www.cadanda.com Computer-Aided Design AND APPLICATIONS

A Reverse Engineering for Manufacturing approach

Salam Ali[1], Alexandre Durupt[2], Pierre-Antoine Adragna[1] and Magali Bosch-Mauchand[2]

[1]Université de Technologie de Troyes, salam.ali@utt.fr
[2]Université de Technologie de Compiègne, Roberval Laboratory UMR 7337, France, alexandre.durupt@utc.fr

ABSTRACT

Defining a Computer Aided Process Planning (CAPP) model from a physical part is an important issue in product improvement, remanufacturing and quality control. Reverse Engineering (RE) is a process that allows to convert low level geometric information like 3D points cloud to high level information such as CAD model, CAPP model etc. There exist two approaches to obtain a CAPP model for a physical part. The first one is to reconstruct a CAD model of the part to be reversed, which then is reintroduced in the conventional product lifecycle. The second one is to directly identify manufacturing operations and define a new process planning from 3D information. This paper proposes an approach called Reverse Engineering For Manufacturing (REFM) which allows to directly obtain a CAPP model from 3D information and the skills of a user.

Keywords: reverse engineering, knowledge extraction, design for manufacturing.

1. INTRODUCTION

This paper focuses on Reverse Engineering (RE) in mechanical design domain. RE is an activity which consists in creating a CAPP model of an existing part from 3D information. The 3D information like 3D points cloud is obtained using 3D scanning technologies. The reasons to apply RE could be: (1) the original design is not supported by enough documentation and no drawing is existing or correct; (2) the original provider of the considered mechanical part has disappeared and does not manufacture the component anymore. As an assumption, this paper considers the following context: there is no information on the part (no drawing or scheme); only the physical part is available. To remanufacture this kind of parts, an approach called Reverse Engineering For Manufacturing (REFM) has been defined and is explained in this paper. REFM is a RE process that combines manufacturing knowledge extraction of the studied part with conventional 3D reconstruction techniques. The combination of these two approaches, enables to define a methodology in order to assist the user in the RE approach.

REFM has to provide a Computer Aided Process Planning (CAPP) model comprising a new manufacturing operations tree. This tree should be selected by optimizing the manufacturing sequence and define alternatives operations which aim to facilitate and improve the re-manufacturing. The management system is based on Design For Manufacturing (DFM) approach and allows to manage manufacturing information (the number of fixtures, the kind of milling operations etc.). REFM aims to incorporate databases that include all the necessary information for the construction of the CAPP model. For this aim, the system of Ashby *et al.* [2] is suitable. The main advantage of this approach is to integrate the manufacturing constraints in the product's lifecycle earlier. Furthermore, RE can also be a recursive process. Routine tasks such as the repetition of similar features can be managed and features that meet specific justification can be defined and reused by the user. Note that our REFM system handles only machined (milling) parts. Indeed, Forging and casting parts are more complex geometrically.

Nowadays, RE approaches including routine tasks start to be carried by Knowledge-Based Engineering systems (KBE) [7]. These systems are able to easily obtain CAD models based on functional features. These CAD models permit to re-design activities and afterwards to define a process planning. Thereby, these systems are not adapted to provide directly a CAPP model by a routine in the RE context. The main problematic of this paper is to explore how to adapt DFM to the RE context. The contribution of the paper is here restricted to suggest a prospective approach in

Computer-Aided Design & Applications, 11(6), 2014, 694–703, http://dx.doi.org/10.1080/16864360.2014.914387

a milling process context. This paper is structured as follow: the following section presents related works on knowledge based system for RE and related works on DFM for RE context; then the third section proposes a prospective approach in a milling process context. The part considered in this paper is a top of a reducer used in order to illustrate our approach. This case study will provide the basis of the analysis given by the system REFM.

2. RELATED WORKS

2.1. Knowledge-based System for Reverse Engineering

RE process, as defined in the scientific literature, is able to convert a manufactured/physical part to a geometrical model [3]; however it can capture a very low level semantics. Or, a CAD model is not only a geometrical model. Furthermore in design phase, functional aspects are frequently attached to geometrical shape. Thus, it is necessary to integrate in a RE process these aspects to the geometry. Nowadays, many researches are discussed the importance of knowledge management integration for RE system. For instance, Mohaghegh *et al.* [15] propose to involve a pre-knowledge on the part before performing the reverse engineering activities. The works of Fisher [10] explore the possibility to extract features even in very noisy data and that by using "knowledge-based" techniques. To select surface types and manufacturing activities, he exploits engineering knowledge and functional constraints with some user assistance. Or in their works, the knowledge is implicit and is not driven by a methodology. Thompson *et al.* [20] describe a classical geometric features-based reverse engineering system (Reverse Engineering Feature-Based - REFAB). The developed prototype creates interactively the CAD model of a part in which the user selects predefined features in a list and chooses where these features are located in the 3D points cloud. So, manufacturing knowledge extraction is achieved implicitly by the user. Only five manufacturing features (such as types of pockets and holes) are performed.

In the same way, Sunil and Pande [19] extract sheet metal features in a meshed points cloud. The first step is a segmentation followed by a primitive type attribution to each sub-mesh. Urbanic *et al.* [21] proposed a library of features based on a specific manufacturing process. They explain that features have accurate mathematical definitions for their geometry and tolerances depending on functional requirements. This approach allows extracting the relevant information and transforming it into relevant design knowledge.

