CAD Model Comparison: Manufacturing cost estimation Based On Unified Feature Technology

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Abstract :

Each product developed by a company enriched its know-how. So this expertise needs to be highlighted for reuse in modeling of new products. The reuse of acquired knowledge engenders time and money benefits. Thus, this paper proposes a new approach for CAD model comparison basing on an unified feature technology, in manufacturing semantics. This feature modeling is used to facilitate the comparison between a new product and a database of CAD models already mastered. The comparison model allows the reuse of the CAM data and the cost estimation of the new product. In this article, the proposed approach is detailed and a case study is presented to highlight the major contributions.

Keywords: CAD Model; geometric entities, unified feature technology, comparison; Digital Mock-Up.

1 Introduction

The majority of industrial companies develop their products using different methods. Nerveless, The employ of a (Digital Muck-Up) DMU, from the geometric modeling phase to the marketing phase, remains a common used tool. The DMU is based on the geometric definition for multidisciplinary engineering applications. Over time, the geometric shape evolves according to the customers' needs. Thus, changes in the product shape into the Computer Aided Design (CAD) and / or subsequent phases are required. This evolution will also impact the technical data specific to each discipline (manufacturing, FE calculations, Assembly, etc.). Thus, each modification realized by multidisciplinary actors enriches the geometric model by information. This redundancy and wealth of information drives companies to retain and reuse data that describes reliable and proven products, as well as capitalize on the knowledge gained in the past. The last strategy allows the company to benefit from expertise acquired during the manufacturing of similar product: reduce the cost and the development time of new products as well as circumvent the problems already encountered.

Thus, this work presents a new tool, based on an Unified Feature Technology (UFT), allowing the comparison of geometric models in manufacturing semantics.

This paper is organized as follows. In section 2, a review of the literature is presented. Then, an overview of the proposed model is described as well as the assumptions and approaches used. Section 4, a case study is detailed to validate the proposed tool. The conclusions and perspectives for this work are presented in Sect. 4.

2 State of the art

The need to reduce product development time and cost initiated the establishment of comparison tool. A decade years ago, numerous researches are interested to the CAD models comparison. Louhichi et al. developed an algorithm to compare two CAD models (initial Work Package (iWP) and modified Work Package (mWP))[1]. The algorithm is based mainly on faces and adjacent faces for the identification of changes between iWP and mWP. This work targets the propagation of changes within a DMU. Souaissa et al. proposed a new geometrical and topological descriptor to compare and localize, automatically, changes realized on models [2]. This comparison scenario is used to perform a partial mesh on modified zones. The complete mesh is avoided [3]. The approach in [2,3] is based on the comparison of the metric and inertial tensors associated to the Boundary Representation (B-REP).

The comparison approaches are used for different tasks as collaborative engineering [4], finite element analysis [5],meshing [6] and manufacturing processes [7–12]: Huifen et al. developed a system, based on FT, to support collaborative engineering, where collaborators can act together from anywhere. This system is founded on CAD, CAPP and CAM features [4]. These features are used as information to characterize a product. A feature classes are defined: general, collaboration, design, manufacturing, shape, process, precision and material. The feature modeling is performed by instantiation and is applied to all features of the proposed system to form a library. For finite element analysis, Richard et al. evaluated current CAD systems and provided recommendations for future CAD systems [5]. There commended architecture of CAD systems respects both manufacturing and analysis constraints. The new system must be based on the features and supports the multidisciplinary activities. Each graphical representation must be able to maintain the shape module as well as adjust and propagate the parameters for the finite element analysis module. W. Duan et al. proposed a solid modeling tool based on features, because features recognition, after extraction, is a difficult task with several limitations [6]. This tool comprises two mechanisms: the first allows designers to define a feature-oriented application; the second provides directly the mesh from the feature definition for downstream applications.

