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GEOMETRIC MODELING OF THIN OBJECTS A REVIEW AND ANALYSIS

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ABSTRACT *Developments in the field of Computer Aided Design (CAD) have been targeted on reducing the time and effort required of designers to define product models. However, the main difficulty encountered in creating time efficient parametric design tools is balancing the trade-offs between speed and design freedom. Many modeling tools are available that enable the users to programmatically perform most of the interactive functions simultaneously; however, it is very time consuming and cumbersome. Even if the concept of User-Defined Features (UDFs) is used, the existing modelers still involve inserting individual features into individual components. Therefore this paper reviews the geometric modelers available for geometric modeling of thin objects in terms of feature modeling, efforts and time consumed*.

1. INTRODUCTION

The parametric, feature-based functionality [32] within computer aided design (CAD) applications has increased the engineering efficiency to a great extent. Well developed parametric models can be reused to produce many similar designs and are capable of simplifying the process of incorporating design changes. Integrated systems transfer information from design tool to manufacturing technique in order to improve product development process. The current market demand for increasing number of product models and shorter time-to-market has put tremendous pressure on the designers and manufacturers to deliver more number of products with even higher number of variations.

This pressure is released by integrating the design phase with the manufacturing stage. In fact, the increase in product varieties is stimulating the research work on integration of design with manufacturing in order to get an aesthetic and technical high quality end product. Manufacturing businesses are becoming more and more globally dispersed and companies are more willing to work closely together in order to remain competitive. A growing national and international focus on developing consumer and industrial products has created an environment, where designers and manufacturing engineers require an integrated system that plays a more substantial role in product development and supports the global nature of business interactions. So to develop an integrated system for design and manufacturing of thin objects like sheet metal and jewelry, existing geometric modeling systems are reviewed and analyzed to provide a framework for speedy and accurate geometric modeling paradigm for thin objects. A thin-walled object can be considered as consisting of one or more thin elements that are joined together. Hence, the product is composed of basic thin-wall sheets. A thin-walled sheet, as illustrated in Figure 1.1 can be planer or non-planer (freeform).

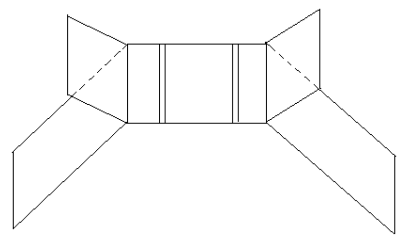

Figure 1.1 A Schematic Thin-Walled Object

2. LITERATURE REVIEW

As an essential part the following issues are predominantly addressed during an extensive review of the literature regarding design development and manufacturing of thin components. The following are the main issues of the literature review:

- Geometric Modeling
- Non-Manifold Geometric Modeling
- Feature Based Geometric Modeling
- Thin Walled, Sheet Metal & Plastic Objects

2.1 GEOMETRIC MODELING

To meet the requirement of industry for the geometric objects identification “Open kernel” geometric modeling systems of an interface was developed by Middleditch et al. [44]. Geometric matching algorithms were examined by Besl [4]. A representations scheme for point, curves, surfaces and volumes was also presented. A modeling structure to model the geometries to include significant parameters of the object beyond solid/geometric modeling in an integrated way for aesthetic presentation was proposed by Kumara et al. [31]. To identify a method for making shape computations, shape grammars were proposed by Tapia [63]. Evaluation of 3-dimensional computer aided design model was presented by Cote et al. [12]. An algorithm which converts a CSG form of representation into a B Rep for validating Euler’s law was defined by Tsuzuki et al. [67]. Structural details of geometries made by man by listing creation principles were presented by Havemann and Fellner [22]. Combined data structures in computational geometry to find solutions for a program library were presented by Kettner [30]. Offsetting methods for solid primitive was outlined by Farouche [17]. The DBMS level management for topological design and implementation was described by Oosterom et al. [45]. This supported the benefits of the topological structure and the easiness of explicit geometric primitives in presentation, querying and analysis. A technique for 3-dimensional object demonstration was presented by Baloch et al. [3] using weighted skeletal graphs. An algorithm for converting a component with holes into solid elements was presented by Woo and Homasma [69] for finite element analysis. Offsets designing problems were discussed by Pham B. [46] and also presented a short survey of existing methods for the offset curves designing and surfaces in industrial applications such as tool-path generation, geometry in NC machining and robot path setting up. CSG models display method using standard, commonly available graphics hardware was presented by Rappoport and Spitz [48]. A structure enabling an aesthetic observation of the aircraft systems with a high end analysis approach, which includes a user friendly interface, was developed by Tarkian and Tessier [64]. An algorithm for dividing thin-plate CAD mesh models into parts based on primitive fitting was presented by Geng et al. [19] in to three parts. Integration 3-dimensional CAD/CAM systems, CNC and metrology which offered a strong mean of capturing geometrical data of complicated shapes, the drawings of which no longer exist was proposed by Kai and Gay [27].

