Nature and role of intermediate representations (IR) in the design process: case studies in car design

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Abstract: This paper aims to show the key role of the intermediate representations (IR) in the design process and especially in the car design process. For a better understanding of the concept of design, which is by nature conceptual, we propose to study the concept of IR. To this end, we will present the three following parts: description of IR in the design process; nature of IR; and role of IR in the design process. We chose to illustrate this paper with our experience essentially in car design because the design process in this field is historically formatted and very formalised and complex. Besides, this activity is based on the intervention of many professional teams.

Keywords: car design; design process; intermediate representations; materialisation; mental and physical representations.

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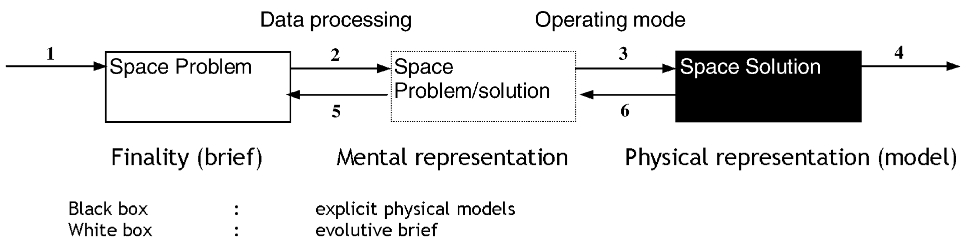
1 Introduction

The elaboration of IR is a main part of the design activity. As cognitive psychologists and design theorists point out, designers need to create multiple representations at different levels of abstraction in order to support their cognitive processes. In industrial design, the most used words are *objects* or *models* (Mohaved-Khah et al., 2003). In fact, mechanical engineers with design interests speak about intermediate objects in order to define the different digital or physical objects produced during the design process. The more and more widespread issues related to the cognitive processes involved in design emphasise the immaterial side of the intermediate objects, that is to say the manner they are produced. While we can also find the term *model* in sociology, we often find the notion of *representations* in psychology (Piaget, 1966; Rasmussen, 1983; Richard, 1990, 1995), and cognitians sometimes use the word *artefact* (Norman, 1991). Nowadays, the elaboration and communication of design mental and physical representations in the design activity is all the more crucial because it constitutes an essential experimental focus of interest for the elaboration of new digital tools. Digital tools are now widely used in industry for detailed design phases (Computer Aided Design, Computer Aided Manufacturing, …). The digital chain tends to spread out into the earliest phases of general concept design.

In the earliest design process phases, any formalised objects cannot be found. For that reason, the notion of IR has to be introduced. In these phases, the term *representations* means *mental representations*, which are more individual for this stage. The first explicit IR are produced for individual use, in the sense that they help the reflexive conversation described by Schön (1994). As soon as they become explicit, the IR can be shared and exchanged with other actors in the design process. Explicit IR are more commonly produced by digital tools now. The word *intermediate* comes from the evolutionary character of the representations in the design process: we define IR as every representation which appears during the design process, from its beginning to its end.

The design process can be seen as the space problem transformation, either an initial system of signs into a space solution, or a final system of signs. Then the diachronous design process is characterised by a global progressive reconfiguration of the space problem (or brief) into a space solution (3D model), according to a recursive cycle in which a partial transformation takes place from the space problem to intermediate space solutions at every representation level (see Figure 1). This partial transformation first occurs by way of the designers mental representations, followed by the generation of physical solutions and feedback evaluation. The term *cycle* is used here in order to express the repetitive loops of materialisation including information, generation and evaluation parts.

Figure 1 Description of a materialisation cycle (Bouchard, 2003)



A design project begins with a *finality* expressed in the form of a *brief* variable in terms of length and precision. The passing on of the brief to the work team constitutes an important step. The brief can be considered as the first formal and shared representation of the space problem including the different constraints to fulfil through the solutions. It leads to a collective exploration process aiming at a clear definition of the problem. In car design, the brief is a formal document written by the design comity, relatively open at the beginning and including development planning and the future product specifications. The brief is verbally explained to the staff and the team exchange different ideas to explore it with an early brainstorming. If the brief is very imprecise, complementary information is searched by the designers in order to complete it.

The different arrows on Figure 1 show the information flow and its transformation:

- the first corresponds to the constitution of the complete initial brief from the given brief and the information searched by the designer to complete it
- the second illustrates the data processing made by the designer in order to produce a first mental representation of the space problem, and iteratively of the space solution
- the third is related to the materialisation process: the designer will fix his mental image through the action of drawing design solutions
- the fourth makes the connection with the following materialisation cycle
- arrow 5 shows the iterations between the formation of the mental image and the reference to the brief in terms of enunciated constraints
- arrow 6 corresponds to the immediate modifications made by the designer during drawing.

The elaboration of IR is based on the use of individual and collective reasoning, involving complex cognitive processes where individual and collective processes are closely imbricated during the progressive evolution of these representations.

Those representations are co-built in order to provide a formalised exchange support. The reduction of the whole design process duration time and the diversification of the proposed design solutions to address the increasing number of needs in personalisation, as well as the limited cognitive capabilities of the designers and their needs in memorisation and communication, prevail not only to the formalisation of the design process but to its digitalisation too.

Shared representations are privileged media for the coordination of different partners involved in a co-design transdisciplinary process. They are formulated, reformulated and elaborated individually or collectively by the cooperation of participants, according to a process that we tried to define in that paper. Working in a context of co-design, the aim of this paper is to attempt to identify the specific role of IR in design, through the three following parts:

- description of IR in the design process
- nature of IR
- role of IR in the design process.

The first part is a descriptive part based on our experience in the car design field; the second part is related to different definitions of the IR concept from cognitive science and from engineering design; and the fourth part is an illustration from the case studies presented in the third part, which one essentially of automotive design projects where we were involved as consultants in order to improve the integration of trends and creativity.

2 Intermediate representations in products design

The design process consists of reducing abstraction through the use of various successive levels of representation integrating more and more constraints. Lloyd and Scott (1994) describe the design process as generative, deductive and evaluative statements in the activity of design. The generative part, creativity, is involved from early idea generation until production of the technical detailed design.

