledge
7	13	Design Heuristic
12	21	Current project
20	37	Data
9	16	Analogy
100	**182**	

Experiment 1.

% of actions	Number of actions	Time spent		% of time spent
21	13	0:05:48	Plan	20
23	14	0:07:47	Elevation	26
56	35	0:15:51	3D	54
100	62	0:29:26	TOTAL	100

% of time spent	Time spent	
46	0:13:01	Global Shape
25	0:07:08	Components
18	0:04:59	Details
7	0:01:57	Assembling
5	0:01:20	Aspect
100	**0:28:25**	

82 %	Non Symbolic
13 %	Symbolic
11 %	Alpha-numeric
27 %	Construction lines
8 %	Matter and texture
46 %	Master curve
4 %	Shadows

% of actions	Number of actions	
0	0	Plan
38	8	Elevation
62	13	3D
100	**21**	TOTAL

% of actions	Number of actions	Time spent		% of time spent
10	7	0:12:23	Oral	30
90	63	0:29:01	Sketch	70
0	0	0:00:00	Gesture	0
100	70	0:41:24	TOTAL	100

% of actions		% of time spent
41	Analyse	33
2	Search	18
51	Propose	34
6	Evaluate	16
100	TOTAL	100

% of actions		% of time spent
49	Aesthetic	53
34	Functional	31
16	Technical	13
1	Ergonomic	2
100	TOTAL	100

TOTAL in percentage	Number of actions	
6	5	General Heuristic
62	54	Meta-knowledge
7	6	Design Heuristic
16	14	Current project
6	5	Data
3	3	Analogy
100	**87**	

Appendix H: Experimentations program.

Contest - « Pick me » project Bid invitation - Philips™

Philips™ pursues in 2007 the widening of its flat-screens TV set range and wishes to launch into the market an innovating multi-function remote control concept.

Thanks to the last results announced by its Search and Development center, domotic demands in private sector increase. The avowed goal of the company being the extension of information technologies among the whole habitat, there is a growing need of an unique interface able to control all of them. This interface will guarantee, according to them, the success of their new « Pixel Plus 3 HD » project.

The results of several research indeed proved that 67 % of the users were satisfied of their TV set but regret the company's lack of imagination concerning remote controls. Among the interviewed subjects:

- 79 % of users regret the remote controls' multiplicity, every one being different for each appliance;
- 63 % argue that the remote control assumes no particular look but rather imitates their « TV set style », this fact leading them to frequent confusions;
- 34 % found them complex to use and need the users' manual to understand each functionality, this statistic increasing more for universal remote controls;
- 17 % accuse prehension difficulties;
- *68 % whish an audacious storage system for their remote control, home adapted.*

In front of these observations, Philips™ proposes to interested designers to develop in cooperation with their technical teams a concept of:

- An unique remote control able to match consumers' needs;
- A remote control able to rule the following Philips™ technologies: TV sets, DVD drivers, video-tape recorders and Hi-Fi systems;
- An innovating and dynamic design, producing an easy recognizable icon, being handy and ergonomically adapted;
- *A practical and easily accessible storage system, combined to the battery charging system;*
- A new and young Philips™ trend mark.

Technical requirements.

Functionalities:

- The remote control will include the following keys:

  - « Stand by/on »
  - « Mute »
  - A set up key allowing to switch between the several uses (TV, Hi-fi,…)
  - Numerical 0-9
  - Of broad selection (for positions up to 10)
  - For the sound system
  - Permitting to switch stations easily
  - « Open/close » for DVD, magnetoscopes and Hi-Fi systems
  - Play, stop, pause, rec, rew, ff. These two last, coupled with the « skip » option, will allow to choose the musical tracks once the Hi-Fi function activated.
  - « Menu »
  - For menus' navigation (up/down/right/left)
  - « Set up/enter »
  - « Teletext »

And the Philips™ logo.

All the new functions' combinations allowing to ease the utilisation are welcome. The texts and icons graphics are totally free.

The term « key » is here used in its first signification' sense. A recent study shows that users, first seduced by the « hi-tech » appeal of tactile surfaces, finally prefer traditional remote controls' touch for the use's comfort, their innate character and their facility of use in dark atmospheres (visual contact not necessary).

- A system will shows the activated mode (TV, DVD, Hi-Fi, …), another will point out the useful batteries' level.

- *Two LED transmission diodes will be integrated for IR function.*

- The remote control will contain 3 AAA rechargeable batteries that must be attainable for an eventual substitution.

- The remote control will have to be shock and splashing resistant.

- *Moreover, the « DeLuxe » version will be fitted out with a removable USB key, design-integrated and permitting media transfers.*

Other constraints:

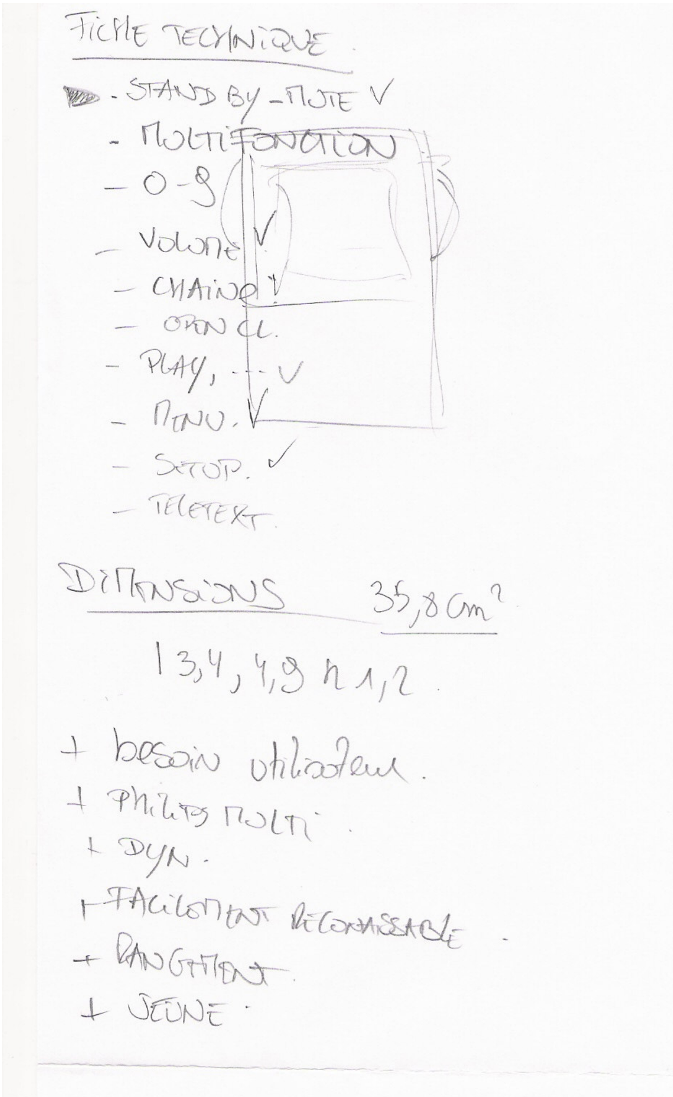
- Matters' choices are free and no aesthetic criteria will limit the shape. On the other hand, the designer will watch over to integrate traditional productions' impositions, technical choices being at his/her disposal.