2.2 NON-MANIFOLD GEOMETRIC MODELING

A data structure for non oriented cells of non-manifold B-rep was proposed by Silva and Gomes [58]. To check the accuracy of dimensions with the original object after Boolean operations, regularization process needed to be applied was proposed by Arruda et al. [1]. A feature-based geometric modeling system was developed by Lee [35] for injection molding non manifold components to facilitate an integrated background for design and analysis. In non-manifold representation, the Boolean operations were introduced for solving the feature removal and interface issue of the feature-based design system. Hence for effortless modeling of thin components capabilities were developed for the sheet modeling. The operations for offsetting for removal and addition of uniform thickness from a non-manifold geometrical model were also described by Lee [36]. To reduce the size of radial edge structure by 50%, partial entity structure was proposed for non-manifold boundary representation. This reduced the storage size of data structure for non manifold objects to half that of the radial edge data structure. While considering without loss of topological efficiency was also proposed by Lee and Lee [38]. A method for evaluation and representation of boundary by using non manifold topology to remove editing and reporting limitations related with the manifold character of existing boundary and an evaluation schemes was presented by Crocker and Reinke [13]. High-end operators for developing and evaluating CAD models, an easy and common formalism was introduced by Jarek [26], which simplified and combined many last attempts. This provided the base for a new method of representation for geometric building and evaluation. An approach to deal complexities to find invalid topologically spanning trees was proposed by Tai1 et al. A new unified subdivision scheme that was defined in n-D space was presented by Changa and Qinb [9]. A regular dealing for non-manifold areas with minimum user interference which supported the boundary and the sharp feature representation was also proposed. Addition of sheets and solids as a single model, by applying offset operation for non-manifold and its variations was described by Sang [50].

2.3 FEATURE BASED GEOMETRIC MODELING

Regliyand and Nauz [49] developed algorithms to recognizing a class feature i.e. MRSEVs (Material Removal Shape Element Volumes- a PDES/STEP library of machining features). Bidarra and Teixeira [5] developed a Semantic model to capture the definite input of each feature in the overall modeling of shape and addressed the difficulty of form feature performance representation for uprightness of problems in feature based modeling. It made possible by Semantic framework to establish naturally and flexibly the preferred validity situation of each feature class and with the ability to permanently monitoring, enhancing the modeling system of every feature's conformity with the unique specifications. Feature Interaction Graph is shown in the Figure 2.1 below:

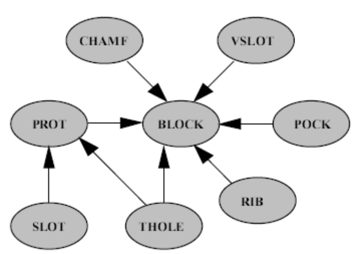

Figure 2.1 Feature Interaction Graph representations

The techniques required for editing the generative designs were presented and discussed by Chen and Hoffmann [11]. All the features attached must be re-evaluated to satisfy the essential constraints and shape in the first stage of design process. Hailong et al. [21] developed feature based parametric product modeling technique (FBPPMT) for minimizing the product design and development time, which is best suited for the integrated engineering design in CIM system environment. After the product design was established on a combined product model, all the product data were connected and provided a range of design features to make easy the product design. Bidarra et al. [6] extended or configured the feature library according to particular requirements of either the application area or an end user of a CAD system. Off-man and JArinyo [23] developed a model based on the basic unit as feature and parts were constructed by an order of addition of feature operations. Venkataraman et al. [68] developed two basic approaches to feature modeling: design by features and feature recognition. Elliott J. [16] proposed a methodology that applies feature-based parametric design (FBPD) to a class of products known as parameter-rich surface models (PRSMs) by union the knowledge of parametric and feature-based design with high level programming and automation techniques to reduce the required cycle time to deliver quality products and also described professional implementations of approach proposed, to show feature and constraint-based design. To facilitate heterogeneous object design, a feature based design methodology was proposed by Qian and Dutta [47]. A method for integration of geometric and parametric data exchange at the single part (object) level, Geometry per Feature (GPF) was proposed by Spitzy and Rappoportz [60]. Bronsvoort et al. [7] proposed the basic concepts of feature modeling system, followed by a summary of four major developments to solve shortcomings in such systems. Sunil and Pande [61] proposed the implementation scheme for geometric models of sheet metal and other objects represented in .stl format for the design of a system for self recognition of features from any type of surface. Scott and Jensen [51] proposed and proved that programmatic operations can component-level design and streamline assembly because a single programmatic operation can create an unlimited number of low-level features, create new components, modify geometry in multiple components, define inter-part geometry links and establish inter-part expressions. Feature recognition software in JAVA was developed and proposed by Malleswaria et al. The STEP file is used as input for the software.

2.4 THIN WALLED OBJECTS

A methodology for geometric modeling for thin objects was described by Lee and Lim [34]. In their methodology a thin object is considered to be a sheet or combination of sheets. Thin parts are modeled by adding, cutting, and bending sheets, which are modeled interactively in a 2D working plane. The primitives for geometric modeling thin parts were proposed by Shpitalni and Lipson (1997) [56]. The authors also proposed a topological invariant for manifold and non-manifold geometries on the basis of specific primitives. Further, Lipson and Shpitalni [39] again analyzed the topological parameters of thin objects and again validated general topological invariant. So it made easier to enquire about manufacturing processes, components number and sequence of bend and weld lines, with the help of a single qualitative model of the object. This capacity is mainly useful in the initial stage of intangible design. They [57] also presented a system for intangible design of sheet metal products by drafting, with the use of early inclusion of computer aided design, rough analysis, and natural interaction. The algorithms for grouping a predetermined set of objects into setup friendly part families that can be manufactured on the same setup for sheet metal parts were described by Gupta [20]. A technique for automatically extracting features from a random sheet-metal part model. These parameters were used for classification and graphical representation of features of sheet-metal model. To extract the features included in a sheet-metal part was proposed by Zhi-jian et al. [72]. The information technology available to aid the design and processing of injection molded plastic parts was investigated by Hsieh and Chavana [25]. An advisor system for design and identification of features module for sheet metal parts was presented by Farsi and Arezoo [18]. The features of sheet metal parts were extracted from three dimensional geometric model of part automatically. An approach called the solid deflation method was proposed by Sheena et al. [55]. In this method, a solid model is generated by using air to inflate a shell that represents the surface of the solid model.

3. REVIEW AND ANALYSIS

An extensive review of literature available in the areas of Geometric Modeling, Non-Manifold Geometric Modeling, Feature Based Geometric Modeling and Thin Walled Objects reveals the following limitations of the existing geometric modeling CAD paradigms-

- In general, the existing modelers do not support non-manifold modeling without converting non-manifold geometries into manifold geometries.
- Most of the geometric modelers do not offer the capabilities of FFM (Feature on Feature) and SFM (Simultaneous Feature) modeling.
- The modeling procedures for thin objects such as sheet metal and plastic parts are cumbersome, error prone and time consuming.

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