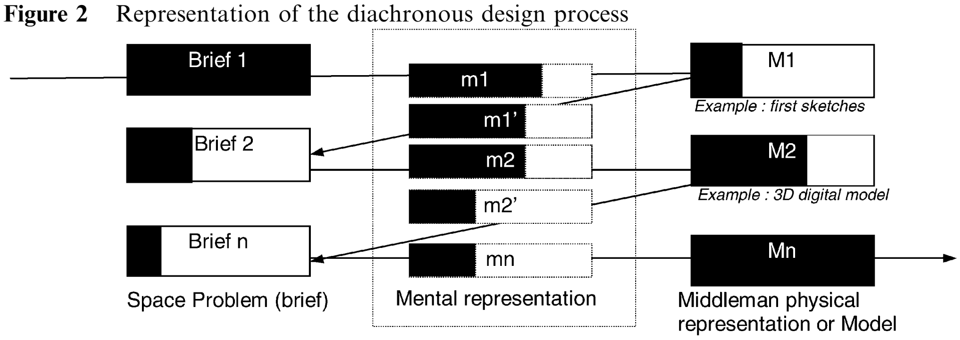
This part consists in the generation of new ideas and new solutions: by means of numerous mental images and from brief data and other information contained in any design project, designers can generate lexical data, digital or physical representations as 2D and 3D models. This requires the use of manual or digital tools, depending mainly on designer skills and on corporate culture. The generative part can be performed in accordance with various *applied creativity* methods and tools, which enable the generation of a large volume of ideas, possibly even including the points of view of other non-designer players (ergonomists, sociologists etc.).

The generative part of the design process intervenes at different levels, but the nature of the constraints and of the generated design solutions becomes more and more precise, with the transformation of imprecise data into dimensional ones. The integration of constraints is often considered as a reduction of the creative potential. However, certain constraints are sometimes considered as stimulating for creativity when they are open enough (in green design for example). The design process is characterised by Wang (1995) as a conceptualisation including an iterative cycle of mental solutions shown with a given problem, where:

- the selection of a solution or partial solutions enables the reduction of uncertainty, keeping in mind the necessary level of vagueness in modifications during subsequent phases (Lebahar, 1992, 1993)
- new constraints are then added while preserving shape and initial ideas
- the display of a new physical representation is going to generate new ideas and new solutions.

Abstract finalised information is transformed step by step into material information, by way of mental representations (transfer of information: darkened part in Figure 2). Mackay (1969) proposes a generalisation of the theory of information: "information is what forms or what transforms a representation." Here, a comparison can be set between the transformation of images and the representations generated by a message containing information. The information modifies the representations so communication can be measured by measuring these changes. A physical system supplies an external memory that modifies the problem of perception in a decisive way. The space problem (expressed goals) as well as the space solution (physical representations) are punctually made explicit by the production of signs, as with verbal codes in the case of the brief, or formal codes in the case of solutions.

Figure 2 Representation of the diachronous design process



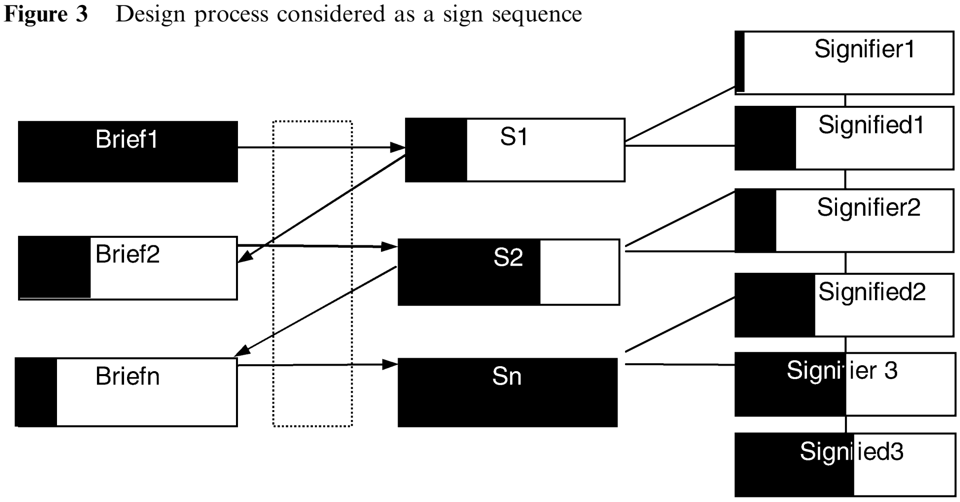
Adapted from Lebahar (1992, 1993)

Each cycle Brief1, m1, M1, corresponds to a specific state of representation. The evolution of the brief is defined by the transformation of ends in purposes, from purposes to objectives, from objectives to criteria, from criteria to more and more concrete technical specifications. The mental representations corresponds partially, as does the physical model. By the definition of every model in a set of attributes, the design process P is then characterised by the succession of cycles: Brief1M1 (A11, A12, A1n), Brief 2M2 (A21, A22 … A2n), Brief NMN (An1, An2, Ann).[1]

For the industrial designers corporation, a semiotic (which pertains to structuralist signs) point of view is very important as well: any process develops a system of information (objectives) in a signs system (solutions), of which recognition and evaluation allow the production of new signs. This point of view is also very relevant because a design representation constitutes an image of the reality. Everything can be considered as a sign. The semiotic approach by the IR allows emphasis on the importance of this phenomena. Signs emanate from the process of the mental composition of an imaginary object into an object readily comprehensible by anyone.

The design process fits into the global plan of the design process presented above (see Figure 3). The space solution, in the context of design activity, has in particular the passage of iconic signs (trend boards, graphic representations, ...) in plastic signs (3D physical models, ...). The space solution is established by a succession of modelled forms.

Figure 3 Design process considered as a sign sequence



Each new modelled form will progressively integrate more and more precise objects through more and more concrete models: this is called the *sign sequence* (Toyama, 1976). The space problem (ends expressed) as well as the space solution (physical representations) are punctually made explicit by the production of signs, as verbal codes in the case of the brief, and formal codes in the case of solutions. From a semiotic point of view, each representation is a sign composed by a *signifier* (a symbol or label) and a *signified* (the physical object or conceptual structure). Each form M1, M2, constitutes a *signified* which is bound by a known referent: the real object which has its own appropriate physical characteristics. The *signified* is linked to the referent by a relation of transformations (isomorphism, specific to the socio-cultural character of the recognition codes) (Groupe Mu, 1992).