- Only one technical constraint resides: 35,8 cm^3 (minimum) of electronic components have to be integrated and a l 3,4 × L 4,9 × h 1,2 cm box must be relieved for batteries. Further economical and technical considerations will be discussed after the contest, this one being only considerated on a preproject level.

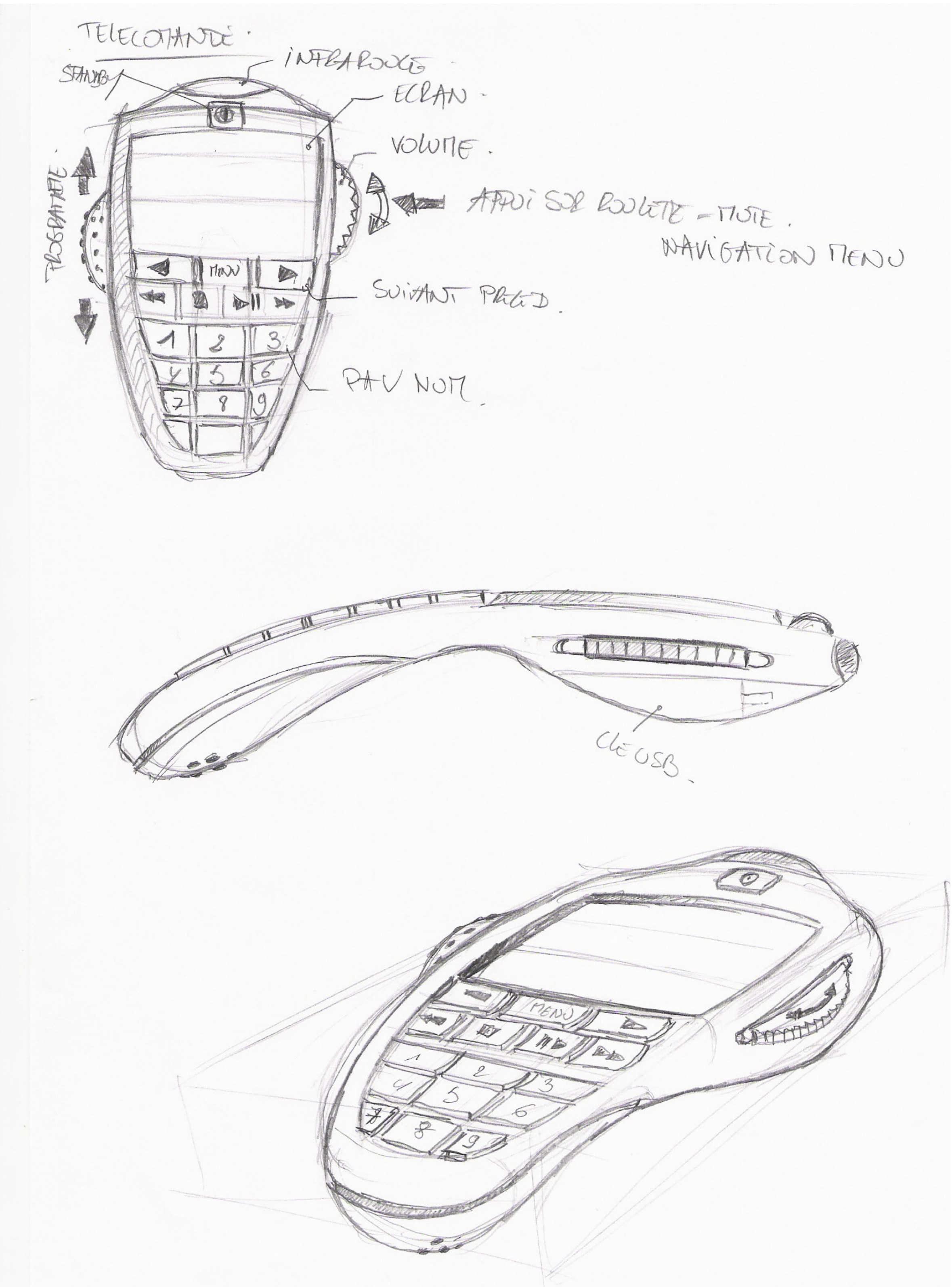
www.philips.fr

Appendix I: Designer 1 project.

