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COLLABORATIVE, FUNCTIONAL AND KNOWLEDGE BASED ENGINEERING USING A PLM ENVIRONMENT

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ABSTRACT
The main purpose of this work consists in developing a design methodology, integrating knowledge based engineering features, such as expert rules definition or design experience feedback, in order to reduce costs, lead time and also improve product qualities and values. This methodology helps the designer to drive parametric product CAD models with product functional requirements and design rules, in a collaborative design process, using a Product Lifecycle Management (PLM) environment.
After a presentation of the industrial requirements, we will present technical and functional analysis, integrated into our self-developed web-based PLM platform and particularly the functional parameters and the specific parameters. Then we present our concepts of generating and automatically driving a parametric product architecture in a commercial CAD software program.
The main advantage of this methodology is to keep the parameters linked together, between the several stages of the product tree (product, subproduct, parts, etc.) in order to help the product architect to impact the entire CAD model, if only one modification occurs on a functional or specific parameter.
To validate our research hypotheses, an experimental case study is chosen: the ground-link system of a racing car design and manufacturing project, including conceptual, embodiment and detailed design phases, and also manufacturing phases.

Keywords: routine engineering, parametric CAD modelling, knowledge management, product lifecycle management, collaborative design,

1 INTRODUCTION
This paper deals with the development of a collaborative design method, which integrates design knowledge, in order to accelerate the routine engineering processes[8]. During the last 20 years, knowledge-based Engineering (KBE) has been developed inside several companies in order to preserve expert knowledge loss [22][27]. In addition, today, in industrial companies, approximately 80% of the time spent in engineering is devoted to routine engineering activities and the remainder 20% is dedicated to innovation [19]. In automotive industry, Chih-Hsing [8] shows how the introduction of parametric tire design methods, applied to car wheels design and manufacturing, significantly enhances the efficiency of the mold design process and reduces the time of the 3D model construction (shortened by around 30%).
In addition, design methods and strategies are little known and not practiced in industry. For example, the ascending design [25] (choose a more or less well-founded solution and checks its behaviour by a calculation-simulation) and descending design (refine a need/problem and search a list of candidate solutions, if possible, convergent) approaches are not well used and combined by designers. Our industrial experience in companies, in several research and development departments, has shown that:

- collaborative engineering is not usually applied in these departments. For instance, when a problem occurs during a project, this problem becomes solely the project manager's problem,
- functional analysis and design methods are not well practiced and deployed in the global design process as recommended by quality management systems,

- no tracability in design decisions is made between design problem and candidate solutions. For example, design actors discover repeatedly, at each new project, the “no-go” solutions,
- current CAD tools can not manage the functional space and constraints that the product must comply with.
- the geometric model stays the reference in the product design and manufacturing process. For instance, only the paper drawing is considered as the reference during a design validation,

In our global market context, where management, designers, subcontractors and customers are geographically distributed [10][9][11], the design process must evolve in order to lock routine design into a collaborative and distributed network [3] [8] .

In this context, this paper proposes a design methodology, which connects collaborative design and knowledge management to improve productivity in a routine design process, through automatic generation of CAD model architecture driven by functional requirements, while sharing data (functional specifications, CAD parts, etc.) and knowledge (expert vocabulary, expert rules, templates, etc.) in our self-developed PLM system.

First, we present our problematic of acceleration of routine design and then we set out our working hypothesis in section 2. Next, we describe the proposed methodology and tools in section 3. In section 4, we present our experimentation applied to the ground-link system of a competition car. Finally, section 5 concludes the paper and describes further work.

2 ACCELERATION OF ROUTINE DESIGN PROBLEMATIC

Today, the design activities of a mechanical engineer, in current research departments, can be described as a parallel and multitask process, with multi-objective optimization design activities [26] [9]. During the embodiment design phase [18], the designer has to extract the functional requirements and parameters (value criteria) from the product specification documents, detailing the main functions of the product in each life situation, and creating a kind of functional tree. Figure 1 present an example of functional tree for one of the various life situations of the product such as driving, maintaining, manufacturing, etc.

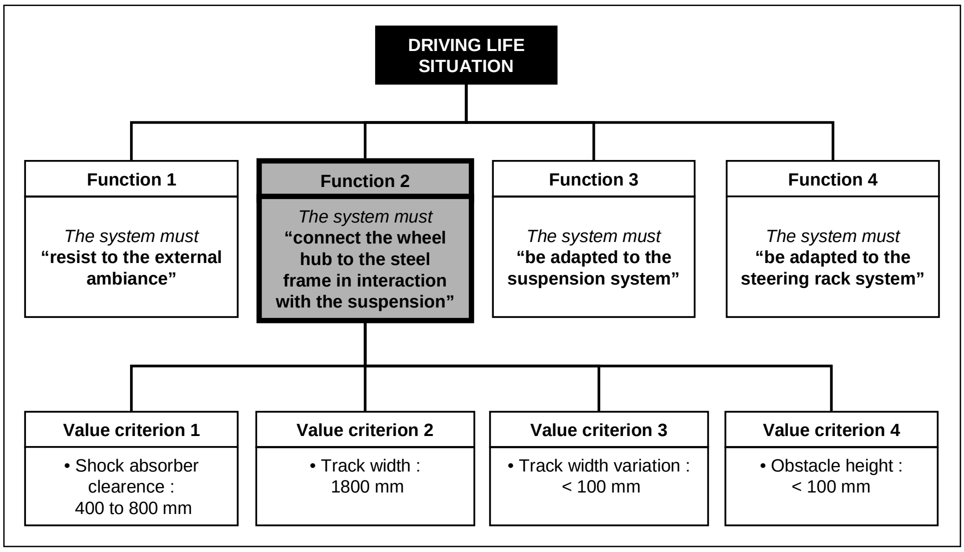


Figure 1 : functional decomposition of a product applied to a driving life situation

