INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'09
24 - 27 AUGUST 2009, STANFORD UNIVERSITY, STANFORD, CA, USA

A NEW REVERSE ENGINEERING METHODOLOGY BASED ON KNOWLEDGE EXTRACTION AND GEOMETRICAL RECOGNITION APPROACHES

Alexandre Durupt[1], Sébastien Remy[1], Guillaume Ducellier[1], Emmanuel Guyot[1]
(1) University of Technology of Troyes, FR

ABSTRACT
Reverse engineering (RE) is a research field where physical models are measured or digitized in order to be virtually rebuilt to obtain a CAD model. Today, rebuilt CAD models using current geometrical approaches are generally "frozen" or barely re-usable. This paper deals with a new reverse engineering approach. This one improves the classical geometrical approach with a knowledge extraction phase. This improvement enables to define a new methodology that assists the user during the reverse engineering process. The obtained CAD model is not a set of surface but a real set of design features structured in a design tree with constraints, parameters, rules and relationships. This structure enables to "unfreeze" the geometry of the model and really allows to re-study and to redesign the original physical model.

Keywords: Reverse engineering, Segmentation, Feature recognition, Knowledge based system

1 INTRODUCTION
Reverse engineering is an activity which consists in digitizing a real part in order to create a numerical or virtual model. There are many domains related to reverse engineering such as, virtual prototyping where people compares a real model with the virtual model, metrology where people checks measurements, maintenance of long lifecycle product, tool design, art, entertainment, museology, protection of the industrial patrimony [1] and competitive analysis. This article proposes, among all these domains, a new reverse engineering methodology where redesign purpose is needed. This proposition focuses on the mechanical engineering domain. It exists several reasons to make a reverse engineering operation on a mechanical part: The original design is not supported by sufficient or existing technical documents, the original supplier disappeared or does not manufacture the part anymore and the original part is damaged or broken and no plan nor drawing are available.
When a redesign purpose is needed, as stated for this article, the aim of a reverse engineering operation is to enable a redesign activity in order to improve the geometry of the considered part or to update this one to fit on better manufacturing processes. The reverse engineering operation concerns little production, specific need, little companies, or providers, which have to manufacture a product where just the real product are available. The process, in the scientific literature, consists in converting a point cloud into an accurate model, minimizing the intervention of the user [2]. Today, according to users, the results obtained using this classical approach are not good enough because the geometry obtained is generally "frozen" (i.e. a set of free form surfaces or a set geometrical features in a manifold static model) and barely re-usable. To be re-usable and to enable redesign activity, a rebuilt model should be like a classical CAD model (i.e. a set of manufacturing and design features in a tree with constraints, parameters, rules and relationships). To provide such a model, people uses approach is nevertheless manually performed and not very integrated in commercial software application.
This article proposes a new approach to enable to obtain such CAD like model in a reverse engineering operation framework. It consists in a combination between segmentation techniques, feature recognition techniques and a knowledge based approach. The analysis of manufacturing processes and functional requirements represents a set of information which is implicitly integrated, as the designer intents, in a CAD model during a classical direct design process. In the reverse engineering context, this set of information, if explicitly integrated in the rebuilt model, allows the

creation of design features as well as the relationships, the constraints and the parameters between them.
The aim of the new approach presented in this paper is to produce a “clever” CAD model in order to enable its reintroduction in a classical product development cycle (Figure 1). This reintroduction will enable redesign activity.
This communication is structured as follow. First, related works on segmentation techniques, feature recognition techniques as well as the main types of knowledge for the reverse engineering process are introduced. Then, the proposed methodology is developed and illustrated.

2 RELATED WORKS

Among a set of current approaches, one way to improve the reverse engineering process is to minimise user intervention in order to minimise the time needed to complete process. A full, accurate and automatic segmentation of a 3D point cloud is still a central problem in reverse engineering. Recent efficient tools such as RapidForm™, Geomagic and like propose powerful algorithms to complete a reverse engineering operation. However, such tools require user intervention. Indeed, fitting surfaces and recognition features are high-performance when the user specifies localization or area to perform in the 3D mesh. Surface fitting and feature recognition are accurate and well performed as long as there is a user intervention. In most of the proposed commercial tools, user has to specify the localization of a given feature within the 3D point cloud (using the segmentation) in order to rebuild the geometry of this feature.

2.1 Segmentation techniques

The segmentation of a meshed 3D point cloud is a research field which consists in the division of the 3D point cloud of a given object into a set of n point clouds representing the n features that compose this object. In the reverse engineering process, three segmentation techniques are commonly used. In a first place, region based technique uses spatial coherence of the data to organize the mesh into meaningful groups. Least squares approximation by plans is the simplest methods. Besl and Jain works [3] allow the classification about the mesh in three under regions: plans, convex and concave faces are recognized. The best techniques are based on the approximation by bi-polynomial surfaces [4] and allow the recognition about simple forms such as plan, cylinder, spherical and conical surfaces. To summarize, an adjacent region to given region is absorbed if it satisfies the estimate by the polynomial surface of a given minimal order. If this adjacent region is not absorbed, the smoothing by a polynomial of superior degree is tried. The process stops when all regions are absorbed or when estimations with all polynomial degrees have failed. Current computers improve execution speed of polynomial degrees but this technique is sensitive to the noise of the cloud or the mesh. Normal calculations or curvatures are often noised and borderlines are not clearly defined.
In second place, technique used is the edge-based method that consists in intending to isolate discontinuities in the 3D point cloud. Break areas such as steps and discontinuities of normal and curvature orientation are recognized. Points detection through parallel slicing sections is the simplest method. Sections are approximated by B-Splines [5]. A second technique consists in performing local characteristics [6].
In a third place, Hybird technique, which combines region and edge techniques, is used. For example, Yokoya and Alrashan [7] [8] have performed the calculation of the discontinuities in the cloud. Region techniques are used in order to finalize the segmentation.
All these techniques lead to surface CAD model which limit possibilities of redesign. However, solutions exist such as the placement by the user of control points of curves [9]. These solutions are useful for complex surfaces such as airfoils but very sensitive at the noise of the point cloud and require accurate point cloud.