3 Nature of the intermediate representations

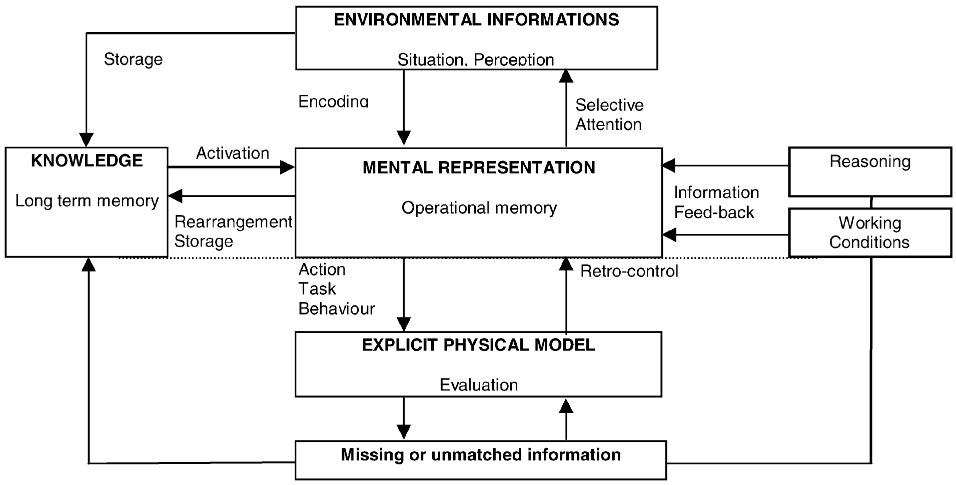
Nowadays, empirical research about the design process is beginning to produce reasonably consistent evidence on which to base models and develop theories (Gero, 2002). In fact, it is essential to explain the cognitive mechanisms through the representations in the case of the product design process, because the generation of representations is a main part of the design activity. Firstly, we define the general notion of mental representation according to the specific points of view of sociology and cognitive psychology. Secondly, we clarify the notion of explicit physical model with the particular case of the graphic representation, and illustrate this notion in the context of car design.

3.1 Definitions of the mental representations

According to Jodelet (1989), a social representation is socially elaborated and shared not only from our experiences, but equally from information, knowledge and models of thought which are received and transmitted by tradition, education and social communication. These social representations aim to organise, control our environment and to build behaviours and communications to establish a common vision in any socio-cultural group. In fact, they are action guides or reading guides. Considering that reality is socially built, then one of the most important characteristics to define the organisations lies on existing perceptions and on the consensually shared visions of the world. The cognitive consensus makes the organisational action easier (Ehlinger, 1998). In fact, this interpretation is very specific to sociology and couldn't be easily transferred to the field of industrial design. The socialisation of an object is more a fundamental property of marketing, but for the designers, the emergence of innovation often lies in contradiction to the recognition of an object by the majority.

In cognitive psychology, the notion of mental representation has two different definitions. In the first definition, the notion of mental representation is related to a set of cognitive elements (knowledge, opinions, believes, ideas . . .) linked to a given object (Ehlinger, 1998). The expression of mental schema is used as well, with the same meaning. This definition is very closed from the previous one in sociology. In the second definition, the notion of mental representation is more linked to the structures of stabilised knowledge which are stored in our long-term memory (see Figure 4). These structures are searched and temporarily activated in order to be used in a particular context for the realisation of a specific task. In the same way, a mental representation can be defined as "an incidental construction created in a given situation so as to meet the requirements of the current task." (Richard, 1990) For Piaget (1948), a mental representation differs from a perception. The first one either constitutes an evocation of objects that are absent at the time, or it doubles the perception of present objects, by referring to other images as well as to similar things. This corresponds to the building of the interpretation, with situated constructions (Gero, 2002) done in a particular context for specific purposes elaborated in a given situation and faced to the requirements of the current task (Richard, 1995). In other terms, Falzon (1969) speaks about an internal model elaborated by the subject to treat situations. This internal model results from a construction which is based on a data analysis of the situation and on the evocation of memorised knowledge. Dubois (2002) sets it against the concept of knowledge: knowledge is often conceived scientific, general knowledge and non contextual while mental representations are linked to the action of the subject, to the specificity of local situations and to their variability. On one hand, mental representations are contextual, temporary and evolve as soon as the situation is changing. They are, on the other hand, quickly available and constitute the operational memory.

Figure 4 Simplified model of human information system by Rasmussen (1983)



The term of representation in that sense differentiates the representations from the shared knowledge accepted in a specific field, as described in the first definition. This second kind of representations or knowledge are, in fact, *coloured* by our vision of the world and consequently more individual. If these representations are then stored in our operational memory, they will become knowledge or belief stored and organised in our memory. The content of the following paper is especially linked with this second definition.

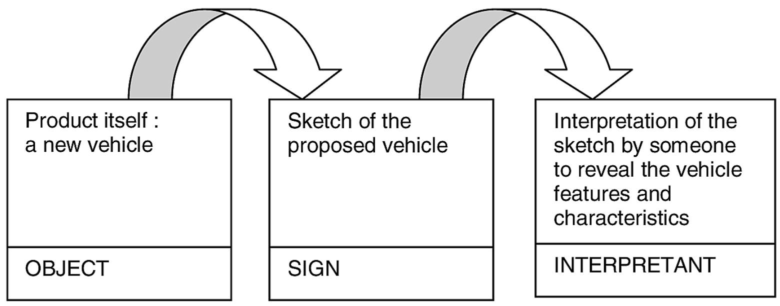
Cognitive processes are made by representations and treatments. As regards the symbolic information, representations are knowledge and interpretations, treatments are inferences and judgments directed to activities of understanding or to decisions of action (Richard, 1990). The function of representation consists in introducing a mental object producing a mediation between the subject and the world. At the same time, it is functional, by reflecting certain properties of the reality (those that the subject perceives of its experience of the reality, and allows to operate on its mental objects and thus to determine rules of action). The notion of operative image, introduced by Ochanine (1966), specifies the notion of representation by simultaneously introducing understanding or evocation and the operativity: "image of an object which adequately reflects its major distinguishing features and which is by the same way appropriate for human action/intervention."

This statement can be linked with the triadic relation of Pierce (1940). According to Pierce, these three components are:

- the object in itself
- the *sign* called the *representamen*
- the *interpretant*.

The *interpretant* is the dimension that gives sense to the correspondence of the two others, as does the IR (Figure 5).

Figure 5 Example of the three components of Pierce's triadic model



In relation to design activities, the initial representation which stems from the brief's treatment will gradually evolve as the uncertainty is reduced, due to the application of the acquisitive process of information, of interpretation (i.e. the construction of a representation which is compatible with expectations), and of the monitoring of the representation's construction by knowledge (activation and transfer of knowledge from long-term memory towards working memory) (Akin, 1978). A design problem is characterised by the simultaneous construction of the problem and the solution, with incomplete data and a multitude of solutions (Falzon, 1969). The designer gradually constructs an individual representation of the *problem – solution* space; the result of the latter will be in any case original, in that it will be particular and different from those that would have been produced by a panel of any experts in the field facing the same problem (Bisseret et al., 1988; Carrol and Moran, 1991).

3.2 Physical representations or intermediates materialisation: the particular case of the graphic representation

Physical representations or intermediate materialisations act as mediators between us and the world, both in execution between actions and the resulting changes to the world state and in perception between changes in the world and our detection and interpretation of the state (Norman, 1991).

Norman states that physical representations are cognitive artefacts: cognitive artefacts are artificial devices that maintain, display, or operate upon information in order to serve a representational function and that affect human cognitive performance. Two main aspects of cognitive artefacts are:

- the relationship between those aspects of artefacts that serve the execution of acts and those that serve the evaluation of environmental states with the resulting feeling of directness of control
- the representational properties of cognitive artefacts: the relationship between the system state and its representation in the artefact.