Then the designer has to find technical solutions, using traditional design methodologies (fishbone diagram, morphologic matrix, TRIZ, etc.) and also has to use his own knowledge and experience. In order to exploit well-founded solutions, the next design step consists in collecting real parts, available in technical books or in shared databases. Lastly, the designer synthesizes all theses data in order to generate 3D geometrical models including standard and specific sub-products and parts, and so define his Bill Of Material. A product tree can be defined and converted in a digital mock-up in CAD tools. Figure 2 presents a structural decomposition of a multilevel system applied to an example of structural decomposition for a racing car.

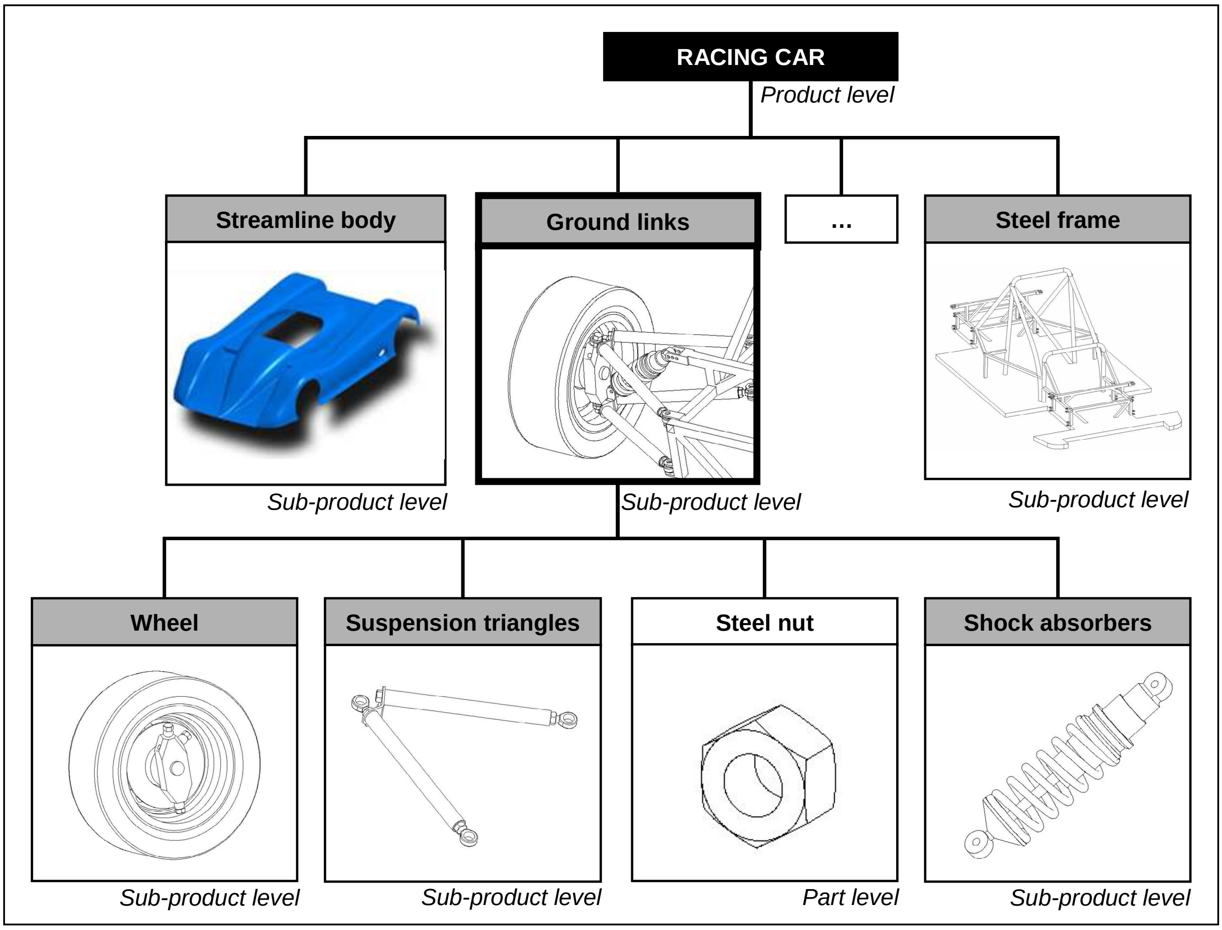


Figure 2 : Structural decomposition of a multilevel system applied to an example of structural decomposition for a racing car integrating Product, Su-product and part levels

In this context, this classic design process can be improved in several ways:

- by linking directly functional design to product architecture specification, using structural decomposition, as proposed by Quality Function Deployment methodology [6].
- by capitalizing on data, information and knowledge extracted from previous case studies
- by building generic CAD models, linked with functional parameters, encapsulating expert design rules[8][4].

