

IMPROVING COLLABORATIVE DESIGN TOOLS IN AUTOMOTIVE INDUSTRY: A CASE STUDY

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Abstract

This paper presents a case study about improvements of collaborative design tools in the automotive industry. The objective is to propose some specifications for the development of a particular information system. This system, integrated into the designers' CAD environment, shall support a method to integrate customer requirements into the design process. The problem of building up a project memory, in order to keep track of the requirements and their evolution (situated in their initial context) is also taken into consideration.

The investigation shows the importance to find connections between different categories of agents, each of them having different rationales, objectives, representations, languages or tools.

The results presented in this paper are the outcome of a field research carried out in a huge car manufacturer, in engineering design teams.

Keywords: Customer requirements, project memory, collaborative design, ergonomics

1. Introduction

1.1 Industrial context

In car manufacturing as in other industrial sectors, intense competition forces companies to find ways of differentiation to approach better customers' demands, and to win new market share, or at least maintain it. The challenge is to first capture these demands and then to translate them into operational requirements, to finally integrate them during the product design phase [1].

After a first change of perspective with the emergence of concurrent engineering and particularly the implementation of product-process integration principles, car companies now face a new challenge: product-process AND customer requirements integration. These requirements, like ergonomics, passive safety, acoustics or thermal comfort, are mainly cross-disciplinary. By essence they are covering a large variety of technical domains, which are frequently spread among different departments. In this context, it is a big challenge to fulfil properly the customer requirements.

The organizational choice, made in the case of our car manufacturer, is to create a new co-operating team, whose role is to represent "the voice of the customer" during each step of design, from the beginning of a vehicle project until the industrialization. The participants of these teams are called "Customer Requirements Pilots" (CRP). They are an interface between the project teams and the "job support entities". These job support entities define the general operational requirements coming from regulations, safety and technical standards (e.g.

ergonomics standards in our case) and also the translation of customers' demands into internal and technical specifications. The activity of the CRP is quite recent and sometimes they lack of know-how and experience.

In our case study, we restricted our investigations to the ergonomics CRP. But as ergonomics is one of the most multi-disciplinary departments, our method can easily be extended to others CRP activities. Ergonomics CRP have to adapt general requirements, defined by the ergonomics department, to the qualitative and quantitative specifications of one particular project. In addition, they have to ensure that the design allows reaching the ergonomic targets.

1.2 Virtual assessment

Like any other industrial manufacturing sector, car manufacturing requires the use of sophisticated and powerful engineering tools, like CAD-CAM, PDM (Product Data Management), computer assisted-production management, simulation systems [2]. More specifically, the phases of product-process design are increasingly based on virtual and computational technologies. Industrial design, but also assessment, validation, simulation and finally - the most significant of all - decision making, are at least computer-aided, and sometimes fully computer supported. For costs and production time reasons, physical mock-ups are more and more replaced by digital ones, particularly in the early stages of design (The "fuzzy Front End" [1]) when the number of design hypotheses is high.

In this context, every agent¹ on the vehicle project, and not only CAD designers, use virtual and numerical objects as a support for their daily activities. While digital mock-ups are natural objects in the aerodynamics or in the crash and passive safety departments, it is not the case in the ergonomics department. As the objectives of the ergonomics department are to ensure that the product (the vehicle) suit to human bodies and gesture (Physical ergonomics) and allow human comprehension (Cognitive ergonomics), the CRP activities are widely connected to perceptual experience. Thus the work of the Ergonomics CRP is not only to adapt general requirements to the specificities of a given vehicle project, but also to adapt perceptual requirements to a virtual assessment.

Digital Mock-up Reviews (also called DMR) are significant milestones in the car development process. During these DMR the vehicle digital mock-up is the main representation shared by the participants of the review.

During these meeting points, the utmost issue is to give every agent, and not only the CAD designers, the possibility to discuss and to argue on the digital objects. This requires providing every agent with an adapted point of view on the project [3] and translating their recommendations into intelligible language for the CAD designers [4]. Then, provided with these proposals, recommendations and assessments, the designer will work as far as it is possible on the integration of all the demands for the next DMR to bring out the incompatibilities.

1.3 Industrial issue and research challenge

This context underlines two major and tightly bound issues in the design process, i.e. information sharing and information capture.