Certain types of knowledge allow extraction of geometrical primitives. As an example in [22], the Virtual Parts Engineering Research Initiative project (VPERI) was created by the US Army Research Office in order to provide the vision, strategy, and methodology to help solving problems of long life cycle product maintenance. The knowledge of the geometric shape is necessary but not sufficient to reproduce the part. Indeed, re-engineering and re-design need functional specifications. Also, a specific design interface is used to allow the additional of knowledge in the form of algebraic equations that represent engineering knowledge such as the functional behavior of the components, the physical laws that govern the behavior, etc.

The use of KBE system for RE context is an interesting solution to reverse a part and obtain a CAD model. However, it is often based on functional knowledge to reverse the part. So, the manufacturing knowledge is not really integrated. As said in the scientific literature, firstly, a CAD model is obtained from points cloud and then, process planning is redefined based on this CAD model. In this process, feature extraction/recognition based approaches are used and often characterized as knowledge-based. For instance, Zhou *et al.* [24] use feature recognition/extraction and feature-based design to integrate CAD and CAPP systems. Or, our approach REFM consists in identifying directly the CAPP model from the points cloud. Hence, KBE process is used to extract knowledge on manufacturing activities. This knowledge explores the possibility to adapt the concept of DFM to the RE context.

2.2. Design for Manufacturing for RE context

As aforementioned, REFM is a RE methodology that aims to directly define a new process planning of a mechanical part. This approach is based on the combination of 3D and knowledge information. These knowledge should be managed and should be integrated in the re-design stage to reach an optimal CAPP model and then to achieve a successful RE process. It is for these reasons that DFM methodologies are perfectly appropriated. In the literature, Kerbrat *et al.* [13] bring a new DFM approach to multi-process manufacturing. This research considers that the selection of the manufacturing processes is based on the determination of the manufacturability complexity and the time and cost estimation at the design stage. The most basic system of Sanchez *et al.* [16] finds out which a manufacturing process is suitable for the features a part. More recent works are based on the analysis of features that model a part. For instance, Zhao and Shah [23] proposed a DFM shell that aids to perform a manufacturing analysis by taking into account techniques and economics data. Technical analysis underlines whether the part can be fabricated while the economic analysis underlines whether the time and cost of the construction are acceptable. Other work aims to reduce the manufacturing cost and time, so it turns to optimize the product form, material selection, and resource selection [9]. Boothroyd *et al.*

[5] developed a Design For Manufacturing Assembly (DFMA) approach to define processes, materials, and to simplify assembly procedure. DFMA is a tool which could be used along the product development in order to understand the decisions effect on the cost. Gupta *et al.* [11] proposed an approach to select processes and materials during embodiment design based on the cost estimation. Shercliff *et al.* [17] used process modeling based on guidelines, empirical data, statistical data, and physical models to perform the manufacturing process selection. CES4.5 (Cambridge Engineering Selector) system of Ashby *et al.* [2] includes a database oriented on the triple characteristics: Process, Material and Geometry. In this database, all numbered characteristics are limited by intervals which show the manufacturability. For this paper, the DFM approach is limited to the context in which a designer has to define a product in the point of view of its manufacturing process. The manufacturing process view in REFM has to be defined by technical data with accurate details such as the fixtures, kind of machines, kind of tools and milling stages. REFM has to integrate databases which include all this information according to the manufacturing resources of the company. In this context, we utilize a database which combines the system of Ashby et al. [2] with other information from handbooks such as [6]. In the following section of this paper, the REFM method will be explained and the prospective interfaces will be proposed through a case study.

3. REFM PROCESS

REFM is a new RE process which is based on manufacturing knowledge extraction methodology. It concerns parts where no information (drawings, scheme...) is available on them. Fig. 1 presents the overall process of the methodology.

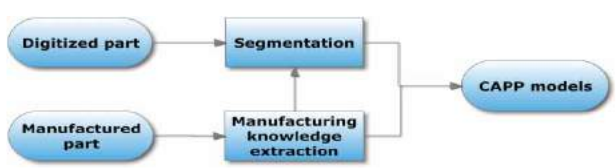

Fig. 1: REFM process.

The input elements of REFM methodology are the digitized part and the manufactured part. Thus, all precedent capitalization of the original product lifecycle is lost. The aim of REFM could be considered such as the combination of geometrical approaches (segmentation) and aided process planning methodologies (manufacturing knowledge extraction) of design context. The main innovative point of REFM is to develop "manufacturing knowledge extraction" and to define how it is possible to adapt to RE context in this proposal. Fig. 2 shows in details the REFM methodology where manufacturing knowledge extraction phase is developed. The different modules used in our methodology are described in the following sections.