By this analysis, the physical representations enhance human ability by the *amplification of the cognitive power of human memory* and by the ability to be communicated because of their external form. It allows the cognitive effort to be distributed across time and people and to change the actions required of individuals involved in the related activity.

In the design process earliest stages, graphic realisations make it possible to fix a mental image as well as to render it physical, in a space that gradually gets closer to the product space. In a setting of a complex of actors, the physical object expresses an unambiguous representation of which the reading is immediate by all the actors, whatever their origin, skills or function. Besides its operative character, realisation thus entices communication. But before being shared, the graphic realisation is used to mediate directly between the person and the object: the artefact presents a virtual object upon which operations are performed to be reflected onto the real object. Actions are performed through a feedback mechanism involving both execution and evaluation phases. The *gulfs* of execution and evaluation refer to the mismatch between our internal goals and expectations and the availability and representation of information about the state of the world and how it might be changed: the *gulf* of execution refers to the difficulty of acting upon the environment and the *gulf* of evaluation refers to the difficulty of assessing the state of the environment (Norman, 1991).

Graphic representation in design can be alternately considered as:

- the realisation of a part of the space problem (state of evolution of the mental representation)
- a "set of means adapted to find solutions to the definition and to the object dimensioning problem." (Lebahar, 1993)

Graphic practice intervenes the upstream phase of the process, as soon as data and knowledge can be understood in spatial terms. It establishes a physical visual support for generating and structuring new ideas. Given its nature and particular position in the genesis and the progressive construction of the object, nowadays more and more research is undertaken on the sketching activities (Scrievener and Clark, 1994), with the hope of integrating this capacity into computer-aided styling tools. The resulting realisation stems from the immediate fixation of a mental image dictated as a whole in sketch form. According to Lebahar, the first graphic performances have to be "quick enough and limited to the information necessary to solve the predicament, by expressing a minimum set of solutions on the object to be designed."

Elaborated forms stem from the:

> "graphic encoding of the constraints which are held in the space problem, as well as the choices that come from the anticipating mental image of an overall picture and finally, from the anticipations of the process. These forms should ensure that the solution research can still be undertaken without interrupting the design process." (Lebahar, 1993)

In order to do so, the designer keeps the volumes he creates vague as long as possible, the strategy being to specify at the right time. The representation is precise enough to express the problem and indistinct enough to enable changes that will not altogether question its very existence. This explains the *elastic and distortable signifiers* of its *composition*. For instance, freehand drawing is an effective method of simulation where each graphic simulation is an operative reversible image. This simulation uses incomplete figures as graphic bases of simulation, which are indistinct and possibly distorted. It also uses a system of signifiers (indications, symbols, icons and plans) that are appropriate for the combined evocation of concrete objects (inspiration sources, whole object or parts of it), as well as of abstracted objects (classes of problems). Thus, research and gradual definition of the object are made by the realisation of graphic representations, which will be increased in accuracy and in information as a result of an *assimilation – accommodation* cycle. The quest for certainty is carried out by fixating certitudes, variables, coordinating different point of views and dimensional coordination (by comparison). In other words, graphic representations make possible the display and preservation of symbols.

The manual realisation of sketches is a means to progressively reduce uncertainty. It enables contemplation of eventual solutions regarding issues such as aesthetic, ergonomic, spatial, technological and economic features. In this sense, "the manual drawing makes it possible to write and erase at the pace of the thought, thus leaving traces of the mental process of the reasoning." (Lebahar, 1993) The latter is plastic and appears to be indispensable in the phases of volume search (3D thinking). This gives birth to an analogical relation of the drawings with the concept, thus enabling to manipulate them as *transformable mock-ups*.

To conclude, the form of representation used by the graphic representation carries great weight in determining its functionality and utility. The choice of representation is not arbitrary: each particular representation provides a set of constraints and intrinsic and extrinsic properties. Each representation emphasises some mappings at the expense of others, making some of them explicit and visible, while others are neglected and the physical form suggests and reminds the person of the set of possible operations. Appropriate use of intrinsic properties can constrain behaviour in desirable or undesirable ways (Norman, 1991).

3.3 Notion of shared representations

Current interest in the design of computer interfaces has forced consideration for the role of real tasks and environments, and therefore for groups of cooperating individuals, for artefacts and culture. Even though individuals build different representations of a same artefact, the social life in which they are involved during the design process induces them to communicate with each other, to influence each other, and to share information. An individual's knowledge has to be shared with other people in order to be diffused (Nonaka and Takeuchi, 1997). That point constitutes the base of the culture which can be seen as a *system of shared knowledge or shared meanings* (Goodenough, 1971). Collectives or organisational representations are mainly described as shared representations. However, Ehlinger (1998) indicates a questioning of the existence of shared representations within organisations, in spite of the existence of interaction and communication mechanisms.

The notion of sharing can also be seen as the ability to communicate one's own representations and to understand those of other people, to introduce diversity in the teamwork and so to arouse confrontations and fruitful questionings.

Knowledge and belief exchanges have to be emphasised, as well as the product of these exchanges, more than their sharing in the sense of appropriation of similar beliefs. As such, the concept of organisational representations which we use here must not be understood as a synonym for shared representations, but rather as a sociological cognitive process which allows the members of an organisation to make decisions and to act together.

According to Nonaka and Takeuchi (1997), there cannot be creation of organisational knowledge without exchange of individual tacit knowledge (specific personal knowledge in the context, belief and concrete knowledge). Tacit knowledge cannot be communicated easily because it is mainly acquired by experience and not easily expressed by words. Tacit knowledge clarifies that feelings, sensibilities and mental models of individuals must be shared in specific contexts to build a mutual confidence, only the transfer of information not having enough effect. To reach this notion of tacit knowledge, Baumard (cited in Ehlinger, 1998) proposes several methodologies of access to tacit knowledge, such as the strategies of confrontation, against-expertise or wear methods.

The notion of sharing does not mean that the organisation's members adhere to common representations, but that the group leaders adhere to it. For the others, it is more about consensus or about mutual understanding which allows the decision taking and the possible collective action. The term of sharing is ambiguous as well, *meaning to possess in common* as well as *to distribute in equal parts*. So from the various manners of the "shared term, it seems that mental collective models make reference to an identical cognitive representation for the group (i.e. common knowledge), as well as a distributed configuration of representations (i.e. any stepping)"; or in a configuration of representations which confirm each other between the members of a group (Klimoski and Mohammed, cited in Ehlinger, 1998).