So, our objective of building in routine design consists in defining new methods and tools to generate automatically product architecture in parameterized CAD models and taking into consideration product data and information, and particularly functional product specifications, contained in a collaborative PLM system. The main objective of this methodology is to reduce time allocated to routine design in order to leave more time for the innovation process.

To perform this methodology, different working hypotheses are considered:

- it is necessary to define a product model integrating more aspects than simply the geometry (the structural, functional, dynamic, physical aspects, etc.) [4],
- the PRODUCT model must be shared in an extended collaborative engineering field including the PROJECT domain, the PROCESS domain and the USE domain [12],
- the design and process tools must be able to integrate functional specifications, constraints and experimental knowledge. For instance, a modification of functional value criteria must generate automatically new possible geometries, complying with all the known design rules, for the same product architecture and geometric topology.
- the Digital Mock-Up (DMU) of the product must be shared in specific sub-products and parts in order to be able to be easily developed, by geographically distributed engineering teams, in an asynchronous design process, with a guarantee of the DMU integrity.

Since 1996, our laboratory has developed a global approach in collaborative design and knowledge management field. This approach considers all aspects and steps of a product design process using a systemic paradigm. This approach can be applied in initial design and re-design studies. The re-design process can also be split into two families. The first one is routine design, where the technological concepts and the product architecture are known and the product configuration and parameter values are unknown (a cell-phone or a self-starter, for example). The second family is parametric design, where the technical concepts, the product architecture and the product configuration are known but only the parameters values have to be defined. For example, a transistor or a ball bearing design process is typically parametric.

Concerning initial design process, two families can also be identified: innovative design (the technological concept is known but the product architecture, the product configuration and product parameter values are unknown) and creative design (everything is unknown: the technological concept, the product architecture, the product configuration and product parameter values) [20][21].

Focused on the redesign field, our problematic can be defined through four points:

- how to ensure that the product design process is performed using common validated knowledge, and answers the client's needs, through the defined functional requirements,
- how to reuse templates or parts designed in previous case studies and performing similar sub-functions,
- how to connect different actors one to another in order to share data, information and knowledge in a collaborative design process,
- how to capitalize on the data, information and knowledge for reuse in future routine design cases.

In this context, the main objective of our research activity, focused on functional design, PLM and parametric CAD, is to spend less time in routine design process in order to devote more time to innovation. In this context, we define a global methodology, integrating several methods and tools, which are presented in the next paragraph.

3 PROPOSED METHODOLOGY AND TOOLS

Our methodology integrates four different steps in order to achieve our goals. Figure 2 presents the main steps of the defined methodology.

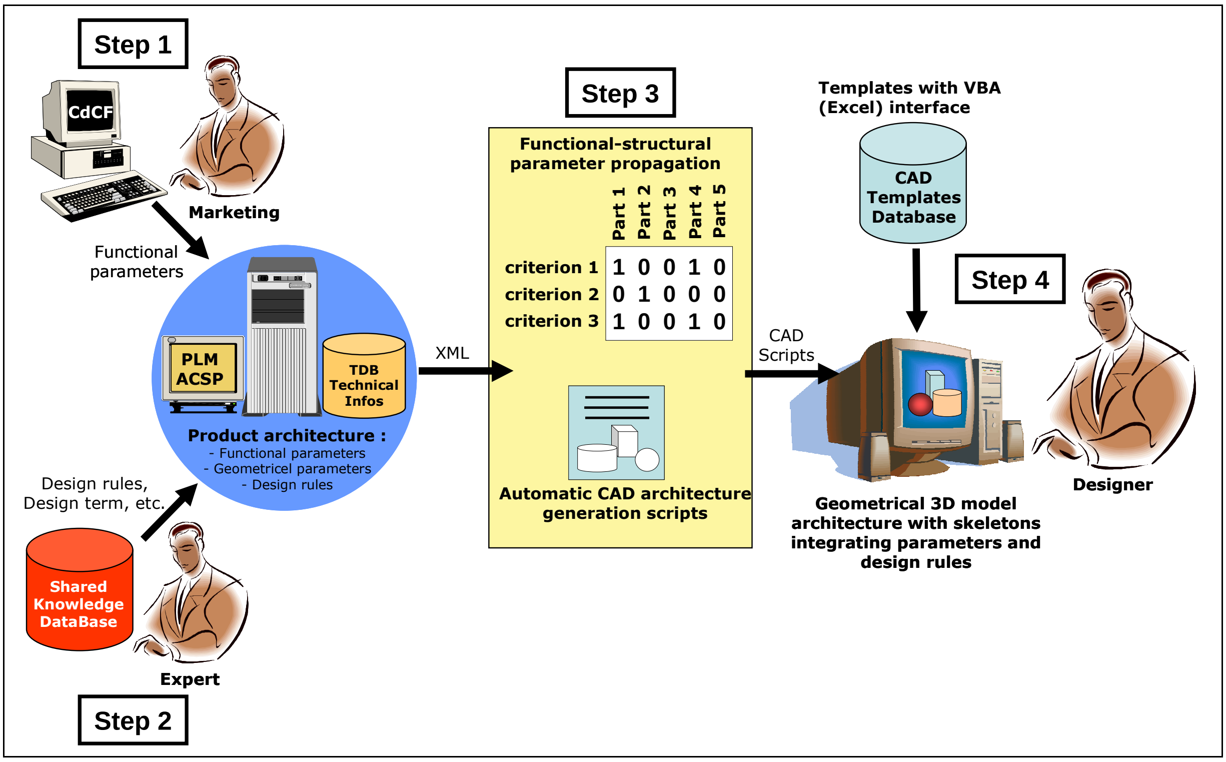


Figure 3 : Global methodology model for collaborative, functional and knowledge based engineering using a PLM environment

The first step is operated by the marketing actor. He has to input the specification into ACSP PLM system, in order to fill the functional parameter forms.