¹ An agent is considered here as a participant of a design project that acts as a specialist of a given domain (i.e. ergonomics specialist, CAD designer, structural engineer, etc.)

- Intelligible information sharing:

The issue is to find a common language or a possible translation between the CAD designers and the ergonomics CRP. The objective of information sharing is twofold:

On the one hand, CRPs need to obtain some information from the designer, which are embedded in the digital mock-up, to assess the ergonomic aspects of the project. The term of “items of information” covers many kinds of objects obtained from extractions and manipulations of parts of the digital mock-up using ergonomics methods and principles: lists of dimensions, 2D or 3D views with sections, projections, abacus positioning, etc. The main difficulty here is, that needed information are not directly related to the designers’ work - it requires an extra work for extracting and compiling the data. This is why the extractions are usually done quite late, if not at all. Other difficulties are due to the recent creation of the CRP activity and to the fact they have no command of CAD: therefore their needs seem not well structured to the designers.

On the other hand, the ergonomics proposals consequently to an assessment have to be relevant and meaningful for the CAD designers, and provide concrete elements for their work. In other words, CAD designers and ergonomics CRP do not speak exactly the same language. The easiest way to overcome this mutual incomprehension is to establish and underline the necessary links between an ergonomic proposal and the consequences on a requirement or a service. This is the aim of the Design Rationale capture and leads to the second issue.

- Information capture:

In order to establish the connections between proposals or warnings on the ergonomic requirements and the resulting ergonomic services, which correspond to customers’ demands, it is mandatory to capture the rationale of the design. In our case, this can be represented, in a first approach, by the history of the ergonomic assessments of the design, which are arguments and instances of specific ergonomic states in the progress and development of a vehicle project. Our aim here is to allow learning from past designs and cases.

The major goal of our work is to provide the two kinds of co-operator (ergonomics CRP and CAD designers) with an efficient point of view on the project, and to share representations of the problem, in an intelligible language for each participant.

2. Case study

2.1 CRP activity: driving the design by customer requirements

Usually, one ergonomics CRP (like any other CRP) has the responsibility to follow the ergonomic aspects all along a vehicle project. This responsibility is divided into two distinct moments during the project:

- At the very beginning of the project, they have to determine the quantitative ergonomic specifications, a translation of the qualitative requests made by the advanced marketing department, which defines, provided by the ergonomics department, the goals of the new car project with the help of general ergonomic specifications.
- Then, all along the project, they verify whether the specifications are respected and, if not, they have to inform designers and/or the project manager of the impact on the customer requirements and to give recommendations for the evolution of the digital mock-up. Thus they try to drive the design by the customer requirements.

In this case study, we particularly focused on the assessment of the physical ergonomics. Presently, the CRP organises the analysis of the ergonomic specifications into reports, which are subdivisions of more global customer requirements, like car accessibility or habitability, front or back visibility, ergonomics of the pedal and gear mechanism, etc. These requirements are directly perceptible by the customers.

These general requirements are subdivided into smaller parts, the reports, which encapsulate rules and methods of analysis. For instance, car accessibility is divided into front and rear car accessibility and accessibility in restricted area. In addition, rear car accessibility is itself subdivided into: type sedan or coupe (no back doors), etc.

Today the ergonomics department defines several hundreds of specific ergonomic dimensions with measuring methods, and many other objects like abacus and calipers. These objects and methods have been grouped into these reports (subdivisions of general requirements) by the ergonomics CRP. This way they have at their disposal an analysis framework of intermediary size: a report is “eloquent”, not like a sum of dimensions, and is therefore “operational”, unlike a global requirement.

More precisely, a report consists in a specific set of CAD 2D and/or 3D views of some selected parts of the digital mock-up. The report mentions ergonomic dimensions, with the placing of ergonomic objects in the context, in particular the standard dummy - that represent the average size of people - in a given position. It may also contain some abacus from the ergonomic department (see example fig. 1).

2.2 An example of an ergonomic report: “longitudinal front car accessibility”

The example presented in this section is voluntarily simple, but it is a good illustration for the issue of information sharing and capture, and the relationship between the two kinds of agents: designers and ergonomics CRP.