2.2 Feature recognition and geometric constraints systems

Feature recognition can be generally defined as the ability to automatically or interactively identify and group topological entities from a solid model into functionally significant features such as faces, cylindrical holes, slots, pockets, fillets (i.e. extracting features and their parameters from solids models). Most common feature recognition methods consist in searching the boundary of a solid according to a pattern of faces and edges that obey given topological of geometrical relationships. Features recognition is very advantageous because it allows solid modeling, which improves quality of

rebuilt CAD model and open redesign possibilities. For example, one of the most famous applications is REFAB (Reverse Engineering Feature Based). Thompson et al [10] presented a classical geometric features-based reverse engineering system. The developed prototype creates interactively the CAD model of a part with a significant number of specialized manufacturing features such as holes, pockets and like. This tool enables the user to fit features such as cylinder and planes onto a point cloud. The segmentation, the fitting and the constraints are performed from the point cloud and the features are used as references. The best advantage about this prototype is that it provides accurate models while the sensor generates noises and allows at the user to change simple forms such as the diameter of a hole. The main difficulty of the feature recognition approach is the establishment of relationships and constraints between features. Recent works are based on geometric constraint reasoning to reply to this difficulty. Two groups can be distinguished and a state of the art of these techniques are presented in the Werghi et al works [11] [12]. In a first place, the rules based approach concerns a set of predicates. Starting from predicates, these approaches apply logical technical reasoning. Nevertheless, this approach is not successful for a big system of constraints. In the second place, the graph based approach define a methodology where each node represents a geometrical element and each link indicates constraint [13]. Nevertheless, the issued constraints by this approach can be contradictory and provoke a long time of execution.
In the scientific literature, features and constraints represent design intents which are the expert knowledge about the product. The extraction of design intents is the key of reverse engineering. Indeed, an automatic geometrical recognition process does not seem appropriate because the extraction of design intents is more than geometric recognition. Thus, user clever interventions have to be allowed. The goal is to keep a control on the reverse engineering process. In the current proposed approaches, the recognition operations are only based on geometrical functions or relationships. The extraction and management of expert knowledge are not often bundled in these proposed approaches. None of the commercial software tools and scientific approaches are governed by a structure or a methodology integrating the extraction of the expert knowledge.

2.3 What is the knowledge for the reverse engineering?

Reverse engineering has to be driven by a knowledge extraction operation. During this step, users or experts could provide hypotheses on the part. Thus, certain types of knowledge allow extraction of geometrical primitives. As an example, the VPERI [14] (Virtual Parts Engineering Research Initiative) project was created by the US Army Research Office in order to provide the vision, strategy, and engineering tools to help to solve legacy systems problem. The knowledge of the geometric shape and size is necessary but not sufficient to reproduce the part. Re-engineering and redesign need functional specifications. A design interface is used in order to allow the addition of knowledge in the form of algebraic equations that represent engineering knowledge of the functional behaviour of the components, physical laws that govern the behaviour, spatial arrangement… This interface provides mechanisms that enable designers to ascertain that the functional requirements are fulfilled and helps designers to explore alternatives by assisting designers to make some changes. Knowledge arises from the analysis and is simply expressed and transcribed in variables that are interpreted by the VPERI tool.
In the same way, REFAB [10] system uses manufacturing features. Manufacturing knowledge extraction is achieved implicitly by the user. Mohagheh et al 2006 [15], in a study case of Turbine Blade, propose a Reverse engineering process that uses information from two different sources: The conventional way (which consists in measuring the model) and the review of design aspects. They preliminary suggest to manually detect specific features which are linked to Manufacturing processes, functional requirements and other considerations before to use segmentation and constrained fitting algorithm. Fisher [16] explores “knowledge based” technique to overcome ‘frozen in’ errors on 3D mesh. The underlying theme behind this set of techniques is the exploitation of general knowledge about the considered object. Indeed, he explains that the full automatic reverse engineering process is not possible because the computers are good at data analysis fitting and humans are good at recognizing and classifying patterns. For example, a human makes hypotheses that a given relationship holds (Two surfaces are potentially parallel) and the computer can either help verify the relationship (Calculate the probability that they are parallel or the separation between the surfaces). With the additional user’s knowledge about the part and using an optimization algorithm, the shape and position parameters are found even with considerable noisy 3D point cloud. In this work, the