The manufacturing process is the aim of most researches using CAD models comparison, based on FT. Zhenbo et al. proposed an approach to generate automatically a 3D assembly dimension chain based on the feature model [7]. The developed module is integrated into CATIA® system based on the Feature Attributes Set (FAS) concept.FAS model requires only information about the closed loop formed by the features, in order to generate automatically the dimension chain. In order to create an automatic system for holding small parts for the rapid prototyping process, Choi et al. proposed a new Reference-Free Part Encapsulation(RFPE) technique [8]. The developed program generates a process plan using the feature-based modeling technology. This software comprises mainly two modules: a feature-based modeling module and a machining data retrieval module. An additional module comprising tools database is used for tool selection corresponding to machining feature. So, the tool database is built firstly. Hoque et al. established a concept to design basing only on manufacturing features [9]. A library of predefined features is taken into account when modeling a product. Hence, machining problems will be detected faster and the best manufacturing solutions will be deduced. As a result, the production cost will decrease. Huang et al. presented an effective approach to retrieving sub-parts of 3D CAD models in order to be reused in the manufacturing process [10]. This approach, based on features, evaluates not only the similarity according the geometric level but also the manufacturing semantics level. For the comparison between features, two filters to search sub-parts.

The first is a designation code describing the part type, the raw material, etc. The second codes the manufacturing features coupling, which uses matrix to describe the distribution of the machining features on a 3D CAD model. The integration of these information on a prototype system, allows the similarity detection between features. Wong et al. developed a feature-based design system to integrate CAD and CAPP (Computer-Aided Process Planning) functions to machine prismatic parts [11]. This approach is based on the conversion of geometric data into input data for the planning process to avoid the feature recognition task. The method imposes requirements as in the case of part modeling with a manufacturing semantics, the designer must first create the raw material and then uses predefined feature to remove material. Holland et al. proposed an approach for feature extraction from a STEP file, in order to be used in a material deformation process [5]. This approach facilitates designer's task, even in the lack of knowledge on metalforming. The method allows estimating the product manufacturing cost.

Kumar et al. [13,14] presented a quality loss function approach to calculate total cost of product. The computation model is based on Taguchi's method. The manufacturing tolerance value are optimized in order to minimize the product cost. Four criteria are adopted for this optimization: Worst case, RSS, Spotts and Estimated mean shift. The calculation of the cost is expressed in exponential model. Ghali et al. [15] proposed an approach allowing tolerance integration into a CAD model, while taking into account functional and manufacturing requirements in an early DMU phase (DMU). The proposed approach consists on broadening the tolerances values of difficult machined dimensions while respecting the functional requirements. Thus, the total cost of assembly decreases. The same mathematical model cited in [13,14], is used.

According to the works cited above [1–12], the FT is the base of different developed approaches. However, different definitions of features are assigned and used according the studied discipline of life product cycle. Thus, a definition of an unified feature is required. In this paper, a CAD model comparison approach based on unified feature for manufacturing cost estimation is proposed.

3 Proposed model

The proposed approach is based on a new concept, the Unified Feature Technology (UFT), in order to compare a Reference Model (RM) with a Company Models DataBase (CMDB). The UFT is uniform, from a structural point of view, and includes multidisciplinary data while adopting the following assumptions:

- CAD data: geometrical and topological structures of CAD model as well as specified dimensional tolerances. The same platform is used to avoid the loss of information when passing through standard formats like the STEP format. The geometrical and topological parameters are standardized. For example, in the case of an open drilling feature (Fig. 1), the geometrical parameters are the diameter, length as well as the two angles α and β. The topological parameter is one cylindrical face (Fig. 2).