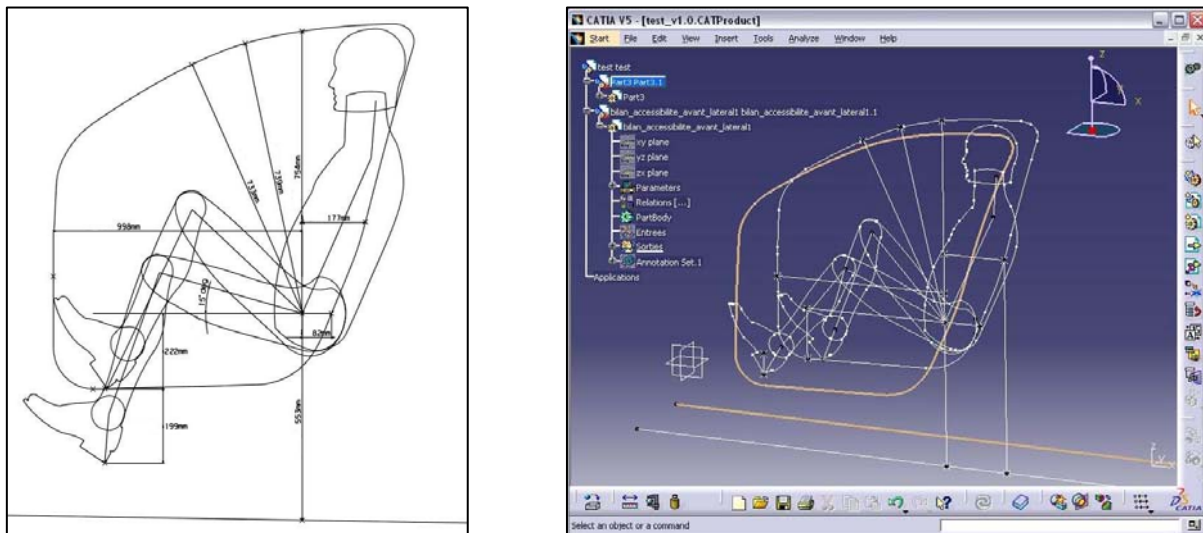


Figure 1. Results of the "longitudinal front car accessibility" report

The objective of the report “longitudinal front car accessibility” is to analyze the ergonomic aspects of the entry/exit of the vehicle, in a longitudinal view. The fulfilment of this report, even if it is a simple one, requires time and specific ergonomic knowledge. The characteristics of execution of the report are given below:

- Input information:

The parts extracted from the digital mock-up needed for this report are the door seal and all items that are in the way in or out. With these elements, the report first allows to build the “accessibility outline”. Then with the project parameters entered, a standard dummy is set up in the typical driving position. Its leg is moved up in a specific “accessibility position”, following an ergonomic rule of positioning, parameterized in the report. The objects are finally projected onto a longitudinal plane.

- Ergonomic methods and construction rules:

In this report, there is no specific abacus to position. Nevertheless, special manipulations have to be done with the leg of the dummy, defined by the ergonomics department. The special position of the leg allows to measure ergonomic dimensions - in the vehicle digital mock-up - used to assess the front accessibility (see fig. 1). The ergonomics department is responsible for the methods of measurement of all dimensions of the report.

- Output information and objects:

A 3D view, a 2D drawing and a list of ergonomic dimensions with their values are the resulting objects of the report. The 2D and 3D views give a global overview of the longitudinal front car accessibility, and the list of dimensions allows analyzing quantitatively the requirements, with the help of ergonomic assessment tools.

2.3 Discussion

This example of a report seems to be well structured, but it is important to underline that structuring information was one of the goal of our research project. The concept of report emerged from the first step of our study, as an item of reusable information, and will be developed in section 3.

This example also clearly highlights the close relationship between the ergonomics CRP and the CAD designers. The formers are responsible for the required methods to obtain the information with the right shape, while the latter are competent with the CAD tools and with the digital mock-up: they have the knowledge of the up-to-date version of the vehicle digital model relevant for the report.

