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"Mediating objects" in new industrial cooperative practices: an empirical *in situ* study.

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Abstract. This paper studies new cooperative practices using an "anthropo-based" approach of "mediating objects". It provides insights into cooperative modalities with draughtsmen and mediating objects' potentials as efficient cooperative medium. It suggests considering design tools' and representations' complementarities instead of maladjustments in order to design cooperative support systems closer to real industrial practices.

1 Introduction

Providing designers with more intuitive and user-friendly cooperative design tools or more accurate design support systems are some of the challenges faced by CSCW (Computer Supported Cooperative Work) and SBIM (Sketch-based Interface for Modeling) researchers. Most of these researchers attach some importance to shared and mediating representations used during design tasks, as they constitute a tangible way to approach such complex activities.

These representations are usually studied according to the tools they proceed from, and this generally leads to a comparative analysis of these tools' pros and cons. This tradition of confrontation occurs for instance in architectural or industrial design, between free-hand sketching and CAD software that remain the main design tools. Indeed, on the one hand, free-hand sketches are said to be the most powerful support to preliminary design phases, without effectively meeting the constraints of collaborative and remote design tasks (Goel, 1995; Cross, 2000; Visser, 2006). On the other hand, it is claimed for a long time that CAD tools fail to support ideation (Whitefield, 1986; Ullman & al, 1989) but ease long-distance communication and documents exchanges. On top of these tools inadequacies, designers have to deal with the numerous issues remote cooperative design occasions: multiplication of large projects introducing relocated skills, increase of exchanged information volume and need for specific competences are some of them.

Whatever the point of view, each design tool presents respective particularities that can (in)efficiently equip the design process. Contrary to all expectations, designers facing these complex tasks, using their "maladjusted" tools, yet go on with successfully completing their goals. They adapt their work practices, their tools and representations to constraining environments and achieve, in a constant evolution process, the work they are paid for. This paper will try to understand how designers effectively reach their goals through the exploitation of their mediating design tools. How do they select them, and according to which characteristics ? Is this choice subjected to changes all along the cooperative process ? What factors do "shape" the use of design tools? To what extent are "new" and "traditional" design tools impacting work and cooperative practices?

2 Theoretical framework

To answer these questions, we suggest to combine the study of "front-to-front" cooperative design practices with an anthropo-based approach of real industrial projects and the study of "mediating objects". The hope is that the better understanding of these "basic" collaborative characteristics (that is, working *in presence* of others using *every-day* tools) will lead to the definition of more coherent and effective remote collaborative support systems, closer to real practices and their current evolutions.

To begin, the paper will present the three stages theoretical framework that structures our research. We will next present our *in situ* methodology and the data's analysis. The main observations will be then discussed.

2.1 Stage one: the "anthropo-based" standpoint

Comprehensive Ergonomics provides sound methods to conduct empirical in situ studies. Through its multi-disciplinary standpoint, this field enables us to better understand the actors of design activity. Without being restricted to the single "end-user" of an application, this scientific approach enables us to study all enclosed profiles, to define the real and prescribed tasks, the strategies, the required competences, ... that could impact the cooperative modalities and the use of design tools.

These observations, interviews and analysis methods help us to take into consideration two major elements. First the impact of new technologies: since the integration of CAD tools in every-day design practices, we should evaluate how designers are able to adapt their cooperative work and competences in regard to what constituted their previous habits, and on the other hand how they adapt their tools to the cooperative context. Secondly there is a need to consider the context's impacts (Dorst, 2008; Suwa & al, 1998), and we would even emphasize the multiplicity of elements to be considered by putting the term in the plural: working contexts, cooperating contexts, physical environments or project types.