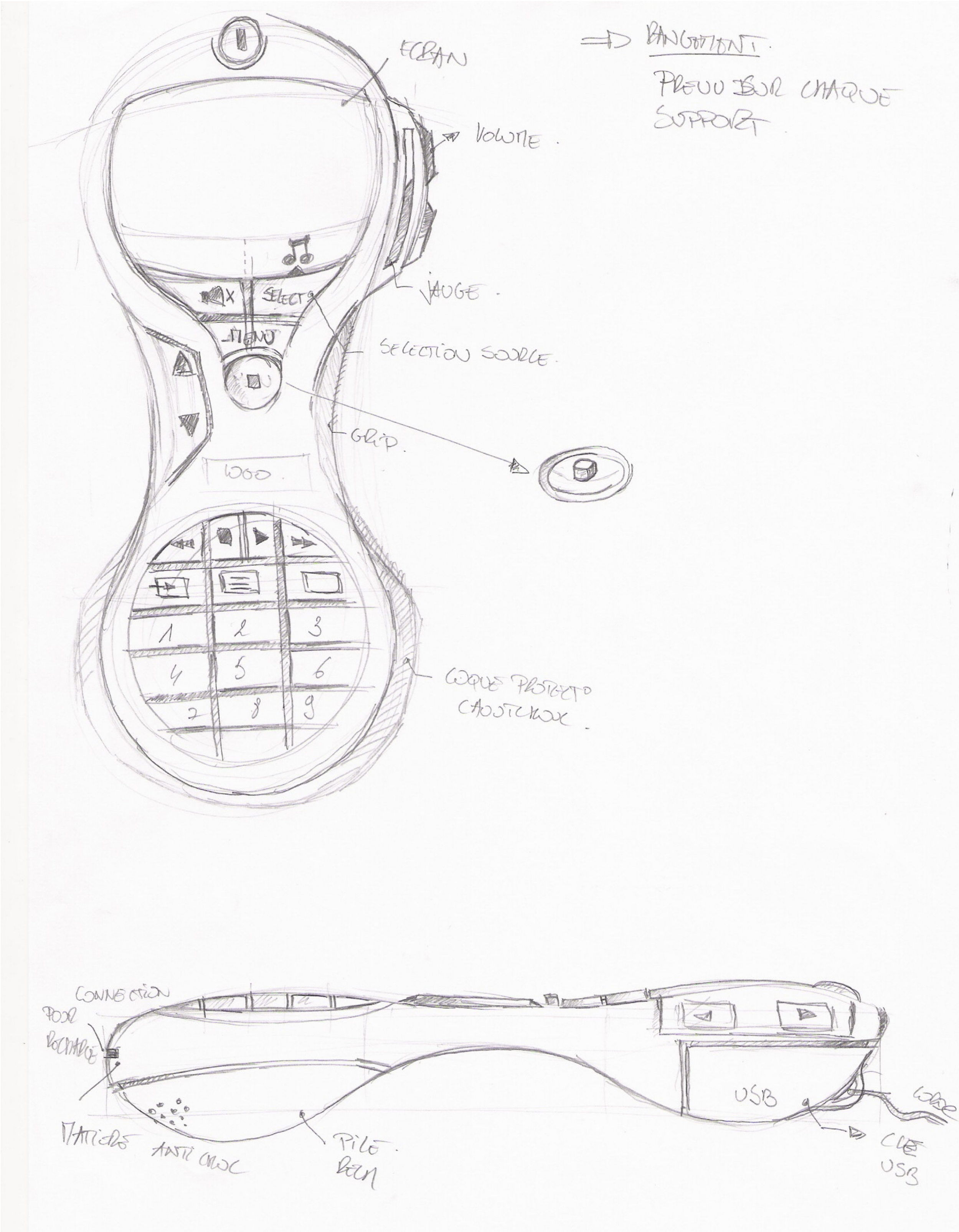
Check list and first conception sketch.



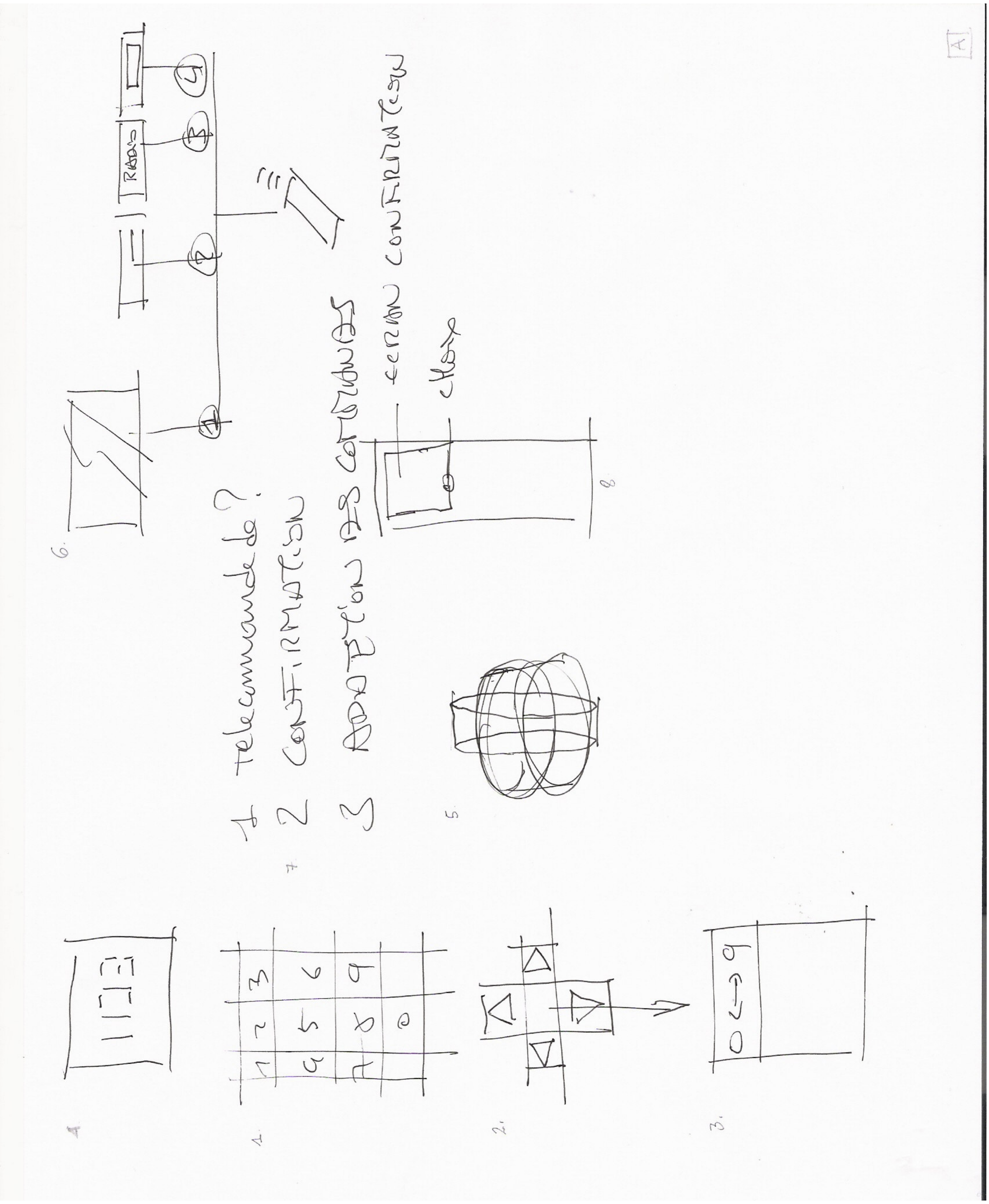
Remote control: solution 1.