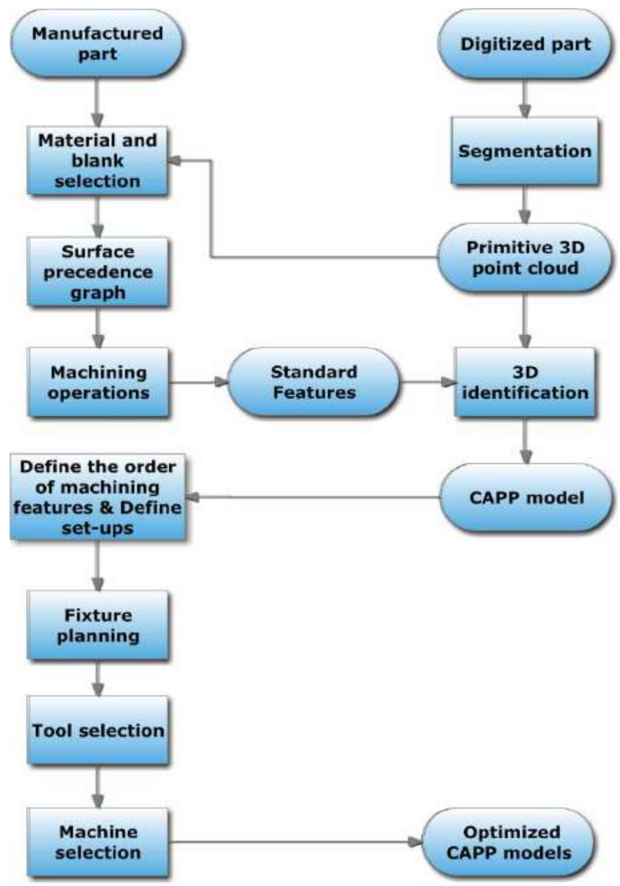

Fig. 2: REFM methodology in detail.

3.1. Segmentation

To start, according to related works on RE, REFM must import RE files such as 3D point cloud or STL (STereo Lithography) file. As an assumption, REFM starts when treatment operations of cleaning STL or points cloud are previously executed. The segmentation phase is used here in order to detect surfaces such as plan, cylinder, spherical, and conical surfaces. It consists in the division of the 3D point cloud of a given part into a set of n point cloud representing the n surfaces that compose this part. In the RE process, this phase can be performed by one of the following three segmentation techniques. The first one is the Region-based technique. This technique is based on spatial coherence of the data to organize the mesh into meaningful groups. The best techniques are based on the approximation by bi-polynomial surfaces [4] and allow the recognition of simple forms such as plan, cylinder, spherical and conical surfaces. The second one is the

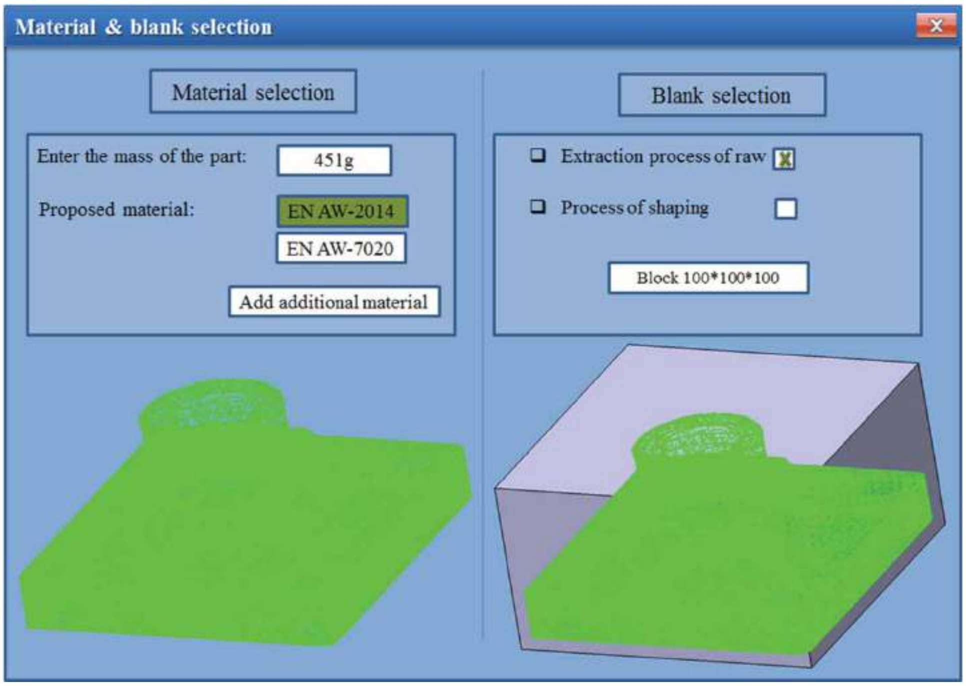

Fig. 3: Material and blank selection in REFM system.

Edge-based technique that consists in intending to isolate discontinuities in the 3D point cloud. Break areas such as steps and discontinuities of normal and curvatures orientations are recognized [14]. The third one is the Hybrid technique which combines Region and Edge technique [1].

If we apply the first technique on the top part of a reducer, the 3D point cloud will be divided into 36 surfaces (fig. 5). Note that if some surfaces are not recognized, the user selects himself the area of the point cloud for unrecognized surfaces. This paper does not deal with the segmentation phase. It is mainly focusing on manufacturing knowledge extraction phase which is discussed in the following section.

3.2. Manufacturing Knowledge Extraction

3.2.1. Step 1: Material and blank selection

After the segmentation phase, the DFM process can start. To select the material of the part to be re-engineered, REFM system asks the user to enter its mass (the user has previously weight the original part), see fig. 3. Then, the system calculates the volume of the part from the 3D point cloud file and so that to obtain the density. Once REFM system has the density, the system CES4.5 of Ashby *et al.* [2] is used. The system proposes some materials and according to its needs and its experiences the user chooses the material that he finds the most appropriate. If the user did not find the suitable material, he can add additional material.