The second step is taken by an expert designer. This step can be done before the beginning of the new project. The expert has to register all design rules, design terms, etc. in a shared knowledge database.

The third step, as the core of our methodology, consists in operating a functional/structural parameter propagation considering the impact of each function (and also the corresponding value criteria, so called functional parameters), in each part of the product. This functional/structural interaction is symbolised by an interaction matrix as shown in Figure 3, step 3.

In order to perform the parameter propagation, in the CAD model product tree, functional parameters of the product (global parameters) are copied into sub-products as local parameters. They are then linked to the previous global parameters, through equality equations, in order to :

- generate a constraint propagation from the top (product) to the bottom (parts) of the CAD model product tree,
- at least, allow designers to perform CAD modelling activities, on a sample of the product Digital Mock-Up (sub-product : suspension triangle, for instance), after a check-out operation of this product sample (sub-product) from the PLM system. This approach preserves the impact of updated parameters on updated geometry and allows the other designers to work simultaneously on the other sub-products.
- interface our ACSP PLM system with commercial and parametric CAD software such as Pro/ENGINEER from PTC or CATIA v5 from Dassault Systèmes. In this context, two points of view can be considered: data exchange between the PLM environment and the CAD tool, and visualization of 3D models, using respectively, SQL and XML [5] technology and VRML, 3DXML, X3D, U3D, DWF, open JT, etc. new CAD file formats [7][7], for the last point of view.

Considering that our problematic is much more focused on automatic generation of CAD scripts from a database, so we have decided to use only XML technology to convert data stored in a database, in a text file using VB script technology.

The fourth and final step consists in the creation and the implementation of part templates interfaced with external software like Microsoft Excel. This step is taken by an engineer in order to carry out the routine design of the product. He creates geometrical 3D model based on the previous architecture and part templates.

This methodology can be applied to several CAD systems, “while” it have been tested with two main commercial CAD software:

- Pro/ENGINEER software using specific features, such as part creation directly in the assembly model, on generation of input parameters and expert rules using mathematical equations,
- CATIA v5 software, using part creation (direct modelling in the assembly or Digital Mock-Up workbench) and the “knowledgeware” features.

In the 2 next sections, we will describe the two main tools used in our methodology : CATIA v5 CAD tool, interfaced with our ACSP PLM environment.

3.1 ACSP PLM environment

ACSP is a web-based environment enabling the collaborative and remote activities of design team members. The ACSP main module is broken down into four sub-modules, which manage data from the project, product, process and use design domains [12].

Each of these design domains can be examined from several aspects (or models) in interaction, as defined in axiomatic design [22][23] and systemic approach [14]. According to system theory, we chose to develop three aspects in each design domain:

- a functional aspect, which describes the main objectives and goals of the system,
- a structural aspect, defining the system elements and architecture,
- a dynamic aspect, which describes the chronological behavior of the system.

In this approach, other design aspects such as physical or geometric models are directly linked to the structural aspect of the system, not so far from the “multi-viewpoints product model” [24]. For example, applied to the product design domain, this kind of association generates functions commonly found in PDM (Product Data Management) or PLM (Product Lifecycle Management) systems [15] [28].

For example, various types of data integrated into the ACSP environment can be displayed:

- project data, such as human and material resources (structural aspect) or tasks planning (dynamic aspect),
- product data, such as product breakdown including the various product components (structural aspect) linked to CAD files (geometrical aspect) or functional specifications (functional aspect) available in different situations in the product's life cycle (Figure 1),
- process data, such as whole manufacturing processes including the different machines (structural aspect) linked to CAD files (geometrical aspect) or production engineering specifications describing various manufacturing, maintenance, recycling, etc. tasks (dynamic aspects).
- use data, such as various Human-Machine-Environment interactions in different life situations (structural aspect), multimedia documents describing dynamic sequences like video-recorded data from human work activities or virtual films (dynamic aspect).

This data is completed with internal and external interactions in the design domains and even communication features (email, forums, etc.).

From a technical point of view, ACSP can be defined as an asynchronous CSCW (Computer Supported Collaborative Work) based on a Data Base Management System (DBMS) connected to various Computer Aided X: CAD, CAM, FEM Solvers, etc.