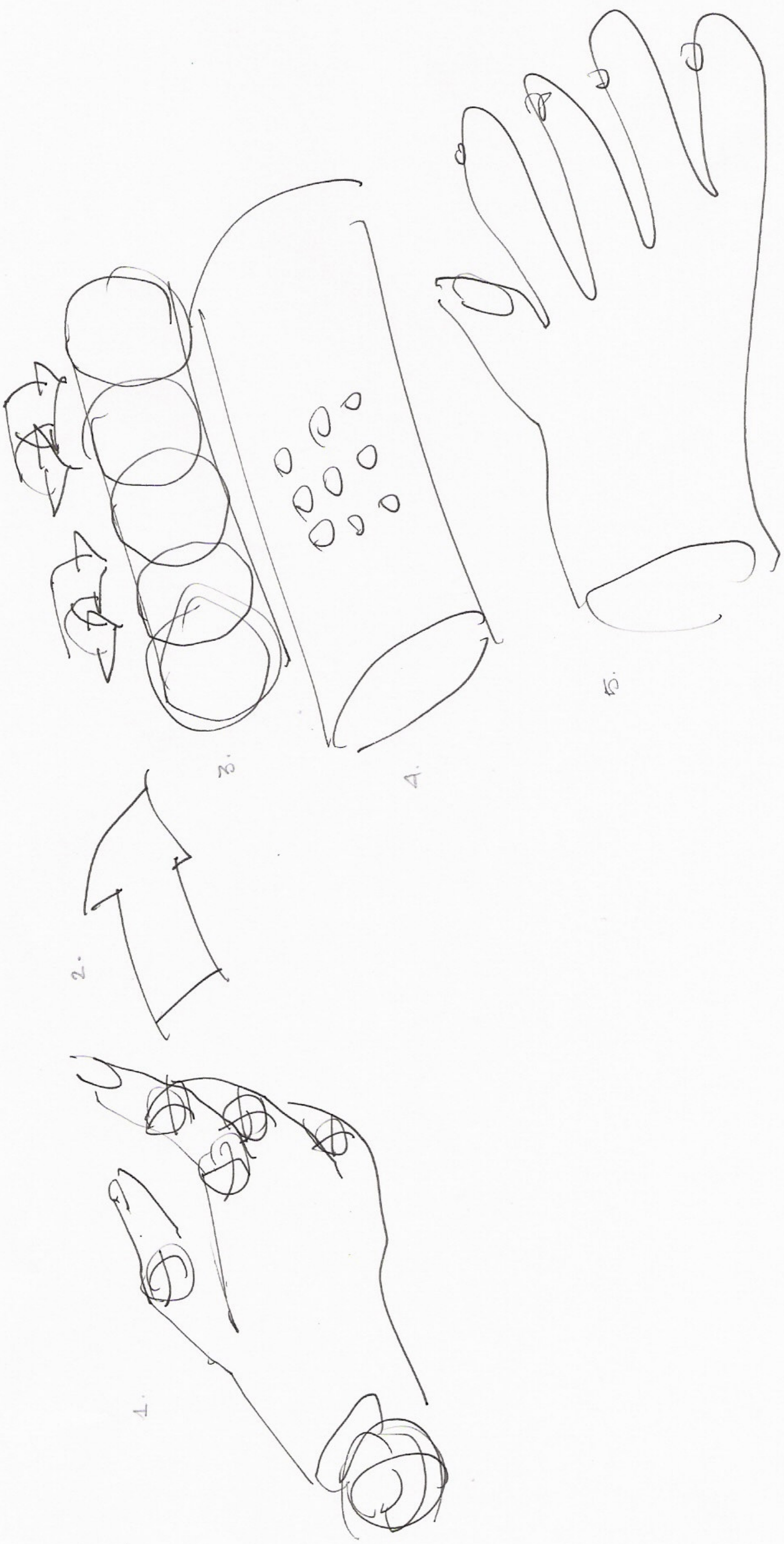


Remote control: solution 2.



Appendix J: Designer 2 project.





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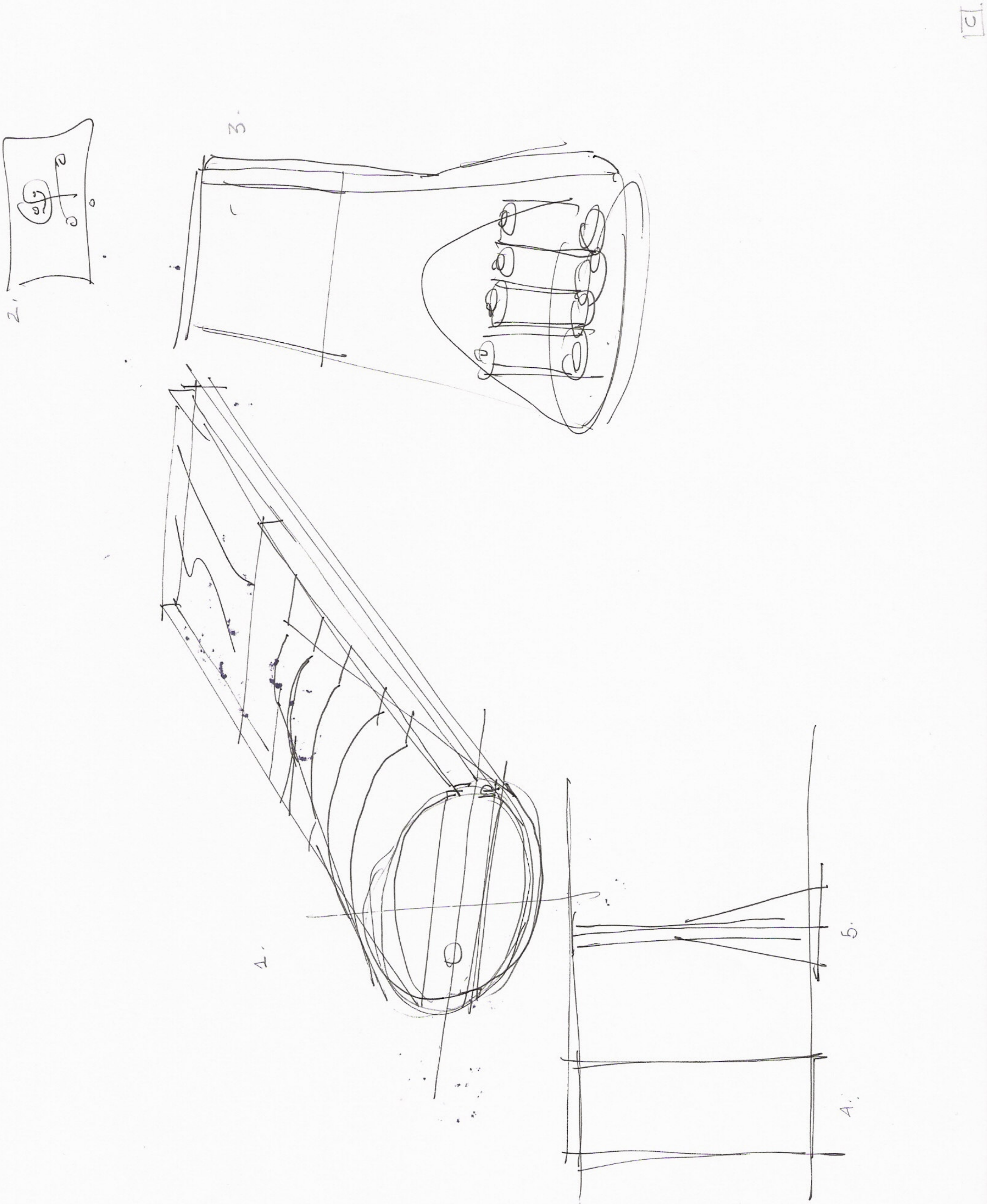