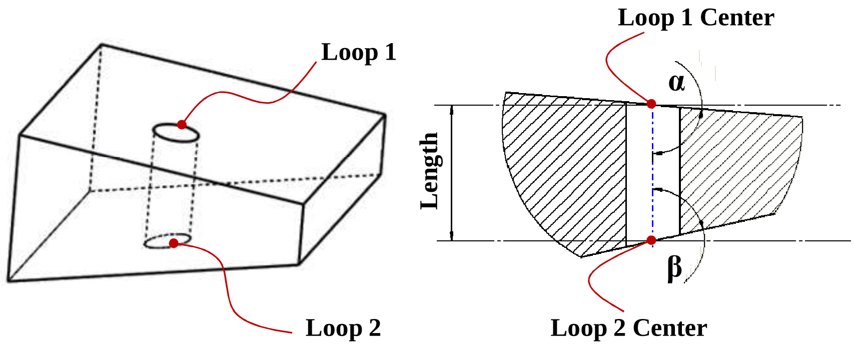

Fig. 1. Geometric parameters of an open drill

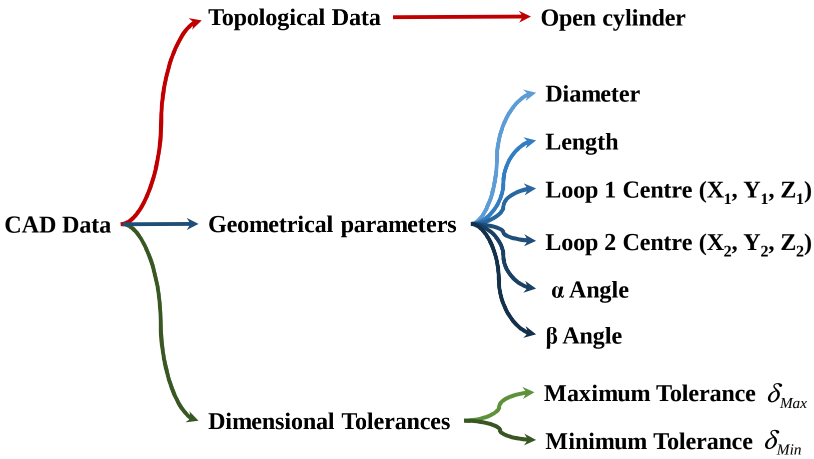

Fig. 2. Standard CAD Data Structure for Drilling Feature

- CAM data: All possible manufacturing parameters (cutting parameters, machining strategies, etc.) are standardized, as quality standard tools and maintenance. For example, standard CAM data structure for drilling feature is shown in Fig. 3. This standard can be used by all engineering disciplines. The chronological order of manufacturing operations specified in plan process is not considered. For the face milling feature, the raw material must be communicated through an interface. A comparison between the bounding box and the Reference Model (RM), the feature will be identified with corresponding parameters (the target face, the extra thickness, etc.). In this work, tree types of CAM features (XF) are fixed: Face Milling Feature (FMF), Turn Milling Feature (TMF) and Drilling Feature (DF). This choice is established only to simplify the approach,. Each feature is studied separately, without taking into account the interaction between features, as realized by Huang et al. [10].