knowledge is implicit and is not driven by a methodology or approach. Urbanic et al [17], about the reverse engineering methodology for rotary components from point cloud data, explain that features have accurate mathematical definitions or specifications for their geometry, and tolerances depending on functional requirements. They also explain that a functional engineering representation is needed, but when current reverse engineering tools are used for design of rotary components, the final model contains a set of surfaces and curves that have no meanings. They conclude that geometrics primitives issued by one or more manufacturing process could be listed with their parameters. For example, in rotary components, the spindle and screw are standard geometry and could be classified in features.
The above references highlight two types of knowledge require to enable redesign operation [18], [19]: The manufacturing knowledge and the functional requirements. Hence, a new reverse engineering process integrating these two types of knowledge allows explaining and justifying the presence of the features in the point cloud. One believes that the "presence" of a given feature represents expert knowledge that is the design intent of the designer. The aim of this paper is to bring a methodology in order to identify these types of knowledge. The manufacturing process and the functional requirement are considered here because they are very important and easier to deduce.

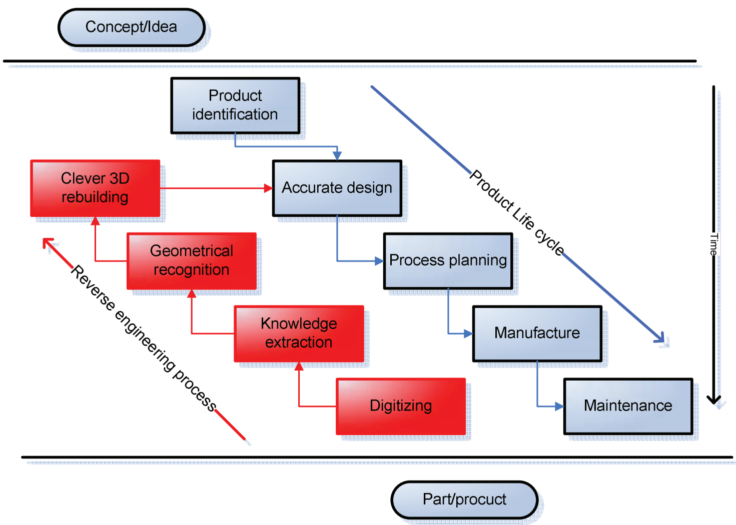


Figure 1. The reverse engineering connects with the product development cycle

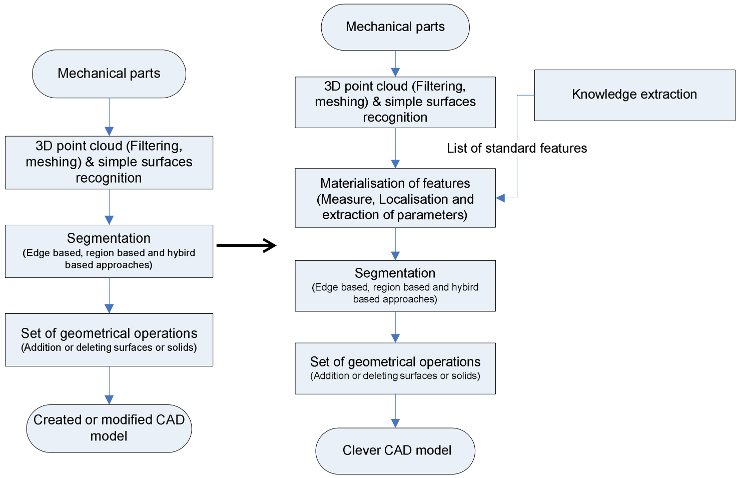
The knowledge extraction phase is close to a design process. The knowledge extraction phase is similar to "product identification" in product development cycle (Figure 1). Here, the starting point is not a concept but a real part. The needs to achieve the knowledge extraction phase are: To improve reverse engineering methodology with manufacturing and functional aspects, and to support routine functions such as repetition of features. Today, the software application system which supports above requirements is the KBE (Knowledge Based Engineering) system. These tools are used to accelerate design routine but also to assign design methodology such as MOKA methodology [20], [21], [22].

3 PROPOSITION OF A NEW REVERSE ENGINEERING METHODOLOGY

This third section proposes a new reverse engineering methodology which integrates a knowledge extraction phase. A prototype software application called KBRE (Knowledge Based Reverse Engineering) combined with a CAD tool (CATIA V5) is developed and supports the proposed methodology. This tool aims to guide the user during all the process time through several interfaces which allowing to aid the re-design choices. These interfaces follow step by step the proposed methodology Figure 2.b In the next sections, the proposition is presented through several mechanical engineering use cases.

3.1 Principle and definition

The usual reverse engineering process could be divided in three steps: The first step consists in digitizing, filtering and extracting 3D mesh of a mechanical part. The second step is the segmentation process in order to detect surfaces. The third step is a set of geometric operations such as features recognitions. The resulted rebuilt model is generally "frozen" (i.e. a set of free form surfaces or a set geometrical features in a manifold static model) and barely re-usable. From this point, it is very difficult to obtain a rebuilt model that looks like a classical CAD model (i.e. a set of manufacturing and design features in a tree with constraints, parameters, rules and relationships).



a) The classical process b) The new process proposition

Figure 2. The classical process and the new process

The new reverse engineering methodology could be divided as follow (Figure 2): The ordered and filtered point cloud is separated in basic surfaces. The Knowledge extraction phase allows to list geometrical primitives called standard features. These features are the design features (features that provide a function) and the manufacturing features (features that enable a given manufacturing process, like drafted surfaces for the forging process).