2.2 Stage two: the focus on "mediating objects"

Among all the possible approaches of human cooperation, there is the theoretical framework of instrumental theory that suggests that any type of activity (and, by extension, cooperative ones) is mediated through the usage of artifacts (Folcher & Rabardel, 2004). This theory, developed by Rabardel and Vérillon (1995), introduces the notion of instrument as the combination of an artifact (material, symbolic, cognitive, or semiotic) and one or more associated schemes. The artifact can be commonly defined as the physical part of a tool. The scheme, on the other hand, is the result of "a construction specific to the subject, or through the appropriation of pre-existing social schemes" (Béguin & Rabardel, 2000). The example usually given is the hammering scheme, ordinarily associated with a hammer, but which could in case of necessity be adapted to a shifting spanner. Both sides of the instrumental entity (the artifact and its utilization scheme(s)) act together as the mediator between the subject and the object of his activity (fig 1).

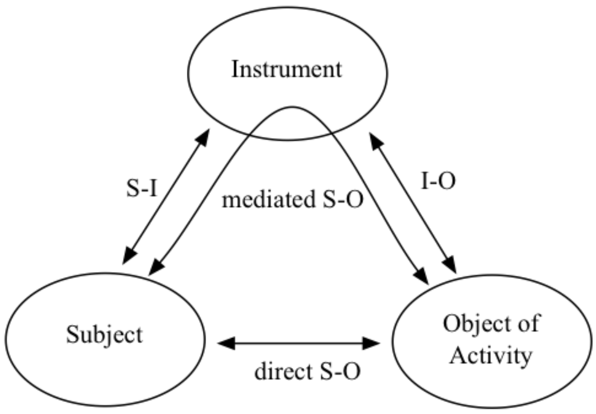

Fig. 1. The IAS Model, "Instrumented Activity Situation", and its three poles: the subject, the activity, and the mediating instrument (i.e. an artifact and an utilization scheme).

As our interest is to better apprehend the use, the sequence of use and the modifications of “objects” inputs all along the cooperative design process, we will define here:
(i) the “object of the activity” as the “act of designing together”;
(ii) the “subject” as an actor involved in the cooperation;
(iii) the “artifact’s” part of an instrument as a “mediating object”. We extend this way the term “artifact” in order to include in its definition not only its physical part (the pen; the computer, the prototyping machine, ...) but also the external representation linked to it (respectively the free-hand sketch; the 3D model or print, the physical model, ...). By considering the artifact this way, we try to avoid the general misunderstanding that can occur between “tool” and “external representation”.

2.3 Stage three: the study of complementarities

As we underlined, a dichotomous way to consider the main design tools persists in literature. This comparative approach also expands to the consideration of designers’ work habits (designers that sketch *vs*. designers that model; designers used to CAD tools *vs*. designers with no modeling expertise).

Our third theory framework, proposed here as an hypothesis, would be to abandon the study of these two opposite profiles of designers working in dichotomous worlds and using dichotomous schemes, but alternatively to consider a flexible mid-way profile taking advantage of the objects’ diversity and complementarities (in regard to the appearing constraints and the cooperative contexts, see fig.2). We indeed believe in the human capacity to adapt to a constraining environment, or to deviate the tools from their original use when necessary, depending on the cooperative environment.

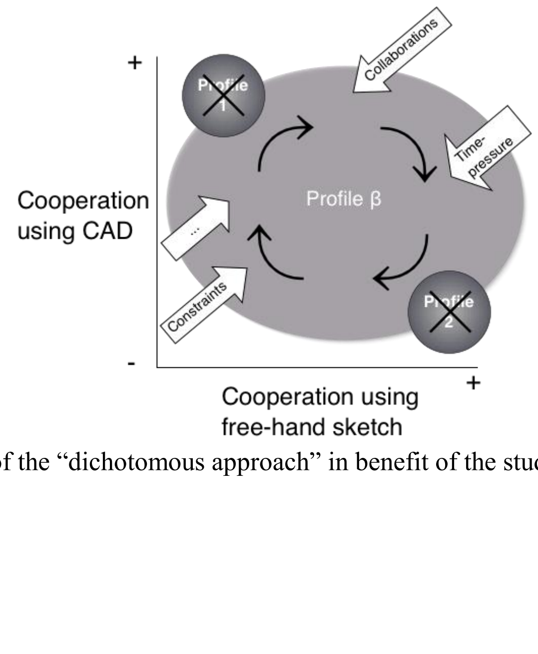

Fig. 2. The undo of the “dichotomous approach” in benefit of the study of complementarities.