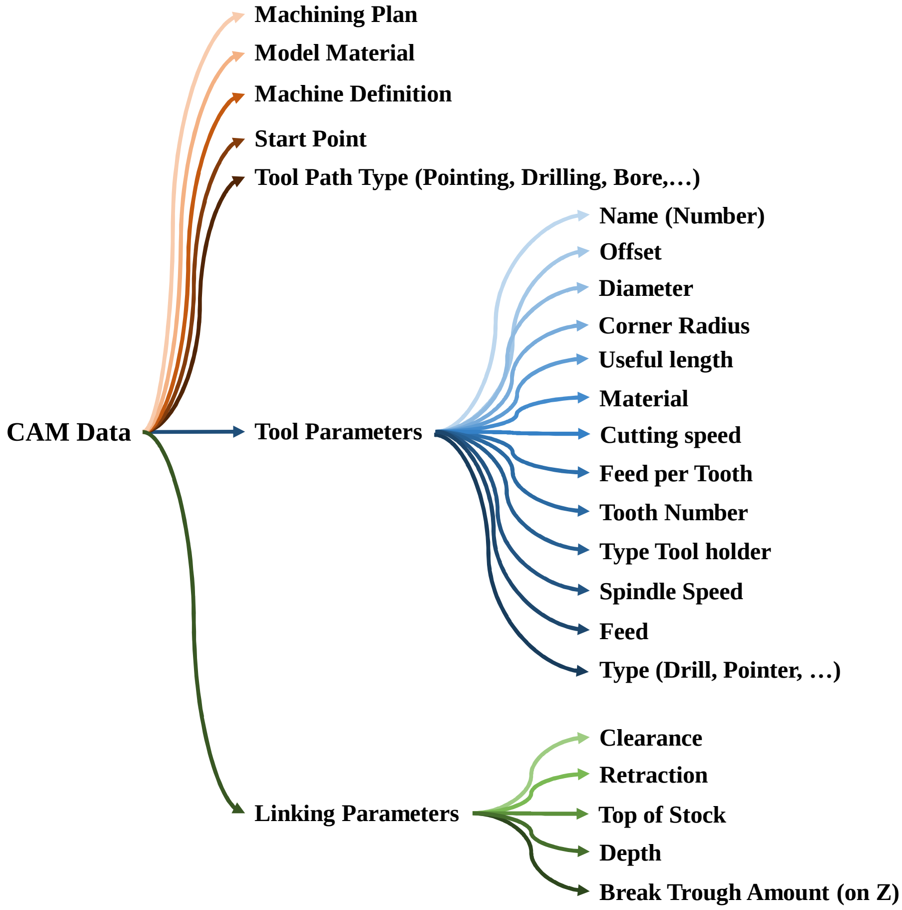

Fig. 3. Standard CAM Data Structure for Drilling Feature

- Two costs are presented for each feature (Fig. 4). The first represents the theoretical average cost of the feature (Eq. 1) which is computed using the exponential function (Eq. 2). g(δ) represents the cost of a machining operation with tolerance δ. C_0 and C_1 are constants obtained by experimental machining [14]. The second represents the true cost of the feature based on real results of manufacturing, i.e. After the product manufacturing, the feature cost is deduced and inserted into the CAM data.

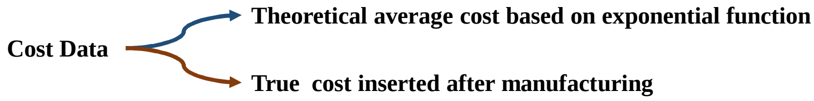

Fig. 4. Standard CAM Data Structure

$$C_{iMoy} = \frac{g(\delta_{iMin}) + g(\delta_{iMax})}{2} \quad \text{; with i is the i}^{th} \text{ XF.} \qquad (1)$$

$$g(\delta) = C_0 \frac{1}{e^{C_1 \delta}} \qquad (2)$$

The proposed algorithm comprises four sub-algorithms (Fig. 5): CMDB organization, comparison based on codes, comparison based on features and manufacturing cost estimation.