3. Research approach

3.1 First steps of the project

First of all, the work related, to the issue of information sharing, has been focused on the reduction of ambiguity and the lack of structuring of the CRP's information needs. Because of the recent creation of the Ergonomics CRP activity, the knowledge and experience of the department were incomplete and distributed among the specialists of the group. The procedures were not uniform and the practices required mutual adjustments between the CRPs and the designers. At that time the level of know-how was relying on one project or two, as the ergonomics CRP had been created only a few years before. Therefore nobody had a clear idea of what should be inquired at any particular meeting time of the project or even at the DMR.

Rapidly anyway, it appears that the knowledge of the department was closely dependent on the context of a project vehicle, and the ergonomics CRP had difficulties to find out precisely which parameters were linked to a given type of vehicle (a small and economical car vs. a

comfortable premium). They also had the feeling that everybody in the group had their own methodology for obtaining the information they needed to make an ergonomic assessment at a milestone of a project. But far from being an obstacle, this close relationship confirmed the importance of the context and the necessary compromises for analyzing customer requirements from pieces of information, which are embedded in the CAD models. This showed us that we had to make a distinction between the extraction of pieces of information from the digital mock-up and their analysis from an ergonomic point of view.

3.2 Research methodology

With the help of the first elements detailed above, we decided to investigate the possibility to build a project memory in line with the work of Nada Matta [6], [5].

We carried out our investigation following these three steps:

- Elicitation of information and knowledge from ergonomics CRP and representing the customer requirements.

This first step consists in particular in making a sorted inventory (even non exhaustive) of the working models and current knowledge used by the Ergonomics CRP, which are provided by the CAD designers, as they are the source of all digital information. The aim is to delimit a domain of shared representations of the vehicle, where the CAD designers can provide the CAD expertise, and the ergonomics CRPs provide the methodologies for extracting relevant data from the vehicle digital mock-up.

- Generation of reusable pieces of information and of an information system in order to share them

In this second step, we undertook to find a way to transform the pieces of knowledge previously gathered into information (models, methods, standards, rules, procedures, etc.) directly usable by the CAD designers. We wanted to link the information to the original knowledge, in order to avoid any loss in the real meaning of these items. The very sensitive point at that stage is to avoid the creation of “black boxes”, as our idea was to automate the most repetitive points of the procedures. This is the role of the information system shared by both, designers and CRP, where, by construction, entries fit the project approach of the CRPs and the CAD designers. At that stage of the project, a new kind of concept emerged: the concept of “generic report”. This is an encapsulation of ergonomic models and methods directly usable by CAD designers, even without any ergonomic background. The generic report is linked to the concept of items of information reusable and will be fully described in the section 3.3.

- Assessment of these items on specific car design project, and capture of “items of information” in situation

The third step consists in instantiating the items defined during the previous step on a given vehicle project, so as to verify customer requirements with the help of the generic reports. The resulting objects of the instantiation (CAD objects, data tables, etc.) are stored in order to build a sequential memory of the ergonomic characteristics in one particular area of the vehicle project (notion of project memory). This project memory allows capturing the history of the ergonomic parameters. The evolution of these parameters can be analysed afterwards by the ergonomics CRP or by the designers in order to learn from the past projects, which in a certain way contribute to increase the knowledge of the group.

3.3 The concept of “generic report”

The first step of our investigation showed that the information needed (recall that the term “information” covers various objects, from the value of a dimension to a 3D view of the digital mock-up) to make a global ergonomic assessment of customer requirements may be put together in order to build up some entities of information, each of them having its own consistency. The term “consistency” means that each entity is quite independent from the others, is applicable to almost every vehicle project and conveys meaning for both designers and ergonomics CRP. These entities of information correspond to the “reports” we defined previously, as subdivisions of customer requirements.

Moreover, the role of these entities is to extract from the digital mock-up ergonomic situations - the metaphor of “taking a picture” is quite useful and relevant in our issue - but not to assess them. The manner to take the picture can be reproduced in any project, but the judgment strongly depends on the context. With the last technical breakthrough of the CAD tools and particularly the parametric technology, and with the idea of creating reusable generic reports, we decided to create some partially automated generic CAD models. These generic CAD models are what we call “generic reports”.

As presented in section 2, generic reports are made up of (1) input information, adapted to the designer’s point of view; (2) ergonomic rules and methods; (3) output information, adapted to the ergonomics CRP’s point of view, and capturing the context of the moment when the report is launched.