This three-phased proposition structures our study of cooperative design's evolution and design tools as mediating objects, as presented next.

3 Case Study

A two months case study afford us to observe *in situ* a design team (6 designers, 4 draughtsmen) who is in charge of industrial projects in the field of contemporary heating devices development.

3.1 Methodology

The observer was allowed to stay 8 hours a day inside the open-space office to interview the subjects and capture (recording or filming) every step of their current designs as well as the cooperative facts (between the team, between members of the team and extern members such as the CEO or the prototypists).

On top of the 8 interviews (based on a semi-directive and retrospective analysis protocol) we selected 5 different products as a basis of observation.

This type of *in situ* intervention presents several advantages. First it avoids the limitations of a non-realistic lab situation by providing the essential contexts elements. Second, it enables a qualitative approach of the fine-grained details of the cooperative processes that would be ignored in a more quantitative study but still constitute a keystone for the whole project's rationale. Finally, it allows a global overview of several projects presenting diverse states of progression (formal, technical and productive). These projects provide a relatively complete view of the design processes, design methods, cooperative modalities and design tools' use without following a 2 or 3 years complete project.

3.2 Data Analysis

The whole data gained has been coded. The goal of this coding is a step-by-step "track" of the cooperative process given the appearing constraints and external representations' evolution (graphic, numeric and volumetric). The code applies to distinct unit of designing actions. One action is defined as soon as the mediating object changes, or as a new type of cooperation occurs.

This coding scheme is exploited to construct the projects timelines of the 5 selected projects (see an example in fig.3). The X-axis represents the project evolution in time, and represents different time scales since the data proceed from interviews or observations. The Y-axis sums up the various variables of the coding scheme (the use of one specific kind of tool - free-hand sketch; CAD tool or prototype, in parallel with the modality of cooperation - with whom, for doing what).

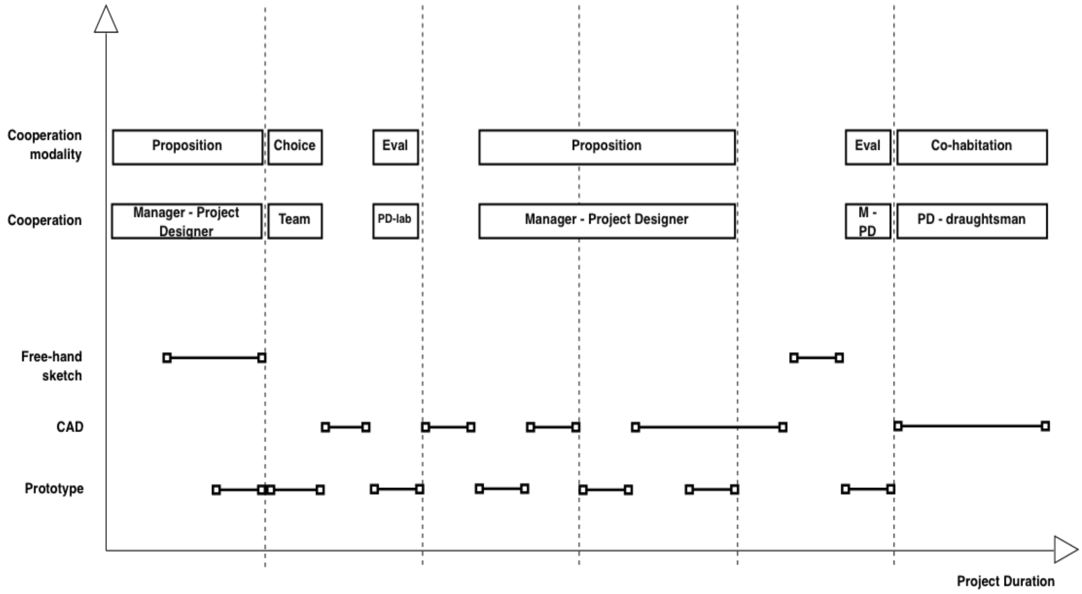

Fig. 3. An example of timeline with some variables (non exhaustive listing).