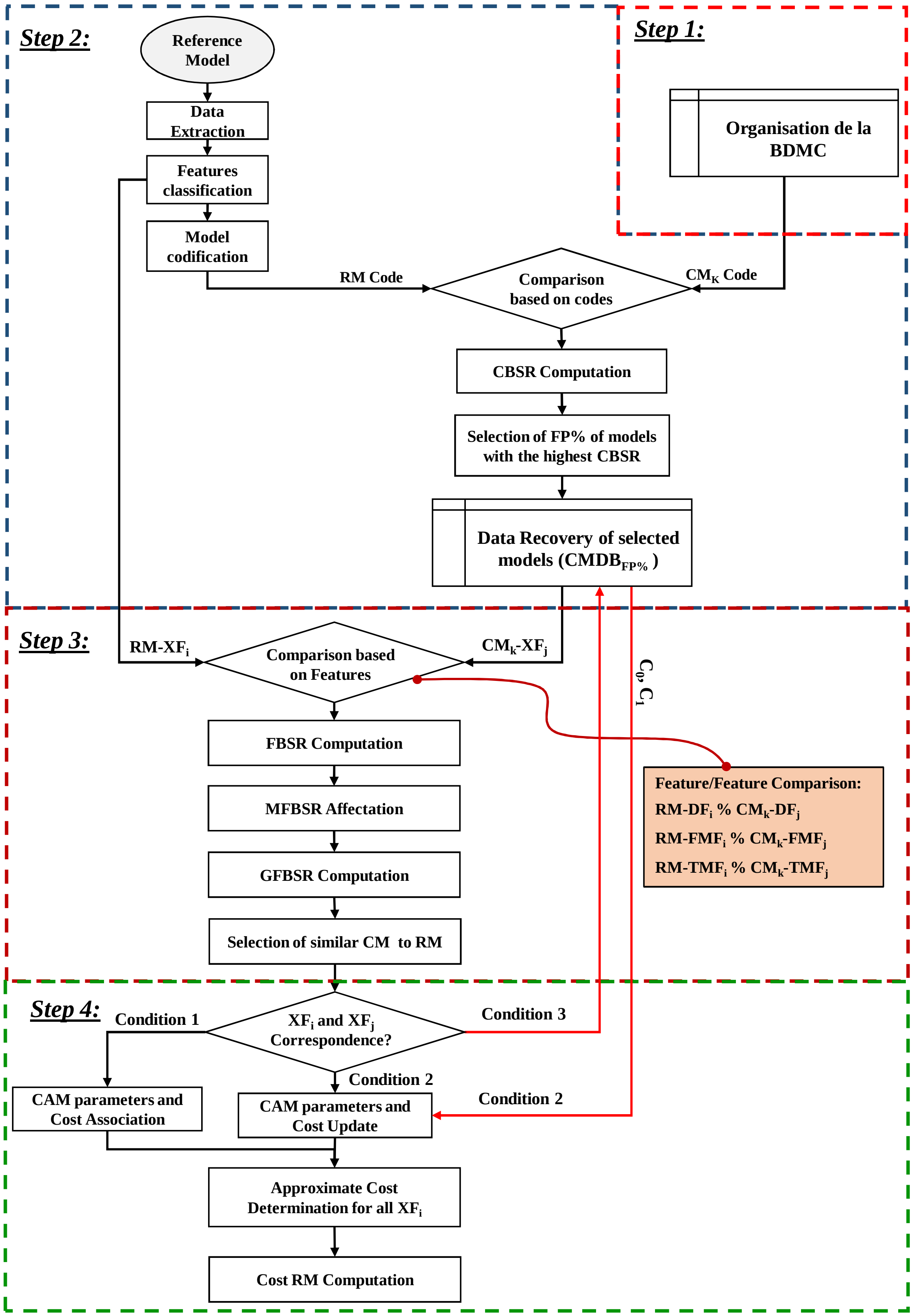

Fig. 5. Proposed model

- *CMDB organization:* The data of all CAD models, used by the company, are extracted. According to the features properties, a codification of models is established (Fig. 6).

Thus, CMDB is defined. The code assigned to each Company CAD Model (CM) becomes the digital communication support as an identifier of the model. This code expresses the type and the number of model features. The data aggregation is based on feature classification. The features are classified into three types, considered in this work (XF: FMF, TMF and DF). Each feature is defined by CAD, CAM and costing data.