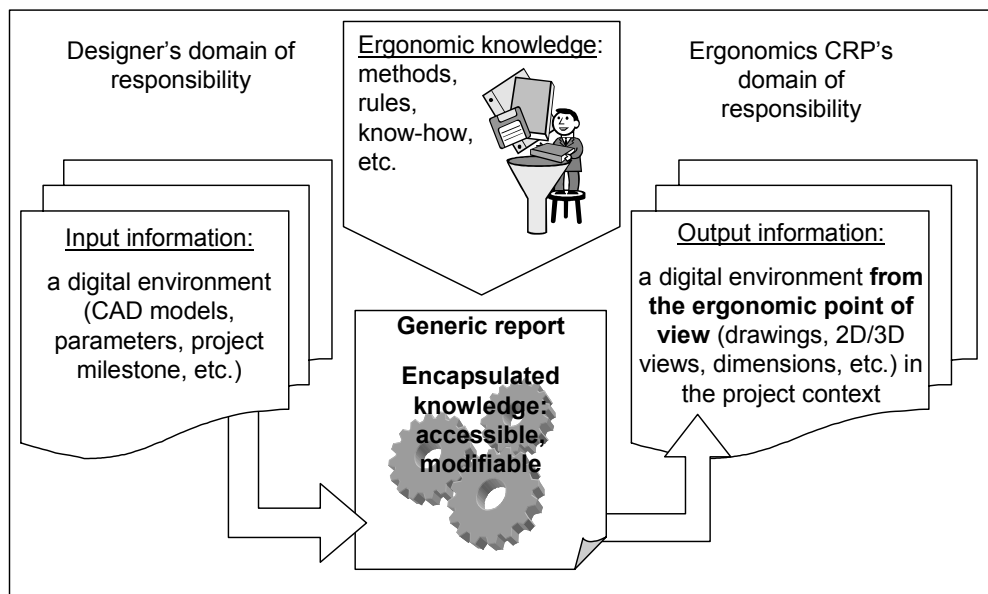


Figure 2: Input and output of the generic report

(1) Input information corresponds to selected elements of the digital mock-up, that is, from CAD models that present several technical hypothesis of the vehicle project. As each generic report ask for a particular state of the inputs elements (solid or surface, closed surface or not, etc.), the digital models may have to be slightly adapted. The CAD designers are responsible for that.

(2) The generic report contains parameterized objects, in particular parameterized dimensions, organized around a default digital environment. This is where the ergonomic rules and

methods are embedded. These parameterized objects are instantiated on the digital environment stemming from an existing project when the generic report is run.

(3) Output information give to the ergonomics CRP an adapted point of view on the project, but do not assess ergonomic requirements. It is the responsibility of the ergonomics CRP to complete the analysis.

3.4 Development and deployment of generic reports

Currently, we are still in a phase of development of these generic reports with the CATIA V5® software package. Seven generic reports have already been achieved - enough to initiate a base of generic reports - and ten are planned for 2005. These models are developed with the help of CAD and CATIA specialists.

The development of the generic reports raised two kinds of technical challenges. First, the state of the input objects (parameters, 3D objects: solid, skin/surface or line?) had to be defined precisely in coherence with the state of the objects coming from the digital mock-up. Secondly, the ergonomic methods and building rules, previously manually used, had to be translated into programs executable by the computer.

The involvement and the participation of both, designers and ergonomics CRP, and other people belonging to the ergonomic department have overcome these two challenges. They participated in the meeting dedicated to the elaboration of the computer specifications of the generic reports. Thus they had an overview of the possibilities and the limits of the models and they were involved in the setting up of the necessary compromises.

3.5 Avoiding black boxes

When using a generic report, the ergonomic analysis of the digital environment is done automatically, this implies that a designer does not still need to be competent in ergonomic methods anymore for extracting the necessary information to the ergonomics CRP.

Yet all the methods and rules encapsulated in the generic reports are kept accessible and modifiable by the user, in order to avoid creating “black boxes”. This point is particularly important for preventing the risk of disengagement or the loss of interest of the designers towards the ergonomic aspects of the project development. The aim of the automation process of the reports is to prevent the repetitiveness of the manipulations, but not to prevent the cognitive involvement of the designer who remains responsible for the validity of the output information.

