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A functional feature modeling method

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ABSTRACT

With the advances in CAD technology, it has been increasingly convenient to model product shapes digitally. For example, in a feature-based parametric CAD system, the product shape could be parameterized and thus altered with the change of parameters. However, without a consistent and systematic CAD modeling method, CAD models are not robust enough to capture functional design knowledge and cope with design changes, especially functional changes. A poorly constructed CAD model could result in erroneous or inconsistent design that requires a lot of expertise, manpower and repetitive computation to rebuild a valid and consistent model. The situation can be worse if the model is complex. The gap between functional design considerations and procedural CAD modeling demands an integrated CAD modeling approach. This paper proposes a functional feature-based CAD modeling method to guide designers building CAD models that are valid and yet agile to represent functional design considerations. A case study is presented to demonstrate the feasibility of the proposed research.

1. Introduction

CAD tools are helpful in the modern engineering design. They accelerate product development by creating virtual product models with highly flexible geometrical features that are easy to be manipulated, for example, blocks, holes, and fillets features, which help to maintain consistency of lower level geometric entities like faces, edges, and vertices based on Euler operators [26]. With the commonly seen procedural modeling approach through manipulating a number of intermediate operations, the desired form of the design artefact can be obtained. CAD systems also have the ability to reuse and make modifications to existing models; hence further extending their usability in the engineering design [9]. Reusability in the CAD domain means that CAD models can be altered to adapt to new use cases with little effort. The reusability of CAD models foster the design reusability because more and more design information is stored in the CAD models and they are becoming indispensable for downstream engineering activities, such as manufacturing [51,38,21], engineering analysis [34,27,31,45,59], and optimization [60]. Reusability requires CAD models to be robust. By saying robustness of a CAD model, the authors mean that it should have the quality of reusability that it is modifiable to certain extent without rendering the model into inconsistency or jeopardizing the model. Therefore, effective representation, expression, and communication of design intents are critical.

Feature-based parametric modeling is widely applied in the industry to create product parts and assembly models. Product models could be parameterized to the extent that each building scheme or pattern of a product, that is to say any feature, form feature, manufacturing feature, and detailed design feature, can be parameterized. The models can then be updated with the changes of parameters; hence the parts and assemblies could be regenerated without designers manually going through the remodeling process. Fig. 1 shows an example of implementing parameterizing feature with expressions in Siemens NX®. Expressions are named parameters with mechanisms to interact with features in NX®, e.g., by remembering their owning and using features. Features provide a manner of representing semantic patterns of design intent. They can be constructed at higher associative assembly level [41,40], and also detailed up to a low level of granularity, e.g., hole features, edge blend features.

By maintaining the feature parentships during the model creation, modeling history could be preserved such that when the model needs to be regenerated due to design changes the changes could propagate downward from feature to feature, thus creating a form of dependencies [5]. Fig. 2 shows some examples of dependencies in CAD modeling, e.g., datum dependencies, parameter dependencies, and geometry dependencies.

However, some issues may arise from the feature dependencies in CAD. Designers might not be fully aware of the feature dependencies and the constructed model is fragile. Some of the

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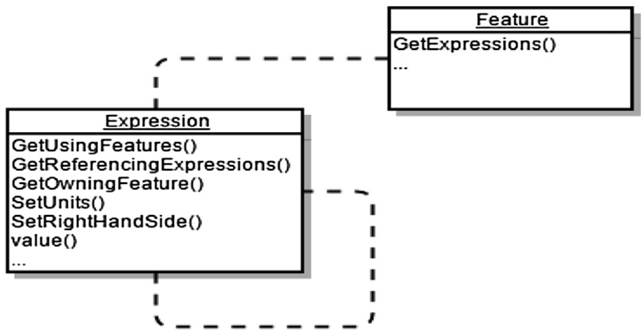

Fig. 1. An example implementation of parameterized feature with expressions.

misbehaviors are easily observable if the model ends up visually and explicitly wrong. Other errors are harder to be detected with human eyes when they are visually less obvious but functionally critical. There is no systematic way to manage the dependencies and designers usually have to redo part of the model operations. Namely, the burden of managing the cumbersome interdependencies of the feature operations lies on the designers [6,9]. A procedural CAD modeling approach is not close to designers' *way of thinking* due to the gap between features, patterns, or shapes designers have in mind, and the modeling functions and operations provided to them [26]. For example, Fig. 3(a) presents the shape of connection rod and (b) shows the corresponding modeling operations. The gap is the one between the engineering design intents behind the features and the applied procedural CAD modeling operations.