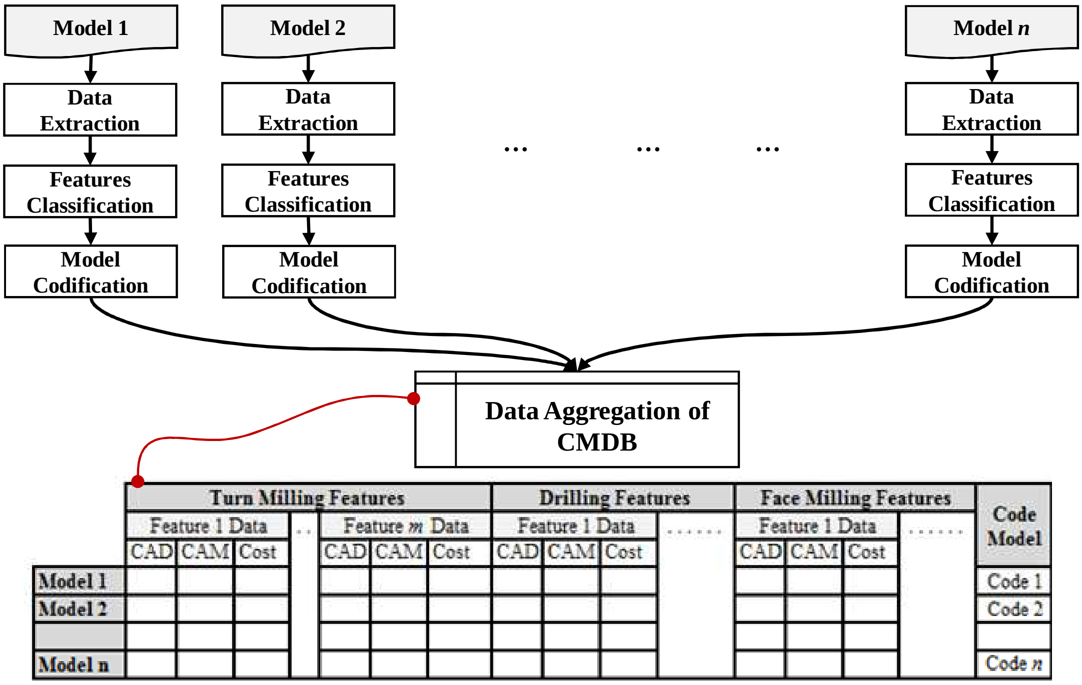

Fig. 6. Sub-Algorithm for CMDB organization

- *Comparison based on codes:* CAD data of the RM are extracted. The RM features are classified. Also, a code will be assigned to the RM that highlights the type and number of these features. To reduce the runtime of the proposed approach, the code-based comparison is established. For each CM, the Code-Based Similarity Ratio (CBSR) is computed using Eq. 3; such as n_{RM} and n_{CM} are the total numbers of RM and CM features respectively. A Filtration Percentage (FP%) is fixed and chosen according to the CM number of CMDB. Thus, a recovered data $CMDB_{FP\%}$ is obtained by the selection of FP% of the highest CBSR.

$$CBSR = 1 - \frac{n_{CM} - n_{RM}}{n_{RM}} \quad (3)$$

- *Comparison based on features:* This sub algorithm consists on the comparison between feature CAD properties of RM (RM-XF_i) and the CAD data of the same feature type of CM (CM_k-XF_j); such as CM_k are the k^{th} CM of $CMDB_{FP\%}$ and XF_i is the i^{th} feature of XF type. A Feature-Based Similarity Ratio (FBSR) is defined according the feature parameters of RM and computed for each CM. For each feature type (XF) of the same CM, the maximum FBSR, denoted by MFBSR, is determined. Indeed, if the RM has k features, then each CM of the $CMDB_{FP\%}$ has k MFBSR. A new Global ratio Feature-Based Similarity Ratio(GFBSR),is computed for each CM. This ratio represents the average of the MFBSR. Subsequently, the CM which has the largest GFBSR is the most similar model to the RM.
- Manufacturing cost estimation: A correspondence between the Feature of Selected CM (FSCM) and Feature of RM (FRM) is established according the three following conditions:

- ***Condition 1:*** If the topological and geometrical parameters as well as dimensional tolerance value are identical, then the CAM parameters and cost of FSCM are directly associated to FRM.
- ***Condition 2:*** If only the topological parameters are identical, then the CAM parameters can be update according the differences of geometrical parameters and tolerance value between the FSCM and FRM. The constant C_0 and C_1 of SCM feature are reused to compute an approximate manufacturing cost of FRM (Eq. 1).
- ***Condition 3:*** If any correspondence between the FRM and FSCM are detected, then a similarity searching in $CMDB_{FP\%}$ based on topology is established. In the case of the detection of topological similarity, the above condition (condition 2) is satisfied.