Among these 5 projects' processes, 13 more particular design "moments" were chosen for the quantitative analysis that will be presented in section 4.3. These 13 selected design moments (all video-taped or recorded) enable us to consider, second by second, a more detailed vision of the mediating objects' use (content, underlying model, ...).

4 Results

The next section presents our main observations concerning design tools and cooperative modalities between co-workers. We first discuss how CAD tools are nowadays completely integrated in industrial designers practices, sometimes since preliminary design (which tends to support our "*non-dichotomy*" hypothesis) and how this integration impacts the cooperation. Indeed, a new kind of cooperative work appears between designers and draughtsmen, whose tasks are part and parcel of a revalued design activity. Design mediating objects are mutually adapted to this new way of co-working, and the last part of the discussion will focus on their identified characteristics.

4.1 New practices, new cooperator: the draughtsman

CAD tools have, without a doubt, greatly impacted design practices. They are recognized as powerful tools to support production and execution stages of design process, but less efficient as early design support tools. Yet, our 5 projects' timelines, observations and interviews all tend to prove that CAD tools' potentials are now also exploited since the preliminary stage of the process (following other scheme of use, though, and in this particular team). They are required as early as possible in the projects, for economic, communication, time or productivity reasons.

Indeed, we observe several back and forth in the use of design tools all along the processes. For instance, a designer begins a project using a CAD tool to construct a "rough" 3D model, instead of using the traditional sketch. This simple 3D model is quickly created using primitive forms, without taking care of real dimensions, to visually test an idea and general proportions. As rough sketches, this 3D dynamic model supports the rapid evaluation of more formal or functional ideas. Having discovered some technical "nodes" in this model, the designer can then be in need of quickly exploring various solutions and in order to do so, comes back to "technical" sketches. These backs and forths between design tools are symptomatic of an effective usage of the tools given their complementarities, which tends to support our "non-dichotomy" hypothesis.

Since designers gained sufficient expertise in the use of CAD tools, we then tried to understand the evolution of draughtsmen's tasks. Interviews and observations revealed that draughtsmen are no longer performers of blue-prints or production plans and subordinates to designers, but take part in the design process since the task distribution's evolution. A graph of draughtsmen's activity has been constructed (following the activity theory's methods) in order to reassess their real tasks (fig 4).

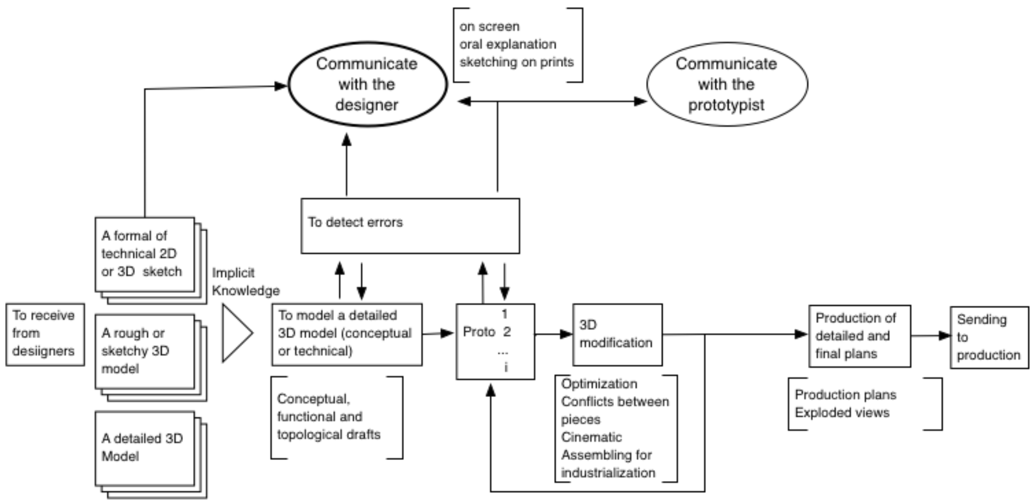

Fig. 4. Draughtsmen's activity graph showing the main tasks and cooperation modalities.