The feature materialization phase consists in localizing, measuring and constraining these features between them. Regarding to the surfaces that are not design or manufacturing features (aesthetic surfaces for example), the classical process is applied.

Finally, a set of geometrical operations is used in order to obtain a solid parameterized CAD model. The parameters of the standard features allow parameterization and, to end up, the redesign possibilities. The standard features represent manufacturing features and design features. The knowledge extraction phase supports repetitive features and specificity geometrical aspects.

This paper does not deal with 3D digitising methodologies and segmentation algorithms as many of them are referenced in the section 2 of this paper. The following section deals with the geometrical formalisation and the features materialisation in a point cloud.

3.2 The functional and structural skeleton of a part.

The creation of the functional and structural skeleton should enable to parameterize the standard features and to drive their geometry. The skin and the skeleton representations are considered. This representation is currently used for the wireframe representation of revolution parts in design process. The skeleton representation consists of 2D elements. Thus, the dimensioning, the parameterization and the constraints addition are simplified.

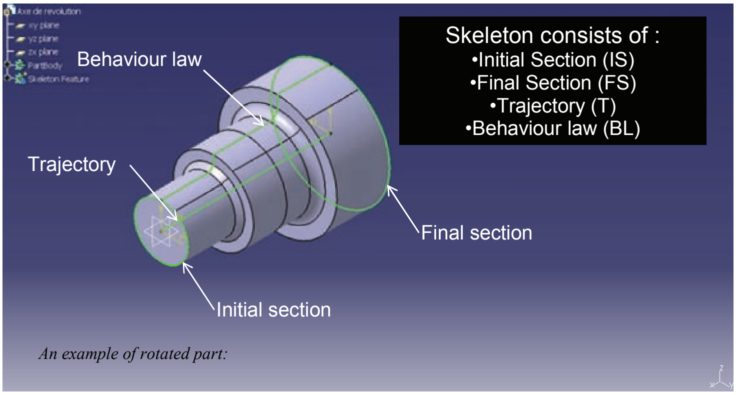


Figure 3. Components of the feature in skeleton representation

A feature in skeleton representation consists of four components: An initial and final section (IS & FS), a trajectory (T) and behaviours laws (BL) (Figure 3~~Figure 3Figure 3~~). The trajectory represents the pathway between sections. The Behaviour law represents evolution of sections along the trajectory. The type, the driving parameters and the position within the product characterize each component of the skeleton. Today, the simple features such as cylinders, cones, blocks and pyramidal blocks are processing. Thus, circular, rectangular and triangular are types of sections. The Linear is the type of trajectory and behaviour law. For example, Radius represents the driving parameter of both sections and Length represents the driving parameter of the trajectory. The driving parameters and the position within the product are the two most important characteristics. Indeed, the driving parameters lead the geometry of the feature. The type and the driving parameters of each component are regrouped in Figure 4~~Figure 4Figure 4~~.

Components	Considered Types by KBRE	Driving parameters
Section(IS &IF)	Circular	Radius (Rc)
	Retangular	Length (l); Width (L)
	Triangular	L_1;L_2;L_3
Trajectory(T)	Linear	Length (L_T)
Behaviour law(BL)	Linear	Angle (α)/Trajectory

Figure 4. Types and parameters of each component

The origin of segmentation result, in order to position a given feature within the model, is the same in the CAD environment. Each feature will be placed according to its position in the segmented 3D point cloud. In the scientific literature, the main proposal is to avoid user intervention. This approach is different; it suggests that user have two interfaces. The first represents a CAD environment for the reverse engineering process and the second represents the segmentation results. Aided by the KBRE tool, the user lists the standards features within the product and uses the result of 3D point cloud segmentation to characterize them and to position them within the model. For example, if the IS (Initial Section) is circular, KBRE will estimate its radius and its position in result of the first segmentation. The set of standard features will be implemented in a first CAD environment. This set of standard features represents the tree of redesign. This tree is called a functional and structural skeleton of the part. Indeed, the features represent the structure and the functional requirements of this part. An example of structural and skeleton tree is represented on Figure 8~~Figure 8Figure 8~~.