4 A case study

In this section, a case study is presented to validate proposed algorithm. Nine CAD models are chosen to form CMDB (supposed to be used and validated by a company) as shown in Fig. 7. The sub-algorithm of CMDB organization allows the codification of the 9 models as mentioned in Fig. 6. The RM features' data are extracted, classified and codified. The RM includes tow drilling, tow face milling and one turn milling features (2DF-2FMF-1TMF). Thereafter, a comparison based on codes is established using Eq. 3. At this step, the CBSR will be allocated to each CM of the CMDB. As a result, a refined database is filtered from CMDB: $CMDB_{33.33\%}$. In this case of study, a FP is chosen equal to 33.33%, which represent tier of the models, because the number of CM is rather low.

Based on geometric parameters of standard CAD data of each features, the FBSR is computed (Tab. 1). Then, the MFBSR is determined. Each MFBSR represents the maximum value of FBSR for each FRM (Tab. 2). After that, GFBSR is computed for the three CM (Tab. 3). Subsequently, the CM_5 , with GFBSR =1.049, is selected as the most similar model to the RM.

A correspondence between the features of CM_5 and RM is established according the three conditions presented previously. This step is essential in order to collect and reuse cost data and manufacturing parameters. Once the constants C_0 and C_1 are identified, the machining cost for each feature is computed (Eq. 1). Finally, the manufacturing cost of RM is deducted by summing the cost values determined previously.

Tab. 1 . Results of FBSR computation

	RM-DF$_1$	**RM-DF$_2$**
CM$_4$ -DF$_1$	1.000	1.100
CM$_4$ -DF$_2$	1.000	1.100
CM$_5$ -DF$_1$	1.100	1.225
CM$_5$ -DF$_2$	0.800	0.900
CM$_5$ -DF$_3$	0.800	0.900
CM$_6$ -DF$_1$	1.200	1.350
CM$_6$ -DF$_2$	1.100	1.225

	RM-FMF$_1$	**RM-FMF$_2$**
CM$_4$ -FMF$_1$	1.026	1.125
CM$_4$ -FMF$_2$	1.692	1.000
CM$_5$ -FMF$_1$	0.804	1.125
CM$_5$ -FMF$_2$	0.533	0.400
CM$_6$ -FMF$_1$	0.693	1.125
CM$_6$ -FMF$_2$	1.255	1.150