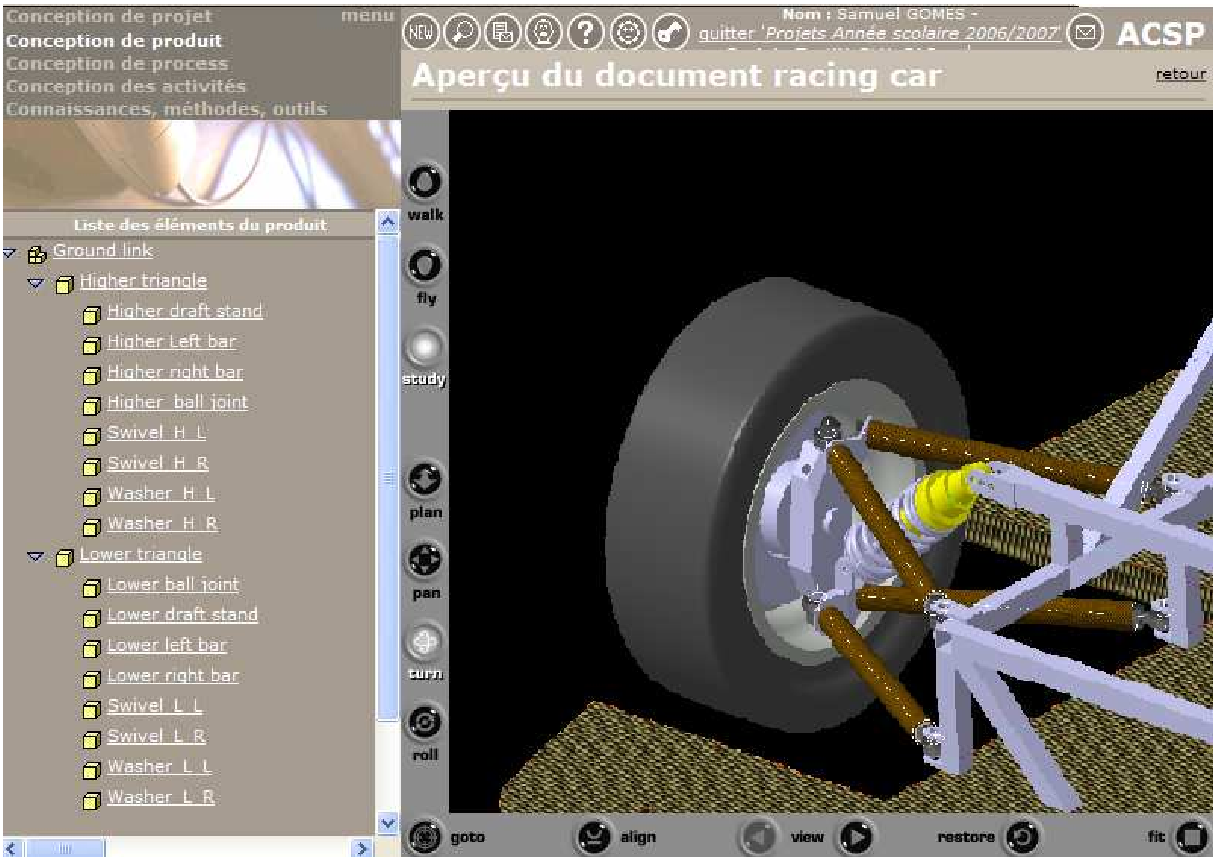


Figure 4 : ACSP screenshot describing a geometric model linked to the product structure breakdown integrated into the ACSP environment

ACSP is available as a Web Server with security layers managing user access [15]. The system has a client-server architecture available to support a variety of environments / operating systems (Windows, Unix, Mac, etc.).

This global approach enables a precise role to be distributed to each participant at the beginning of a project in order to give "the right data, to the right person at the right moment"[20].

During the project, design managers can archive project data, such as project memories using XML Technology [1]. These XML project memories can then be browsed as HTML static pages, by using XSLT standards. They can also be read by other software applications (Microsoft Excel, CATIA v5, etc.) in order to facilitate data, information and knowledge migration from the ACSP database [13].

3.2 CATIA v5 parametric CAD environment

Today, Dassault Systems' CATIA v5 is one of the most advanced CAD software programs within the field of knowledge-based engineering. The specific workbenches, for instance "knowledge adviser" or "product knowledge template", include some features which are useful for our problem and methodology. With these features, we can set number of operations, such as defining parameters and rules, performing checking steps, etc.

Moreover, CATIA v5 allows parametric CAD models to be designed with a skeleton approach using contextual links. This feature constitutes a base for our CAD modelling methodology, which promotes the product architecture modelling step before the traditional geometric building steps (sketching, extrusion, sweep operations, etc.).

Another interesting point about this CAD software, is the possibility of inter-connexion with other tools like Microsoft Excel or Text files. Effectively, a CATIA v5 model can be driven by a MS Excel interface, and that can be highly productive in our global methodology.

Other possibilities are offered by the MS Visual Basic technology (VBA). With the same technology, it is possible to write scripts in order to generate models automatically (product architecture, 2D geometric features for skeletons, 3D solids, parameters, rules, equations, etc.). The main point of this function is that we are now able to automate several CATIA v5 modelling routines with one type of text file with a catvbs extension.

To conclude on CATIA v5 technology, it is possible to create generic models, such as part templates stored in libraries. With this approach, we can share a database with parametric components like springs, screws, bearings or, more important parts like gears or transmission shafts. All of these parts are parametric and can be automatically fitted to a new system. To resume, an effective generic model is basically reusable in different projects and environments, without affecting the integrity and stability of the CAD model.