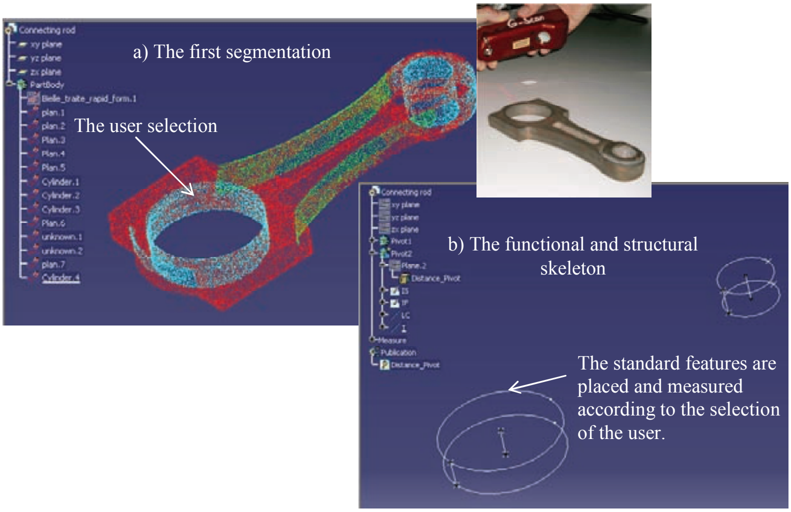


Figure 5. The materialisation of the features from the first segmentation step

The first segmentation consists in separating point cloud in primitive surfaces. Plan, cylindrical, conical surfaces are extracted and listed. In the connecting rod case, in the Figure 5, the point cloud is divided in plan surfaces (red), cylindrical (bleu) and others surfaces (green) (Figure 5.a). This division facilitates and accelerates the localization of features. The user assigns divided surfaces to ensure the localization and the measure of the selected feature. Thus, the localisation of features is partially automatic. One of functional requirements about connecting rod is to ensure two pivots linkages. Two "pivots" standard features are going to place and to measure from the user selection. Next, the system creates two standard features in skeleton representation. The issued design tree forms the functional and structural skeleton of a part (Figure 5.b). The features are constrained between them in the skeleton. The parallelism and perpendicular constraints are performed between trajectories. In the connecting rod case, the parallelism between two pivots generates a functional dimension which corresponds to the length between both axes of pivots. Each component of each feature and functional dimensions are modifiable. Thus, the functional and structural skeleton ensures the parameterization of a part. Indeed, a feature modification affects the neighbouring geometries.

This materialisation is close to REFAB system [10] but, in this paper, the particularity of the suggested system is that "Knowledge" and "Segmentation" are combined and define a methodology. The "Knowledge" is used for listing standard features according to a structured approach. The analysis steps of the manufacturing processes and the functional requirements support this approach.

3.3 The manufacturing process analysis

The manufacturing process that has been used to create a part can be found by observing it. The knowledge of this process can enable to improve a reverse engineering operation. Indeed, mould, casting extraction, milling operation and like leave traces on surfaces such as line of joint for mould process. The above process rule could be extracted from the part. According to handbooks about manufacturing processes, two kinds of rules can be considered: geometrical rules and expert rules. The geometrical rules influence the geometry of the part. The expert rules concern processes themselves. For stamping process, "Final model have draft angle" is a geometrical rule. Another example, for the hammer forging, "Homogenization of material flow" is an expert rule. Therefore, in KBRE, a database is built using these rules and manufacturing processes are classified according to their types (primary, secondary and tertiary) [23].

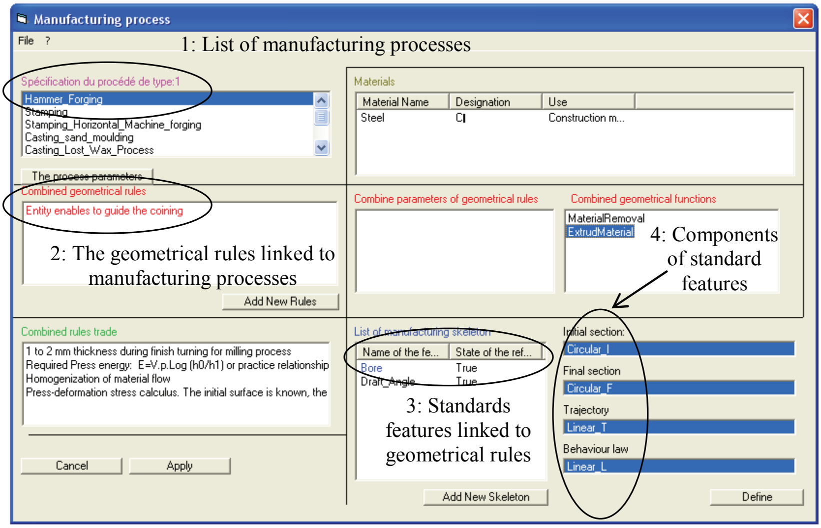


Figure 6. KBRE interface for the manufacturing process analysis

In Reverse Engineering, the geometrical rules are more important than the expert rules because of their influence on the geometry of the part. For each geometrical rule, one or more standard features, called manufacturing skeleton features, are referenced. The user can select referenced manufacturing skeleton feature or add a new one and redefine each component of all standard features (Figure 6~~Figure 6Figure 6~~).

In concurrent engineering context, it is interesting that several manufacturing processes could be applied on the part. According to a brainstorming, the final user could select the more suitable process. For example, Figure 7 reveals KBRE architecture knowledge extraction through a journal cross of a Peugeot 403 case of study. The tree analysis is a structure which represents several assumed or applied processes.

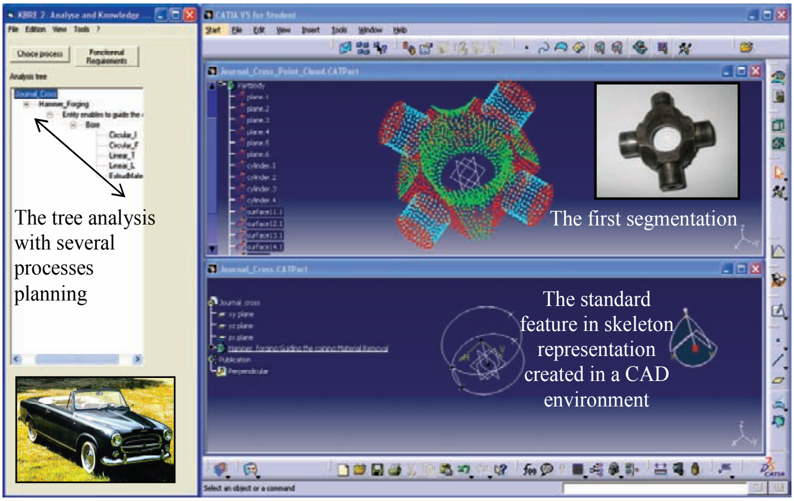


Figure 7. The manufacturing process analysis and the addition of standard features