The following step of DFM analysis is to determine the original blank of the part. As a reminder, REFM system concerns milled parts. So, the blank comes from a precedent process step of the part. REFM system can propose an original blank from primary processes: the extraction process of raw (rolling, extrusion etc.) or the process of shaping (casting, forging…). Indeed, the DFM database of Ashby *et al.* [2] in CES4.5 classifies the manufacturing processes according to the fig. 4.

In the case of the reducer top, the original blank is a parallelepiped (grey box in fig. 3). REFM system is able to perform the blank definition according to an algorithm based on a box detecting (fig. 3).

3.2.2. Step 2: Surface precedence graph

The surface precedence graph connects machining surfaces between them by starting from raw surfaces (fig. 5). Each surface is represented by a circle containing the label of the surface (B: raw surface, F: flat or free form machined surface or A: bore machined surface). The type of a surface is linked to the point groups of the segmentation. It means that the sketching of surface precedence graph is interactive. The user selects a group of points in the segmentation screen (fig. 5) and dedicates a label (B, F or A). The selection is thus added in a graph. The user also sketches, using the arrow tool of REFM system, the dependency of each surface. For example, the arrow between two surfaces shows the manufacturing order and the functional dependency. It means that the starting surface of the arrow must be manufactured

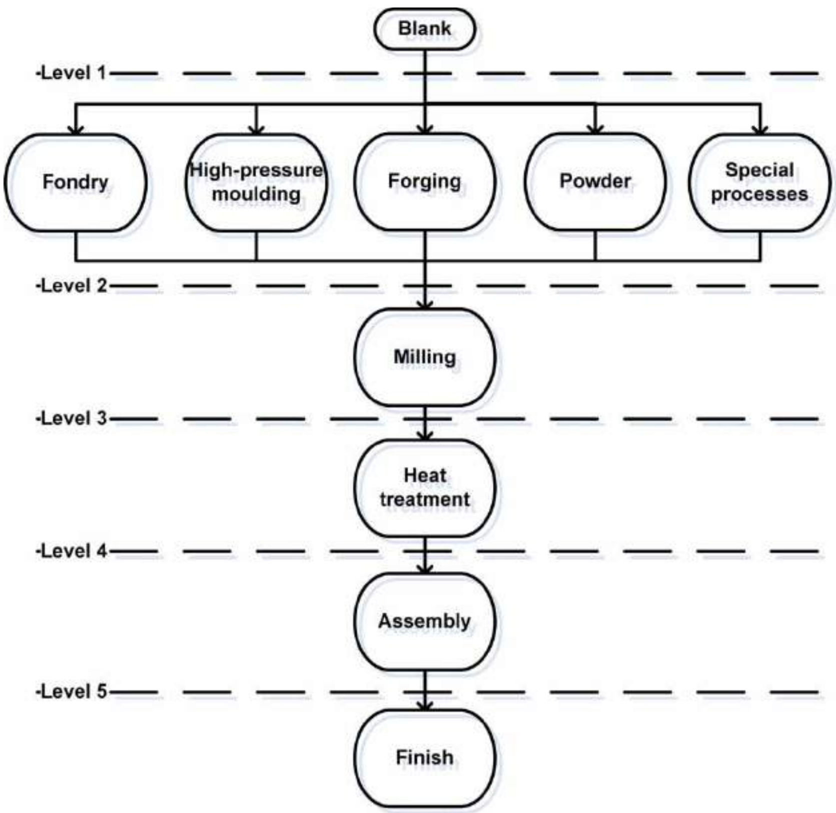

Fig. 4: The classification of manufacturing processes in CES4.5, [2].

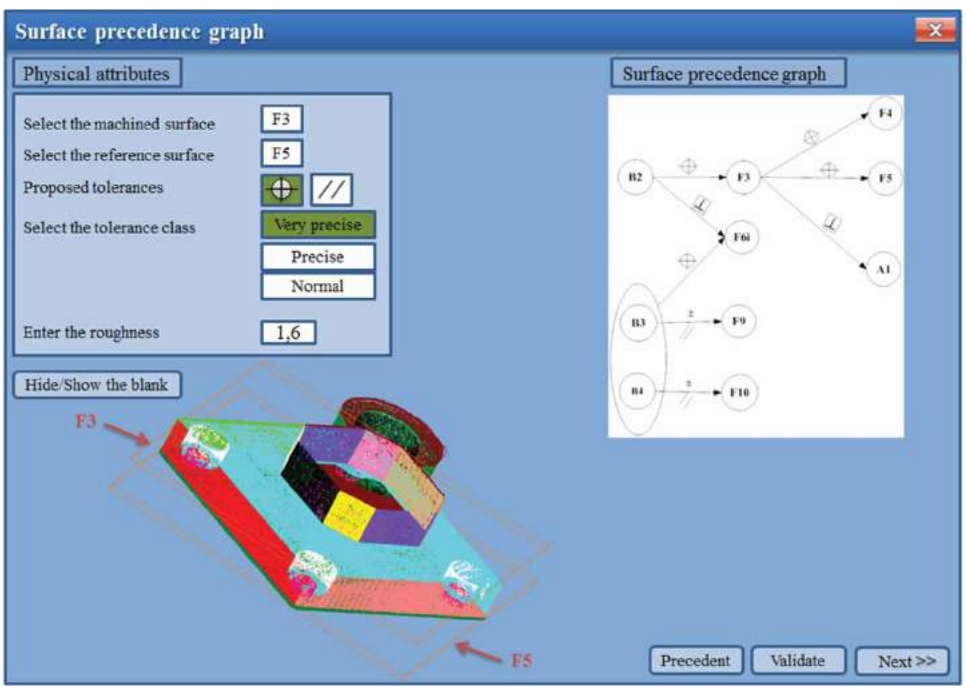

Fig. 5: Interface of the surface precedence graph in REFM system.