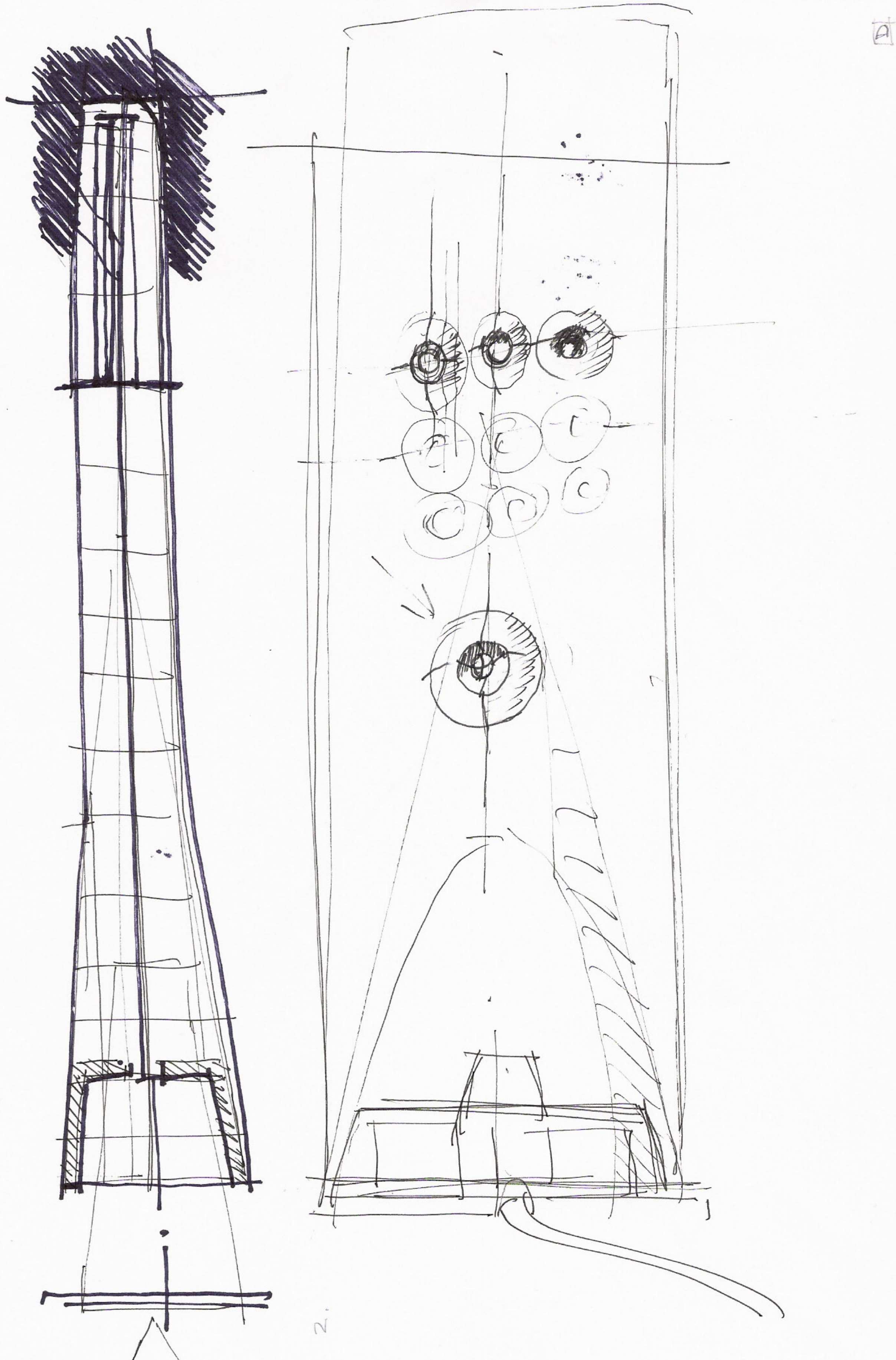

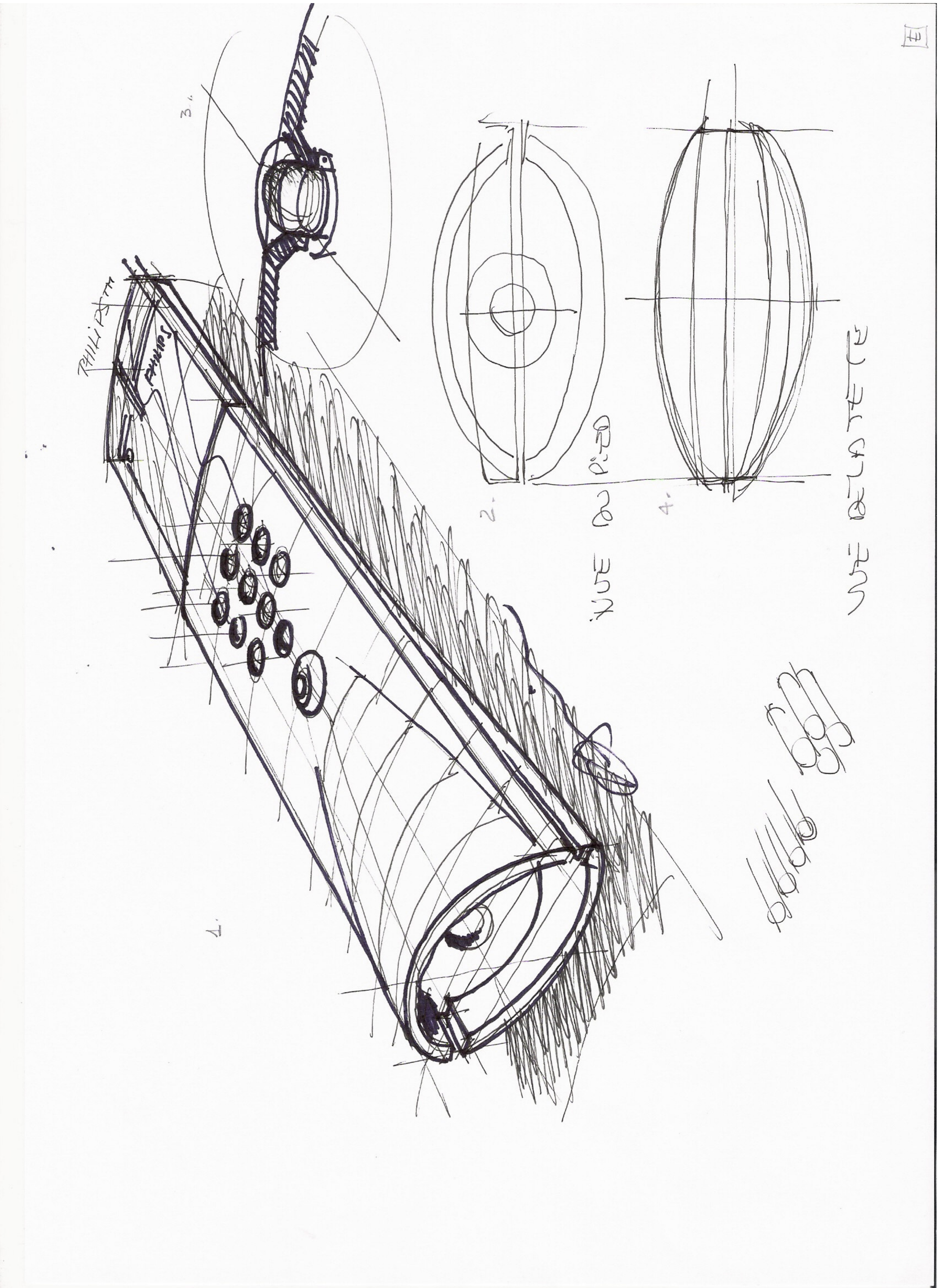
PHILIPS
VUE DU PIED
1.
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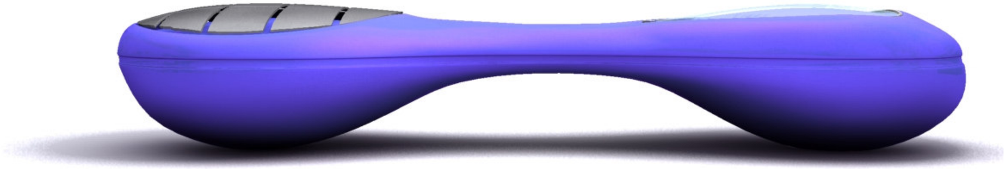
Appendix K: Graphic Designers' methodology.

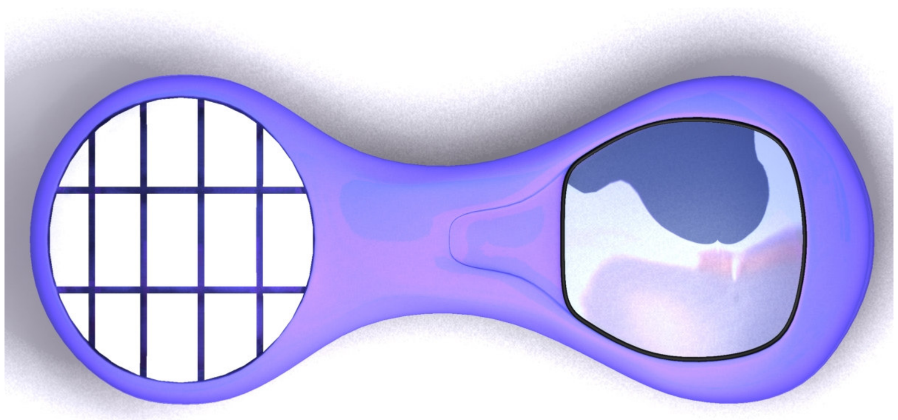
Etape n°	Vue	Description de l'action	Nombre de clics
		PREMIÈRE METHODE : EXTRUDE EDGE	
1	plan-profil	insertion des images scannées dans 3D Studio Max	
2	"	mise a échelle des images par box modelling	33
3	profil	création d'une sphère, placement de celle-ci, diminution du nmbre d'arêtes	11
4	"	couper la sphère en deux	5
5	"	déformation de la forme en 4 phases	12
6	"	modif opacité de la forme pour travail en transparence sur les vues de l'objet	12
7	"	modification de la position de 9 points	27
8	plan	travail de la forme d'un autre point de vue, travail sur 1/2 dessin par sym, 5 points modifiés	15
9	profil	méthode "extrude edge" : extrusion des arêtes. 3 aretes extrudées, une déplacée	12
10	3D	évaluation de la forme	
11	plan	5 points et aretes déplacés	15
12	3D	visualisation	
13	profil	symétrie dans ce plan est activée, 2 arêtes modifiées	20
14	"	modif de l'épaisseur de la coque, prise en compte de contraintes de production	4
15	plan	2 coques symétriques à lier ensemble	
16	"	attacher 3 points : passage systématique par un sous menu	11
17	"	définition de la symétrie dans le plan longitudinal (déf du plan, duplication)	19
18	3D	evaluation	
19	plan	recherche des lignes maitresses pour poursuivre le projet. 4 points modifiés	12
20	profil	extrude edge sur 13 arêtes	39
21	"	modification de la position de la ligne de joint, déplacement de 2 points	16
22	3D	contrôle	
23	profil	moitié du bas de la télécommande : terminée	
24	"	déplacement d'un point	3
25	"	récupération de la forme du dessous pour crée la coque supérieure par symétrie	
26	"	duplication de cette coque, effet miroir, positionnement	13
27	"	désactivation du calque comprenant la partie inférieure	3
28	"	attache un point de référence à l'avant de l'objet	3
29	"	attache 6 points, en déplace 14, 2 déformations globales	66
30	"	7 points déplacés, écrasement de la forme globale	29
31	"	considération du lissage global et déplacement de 5 nouveaux points	26
32	3D	vérification du maillage global	3
33	profil	attacher les 2 coques ensemble (activation de tous les calques)	7
34	3D	attacher 7 points	21