A lot of questions could be asked for designers when creating CAD models [6], for example, which sketch plane to use, what kind of complexity should it be, what references need to be used to create constraints, when to apply the *Boolean* operations and which one of *Boolean* operation should be used, how to choose the sequence of the modeling, etc. These questions are tricky because the answers are the keys for the varieties of ways to create a geometrical model in CAD. Sadly designers are often content in creating the shape of the design artefact without giving much thought on the robustness of the model, which is, based on above discussion, clearly insufficient. The authors believe that the question is less of the procedural modeling approach itself, but more on how to apply the procedural modeling more effectively for functional modeling from the angle of engineering innovation.

The approach adopted by this research work is to tackle the CAD modeling efficiency problem from functional perspective in a top-down manner [12]. Top-down design is an assembly modeling approach that can drive multiple part designs by using a single "parent" part, where users create geometry at the assembly level (the parent part) and then move or copy the geometry to one or more components (children parts). The generic idea of top-down design is taken as a starting point for current research, instilled with functional flavor. With the understanding of multiple possibilities to create a specific product model, a functional understanding of the design is not only important in the conceptual design stage but also critical to provide modeling guidance during the process of model detailing and the subsequent derivation of other downstream engineering models and activities. By incorporating the functional design considerations into CAD models, the authors believe that the functional usability of the CAD model can be significantly improved – this belief led to this research effort, i.e. improving robustness of CAD models by conveying design intents explicitly in the model construction.

The rest of the paper is organized as follows. Section 2 presents the related literatures to this research, including feature modeling, communication of design intent, representing function in engineering design, and other intelligent methods to build robust CAD models. Section 3 introduces the proposed method within general framework of functional features, some of the key elements of functional features that are pertinent to the current research, and CAD modeling procedure to build robust function-oriented CAD models. A case study is demonstrated in Section 4, which incorporates the proposed method and proves the validity and effectiveness of proposed method. The last section concludes the paper.

2. Review of related works

2.1. Feature technology and CAD modeling

According to Shah and Mantyla [49], features represent the engineering meanings or significances of the geometry of a part

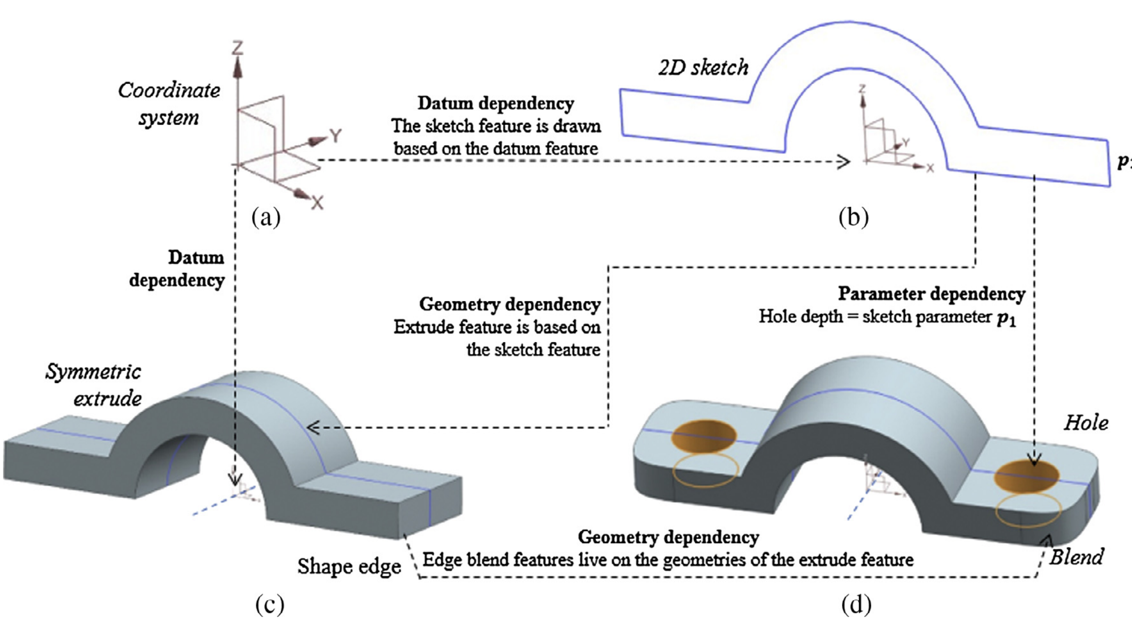

Fig. 2. Some examples of dependencies in CAD.