Most recently, the concept of Design Intermediate Object (DIO) appeared in the engineering design community (Mohaved-Khah et al., 2003; Vinck and Jeantet, 1995) in the context of Computer Aided Supported Collaborative Work (CASCW). The results of the studies in this field concern the DIO, which contain internal elements (entities) associated with external elements (relations), which are taken as coordinators and indicators of design project progress. The centre of interest focuses on collective computer systems for the exchange and the sharing of the IDO with the aim of defining the classes of entity and relation of an DIO (Mohaved-Khah et al., 2003).

3.4 Illustration of the representations levels: the example of car design

The preceding considerations about the representations in the design process constitute a synthesis of the actual works from a theoretical point of view. The purpose of this section is to illustrate the theory with more practical reflections coming from the field of car design. We will present various ideas resulting from our experience in the automotive sector, completed by the point of view of several professionals of this sector.

In architecture, the operative representation of the *problem – solution* space refers to a set of normative references (Prost, 1992), which stems from the designers active cultural collection (signified references and signifiers: archetypes, proportions, sources of inspiration, personal experience and spatio-temporal position) and are projected in the object. The same phenomena happens in car design, where designers assimilate the brief's data from the outset of the project. During the brainstorming phase, their mental image integrate forms associated to a type of vehicle and often to a brand. Each designer then orally describes her or his own representation to the others, which ultimately results in the verbal description of a common representation (see Figure 6). The language used often refers to objects or to human beings by analogy. Thus, individual mental interpretation is beginning to appear on paper. The designers become so impregnated with strong verbal and visual codes (type, brand image, target consumers …) that they can materialise with notes or sketches. The latter, in turn, will be completed by an informative watch, which will enable the designers to formally imagine the concept. In the first sketches elaboration, mental representation is characterised by a succession of global and vague[2] images of the concept (outline, lines, proportions) that go hand in hand with a particular atmosphere, for example a *hostile city*.

Figure 6 Transformation of the representation levels and their function in the traditional process

The vehicle is thought of as if it was in movement, denoted by a dynamic tension. At this stage of the process, no precise geographic environment nor any detail are imagined. The global shape, which leads to a structure and the basic lines are only envisioned at this point. Here, the stylist is the unique actor able to estimate the gap between his mental representation and the first realised sketch. To reduce this mismatch, the stylist attempts several endeavours until he finally reaches satisfaction. The succession of mental representations expresses itself partially through the succession of drawn sights (3/4 left, perspective, 1/4 front, 3/4 right, 1/4 rear and orthogonal sights). According to this chronology, one might think that the designer imagines a concept that revolves on itself in a movement which is here punctuated by mental and graphic fixations. The undertaking of numerous different sights thus enables oneself to fully imagine the vehicle. This revolving is dictated by a compromise between the informative need, which is necessary to completely imagine the volume and the convenience to construct graphic representations. Most designers say they mentally visualise various images prior to the drawing of the first sketched lines.

A famous car designer in the USA, Edson Armi, wrote his point of view about the traditional design process. According to him:

> "the automotive designers, in order to have control on the complex sculptural forms on which they work, imagine forms in the mental space while they conceive them. This simulation and visualisation of the imagined real space establish the field in which the *conceptual battle* takes place. It can be said that the mental process goes back and forth in this space, as if the designer was trying to grasp the latter mentally as well as physically. It also appears that the space itself seems to undergo a distortion, a blur, as if ideas oscillated through itself." (Edson Armi, 1991)

Kim, another car designer, adds:

> "the visual thinker (. . .) makes several drawings, which are quickly drawn. Searching and forming an idea does not correspond to a static image. Besides, ideas are rarely grasped in a faithful representation, they change and disappear." (Kim et al., 1991)

According to Birtley (1998), during the realisation of sketches the space problem corresponds to, "an objective which the designer is going to estimate in an almost subconscious way": it is only by the means of the interpretation of physical visual messages that the designer knows that the image corresponds to the one he had originally intended to make. Kim puts forward the notion of intuition: presentiments, feelings and intuition are major steps in a field which is usually approached in small steps. He underlines that intuitive capacity, which increases with experience, is crucial at this stage. Car designers try to find innovations in researching something *bizarre*. To this end, they tend to avoid any clarification in the earliest phases of the design process, or certain constraints as well. If the mental representations were to precisely defined, they could be blocked. It is then by this back and forth process with many readjustments, that they will be able to integrate more and more constraints. The designer can eventually explain this intuitive process à postériori.

These considerations build a common corpus among designers, of which holistic activity is connected to a wide action of watch (Tovey, 1992, 1997). During the making of the final sketches, mental representation consists of a succession of accurate and detailed images (shape, constituents, aspect, impressions linked to the environment, coloured background or detailed environment of the vehicle with individuals), which offer more acuteness and a more realism.

> "In spite of a precise definition of the concept by means of sketches, the interpretation of the 3D sketches can only be mental, thus without measurement, and subsequently entails inevitable exaggerations during the realisation." (Birtley, 1995)

During the 3D modelling, it is only when all the surfaces of the model are clearly defined, that the stylist exactly imagines the details and constituents that had only been represented until then by simple lines of outline (for example bumper lines). Mental 3D images play an important part in the decision process and advice of the stylist to the modeller. The natural capacity of the modellers to think in 3D and to express their own interpretation is an undeniable help. Satisfaction is never absolute or unanimous in regards to the adequacy between expected and produced images.

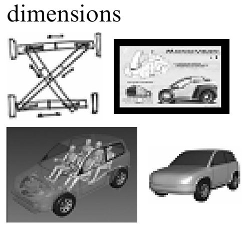
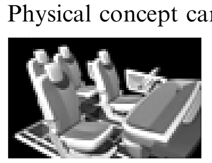
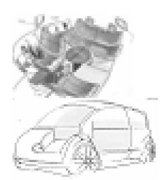
4 Case studies

Our understanding related to the role of the intermediate representations in the design process has been based on our experience in collaboration with European companies, mainly on three case studies in the field of car design coming from three different design projects where we can find a common ground as well as specificities (see Table 1). In this way, their theoretical contribution will be presented in Section 4 under the form of a common model. The field of car design constitutes a very closed circle. Consequently all of these projects will be partially illustrated because of confidentiality.