Etape n°	Vue	Description de l'action	Nombre de clics
35	"	visualisation maillage, 3 points rattachés	9
36	profil	4 aretes déplacées pour uniformiser répartition des aretes	12
37	3D	contrôle	
38	profil	1 point déplacé	3
39	3D	contrôle	
40	profil	3 points déplacés	9
41	"	lissage de la forme globale	7
42	3D	contrôle par activation de la fonction "ombrage"	
43	profil	modification de quelques points de la maille	7
44	"	suppression d'une arete pour éviter les points de concentration	3
45	"	dessin d'une nouvelle arete	4
46	"	suppression de 8 aretes	24
47	"	création de 4 aretes	16
48	"	déplacement de 3 lignes	9
49	3D	évaluation de la forme	
50	"	déplacement de 7 points	21
51	3D	vérification et déplacement de 2 points	6
52	plan	1 point déplacé	3
53	profil	lissage de la forme globale	
54	"	concentration de 9 aretes et 1 point déplacé	37
55	plan	3 points déplacés	9
56	3D	visualisation	
57	plan	modification de 2 points	6
58	3D	lissage, concentration de 4 aretes, 3 déplacements, 2 liens	28
59	plan	1 lien	3
60	profil	3 points déplacés, 3 liens	18
61	3D	vérification et déplacement de 1 point	3
62	plan	4 points modifiés	12
63	"	lissage	14
64	"	1 point modifié	3
65	profil	3 liens, 1 point déplacé	12
66	"	lissage	
67	"	suppression d'une aretes	4
68	"	introduction d'un nouveau plan de symétrie	9
69	plan	dédoublement des deux parties, pivot et translation	8
70	profil	déplacement de 2 aretes	7

Etape n°	Vue	Description de l'action	Nombre de clics
71	plan	déplacement d'une partie de la forme, déplacement de 17 points, modif. De la forme globale	61
72	profil	8 points rattachés	24
73	3D	evaluation	
74	plan	1 point déplacé	3
75	profil	7 points déplacés, 2 aretes crées	29
76	3D	lissage et évaluation	
77	profil	3 aretes supprimées, 4 déplacées	21
78	3D	lissage	
79	profil	3 points déplacés, 2 aretes supprimées	15
80	3D	évaluation de la forme globale finie (47 minutes de travail)	
AUTRES DETAILS			
81		Creux pour clavier	
82		détermination des touches par booléens	
83		textures	
84		creux pour écran	
85		texturage écran	
86		couleur forme globale	
87		rendus et contextualisation	
TOTAL DU NOMBRE DE CLICS			**896**
SOIT UN CLIC TOUTES LES 3 SECONDES			
SECONDE METHODE : BOX MODELLING			
1	3D	définition de 2 sphères et un cylindre couche	9
2	"	suppression des faces internes	14
3	"	8 points attachés	24
4	profil	écrasement de la forme globale	4
5	"	déplacement d'un groupement d'aretes (9 groupes déplacés)	22
6	plan	déplacement de 3 groupes	8
7	3D	vue lissée	
8	profil	introduction d'un nouveau plan de symétrie	3
9	3D	évaluation en vue lissée (moins de défauts)	
10	profil	1 point déplacé	3
11	plan	1 point déplacé	3
12	3D	évaluation de la forme globale finie (14 minutes de travail)	
TOTAL DU NOMBRE DE CLICS			**90**
SOIT UN CLIC TOUTES LES 9 SECONDES			

Appendix L: Graphic Designers modelling.





Appendix M: EsQUIsE Multi-Agent System.

This text comes out from [Juchmes, Leclercq & Azar, 2005] and explains the Multi-Agent System that underlies the EsQUIsE software.

The multi-agent approach is a very dynamic field of research, which has developed rapidly since the beginning of the 90's and the work into distributed artificial intelligence, such as that by Minsky [20] or Brooks [3].

Since then, the scope of application of agents has greatly expanded, making it difficult to define the limits of this field. In fact, there is not even a consensus within the scientific community concerning the real definition of what constitutes an agent. Depending on whether one is interested in "computational agents", "robotic agents", "mobile agents" browsing the Internet or "artificial life agents" plunged into a hostile environment, the definitions of agent can be very different, even contradictory. We have chosen to refer to the largely accepted "weak notion of agency", cited by Wooldridge and Jennings [21].

According to this definition, to be an agent, a system must display the following four properties: autonomy , social activity, reactivity (sensing and acting), and proactiveness (goal-oriented). In the following sections, we show how the agents present in our system *(understand EsQUIsE Architecture)* correspond to this definition.

Interpreting freehand sketches is a very difficult problem to resolve and a relatively young field of research in which a great deal of progress remains to be made. We believe that the multiagent approach is one of the paths that will enable researchers to meet the future challenges in this field. Three particularities of this problematic incited us to adopt a multi agent approach for interpreting sketches:

- The sketch corresponds to a dynamic and unpredictable environment. The agents can never know if the next stroke drawn will be integrated into the current sequence or traced in a completely different location in the sketch, nor even whether it will be a stroke, a gesture ordering something or simply the user who points an item in the sketch with a pen. Indeed, contrary to traditional assisted sketch software, the users never announce the action they intend to perform (no selection in the menus). One of the characteristics of the agents is to be able to act in such environments.
- A multi-agent system is a system for breaking down a problem. One of the fundamental ideas behind the multi-agent approach is that complex forms of behaviour can emerge from the interaction among simpler forms of behaviour. The interpretation of a sketch is a very complex objective, but the simpler sub-targets can be easily identified: the recognition of isolated graphic symbols is relatively simple and the complexity in this process arises because there are multiple elements all having different relations among themselves. Likewise, we believe a multi-agent approach is a form of modelling well-adapted to a system for interpreting sketches.
- A multi-agent system is open to change.