In order to illustrate our methodology, next paragraph describes an application case: a design of a suspension triangle system for a racing car.

4 APPLICATION TO THE DESIGN OF A SUSPENSION TRIANGLE SYSTEM

To explain our methodology, an application case is chosen. Every two years, our mechanical engineering and design department has to develop and prototype an entire new racing vehicle. In order to simplify the demonstration, we choose to limit the experimental case study to a sub-product of the racing car: the ground-link system as shown in Figure 2. This sub-product of the racing car includes many mechanical parts linking the wheel to the steel frame. This ground-link system design is typically a routine design case because the product architecture and components are known, but the product configuration and parameters have to be defined. Different steps of our previously presented methodology are applied in this experimental case. These steps are described in the next paragraphs.

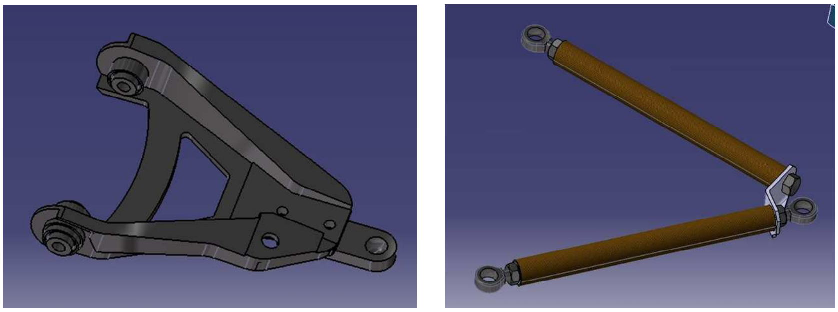
4.1 Step 1: Taken by the marketing actor

At the beginning of a project, the marketing actor has to write the client specifications which can be functional and/or specific. The methodology used to define the specifications is traditional functional analysis methods [16] [17]. Several function have been defined such as : Connect the wheel hub to the steel frame in interface with the suspension (Service Function), Resist to the environment (Constraint), Be adapted to the steering rack system (Constraint). For instance, concerning functional value criteria, our triangle suspension system, as illustrated in Figure 1, has to be adapted to a Track width (real, 1800 mm ± 100 mm) and must resist to a shock when hitting an obstacle (real, 100mm height) at a speed of 50 km/h.

For the specific requirements, our product as to be adapted to the number (integer, 2 or 4) and position of hub fixations, the number of fixations on the Steel frame (integer, 4 or 8), the diameter of this fixation (real, in mm) and a Bounding Box (BB Length x, BB Lengh y and BB Lengh z).

When the specifications are written, the project marketing actor has to choose the kind of ground-link configuration he wants. For example in our case, we can find various configurations depending from the chosen technology : Molded Triangle, Assembled Triangle, Flexion bar, etc.

The functional parameters are available for any configuration, but specific parameters depend on each chosen configuration. In our case, we select the Assembled triangle architecture presented in Figure 5.



Molded Triangle **Assembled Triangle**

Figure 5 : Examples of triangles architecture and technology

4.2 Step 2: performed by an expert designer

This step is fed from older projects where other ground-link systems with different architectures have been designed and built. At each project, the expert collects the design rules, the different architectures, the design terms, etc. for knowledge capitalization. The methodology used to define the expert rules is KNOVA-SIGMA methodology [20]. These data are introduced in the ACSP database, using an Expert Knowledge Editor (EKE), and shared with other designers. When this choice is approved, the actor has to complete the known expert rules available in the ACSP PLM environment with the new design rules. In the future, this step will be directly implemented in the ACSP system in order to help the design actor to create the same architecture automatically, in a CAD system, using functional parameters and expert rules, defined and shared in the PLM system. For instance, in our example, these rules can be equations or algorithms as shown in Figure 6. These several parameters and expert rules are stored in the ACSP database and can be visualized by all the actors.

Objective	*Track Width Variation Computing*
Variable Domaine	*Dynamic behavior*
Rule	$\Delta t\_db = Ho\_db \times \tan\left(\alpha\_db \times \frac{\pi}{180}\right)$

Variable definition	Variable name	Value	Unit
Dynamic_behavior_track_width_variation	Δt_db	[0;100]	mm
Dynamic_behavior_obstacle_height	Ho_db	[0;10]	mm
Dynamic_behavior_angle	α_db	[0;60]	deg

Objective	*Stiffness Computing*
Variable Domaine	*Anti rolling*
Rule	$If\ BT\_ar = Empty$ $Then\ Mi\_ar = \left(\frac{\pi}{2}\right) \times \left(\frac{\phi ext\_ar}{2}\right)^4$ $Else\ Mi\_ar = \left(\frac{\pi}{2}\right) \times \left[\left(\frac{\phi ext\_ar}{2}\right) - \left(\frac{\phi int\_ar}{2}\right)\right]^4$

Variable definition	Variable name	Value	Unit
Anti_rolling_bar_type	BT_ar	- Empty - Full	None
Anti_rolling_inertia_moment	Mi_ar	?	N_mm
Anti_rolling_external_diameter	Øext_ar	[10;60]	mm
Anti_rolling_internal_diameter	Øint_ar	[5;55]	mm

Figure 6 : Example of functional and geometrical parameters and rules, inserted in ACSP PLM environment

4.3 Step 3: taken by the ACSP and the product designer

This third step, at the core of our methodology, starts after describing the product requirements to specify the functional parameters of the product (Step 1), and after integrating expert rules linking various functional and the specific parameters (Step 2). As shown in Figure 7, the ACSP PLM system can not directly create the CATIA v5 script file. Therefore, a self-developed MS Visual Basic application is used in order to perform this step.