before the arrival surface. The functional dependency is mainly determined by the skills of the user. The surface precedence graph is a tool to support the user analysis. However, the analysis is semi-automatic. It means that REFM system suggests to the user three kinds of tolerances such as parallelism, perpendicular

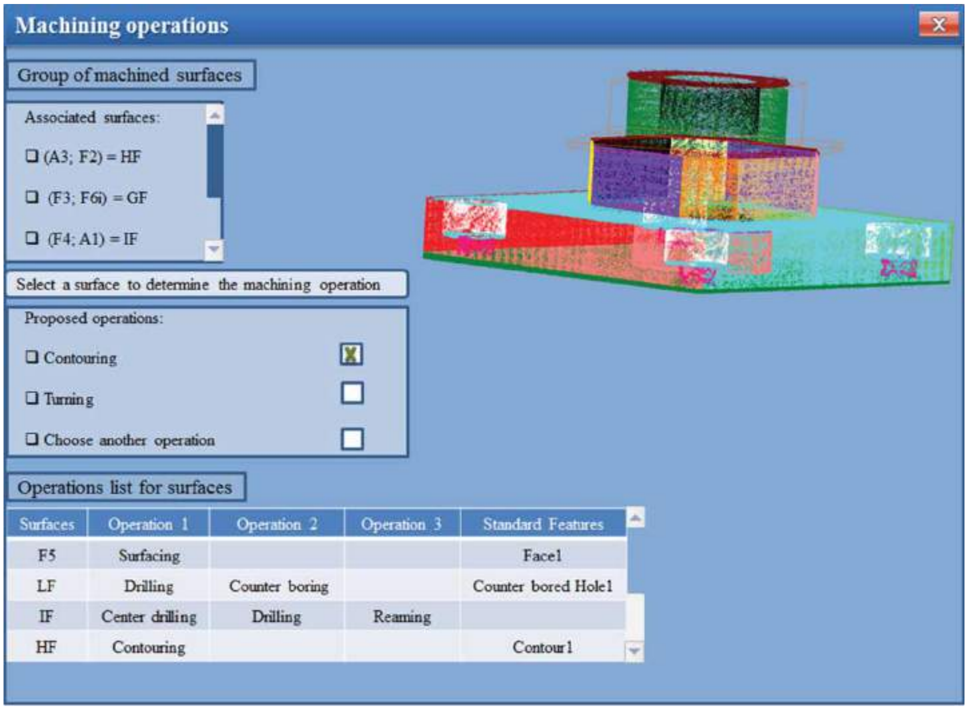

Fig. 6: Interface of the selection of machining operations in REFM system.

and localization. Simple algorithms are performed between surfaces linked by an arrow and are based on angular detection between the referenced point groups. According to the angular value, REFM system suggests one of these kinds of tolerances.

According to Ashby database [2], REFM system can suggest a list of tolerance class according to the part material and the roughness data (which comes from a previous roughness measuring). The user chooses by assumption (based on his own skills) the tolerance class and the roughness of the surface (the user can previously measure the roughness by a roughness meter).

To sum up, based on this manufacturing method description, REFM system asks the user to select a machined surface and its reference one, then REFM system proposes one or more tolerances and the user can choose the tolerances that he finds the most appropriate, as shown in fig. 5.

Hence, the surface precedence graph is a representation of a machining map of a part. The raw and machined surfaces are referenced but also the machining order between them.

The graph is saved in a REFM database in order to be reused in a new similar case study. Thus, the graph must be sketched for the first time because the database is empty.

3.2.3. *Step 3: Machining operations selection*

Using the above data and based on a cutting tools database [12], the user searches for a logical grouping of machined surfaces. Indeed, the accessible surfaces by the same tool should be grouped to be machined at the same time (in the same operation). The group of surfaces is based on the surface precedence graph. The user surrounds the group of surfaces by a surrounding selection tool. For example, selected surfaces (A3 and F2) in fig. 6 are combined in a group called HF. In addition, REFM can propose groups of surfaces in the case of routine tasks. Indeed, REFM can store groups of surfaces of each studied part in a database so that it can be reused another time for a similar case.