The manufacturing process analysis is the first step suggested by KBRE. It allows to understand or to assume manufacturability of the part. Regarding to the case of study in Figure 7, the journal cross has a material removal in the middle. After consultation of expert, the material removal is used to guide the coining during the hammer forging process. For this process, the database of KBRE suggests this following geometrical rule: “Entity enables to guide the coining”. The assigned standard features are a simple hole and a drafted hole. This rule corresponds to the hypothesis. So, the drafted hole is considered. The initial and final sections of the feature linked with faces of first segmentation are selected in the CAD environment after the user validation. The aim is to measure and to localize the standard features. All issued information of this first analyse are integrated in the functional and structural skeleton of a part (Figure 7). The database of KBRE is implemented with several ordinary manufacturing processes and linked with geometrical rules and standard features.

3.5 The functional requirements analysis

A machine, a system or a part is a study case and was designed and manufactured in order to answer an industrial need. As a part within a given product is used for Reverse Engineering operations, the knowledge about its functions can enable to improve the rebuilt model as each part ensures one or more known functional specifications. According to the interaction between the part and the rest of the product, its environment is known and can enable to explain the presence of certain features within the part. “Environment” and “function” terms lead to the concept of functional analysis. This is essential for the reverse engineering of an old system to understand its specificities and functions. The extraction of the internal and external functions allows revealing specifications of many domains (mechanical, electrical, thermal …). It would be interesting to integrate this type of analysis in KBRE. In this paper, only mechanical functions are considered because it deals with the reverse engineering of mechanical parts. The functional analysis enables to assume the mechanical interaction between the considered part and its environment. As a hypothesis, the knowledge about the environment parts is known. In fact, the model of the part is rebuilt because someone needs this model because he needs to restudy the part. This person should have the functional knowledge about the part that is required for the proposed KBRE approach.

In KBRE, each mechanical linkage is a functional feature that is also represented in the skeleton form. Simple mechanical linkages are integrated in KBRE and are summed up a sort of linkage graph called the “graph linkage”. The number of linkages, the type of linkage and the number of contact are integrated in this graph.

In the study case of the journal cross (Figure 8~~Figure 8Figure 8~~), the two yokes are the environment parts and the journal cross ensures two pivot linkages with four cylindrical contacts (Two per pivots). The number of contacts reveals the number of standard features.

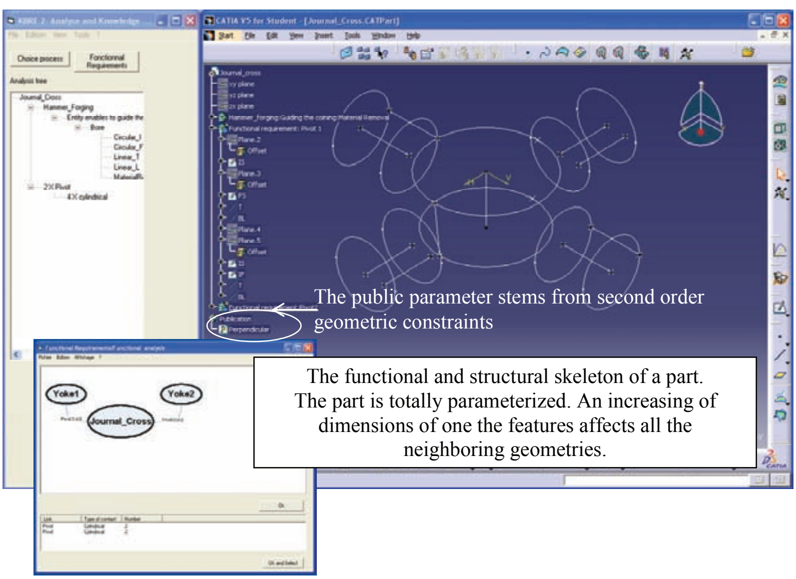


Figure 8. The functional and structural skeleton built from knowledge extraction

When the number of contact is superior or equal to two, KBRE considers automatic constraints. In the study case of the journal cross, a pivot linkage with two cylindrical contacts generates two coaxial standard features. KBRE will integrate these constraints called first order constraints.
In the end of this phase, a list of standard features is registered. All standard features are positioned and measured. To allow a good parameterization of the functional and structural skeleton of a part, KBRE will search for geometrical constraints called constraints of second order.