Table 1 Case studies (Bouchard, 2003)

	Project 1	*Project 2*	*Project 3*
Simplified brief	Design of a new modular platform	Design of a new modular interior vehicle	Design of a new cockpit by wire
Length of the project until prototype	1 year	3 years	2 years
Main involved skills	Ergonomics, design, innovation, architecture, marketing		
Overall creativity method	Functional analysis and interdisciplinary brainstorming based creativity session	Cards based interdisciplinary creativity session	Cards based interdisciplinary creativity session
Strong input constraints	Innovation Architecture	Design Innovation Marketing	Ergonomics Architecture
Input data for the creative session	Keywords related to consumer values, lifestyles and activities in order to identify the new potential silhouettes of vehicles in the future. Illustrations of the historical evolution of automotive vehicles platforms	Cards from marketing Cards from ergonomics Cards from colour and trim Cards from design Cards from architecture Cards from product Cards from equipments	Cards values from marketing Cards use from ergonomics Cards solutions from innovation Cards functions from engineering

Table 1 Case studies (Bouchard, 2003) (continued)

	Project 1	*Project 2*	*Project 3*
Methodological tools for the creative session	Method: Generation of concept cars and technical principles related to the corresponding silhouettes, modularity and functional analysis. Specific tools: *Purge* *Brainstorming* *Scenarios of use* *Functional analysis* *Concepts generation* *Revision oriented towards the specific professional fields*	Method: Generation of concepts of interior vehicles with customised parts. Specific tools: *Concepts generation based on cards integration in small workgroups* *Revision oriented towards the specific professional fields*	Method: Generation of concepts of interior vehicles integrating by-wire commands. Specific tools: *Concepts generation based on cards integration in small workgroups* *Revision oriented towards the specific professional fields*
Output data for the creative session	Concepts of vehicles Concepts of technical platforms	Concepts of global vehicles interiors	Concepts of vehicles cockpits
Intermediate representations	Roughs with global keywords Sketches with special fields oriented keywords of concepts Digital images of concepts and dimensions 	Roughs with global keywords Sketches with special fields oriented keywords of concepts of vehicles interiors Digital images of concepts and dimensions Physical concept car 	Roughs with global keywords Sketches with special fields oriented keywords of concepts of vehicles cockpits Digital images of concepts and dimensions Physical concept car 

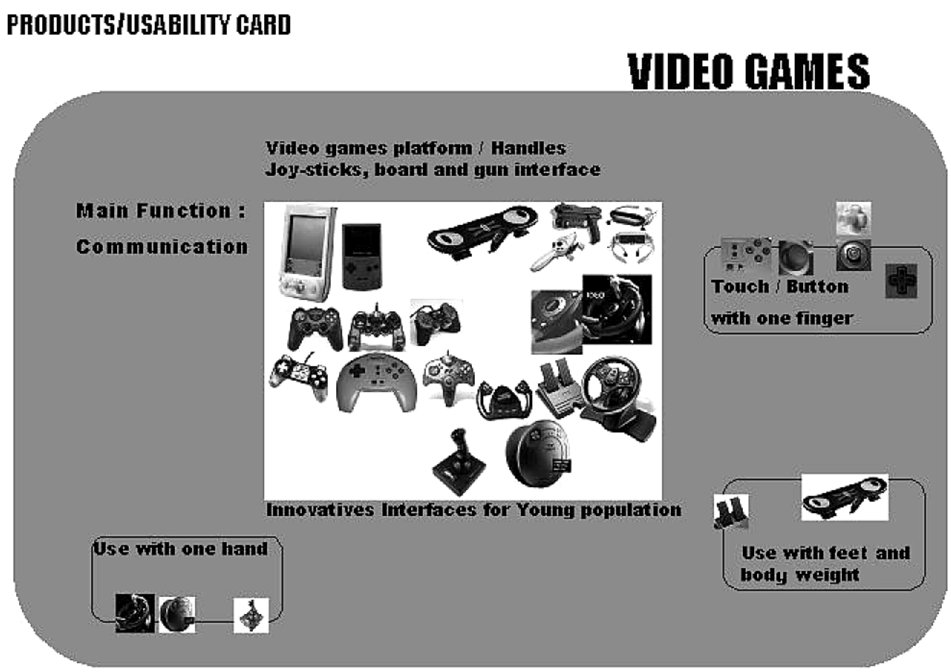
4.1 Project 1

This project aimed at developing a new modular platform for automotive vehicles, in order to meet the needs arising from the new shapes of innovative vehicles. At the beginning, the creative session was not supported by any object (physical representation), except by the people themselves. In fact there was no preparation from the different professional fields. After concept generation, people participating in the creative session characterised these concepts according to their specific professional field. This level of concretisation by professionals is necessary at this stage for further exploitation of the results. Previous experience showed that if concept generation is not followed by field characterisation, the passing from creativity to innovation is not possible.

4.2 Project 2

This project was a specific innovative experimental project with the intention of developing a concept of interior vehicle partially dedicated to serial production. It was especially oriented towards the generation of customised parts. The innovative side of this project was centred on communication aspects. There was a preparation phase before the creative session where each specific professional field had to produce corresponding representations in the form of cards, able to show their most recent innovations and fields of influence. These representations had to be very simple and easy to understand by the other corporations. In that way, each corporation had to prepare an explicit representation of his own point of view on innovation in order to share it during the creative session. Cards have a playful effect, recognised for its efficiency during creative sessions involving sometimes conflictual debates between different corporations. Each card was composed of visual and lexical contents allowing the description of an universe (Figure 7). The use of visual matter, such as illustrations and photographs, and of simple keywords, answered the need for very simple representations.

Figure 7 Example of products/usability card as input for the creativity session in car design



4.3 Project 3

As in the preceding project, this project was a specific innovative experimental project with the intention of developing a new concept of interior vehicle partially dedicated to serial production. As in the preceding case, cards were produced by each professional field in order to have some popularised matter to share during the creative session. This project was initiated by ergonomics. The creative session came later and it was difficult to realise a phase of divergence, because some people already had solutions in their mind. The maturity level on the project differed from person to person. The specific use of cards helped to bring people into line.

4.4 Common ground and specificities

The three projects were supported by applied creativity methods. These involved many professional skills like ergonomics, design, innovation, architecture and marketing. These methods enhance innovation by way of a multidisciplinary approach, based on communication and allowing the generate and memorisation a great number of ideas with the in-real-time solutions accepted by all the different corporations. The use of cards is relevant for the communication between people of different professional fields. This new representation plays two major roles: makes for easier communication between different professional fields involving conflicts of constraints and stimulates collective creativity. The comparison between the first project (without any cards) and the two others shows that the convergence phase is more difficult in the first case. A long time is spent in solving misunderstandings coming from the specific jargon of the different corporations. These misunderstandings increase the notion of conflict of constraints.

The advantages of the formalism in this case is very clear. A design project related to a complex product, like an automotive vehicle, requires many skills. The communication among these different skills plays an important role in innovation. In each specific professional field, people propose innovations based on a state-of-the-art. No other corporation would be able to propose an innovation in this specific field. The global innovation side of a concept car lies in a good integration of the different skills very early in the design process, following the way of concurrent engineering. Concurrent activities between the different corporations need to be supported by specific representations in order to solve the language and conflicts of constraints problems.

5 Role of the intermediate representations in the design process

As presented, the design process can be seen as an information process, as a set of successive cycles of realisations of the design information with the manipulation of more and more concrete representations of physical objects until the final solution. The realisations mentioned here concern the formalisation of input data in the form of intermediate mental and physical representations from the technical specifications. In this information process, the design space problem is progressively transformed into a space solution. IR and materialisations are intermediate objects in two ways: the active and constructive perception of the environment and the elaboration of answer and action (Avenier, 1997). In that sense, the communication impact of the explicit representations between the different actors is also crucial.