Our application automatically generates a CATIA v5 script file (Figure 9) with the same product architecture, the same functional parameters, the same geometrical parameters and the same design rules as in the XML file (Figure 8). This application also operates the constraint propagation from the top (product) to the bottom (parts) of the product tree, considering the functional/structural interaction done by the designer in the ACSP PLM environment.

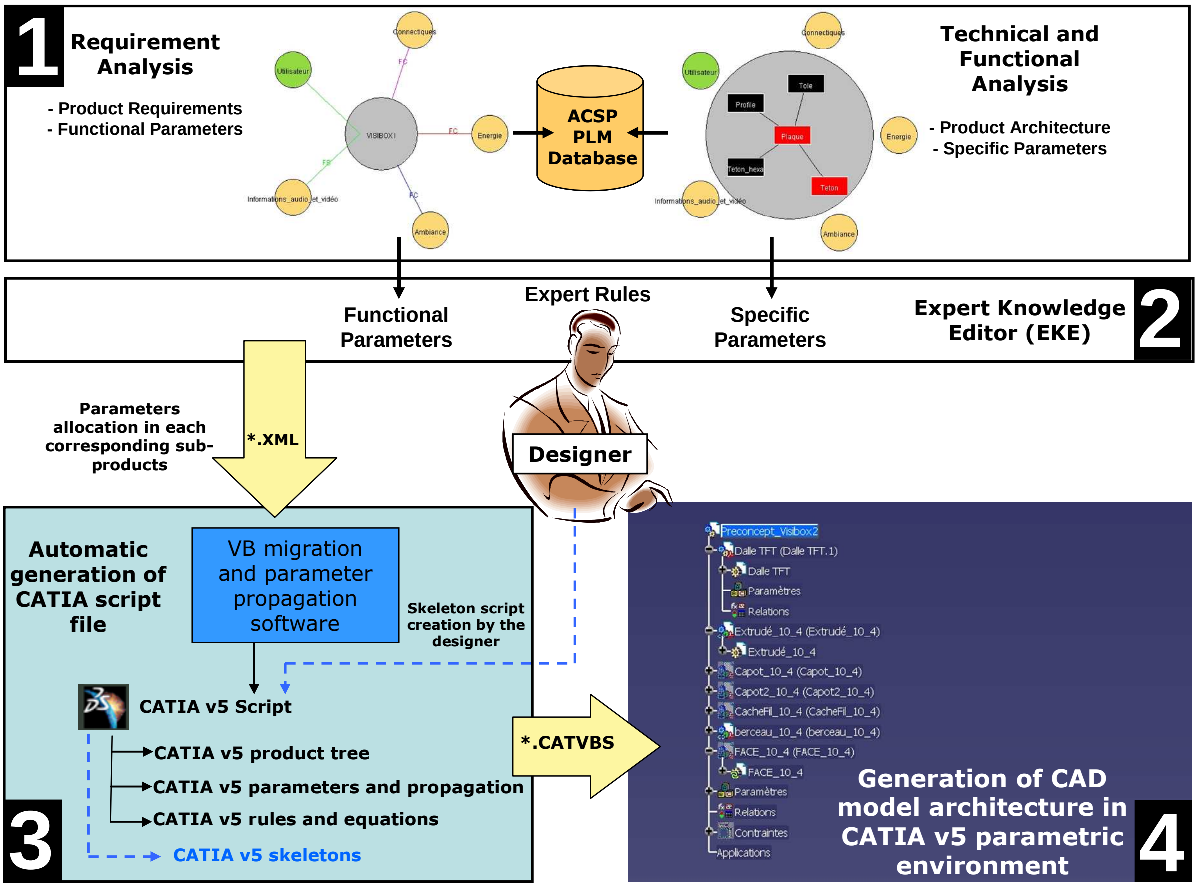


Figure 7 : Detail of the 4 phases of our methodology describing data migration from ACSP database to automatic implementation in CATIA v5