This simplified model underlines several observations. First, the draughtsman receives from the designer a "rough" representation that can either be a free-hand sketch, a rough 3D model or a sketch on a print. The main draughtsman's activity consists in detecting the errors and making the project evolve towards a final production plan (through the production of prototypes in this particular design field). Discovering these design errors (pieces' conflicts; production unfeasibilities…) the draughtsman sometimes even suggests solutions through a quick technical sketch, using this way a design tool he/she is not supposed to manage. We can say that draughtsmen develop in a few years a great expertise in this specific (and very technical) design field and are consequently totally able to co-operate with the designers in a win-win relationship.

This way of using both design tools as early in the preliminary design process without consideration for respective expertise lead us to two major conclusions. First, there is a need to distinguish "rough" sketches and "rough" CAD models or representations (that stay ambiguous and support ideation), from "technical" sketches and "detailed" CAD models (that focus on a more specific sub-problem and tend to a production goal). This questions the conventional boarders of "traditional design tools" in "preliminary design". Second, there is a new type of cooperation between designers and draughtsmen. A shared reference system is constructed between both actors as a function of the expertise and experience levels, and leads to a "co-design" situation at the highest and most effective point.

These first results tend to prove that the usual dichotomy (or hierarchy) that link designers and draughtsman indeed disappeared since the integration of CAD tools in work practices.

4.2 New ways of mediating the cooperative activity

This new cooperative work involves new ways of mediating the design activity through tools and representations. Since both designers' and draughtsmen's profiles aren't equal but just complementary, we try to understand how design actors respectively exploit the objects as a media of their cooperative activity.

The indistinct use of design tools whatever the profession is typical of a deep sharing of competences and sharing of the reference system. The verbatim suggests that co-workers are aware of this phenomenon and fit their cooperative modalities to ease each other procedures. For instance, one draughtsman explained that "the question of how to model has to be more often asked that the question of what to model". The draughtsmen have to develop a specific "way of thinking" to start the 2D or 3D virtual model, that leads them to question the essence of the sketchy representation they receive (phenomenon we call of *transition gymnastics*). Where and what are the "technical nodes" (or difficulties) of the product ? What kind of cinematic behavior will the product have ? How will it be possible for the prototypist to physically put a screw in such a tiny fold ? And last but not least, how will this piece co-exist with the pre-existing environment ? Clearly, draughtsmen learn how to interpret in essence the drawings or rough 3D models they receive, presenting heating devices technological details.

Designers, on the other hand, adapt their representations (in content and in aspect) to communicate with draughtsmen. They will for instance annotate the drawings, over-trace the main lines, use shadows or textures to suggest a material or draw arrows to define a cinematic behavior (these drawings' particularities being not exploited in a personal sketch).

Even if mental transitions (from 2D to 3D and vice-versa) are different between designers and draughtsmen, i.e. between the author of the sketchy representation and the interpreter, they always find the interface that will support their discussion. Generally speaking, as we will develop in next section, involved partners always tend to cooperate using the external representation the closer to their shared system of reference.

This cooperative interface sometimes is not totally appropriate to mental representations. In case of maladjustments, the subjects are able to adapt themselves to the constraining environment or sometimes transform their mediating objects to fit the cooperative situation (*catachresis* phenomenon). See in fig. 5 an example of this phenomenon: the prototype is diverted from its primary goal to be used as a drawing support, in order to ease cooperation between a senior designer and a junior draughtsman.