Through the preceding case studies in the field of car design, we propose in Figure 7 a common model of the design process with its explicit representations. The corresponding projects were mentioned as research and innovation projects in the company. This kind of project aimed to prepare innovative concepts for future vehicles. These concepts were centred on the onboard life in the cockpit. They had mainly to take into account comfort and pleasure. The final outputs are demonstrators (internal concept cars), which have to pass by obtaining intermediate results in the form of sketches and intermediate models. The purposes of the demonstrators are the following:

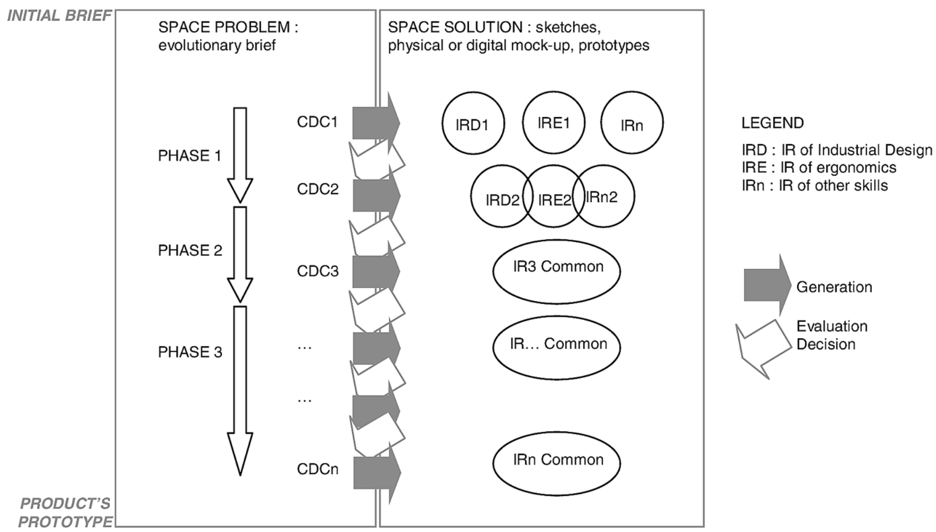
- to emphasise the proposals of new performances
- to make a synthesis of all the innovative work in the company
- to consolidate the methods of consumer and user centred design
- to provide a support for the diffusion of knowledge and the evaluation of the synthesis.

Both of the projects that allowed us to build a common model of the collective design process and its representations, were centred on interior design, emphasising mainly the ambience design and the usability, and other skills, such as man machine interfaces, interior equipment design, and synthesis.

In fact the different actors in the design team seem systematically to have to go through the three following phases (see Figure 8). Our purpose is finally to produce explicit representations at least at the end of each of these phases, in order to facilitate the communication and appropriation process concerned in teamwork. These three phases are the following:

- Phase 1 – *impregnation*: the building of specific explicit skill representations related to the initial brief: we illustrated our example in car design with the following skills – design, ergonomics, and so on.
- Phase 2 – *integration*: the initial integration of skills through a discussion about the explicit skills representations of preliminary concepts and their mutual validation.
- Phase 3 – *implementation*: the building of a common inter-skills representation where the integration of details will follow a more or less synchronic process between the different skills.

Figure 8 Evolution of the IR through the concurrent design process



5.1 Phase 1: impregnation

The initial brief is formulated around a common goal. Where the context deals with a complex design process, as in the field of car design for instance, the first mental and physical representations are more related to a single skill. In other terms, the first steps from the initial brief involve specific skill representations (design representations for industrial design IRD, usability representations for ergonomics IRE, technological representations for engineering IRT and so on), which have to be formalised and made explicit before building common representations. At this stage, we experimented with several paths, and found a very useful approach based on the preparation of the second phase with appropriated inputs. These inputs were the different specific skills representations translated in the form of cards for the creativity sessions, in a unique format with simplified contents such as keywords and illustrations. The illustrations concern watch inputs as well as the innovative productions of the different skills. The specific skills cards are helpful for the following processes involved in the second phase.

5.2 Phase 2: integration

After defining the brief, the global design takes place. This phase is crucial because it corresponds to the inter-skills communication based on a collaborative work and more particularly on collective creativity. Actually the cooperation process is a characteristic of the emergence. Each skill group presented their own point of view, with skills representations that are inevitably coded. Decoding is done between skills language by way of an organised creative process (the creative session), using the cards which have been produced in the preceding phase. The applied creativity process allows a privileged open-minded context for compromise, communication and finally the elaboration of a new shared representation between the different specialised skills (common representations). The new convictions generated during the interactions are re-appropriated by the individuals, in order to find out progressively a new common representation through the global design of new concepts. The challenge is here to build a common ground based on a common vision of the design process to achieve the goal of new product development. To this end, the organisation becomes a *learning organisation* to attain the elaboration of a shared vision (Senge, 1990, cited in Ehlinger, 1998). But the end result is not obtained in summing up the results provided by each skill. It takes place in a more complex move which results from the confrontation and the adjustment of the different skills, bringing in heterogeneous constraints. The shared experience allows any actor to project themselves in the thought process of other actors, through direct dialogue, to reach the common goal. Conflicts and disagreements will push the different members to give a new sense to their experience. Richness and, in this sense, originality come from the divergence of points of views as well as the ability of the actors to rebound mutually on the ideas of each other in real time. Finally a shared vision leads to a certain degree of compromise. In the case of a design *plate-form* organisation, the compromise comes very early in the process. The advantage of the new common representation is that it is instantaneously decodable by all the actors

5.3 Phase 3: implementation

In this last phase, which is more linked with detailed design, the common representation RI3 will be progressively implemented by the team until the production of a final solution, through several refinement phases, by refined briefs, and by evaluation, selection and implementation processes. The implementation corresponds to a skills and project oriented deepening of the common representation. The end of this phase corresponds to the 3D validation of the detailed concept. The early, possible conflict, phases will finally tend to a progressive consensus with plenty of discussions. In this way the risk of errors coming from misunderstandings between the different skills (as in a more sequential process) becomes reduced. New specialised skills have to be involved at this stage, such as transverse skills or hybrid skills. The skill of engineers/designers, for instance, led in the projects because engineers/designers have a more pragmatic point of view than traditional designers. They are more turned toward the development phases and can be very creative as well. However, both skills are necessary, the traditional and the new. This point sometimes becomes problematic because of certain actors who fear to see themselves dispossessed of their own functions, or of their status.