Many details affect the selection of machining operations such as: the shape, accuracy and surface finish requirement of the surface, the overall structure of the part, and the workpiece material. In fact, Ashby et al. [2] explain that the best solution of design for manufacturing is retained if decisions of materials, geometry and processes are taken into account simultaneously. And based on the surface roughness, the system determines the number of operations to reach the final surface finish requirement (rough, semi-finish, finish). REFM tries to select alternatives routes to machine each surface or group of surfaces. For instance, in fig. 6, REFM detects that it is possible to machine the group of surfaces HF (HF is a group of cylindrical and plan machined surfaces) using the contouring or the turning operation. And thus, the user has the option to choose its appropriate route. Note that the user can change the machining operations according to his requirements. After that, standard features (see section 3.2.4) can be

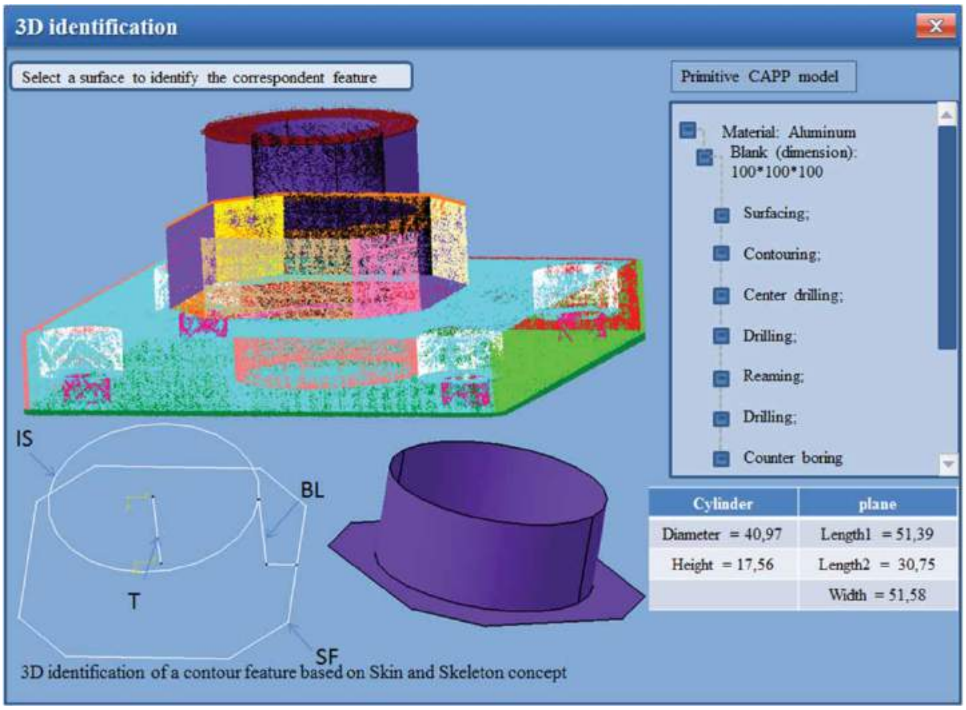

Fig. 7: Interface of 3D identification module in REFM system.

generated. Indeed, a feature is the combination of surfaces coupled to a milling operation.

3.2.4. Step 4: 3D identification

The previous steps allow the user to obtain machining operations, standard features and so on. Each operation, for example the contouring of the feature selected in the fig. 6, should be linked to geometry. This geometry will start from the blank and will be decomposed to obtain the final part. 3D identification serves to translate operation steps of manufacturing process in geometry. To make this modeling, REFM system uses Skin and Skeleton concept. In fact, for each Skin and Skeleton element [18], an included script in the database performs an algorithm based on the least squares approximation. This concept allows representing customized geometric features (fig. 7):

- Skin: it represents the functional surfaces.
- Skeleton: it represents the geometrical and topological structure.

A skeleton consists of four main elements: an initial and final section (IS and SF), a trajectory (T) which represents the evolving in the space of the initial section to the final section, and the behavior law (BL) which represents the evolving of the skin.

To fit features in the point cloud, the user has to select one or more regions (from point group) which correspond to the feature localization. Therefore the fitting feature is in our case semi-automatic.

The output of this module is a primitive CAPP model including machining operations that are not yet sequentially defined.

This paper does not deal with 3D identification algorithms. However, this module is mainly based on results published in our previous work [8].

3.2.5. Step 5: Define the order of machining features & Define set-ups

The order of machining features of the re-engineered part depends on non-geometric information such as geometric dimensions and tolerances. So to reach feature sequencing, REFM system returns to the data mentioned in the Surface precedence graph module. In addition, REFM system will integrate simple rules taken from Handbooks such as [6] which include constraints on the optimization of cutting conditions to perfect the ordering of machining features. For instance, if the part to re-engineer contains a hole on an inclined surface, so it is optimal to machine the hole before the inclined surface since holes cannot be machined accurately on an inclined surface. Or, if the part contains a hole on a flat and smooth surface, so we start by the milling operation and so that not to plug the hole as in our case.