The generic reports, which are parameterised CAD models, are stored in the company PDM in a specific area, following a specific structure. The output information is also stored in the PDM, following the same structure than the parts of the vehicle digital mock-up.

Actually, the numerical parts and assemblies - an assembly is a state of sets of pieces of the digital mock-up, at a given milestone of the project development - are stored in an treelike structure, first by type of project, then by vehicle project, then by milestone and finally by location in the car architecture. This “area” of the PDM meets the needs of the designers in terms of information storage and organisation. The new storage “area” of the output information of the generic reports meet the needs of the ergonomics CRP and is linked to the former. Every output of a generic reports mentions the date of realization, the name of the project, the project milestone and the state of the project parameters.

4. System organization

4.1 The new system for information sharing and capture:

During the development of a vehicle project, a considerable quantity of digital models is produced. Most of them are stored in the PDM, which structure is defined for the use of CAD designers. We created a new storage “area” for the ergonomic information extracted from the digital mock-up by the means of the generic reports. The structure of this new area allows capturing the information with the project context.

The generic reports play the role of a filter that allows analyzing the digital mock-up from an ergonomic point of view, and allows capturing the context of the project at the same time.

Figure 3 synthesizes the information system. We can see on this figure that, if digital items, coming from the development of the vehicle project, are directly stored in the PDM, they correspond to the design point of view. The ergonomic point of view consists of digital items “filtered” by the generic reports. But as the context is also captured, the links between the two points of view are preserved.

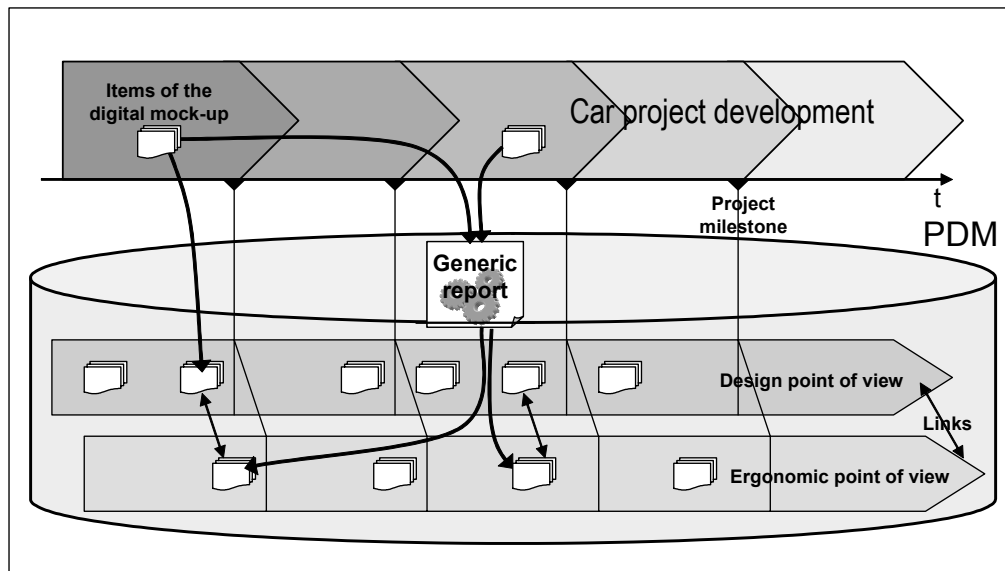


Figure 3: Overview of the information system structure

4.2 Contribution to the collaborative design

The first improvements brought by this new information system to the collaborative design process are of two kinds:

- Reasoning on cases

In the design process of products of high complexity like cars, it is extremely difficult to evaluate the consequences of non-respected specifications. In particular in the case of ergonomics, the exceeding of some dimensions, going against some requirements specifications, may have such a significant impact on the product that a redesign becomes necessary, at the risk of an important weakening of the ergonomics requirement. But it may also be totally transparent, thanks to the configuration of the other elements of the car! These

two extreme scenarios are particularly difficult to anticipate and therefore appears very late in the process, due to the complexity of the product.