	RM-TMF$_1$
CM$_5$ -TMF$_1$	0.991
CM$_6$ -TMF$_1$	0.267

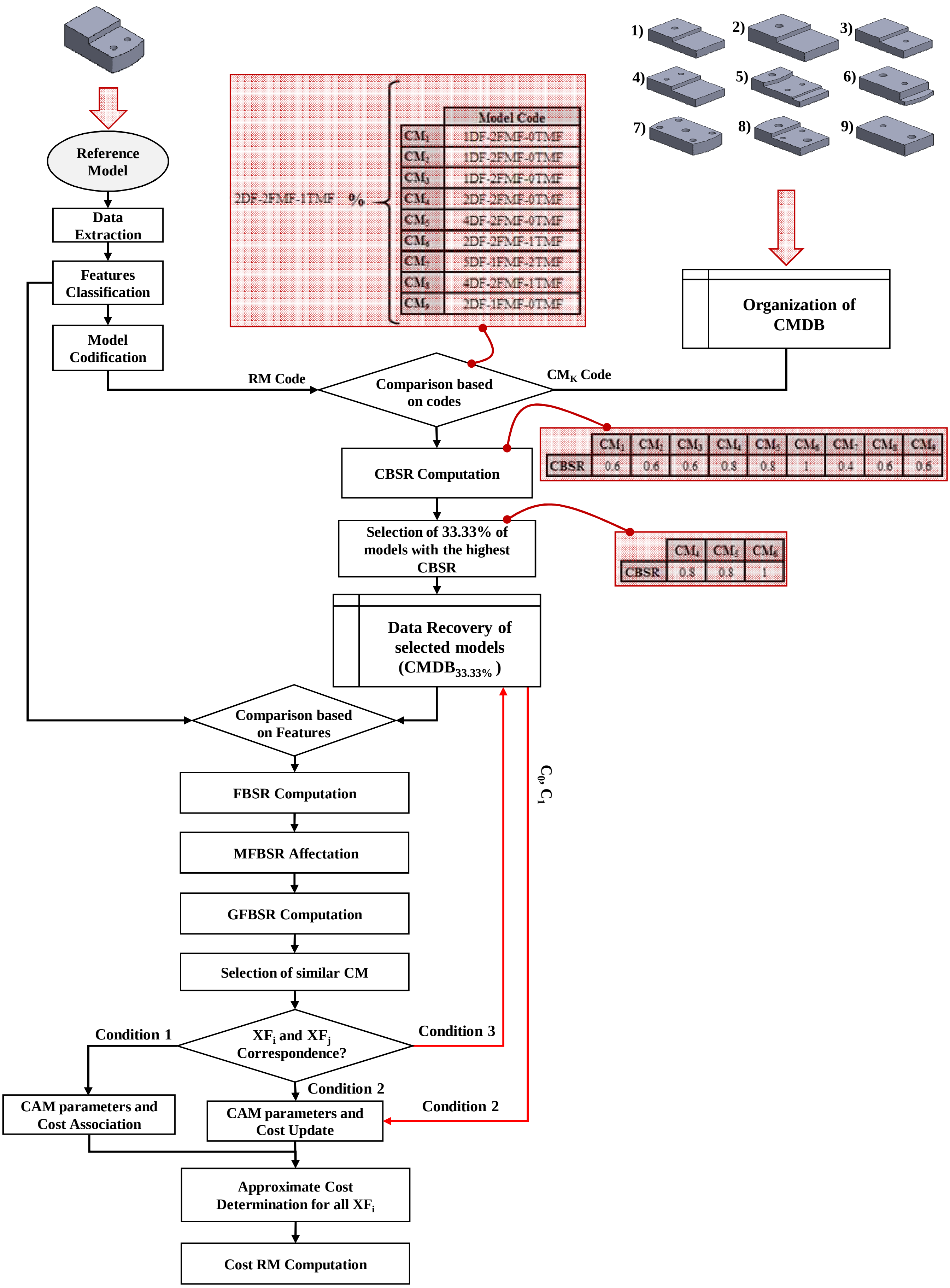

Fig. 7. Result of the application of proposed algorithm on the case study

Tab. 2. MFBSR Affectation

	RM-DF_1	RM-DF_2	RM-FMF_1	RM-FMF_2	RM-TMF_1
CM_4	1.000	1.100	1.692	1.125	0.000
CM_5	1.100	1.225	0.804	1.125	0.991
CM_6	1.200	1.350	1.255	1.150	0.267

Tab. 3. GFBSR Computation

	GFBSR
CM_4	0.983
CM_5	**1.049**
CM_6	1.044

5 Conclusion and perspectives

In this paper, a new approach to compare 3D CAD models, in manufacturing semantics, is detailed. The method is founded on the definition of UFT including multidisciplinary data (CAD, CAM and Cost data). In order to reuse the company knowledge (CAM and Cost data), with a reasonable run time, four sub-algorithms are developed: CMDB organization, comparison based on codes, comparison based on features and manufacturing cost estimation. As a consequence, time and money benefits are generated.

The proposed algorithm is flexible to be optimized in future works. The approach might be generalized to consider other features and environmental constraints. Also, the cost computation model can be optimized by integrating all standard parameters of each feature.

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