After that, based on the surface precedence graph, REFM system groups the features into set-ups. Set-up design should be such as a maximum number of features can be machined with a minimum number of set-ups. Indeed, each new set-up introduces the possibility for additional positioning errors to occur, so

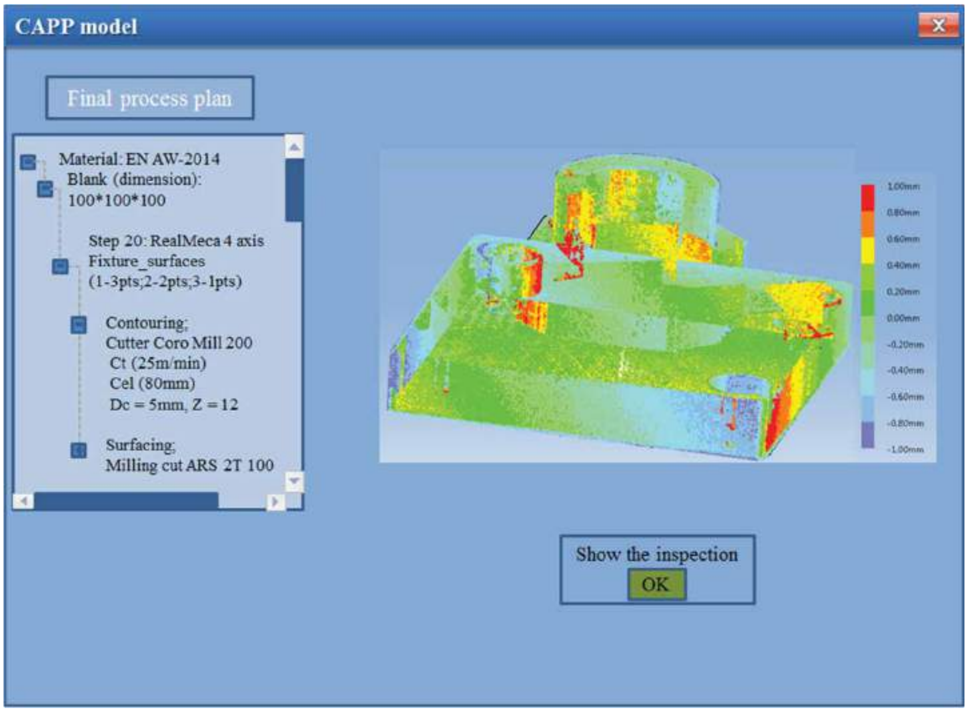

Fig. 8: The final CAPP tree and the inspection with the RE files.

reducing the total number of set-ups increases overall accuracy of the part to re-engineer. Before proceeding to the next step, REFM system asks the user if he is satisfied with the proposed sequence. If not, he is allowed to change the order, based on his own experience and knowledge.

3.2.6. Step 6: Fixture planning

Fixtures are used to ensure a suitable position for machining operations on parts. The critical problem is the optimization of support, locator, and clamp. This optimization is essential to minimize parts geometric and machining accuracy errors. To respect the principle of isostatism i.e. the positioning of the part without ambiguity in the space, the most popular locating method used for prismatic parts is 3-2-1 method: three datum points support the part (plane locating element), two datum points locate a flat part surface (guide locating element), and a single datum point locates a second surface perpendicular to the previous surface (endwise locating element).

An interface of definition set-ups is used. A calculation of isostatism degree is also integrated. Then, according to the locating method, the user can select the surfaces of fixtures.

3.2.7. Step 7: Machines selection

Depending on re-engineered part characteristics (part type, part size, feature tolerances and feature surface finishes), machining operation characteristics (operation type and machining power) and batch size, REFM system suggests machines. For each and every operation one or more machines are candidates. The database of REFM system allows modeling of the machining resources of the user's company. To choose the best one, REFM system considers a set of 3 mains criteria such as the number of fixtures and subfixtures, the finishing surface possibilities, and the kind of operations. This set of criteria is already determined thus, the REFM database allows referencing of machines and suggests them to the user. For example, the most suitable machine among those that are previously candidate, is the machine that realizes the maximum number of operations with the minimum number of set-ups.

Once the machines are chosen, the machining dimension value of the tolerance interval of each feature could be automatically calculated and included in the surface precedence graph.

3.2.8. Step 8: Tools selection

The selection of cutting tool is based upon machining operation and its associated machining feature. The basic idea in selection is that for each machining feature and machining operation combination there is a corresponding cutting tool to be used to generate that feature. In addition, cutting tool selection depends on finished surface requirements. So, REFM system selects for each feature, from the cutting tools database of Sandvik [12], several cutting tools based on geometric parameters and finished surface requirements of the correspondent feature. And then the user can choose the suitable one according to him.

Thereby, the process plan tree is generated by REFM system (fig. 8). In addition, the user can show by inspection, the distances between the RE files and the CAPP model decomposed in machining operation steps.

4. CONCLUSION

This paper proposes a new method for re-manufacturing mechanical parts. The fact is that industrial companies of the cluster NOGENTECH (French cluster of 62 companies specialized in metal forming process) have to define a new process planning from 3D information (point cloud, drawings, etc). Or, previous commercial solutions, such as Geomagic™, RapidForm™ and CATIA™ are more efficient to obtain a CAD model. Nevertheless, an industrial who needs to define a CAPP model redefines the process planning from this CAD model. REFM is a methodology based on DFM approaches and focuses on the milling process. As mentioned in the paper, REFM system refers only on milled parts and proposes an original blank from primary processes. According to the related works, the Ashby et al. [2] classification seems to be a way of solving the problem.

The future REFM system must provide a Computer Aided Process Planning (CAPP) model including new manufacturing tree. This tree must be selected by optimizing the manufacturing sequence and define alternatives operations which aim to facilitate and optimize the re-manufacturing. Each milling operation is a Skin and Skeleton feature which is fitted in the 3D identification. Or in 3D identification module, errors of approximation can be detected which provide localization errors between the different features. Therefore, to use the final CAPP model it's necessary to correct these errors.