3.5 Parameterisation of features and natural surfaces processing

The second order constraints are not revealed by the "graph linkage" but are the result of the placement in the point cloud by the user. Indeed, KBRE integrate a geometrical algorithm to consider the analysis of parallelism and perpendicular constraints between the features. This algorithm is based on the trajectory of the features. If the angle between two trajectories is close to ninety degrees or zero degree then KBRE performs a parallelism or perpendicular constraints. KBRE creates, in these cases, public parameters which correspond to functional dimensions. In Figure 5, in the connecting rod case, the public parameter of length is created. In Figure 7, in the journal cross case, the public parameter of angle is also created. In the end of this phase, the functional and structural skeleton is completely built. This skeleton is also completely parameterised.
The next phase consists in generating the skin on each feature. The created skin generates functional faces of the part. A sweep operation between the initial and final section, using trajectory and behaviour law like guidelines allow creating these surfaces.
To achieve a fulfilled parameterization of skins according to the functional and structural skeleton of the part, KBRE will carry out offsets about sections of surfaces linked with standard features. The evolving of sections will offset linearly the linked surfaces. The linked surfaces are called the associate surfaces with the standard feature. Considered the journal cross case of study, an increasing about the diameter of a pivot will prompt an increasing of sections of linked surfaces (Figure 9).

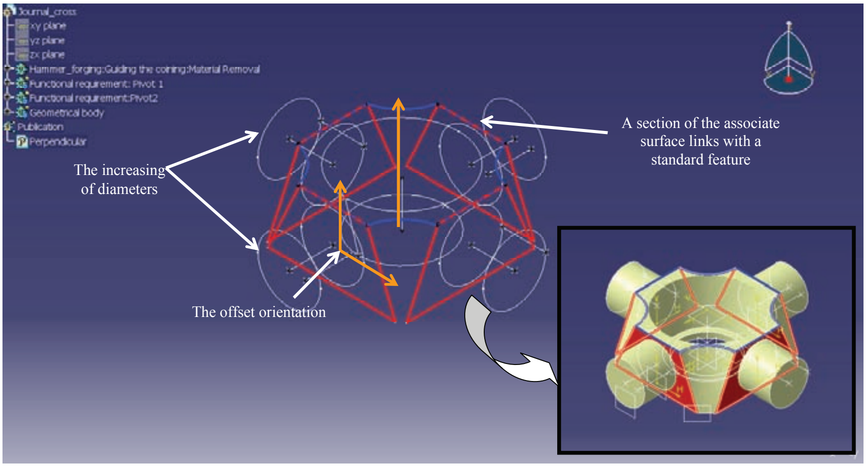


Figure 9. The parameterization of natural surfaces towards a parameterized surface CAD model

The recognition about aesthetics surfaces called natural surfaces also has to be processed. In perspectives, KBRE will have to process these surfaces to obtain a completely closed surface based CAD model in order to generate a solid CAD model.

4 CONCUSION

The RE based on geometrical approach often provides a frozen and not reusable model. A CAD model cleverer than the resulted geometrical model of current approaches is needed. The aim of this paper is to provide a clever CAD model which can be reintroduce in product development cycle in order to improve the possibilities of redesigning. For this reasons, the proposed approach focus on the classical design approach adapted to RE issue. This paper defines functions of the part based on the interaction of multiple expertises in order to identify and classify standard features. The standard features come from the manufacturing processes that have been used to make the considered part and from the functional requirements of the considered part. The analysis of the manufacturing processes and functional requirements is required in order to identify the expert knowledge of the case of study. KBRE is developing and proposes a methodology which combines a Knowledge Based System with the geometrical recognition techniques. KBRE allows the redesigning of $2^{1/2}$ prismatic parts for the milling process and casting parts without complex surfaces. It is a prototype software application and use CATIA V5 like a viewer. In perspectives, KBRE will integrate high performance segmentation techniques and will reference more standard features in the database. The resulting geometries will be built according to the STEP (AP203 2nd Ed.) exchange format in order to export the geometry in other CAD environment. Through several cases of study, KBRE will be tested near to qualify companies in reverse engineering.

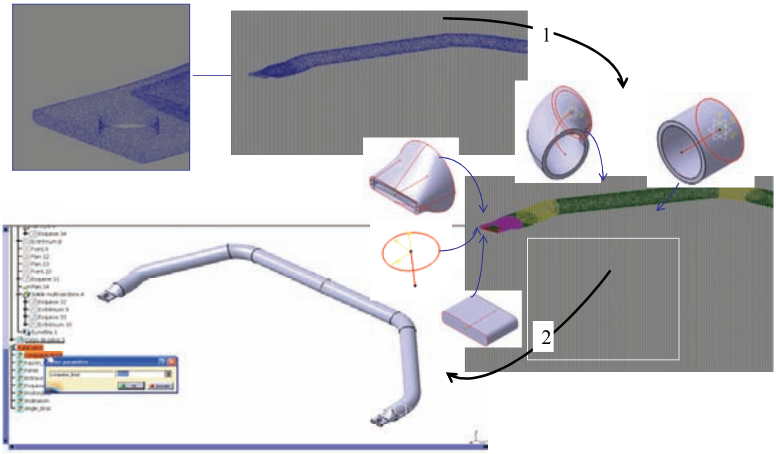


Figure 10. An example of a real industrial application, the stabilizer bar of car

However KBRE is a viewer state, it was tested in a several real industrial needs such as the stabilizer bar of car. A bar was digitized and redesign using KBRE methodology.

Finally, this work is linked to the PHENIX project (Product history based reverse engineering: towards an integrated expert approach) which suggests to develop a software tool in order to combine geometrical recognition and knowledge approach. In this tool, a PLM (Product life cycle management) will be integrated in order to manage multi-expertise and multi-knowledge of the extracted knowledge.