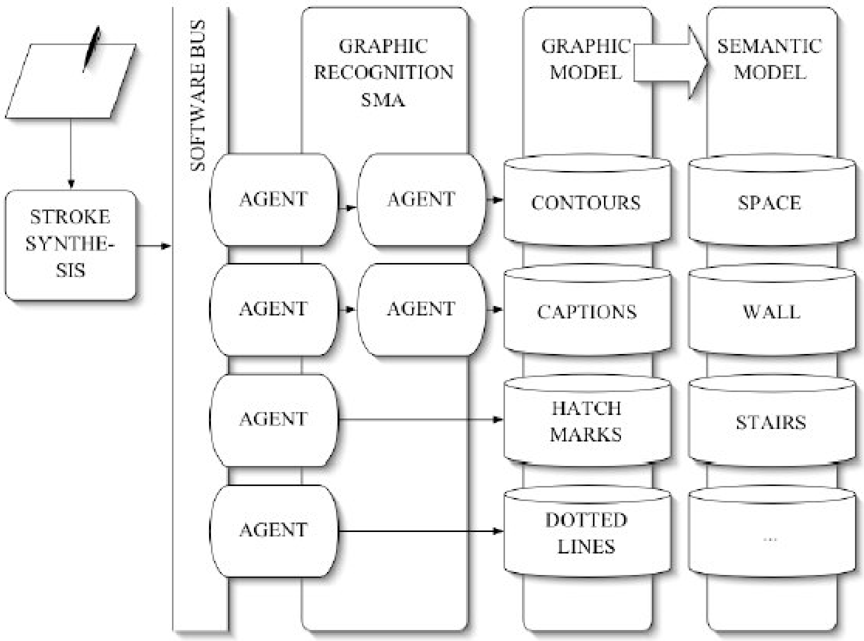


Figure 6. General system operations.

The figure 6 depicts the general system operations.

On the top is depicted the user drawing freely on a graphic tablet. Let's consider the example of an user drawing a simple stroke. The user's drawing is captured by a first module that converts raw data sent by the input device (x and y coordinates, pressure and tilt according to the x and y axes) into strokes. The stroke is the structure of data used by recognition agents. This module also performs stroke pre-processing by polygonal approximation. The strokes thus formed are deposited into a stack of strokes and a message is sent by bus software to all of the agents to inform them that a new stroke has just been traced on the sketch. According to their internal state and/or the characteristics of the new stroke, the agents choose whether or not to react to the event. If the new stroke is interesting to them, they attempt to use it to successfully complete their recognition objective. When an agent uses a stroke, it places a flag next to the stroke in the stack. This flag does not prevent the other agents from using the stroke, but it serves to inform them that another agent is also interested in the stroke. This mechanism makes it possible to initiate a direct dialogue between two agents.

When a graphic element is recognised by an agent with a certain probability, it is added to what we call the graphic model. The graphic model is a description of the user's sketch, no longer based on strokes but instead on higher level graphic elements: texts, symbols, contours, hatch marks, etc. If several agents propose incompatible interpretations of the sketch, a dialogue will take place to resolve the conflict. This graphic model will be used by EsQUIsE to construct the architectural model, a veritable "semantic" representation of the building on which the different evaluators of the project can work.

We can classify the agents that make up the system according to the input they need to carry out their objective successfully.

- "One stroke" agents : the simplest behaviour we can identify among the EsQUIsE agents is the immediate reaction to an input (reactive agents). The gesture recognition agents display this behaviour.
- "Multi-stroke" agents: the second type of agent we find in EsQUIsE are those that must attempt to recognise groups of strokes. These strokes may have chronological, topological or geometric relations. The simplest forms of behaviour in this category are the recognition of dotted lines or hatch marks.
- "High level" agents: some agents do not work directly on the strokes drawn by the user, but use a result produced by other agents as input. This is the case for instance in the recognition of captions. A "character recognition" agent, which is comparable to the dotted line or hatch mark agents described above, monitors the strokes being input to search for symbols that are aligned and that may be part of a caption (numbers, letters, punctuation marks, etc.).

The following section describes some features generally associated with our agents and their characteristics in our prototype. The EsQUIsE agents are:

- Permanent: they are created when the application is launched and will remain alive until it is stopped. However, the current prototype provides the user the possibility to manually activate or deactivate the agents according to the graphic elements the software is supposed to recognise.
- Distributed: the agents can be distributed on several machines to spread out the computational load within the framework of an embarked application. When the skill of an agent is needed to perform the interpretation, the client application contacts the "agent station" (on a server or on the same machine) which starts up the requested agent as a new process. The client can then connect directly this agent. All the agents use socket communications to exchange informations.
- Autonomous: they are capable of acting according to their own objectives with no human intervention. As planned, no general control system drives the recognition application.
- Located within a dynamic environment: the environment perceived by the agents is the sketch currently being drawn. They can browse this environment searching for information that interests them or reacting to modifications in this environment (a new stroke, the erasure of a stroke, etc.).
- Reactive: capable of responding on time. Since our system interprets the sketch in real time, the agents are able to respond instantaneously to the events they perceive despite the fact that the EsQUIsE prototype is developed in a symbolic interpreted language (in this case MCL), which is relatively slow compared to a precompiled language.
- Sociable: capable of collaboration.
- Proactive: the EsQUIsE agents do not act simply in reaction to the stimuli they perceive. They elaborate strategies, in particular for interacting, basing their actions on scenarios so as to interpret as pertinently as possible the elements that make up the sketch.

Two major limitations hinder the effective use of EsQUIsE in a professional context:

- The building model is not a real 3D but a 2.5D model as the spaces and walls are constructed by extrusion of the plannar elements. This first and reduced approach is often possible in architecture because of the role of gravity which forces building elements to be mainly vertical or horizontal (walls and floors). One of our goals for the future is to extend the model to real 3D by crossing information from different projective views.
- The system doesn't feature a learning interface to personalize the implicit knowledge base. The actual database included in the system contains only our knowledge, relative to our practice, country, rules of thumb etc. To be efficient, the system has to allow the users to insert their own knowledge in the database.

Corresponding sources :

- [3] Brooks R.A. : Intelligence without representation. Artificial Intelligence, 47(1-3) (January, 1991), pp. 139-159.
- [20] Minsky M.: The Society of Mind, Simon & Schuster, New York, 1988.
- [21] Wooldridge M., Jennings N.R. : Intelligent agents: theory and practice. Knowledge Engineering Review, 10(2), 1995, pp. 115-152.