In the other hand, REFM system includes routine tasks. Indeed, it can store the surface precedence graph of each studied part in a database so that it can be reused another time for a similar case. The aim of REFM system is essentially to propose prototype software which can be coupled with CATIA V5 and Solidworks, CAD software. It means that REFM system is independent but could use the geometrical resources of commercial software. Today, REFM system is a demonstrator; it is performed manually and uses results from existing algorithms such as segmentation and 3D identification. The surface precedence graph is sketched manually and is tested on 3 axis parts. A final version is desired based on PYTHONOCC (OpenCasCade™) resources in order to propose a complete independent demonstrator. After REFM further works will be done such as to add a database integrating: the cost aspect (evaluating the cost milling), the time consuming (the time of the process milling) and the sustainable aspect (to produce milling part in respect of environment).

ACKNOWLEDGMENTS

The acknowledgment concerns the Champagne Ardenne region through the ESSAIMAGE program. The works are financed by the region.

REFERENCES

[1] Alrashdan, A.; Motavalli, S.; Fallah, B.: Automatic segmentation of digitized data for reverse applications, IIE transactions on robotics and automation, 15, 1999, 57–65.
[2] Ashby, M.F.; Brechet, Y.; Cebon, D.; Salvo, L.: Selection strategies for materials and processes, Materials & Design, 25, 2004, 51–67.
[3] Benko, P.; Varady, T.: Segmentation methods for smooth point regions of conventional engineering objects, Computer Aided Design, 54, 2004, 36–51.
[4] Besl, P.; Jain, R.: Segmentation through variable order surface fitting, IEEE transaction on pattern analysis and machine intelligence, 1988, 167–191.
[5] Boothroyd, G.; Dewhurst, P.; Knight, W.: Product design for manufacture and assembly, Marcel Dekker, ISBN 0-8247-9176-2, 1994.
[6] Chevalier, A.; Bohan, J.: Guide du technicien en productique, Hachette Technique, éd. 13, ISBN 978-2-0116-7584-2, 2010.
[7] Durupt, A.; Remy, S.; Ducellier, G.: Knowledge based reverse engineering: An approach for reverse engineering of a mechanical part, Journal of Computing and Information Science in Engineering, 10, 2010, 1–4.
[8] Durupt, A.; Remy, S.; Ducellier, G.: KBRE: a knowledge based reverse engineering for mechanical components, Computer-Aided Design and Applications, 7(2), 2010, 279–289.
[9] Feng, S.; Song, E.: A manufacturing process information model for design and process planning integration, Journal of Manufacturing System, 2003, 22.
[10] Fisher, B.: Applying knowledge to reverse engineering problems, Computer Aided Design, 36, 2004, 501–510.
[11] Gupta, S.; Chen, Y.: A system for generating process and material selection advice during embodiment design of mechanical components, J. of Manufacturing System, 22, 2003, 28–45.
[12] http://www.sandvik.com/
[13] Kerbrat, O.; Mognol, P.; Hascoet, J.: A new DFM approach to combine machining and additive

manufacturing, Computers in Industry, 2011, 62, 684-692.

[14] Meyer, A.; Marin, P.: Segmentation of 3D triangulated data points edges constructed with C1 discontinuous surface fitting, In Computer Aided Design, 36, 2004, 1327–1336.

[15] Mohaghegh, K.; Sadeghi, M.H.; Abdullah, A.: Reverse engineering of turbine blades on design intents, International Journal of Advanced Manufacturing Technology, 32, 2006, 1009–1020.

[16] Sanchez, J.; Priest, J.; Soto, R.: Intelligent reasoning assistant for incorporating manufacturability issues into the design process, Experts systems with applications, 12, 1997, 81–88.

[17] Shercliff, H.R.; Lovatt, A.M.: Selection of manufacturing processes in design and the role of process modeling, Progress in Material Sciences, 46, 2001, 429–459.

[18] Skander, A.; Roucoules, L.; Klein Meyer, J.S.: Design and Manufacturing Interface modeling for manufacturing processes selection and knowledge synthesis in design, International Journal of Advanced Manufacturing Technology 37, 2008, 443–454.

[19] Sunil, V.; Pand., S.: Automatic recognition of features from free form surface CAD models, Computer-Aided Design, 40, 2008, 502–507.

[20] Thompson, W.; Owen, J.; De St Germain, H.; Stark, S.; Henderson, T.: Feature based reverse engineering of mechanical parts, IEEE Transactions on Robotics and Automation, 1999, 15, 57–67.

[21] Urbanic, R.; Elmaraghy, H.; Elmaraghy, W.: A reverse engineering methodology for rotary components from point cloud data, International Journal of Advanced Manufacturing Technology, 2008, 37, 1146–1167.

[22] VPERI.: Army research office virtuals parts engineering research initiative final report. Workshop, http://www.cs.utah.edu./gdc/Viper/Collaborations/VPERI-Final-Report.pdf, Salt Lake City, USA, 2003.

[23] Zhao, Z.; Shah, J.: Domain independent shell for DFM and its application to sheet metal forming and injection molding, Computer-Aided Design, 2005, 881–898.

[24] Zhou, X.; Qiu, Y.; Hua, G.; Wang, H.; Ruan, X.: A feasible approach to the integration of CAD and CAPP, Computer-Aided Design, 2007, 39, 324–338.