Fig. 5 An example of catachresis phenomenon.

4.3 Design tools' characteristics.

The previous sections suggest that the dichotomy principles are no longer adapted to the designers' realities, to their actual practices or design tools, and that a new proposition is needed. We will now investigate how the mediator objects complete each other and on which principles the actors select them in order to test our "complementarity" hypothesis.

As far as respective contributions and selection principles are concerned, each actor develops his/her own strategies but some constants can nevertheless be identified. The fig.6 presents the repartition (in percentage of occurrences) of use of the main design mediating "objects" (including here the oral; gesture or designation modalities) during the 13 design moments we chose earlier.

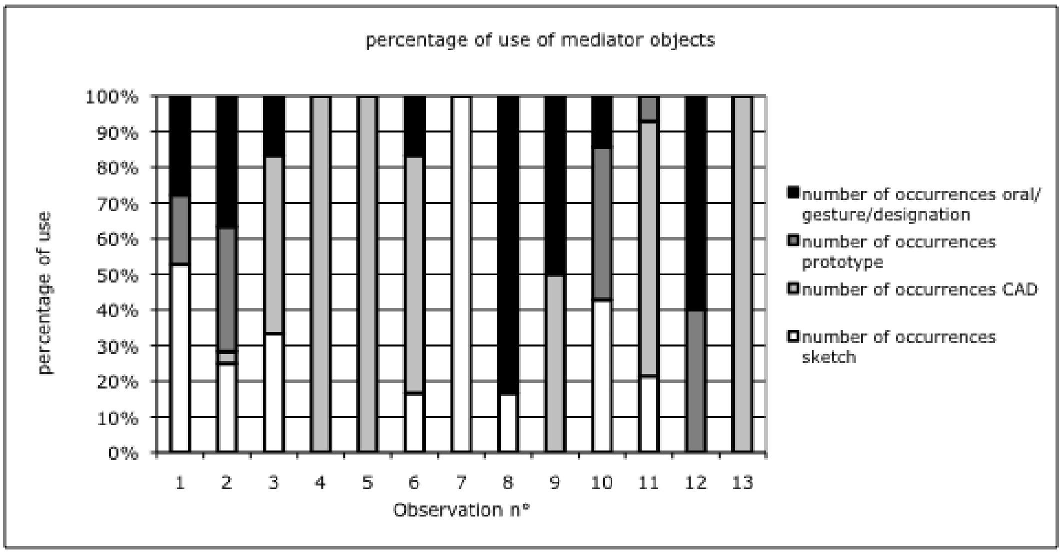

Fig. 6. Percentage of use of the main mediator tools.

The occurrences are globally balanced, with a maximum for sketches (sketches = 30,1%; CAD tools = 19,8%; prototype = 21,8%; oral/gesture/designation = 28,2% of total occurrences). We observed that two designers can easily understand each other simply by watching a computer screen and pointing at a virtual model. On the other hand, when a prototypist explains to the designer the difficulties encountered to build the first physical model, the support of cooperation is either the previous prototype or 2D prints, which also remain the main interface during larger meetings with sales managers. The sketch as a last example will remain the favorite support of cooperation between two designers co-working on an idea. We underline also the great importance of oral, gestural and pointing modalities to complete the information supported by the representation.

We observed that the interface of cooperation always stay the closer to the mediating objects all actors commonly exploit.

The objects' selection principle will also depend on the tools' features. We already summed up in introduction what generally appears in literature, and we present here our own observations.

The free-hand sketch specificities.
The free-hand sketch is mainly used during the definition and specification of a new solution, either conceptual, formal or technical. Sketch remains faster and more profitable than CAD tool for the quick exploration of diverse alternatives, although, as we saw before, this dichotomy nowadays tends to fade. One of the differences between the “rough-sketch” and the technical sketch is that this last one needs a geometrical environment to define some proportions (drawing on a 2D print for example with geometrical basis).