A well-known way to overcome these difficulties is to rely on previous similar scenarios. The information system presented in this paper, which allows capturing ergonomic situations with the generic reports all along the design process (we used the metaphor of taking “ergonomic picture” in section 3.3), makes available the chronology, the evolution of pieces of ergonomic requirements. The storage, in the company PDM, of the evolution of ergonomic situations constitutes a base of cases that may be used by the stakeholders as a source of information. We can also imagine in the future that a case based reasoning system may provide more accurate information when the base will store thousands of models.

- Objective comparison of several solutions

During the design process, several technical solutions may be in competition, and the choice may have an impact on different agents and requirements. Thus all agents must express a point of view on the solutions, and give their constraints, but it is particularly difficult to sort out all the demands and constraints. So it is quite impossible to obtain an objective assessment of the solutions from all the involved points of view as the expression of the agents is free and non repetitive, depending on the persons.

Generic reports help to reduce the complexity of analysis of several solutions in competition. The use of the generic report then allows analyzing and comparing, in a systematic way, any solution, on predefined ergonomic points of view. This is a progress toward objectivity of the assessment.

4.3 Observing the tool appropriation process

Although the development of the generic reports is still in progress, we have already started the deployment of the available reports. After a few months of observation, we discovered some unanticipated use of the generic reports, leading to new requirements in terms of functionalities.

In fact, the development of the generic reports, which provides the designers with semi automated tools, and with the structuring of an information system for the capture and the storage of ergonomic views on a vehicle project, has brought a kind of formalization. This is in fact an implicit contract between the designers and the ergonomics CRP. The information sharing between them has now an organisational and material support. The CAD designers have at their disposal tools for extracting the ergonomic aspects of the digital models of their designs. The generic reports are of easy use, accessible in their working environment (as shows fig. 1); they do not require any ergonomic ability but only an up-to-date knowledge of the actual digital mock-up state; they allow quantitative and objective ergonomic analysis of the technical solutions, which the designers develop.

After a period of observation, we noticed that the designers were transforming the use of these tools. In addition to the answers made to the CRP’s requests, they were using the generic reports as simulation tools for anticipating the ergonomic CRP “official” assessments. In fact they were reversing the process, to analyze, before the enquiry of the ergonomic CRPs, the ergonomic quality of their design, in order to modify it – or prepare arguments to justify their choices - if necessary, upstream of the assessment at a milestone. The generic reports, though they are not planned for that, were used as tools for assisting the designer by simulating design scenarios. The CAD designers even pointed out some limitations of the generic reports, arguing they were not flexible enough for testing some configurations of the digital

mock-up. This unanticipated use leads to new requirements for the generic reports that are being discussed by the development team.

This is what we call an appropriation effect. The new organization of the relationships with the ergonomics CRPs, this formalisation by implicit contract has modified the use of the generic reports and created new needs for functionalities, transforming them from analyzing tools to tools of design assistance. This effect needs to be more deeply studied in order to understand the new requirements and integrate them in the generic reports.

5. Conclusions

In this paper, we have presented a case study illustrating the information sharing and capture issues in collaborative design teams in the automotive industry. The context was the integration of customer requirements in the design process of complex products. The organizational choice made by the company for ensuring the achievement of these customer requirements led to the creation of an interface agent: the Customer Requirements Pilot, with this responsibility. The role of the CRP is to drive the design by the customer requirements in a constant interaction with the CAD designers.

We propose in this paper the research methodology we followed in order to build a project memory, as a response to the industrial issues of information sharing and capture. From the implementation of the methodology emerged the concept of generic report, as a key element for extracting and analyzing information from a particular point of view and connected to a particular customer requirement. The generic report is the principal core of the information system, where the extracted information is stored to capture the history of the vehicle project design, from a particular point of view.

This information system has two main functions: it allows case based reasoning for anticipating the evolution of requirements and learning from past designs, and it gives to the designers a tool for extracting and comparing technical solutions in a totally reproducible and objective way. Besides we stressed the importance of knowledge sharing between the two agents. The black box effect has been avoided by the creation of an opened architecture which gives access to the models embedded in the generic reports.

This research project showed that, like in any issue of information sharing and capture, two parameters are of prime importance: the implication of the agents and the transparency of the created objects, as it allows sharing representations between the agents and knowledge creation. We also had the opportunity to observe through the deployment of the information system the appropriation effect which led the designers to require new functionalities. This project is still running and currently we are more deeply studying the deployment of the tool.

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