REFERENCES

[1] Laroche F. Bernard A. and Cotte M. Methodology for simulating ancient technical systems. International Review of Numerical Engineering. *Integrated Design Production ,2* ,2006 , pp.9-28.

[2] Benko P. and Varady T. Segmentation methods for smooth point regions of conventional engineering objects. In *Computer Aided Design, CAD'04,* Vol. 54, 2004, pp.36-51.

[3] Besl P. and Jain R. Segmentation through variable order surface fitting, *IEEE transaction on pattern analysis and machine intelligence*,10 ,1988, pp.167-191.

[4] Hoffman R.L. and Jain A.K. Segmentation and classification of ranges images, *IEEE transaction on pattern analysis and machine intelligence*,19 ,1987, pp.606-620.

[5] Sapidis N. and Besl P. Direct Construction of polynomial surfaces from dense range images through region growing, *ACM transactions on Graphics*, 14, 1995, pp.171-200.

[6] Meyer A. and Marin P. Segmentation of 3D triangulated data points edges constructed with C1 discontinuous surface fitting, In *Computer Aided Design, CAD'04*, Vol. 36, 2004, pp.1327-1336.

[7] Yokoya N. and Levine M. Range image segmentation based on differential geometry: A hybrid approach, in *IEEE transaction on pattern analysis and machine intelligence*, 11, 1989, pp.643-9.

[8] Alrashdan A. Motavalli S. and Fallah B. Automatic segmentation of digitized data for reverse

engineering applications, in *IIE transactions on robotics and Automation*, 15, 1999, pp.57-65.
[9] Tai C.C. and huang M.C. The processing of data points basing on design intents in reverse engineering, In *International Journal of Machine Tools & Manufacture,* Vol. 40, 2000, pp. 1913-1927.
[10] Thompson W. Owen J. De st Germain H. Stark S.and Henderson H. Feature based reverse engineering of mechanical parts, In *IEEE Transactions on Robotics and Automation,* 15, 1999, pp. 57-65.
[11] Werghi N. Fisher R. Robertson C.and Ashbrook A. Object reconstruction by incorporating geometric constraints in reverse engineering, In *Computer Aided Design, CAD'99,* Vol. 31, 1999, pp.363-399.
[12] Mills B.I. Langbein F.C. Marshall.A.D. and Martin.R.R. Approximate Symmetry Detection For Reverse Engineering, In *Sixth ACM Symposuim on Solid Modelling and Applications, ACM 2001.*
[13] Karniel A. Belsky Y. and Reich Y. Decomposing the problem of constrained surface fitting in reverse engineering, In *Computer Aided design, CAD'05,* Vol. 37, 2005, pp. 399-417.
[14] VPERI. Virtual Parts Engineering Research Initiative, The final report (http://www.cs.utah.edu/gdc/Viper/Collaborations/VPERI-Final-Report.doc), 2003.
[15] Mohaghegh K. Sadeghi.M.H and Abdullah A. Reverse engineering of turbine blades on design intent, In *International Journal Adv Manufacturing Technol,* Vol. 32, 2006, pp.1009-1020.
[16] Fisher R.B. Applying knowledge to reverse engineering problems, In *Computer Aided Design, CAD'04,* Vol. 36, 2004, pp.501-510.
[17] Urbanic R.J. Elmaraghy H.A and Elmaraghy W.H. A reverse engineering methodology for rotary components from point cloud data, In *International Journal of Advance Manufacturing Tool*, Vol. 37, 2007, pp.1146-1167.
[18] Durupt A. Remy S. Ducellier G. and Eynard B. From a 3D point cloud to an engineering CAD model: A knowledge product based approach for reverse engineering. *Virtual and Physical Prototyping,3,* 2008, pp.51-59.
[19] Durupt A. Remy S. Ducellier G. and Derigent W. A New knowledge based approach for the reverse engineering of a product, In *Design 2008,* Vol. 1, Dubrovnik, May 2008, pp.753-760.
[20] Yong C. Peien F. Zhougqin L. A genetic based approach for the principle conceptual design of mechanical products. In *International Journal of advance Manufacturing technology*, 2005, pp.225-233.
[21] Skarka W. Application of MOKA methodology in generative model creating using CATIA. *Engineering Applications of Artificial Intelligence*, Vol. 20, 2007, pp.677-690
[22] Chapman C. and Pinfold M. The application of a knowledge based engineering approach to the rapid design and analysis of an automotive structure. *Advanced in Engineering Software,* Vol. 32, 2001, pp.903-912.
[23] Ashby M.F. Brechet Y.J.M. Cebon D. and Salvo L. Selection strategies for materials and processes, *Materials and Design,* Vol. 25, 2004, pp.51-67.

Contact: Alexandre Durupt
University of Technology of Troyes
Laboratory of Mechanical Systems and Concurrent Engineering LASMIS
12 rue Marie Curie
10000 TROYES
FRANCE
Tel: +33 (0) 25 71 58 44
Fax: +33 (0) 25 71 56 75
Email: alexandre.durupt@utt.fr
lasmis.utt.fr

Alexandre Durupt is a PhD student in the Laboratory of Mechanical Systems and Concurrent Engineering (LASMIS) at the University of Technology of Troyes. He researches on the Reverse Engineering. He suggests a cycle knowledge based approach for the Reverse Engineering of a product. He is managed by the Sébastien Remy, associate professor in the LASMIS.