The principle of selection, inside the sketching modality, between a plan (or elevation) and a perspective depends of what kind of element has to be tested. The perspective drawing is efficient to quickly evaluate a functional aspect, a production method (such as a fold or assembling principle) or pieces’ imbrication. It allows a faster “3D test” than a 3D model or a 3 views drawing. A 2D representation in a complementary way is sufficient to test dimensions, volume or intern functions.

The CAD tool specificities.
The CAD tool used (Pro-Engineer here) is particularly well adapted to the dynamic visualization of a piece assembling, alone or inside a pre-existing environment. This pre-existing environment visualization lightens the designer’s memory load (it eases the reintroduction of a smaller piece in the whole heating system for instance). It allows the designer to check if no more conflicts subsist (static or cinematic), and to validate the geometric, volumetric and proportional sides of the project.

The main limitation is the time-consuming characteristic of a detailed 3D modeling. That’s why the designers sometimes “divert” the tool from its first usage to make “quick and dirty” 3D models and to avoid time-expensive back and forths at later phases. There is also no “freezing” of attributes, which could lead to unexpected modifications after a parametrization of a linked piece.

The prototype specificities.
Prototypes are very helpful to evaluate and validate some formal concepts, to warn about production difficulties and as a support of team meeting. They nevertheless stay expensive.

Besides these selection principles, designers and draughtsmen underline the necessity of associating several objects in a “multi-modality spirit”. This multi-modality is, according to Rabardel, the realization of a redundancy effect that allows the subject to make the better choice and achieve a balance between economic and efficient objectives (Rabardel 1995).

4.4 Representations' characteristics.

We will here study representations and their modalities. It appears that these representations aim at different functions. We code the occurrences in terms of usage: question or a communication (which will of course stay the main functions during a cooperation); generation of ideas; evaluations and modifications, or production issues.

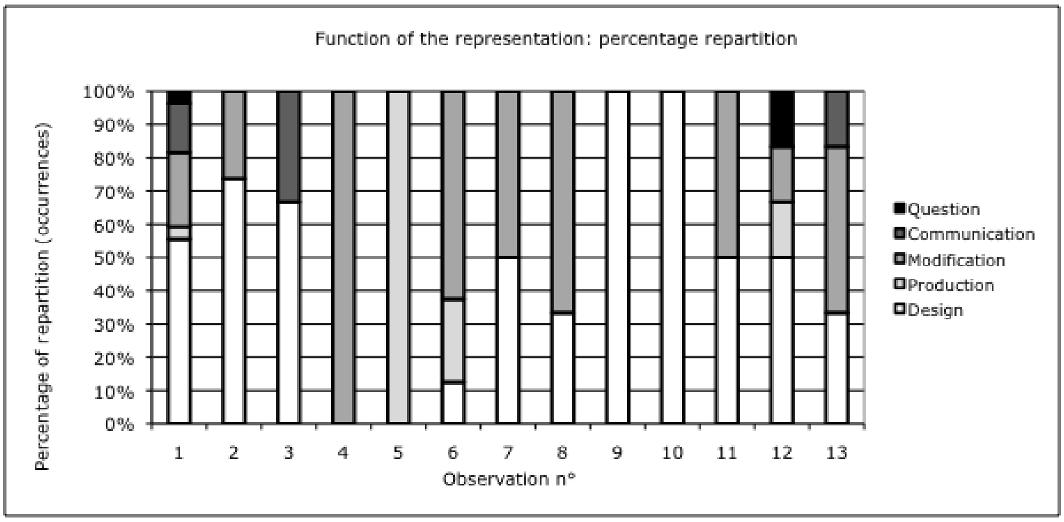

Fig. 7. Functions of representations: percentage of repartition.

Fig. 7 shows the percentage of repartition of these different functions. We see that generation (design) and modification present the highest occurrence in the 13 moments of design we selected, with respectively 52,4% and 31,7% of occurrences. This graph helps us to realize that one type of representation can support several functions and that the addition of several representations can diversify the design process.