In order to reduce costs and delays with more variability for personalisation, it is necessary to apply new approaches too, based on the collaborative work and supported by New Technologies of Information and Communication (NTIC). These evolutions towards innovation have to be reinforced by high management levels and require fundamental changes and acceptance in the company's corporate culture.

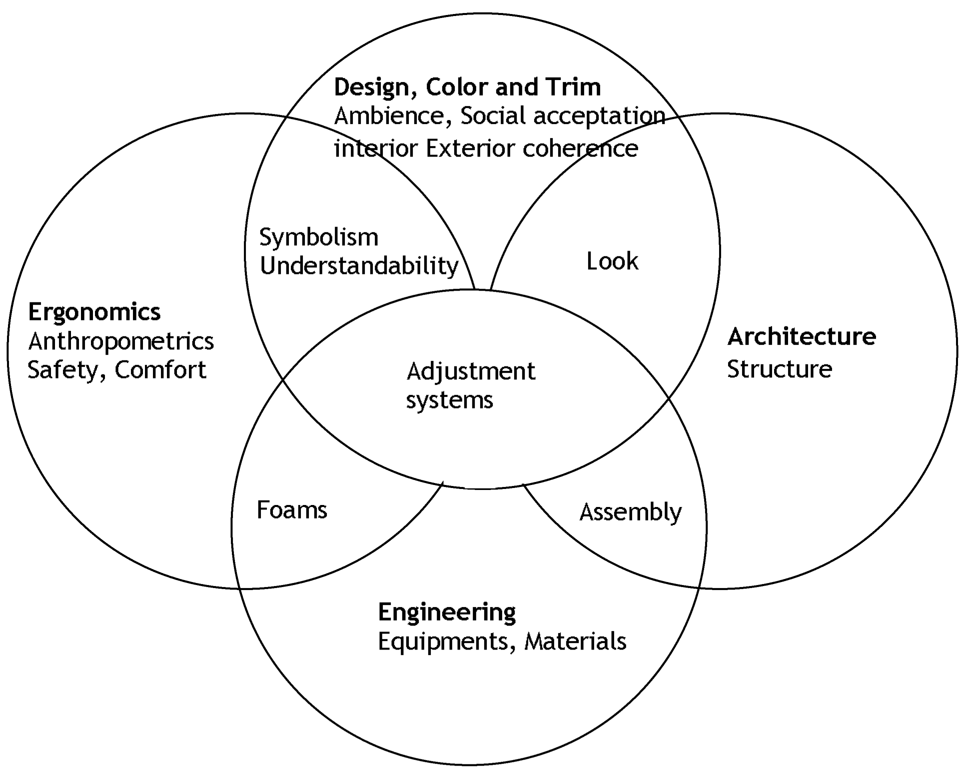
5.4 Discussion

Each of these phases involve an iterative conceptualisation process, with many go-and-back loops. Finally it is essential to organise the innovation to rationalise design, but in practice there is much uncertainty in the conceptualisation process. The mental images are indispensable in imagining the two correlated spaces with constraints and without constraints, but they don't reflect all the richness of the stage in which one is. Sketches (digital or manual) are the representation objects which enable more dynamic progression. IR allow to make the thought process more explicit: they clarify by their explicit character the different phases of the design process, and support in this sense the collective work.

The links between the different points of view of the various skills can be more or less conflictual. The divergence and convergence between the different points of view will emerge explicitly by the use of common representations. The explicit common representations (or Design Intermediate Objects; DIO) depend on different dimensions, such as their autonomy (faced to the other DIO) and their concretisation level (more or less detailed design). The concretisation level evolves until the final implementation phase, while the autonomy between the different skills representations becomes more and more reduced.

As we can see in the following example (Figure 9), the different skills – *ergonomics, design, etc.* – couldn't be worked separately, and the IR are the only relevant supports for communication between the different points of view and skills, for collaborative building and implementation.

Figure 9 The different points of view of the various skills related to the seats in interior vehicle design



6 Conclusion

In the traditional design approach, different skills were acting relatively sequentially in the collective design process, with very costly iterations in time/energy. In the car industry, a new concept of design, platforms, was introduced to solve the early communication problems between different skills. Platforms are:

> "geographic places regrouping the various actors during the project's reviews, where various physical models are exposed to quickly show the problems, and to stimulate creativity while generating a strong constituent of collective learning." (Midler)

Midler explains how the car design project managers ensure a management by projects, which supports according to him:

- the acceleration of informational flows
- the resolution of the problems
- the optimisation of the assignment-use of the resources.

Simultaneous engineering allows the anticipation of problems by the simultaneity of points of view, and so avoids delays and additional costs due to late modifications (reduction of the times of development from 30 to 50%). This innovative approach is based on a logic of compromise by the definition of common objectives among the various partners, and is given the name 'concurrent engineering'.

While designing a new vehicle, the treatment of the various conceptual or technical objectives on a hierarchical basis is all the more difficult as they vary according to the skills point of views. In that process, physical representations play an important role in design performance, because of their role in enhancing cognition, as well as their representational format and because of their communication impact in design teams. They provide an earliest consensus between the different skills, allowing consequently a reduction of costs and delays. Models constitute common explicit representations which are progressively developed in an individual – collective cycle, with the possibility of simulation and adjustment of the action. The explicit IR bring a formalisation of the interactions to the interfaces (assemblies, style, manufacture ...), and make explicit the problems ignored during the sequential process. The modifications take place before the execution of these representations, thanks to a compromise induced by simultaneity.

Major occurring problems in concurrent engineering organisation are linked to its superposition with the traditional hierarchic organisation. The managers have to reinforce communication aspects to facilitate transition within the existing structure. Besides, communications problems linked to the variety of expertise persist at the beginning, and generate conflicts. The use of physical supports allows thus to improve decision making aspect according to global goals and to reduce risks, while favouring innovation.

To our mind, the ideal conditions to support the emergence of this approach and to diffuse it in the company concerns the relevant association between applied creativity methods and IR, allowing improvement of the generation, evaluation and decision processes in design, both during specific skills phases and collective ones. Even if the creativity sessions allow the provision of systematically early generated shared IR, difficulties often remain in the evaluation and formalisation processes supporting decisions. IR must help in the evaluation and decision phases too. The future of the IR should actually move towards these two phases of the industrial design activity.

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Notes

[1] We can find models M1 sketches, M2 model 3D in the scale, M3 final 3D models, M4 digital models, M5 produced prototype, M6 produced pre-serial, M7 produced serial, as well as for the global concept, that for subsets or finally parts. Attributes vary according to the type of model. In every case they send back to internal characteristics of the made object (materials, process), and external in reference to the utility and to the features of the end product.

[2] According to many designers, their premature mental image of vehicles or forms/shapes are very vague (and subject to fluctuation). They are able to see a real image but the latter fluctuates. The shape and details change just as would a myriad of diverse thoughts. What is fixed/written on paper might be a mixture of these different thoughts.