Another possibility offered by the script file is the automatic generation of geometrical elements. Effectively, it is possible to automatically create a skeleton when the script is hand-made. The skeleton is a part of our design method. A skeleton is composed of various surface elements (axis, plan, dot, circle, etc) which make it possible to build the various solids (analogy with the creation of muscle and skin around the human skeleton). Thus, the same element of a skeleton (circle representing the nominal diameter of an axis) will be used to build several solids (axis, shaft, internal diameter of a plain bearing, etc). Indeed, the modifications of the same element of the skeleton will impact several solids. In the same way, skeletons must be used, instead of solid features, in order to establish kinematic connections. This approach preserves the kinematic links during the modification of the solid features as detailed in [2][2].

```xml
<?xml version="1.0" encoding="UTF-8" standalone="no" ?>
<table_solveur_variables>
- <solveur_variables>
    <ID_VARIABLE>294</ID_VARIABLE>
    <ID_PRODUIT>262</ID_PRODUIT>
    <ID_ELEMENT />
    <LOGIN_AUTEUR>JBLUNTZE</LOGIN_AUTEUR>
    <NOM>Ho_db</NOM>
    <PRECI>1</PRECI>
    <BINFEGAL>0</BINFEGAL>
    <BSUPEGAL>10</BSUPEGAL>
    <BINFSTRICT />
    <BSUPSTRICT />
    <SINGLETON />
    <UNITE>mm</UNITE>
    <CHAINE>Ho_db : [ 0;10] (mm) de précision 1</CHAINE>
  </solveur_variables>
- <solveur_variables>
    <ID_VARIABLE>293</ID_VARIABLE>
    <ID_PRODUIT>262</ID_PRODUIT>
    <ID_ELEMENT />
    <LOGIN_AUTEUR>JBLUNTZE</LOGIN_AUTEUR>
    <NOM>Δt_db</NOM>
    <PRECI>1</PRECI>
    <BINFEGAL>0</BINFEGAL>
    <BSUPEGAL>100</BSUPEGAL>
    <BINFSTRICT />
    <BSUPSTRICT />
    <SINGLETON />
    <UNITE>mm</UNITE>
    <CHAINE>Dt_db : [ 0;100] (mm) de précision 1</CHAINE>
  </solveur_variables>
```

Figure 8: Example of XML File for an architecture element extracted from ACSP PLM database

```vbscript
Language="VBSCRIPT"

Sub CATMain()

'Product generation'

      Set documents1=CATIA.Documents

      Set productDocument1=documents1.Add("Product")

      Set product1=productDocument1.Product
      product1.partNumber="Racing Car"

      Set parameterSets1=product1.Parameters.RootParameterSet.ParameterSets

'Product parameters generation'

      Set dimension1 = product1.ReferenceProduct.Parameters.CreateDimension("Ho db", "LENGTH",10)
      Set dimension1 = product1.ReferenceProduct.Parameters.CreateDimension("alpha db", "ANGLE",60)

      'Sub-Product generation'

      Set products1=product1.Products

            Set product2=products1.AddNewComponent("Product","Ground link")

            'Sub-Product parameters generation'

                  Set realParam1 = product2.ReferenceProduct.Parameters.CreateDimension("delta db", "LENGTH",100)

            Set product2=products1.AddNewComponent("Product","Powertrain")
                  Set realParam1 = product2.ReferenceProduct.Parameters.CreateDimension("Input couple", "MOMENT",30)
                  Set realParam1 = product2.ReferenceProduct.Parameters.CreateDimension("Input diameter", "LENGTH",20)
                  Set realParam1 = product2.ReferenceProduct.Parameters.CreateDimension("Output diameter", "LENGTH",30)
                  Set realParam1 = product2.ReferenceProduct.Parameters.CreateReal("Ratio",3)
```

Figure 9 : Example of a script code for an architecture element generated automatically with our migration software

Our further work consists in developing this script file generation directly in ACSP PLM System, without any Visual Basic interface.

4.4 Step 4 : Taken by the product designer

During this last step of the methodology, the field is now ready in order to perform the product design and geometrical modelling tasks. When the CATIA v5 script file is launched, several features are automatically generated in CAD environment and particularly the product tree of our ground-link system with: sub-products, parts, skeletons, expert rules and functional parameters dispatched in the whole CAD model tree. In current state of implementation, only skeletons are hand-made in the script file in order to perform our methodology. At this level designer can now use part templates to be fitted on the parametric skeletons, which are driven by functional requirements.

5 CONCLUSION AND FUTURE WORK

To conclude, collaborative engineering and technical data management tools are becoming a reality in companies in order to improve quality, lead-time and productivity in engineering phases. Functional design methods and tools are emerging gradually in design departments. Moreover, new CAD methodologies make it possible to dissociate the architecture design (skeleton modelling) from the detailed design (context solid modelling) and the possibility of using CAD models templates, complying with the design rules, which are now available in various CAD tools. Once script created, its launching enables us to generate automatically our product architecture, the various parameters and the expert rules in our CAD environment. That enables us to have a healthy base in order to be able to design our skeletons and to allow an optimal implementation of each product element.

Moreover, the experimentation carried out in this article enabled us to validate our working hypotheses and our methodology in routine design. Indeed, a routine, integrated into our system, makes possible the automatic extraction of the various criteria from the product functional requirements (functional parameters) and the product architecture, in order to compile them in XML files. These XML files enable us to generate automatically a CAD script (VB Script) via a file migration application developed with Visual BASIC.

But a difficulty remains with the automatic generation of the expert rules. Indeed, the relations between the various rules and the various parameters remain unstable during the automatic generation and must often be handmade. Some works are currently performed in order to make it possible to solve this difficulty.

The next step would consist in improving the coupling operations between PLM systems, functional analysis and parametric 3D CAD containing expert rules. Further work consists in developing an application for optimization of the product by using an optimization algorithm to minimize one objective function such as: weight, number of parts, etc. This kind of optimization loop should help the designer to choose optimized solutions, among those automatically generated.

6 AKNOWLEDGMENTS

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