Fig. 8 presents the underlying models of representations following Leplat proposition (Leplat, 2000). It codes the procedural aspect (the representation guides a procedure - generally a production method); the operative aspect (the representation supports the realization of an action - the act of designing of course but also the various other actions necessary to realize the project); the declarative aspect (the representation permits to declare a criterion, a characteristic, an opinion, an intention, ...) and the figurative aspect (formal representation).

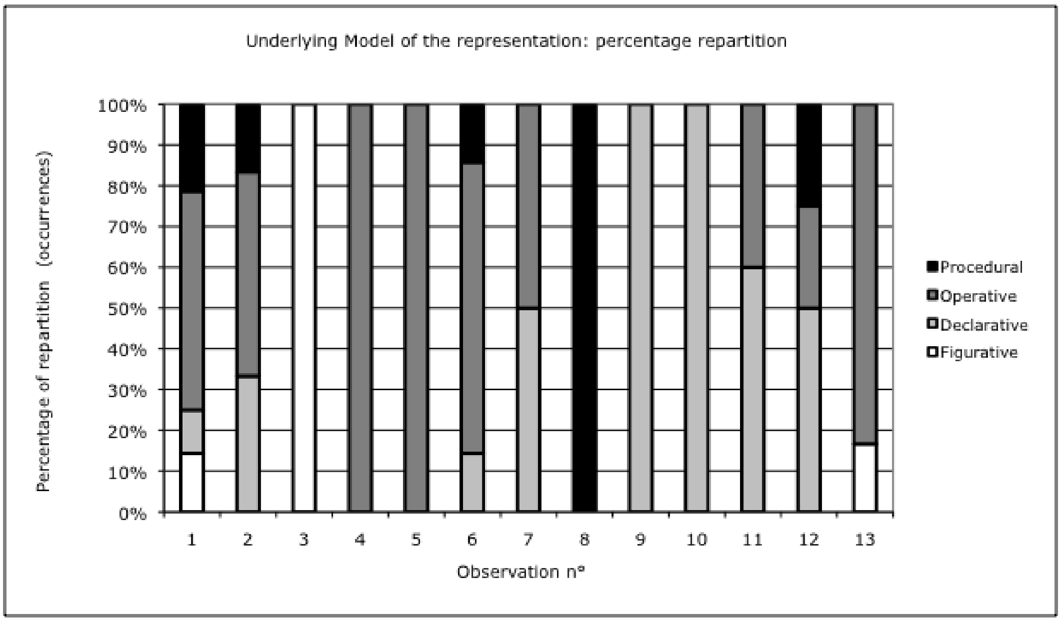

Fig. 8. Underlying models of representation: percentage of repartition.

The operative and declarative models, representative of the act of designing, are widely represented (respectively 50,6% and 22,8% of the total occurrences). This graph demonstrates the ability for representations to support several underlying models (in order to fit the contexts and appearing constraints) and always in a complementary way.

5 Conclusions

We assume that this work, considering its unavoidable sample's limitations, entertains futures possibilities for the development of cooperative support systems. These systems should take into account design tools' and design actors' complementarities and evolutions. Furthermore, instead of focusing exclusively on one cooperative channel (i.e. asynchronous data exchanges; virtual communication through avatars, tags and annotations,…), we suggest to consider all tools involved in every-day work habits and to study their complementary uses. Work actors constantly deviate and "misuse" them, adapt them to the constraints of their cooperative tasks, and enlarge the common boarders of what we usually call the "preliminary design phase" and its "traditional tools". The study of these deviations could provide interesting potentialities for further specifications.

Ergonomics and activity theory seem to constitute an interesting theoretical framework, that enable us to expand studies at all involved actors, in order to examine the several facets of the cooperative work. There aren't dichotomous profiles but flexible ones, actors adapting their work habits to the contexts.

In the field of industrial design, there is naturally an urgent need to analyze other teams and other processes to test the results. These projected *in situ* interventions will also enable us to deepen the study of “rough” and “detailed” representations’ contents.

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