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A framework for negative knowledge to support hybrid geometric modeling education for product engineering

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ABSTRACT

Due to the full integration of CAD systems into modern product development and engineering, the competency to create usable geometric models has become an essential requirement for current CAD users. To avoid serious repercussions for future engineering labor, the focus of CAD education needs to be raised from the teaching of knowledge that is merely aimed at operating a system, to the development of basic strategic knowledge. From a pedagogical point of view, this situation represents a challenging task that requires new, innovative teaching methodologies. These new methodologies must facilitate the development of know-how and cognitive ability to organize domain knowledge within a holistic mental model allowing for accurate perception of the significance of circumstances and the possible consequences of actions. In this paper a new direction for CAD education is presented, based on the integration of traditional teaching methods with an educational approach based on negative knowledge. Analysis of first empirical results of this newly developed and implemented approach showed promising results. Improvements were observed in a better understanding of issues related to the usability of CAD models and an increased capability to recognize critical modeling situations and thus prevent the mistakes typically made by novices. Also, successful autonomous attempts could be observed of recovery from situations caused either by an accumulation of small mistakes or by severe modeling errors, which usually require remedial intervention by academic supervisors.

1. Introduction

Nowadays, computer-aided design (CAD) systems are deployed widely in the field of industrial engineering. They are used to create geometric models, which, representing the core of virtual prototypes, can be utilized within systems for analysis and simulation, in order to support designers during decision-making processes, while also being used for product documentation purposes**.** Diffusion and application of CAD systems in product engineering have also been supported by, and have benefited from, the introduction of specific CAD courses at engineering faculties of institutions of higher education (cf. Butdee, 2002; Dankwort, Weidlich, Guenther, & Blaurock, 2004; Xue, 2005; Ye, Peng, Chen, & Cai, 2004). In many cases those courses are based on laboratory and practical exercises, aimed at providing training in the use of a geometric modeling system. However, the most challenging objective is teaching how to produce models that are *good enough* to be used within the product development process, and adequately addressing this matter still has many shortcomings.

The concept of *good enough* of course depends on the specific application domain and it may require advanced engineering knowledge related to the production processes (see examples in Bronsvoort and Noort (2004), Hamri, Léon, Giannini, and Falcidieno (2010), Hamri et al. (2004), Martin, Hadzistevic, Hodolic, Vukelic, and Lukic (2012)**)**. However, first there are some basic requirements that need to be fulfilled solely at the geometric level.

In other words, the concept of *usable* model can be approached at different dimensions and levels of abstraction. Here the lowest level is represented by the geometrical level. At this level, a geometric model can be considered *usable* if it does not contain any severe geometric defects and spatial anomalies, which could impede the role of a model for being used in further steps of the modeling process. For example, the shape of a model can be considered usable at the geometric level, if its geometry is free of geometric deficiencies (such as self-intersecting surfaces, overlapping surfaces, gaps between faces) and it has been modeled according to an appropriate tolerance value. Above the geometric level, we can consider the analysis level. At this level, a model can be considered

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usable if it meets all the requirements necessary to perform a particular model analysis. For example, a model can be considered usable, when its shape is sound and structured as to allow for conducting a finite element mesh (FEM) analysis, a computer-aided engineering (CAE) analysis, or a CAM simulation. At this level related to analysis usability, the criteria associated with the geometric level are linked to, for example, the avoidance of gaps between faces, a suitable degree of continuity between patches, etc. At the next higher level of abstraction, one can consider the functional level. At this level a model can be considered usable if it meets all the requirements for the manufacturability, assemblability, or functioning of an individual component or an assembly, its geometric representation was designed for and implemented. For example, the shape of a model can be considered usable at the functional level if it allows for injection molding production. Here model usability is determined, among other things, by criteria linked to the basic geometric level such as, for example, an appropriate wall thickness, the absence of undercuts. In general, for any virtual prototype considered to be usable at a particular level as outlined above, a necessary pre-condition is that it is considered usable at the basic geometric level of abstraction.

The traditional approach to CAD education is based on the explanation of system commands, user interface tutorials, and best practices, all aimed at operating a CAD system. However, this approach is insufficient for developing an awareness of geometrical deficiencies that may affect a model, when a poor or inappropriate modeling strategy is applied. When students have to face new modeling situations not explicitly mentioned during lessons, due to being novices they usually do not recognize that certain strategies may lead to modeling situations best avoided. This is because tutorials and best practices usually teach "*what to do*" (positive knowledge), when in many situations knowing "*what not to do*" (negative knowledge) is equally important to achieving a desired outcome.

In this paper a novel framework is proposed for supporting a new teaching approach, which includes training in recognizing critical situations and consequent prevention of actions that may lead to deficiencies rendering a CAD model useless for subsequent engineering tasks. This approach, which employs negative knowledge, is aimed at enhancing education within CAD courses in industrial engineering and mechanical engineering at institutions of higher education.

2. Background, objectives, and research outline

2.1. Virtual prototyping in education and engineering practice

Over the last decade developments in geometric modeling systems have signaled an undeniably intensifying trend in the integration of different model representations such as surface models, solid models, mesh models. This trend appears to be particularly evident in the context of product engineering. The major reason for such developments is the need to increase the support for several product engineering processes, like design, analysis, simulation, and production processes. In case of design, individual processes such as shape engineering, mold and cavities design for injection molding processes, and fixture design (see Hirz, Dietrich, Gfrerer, & Lang, 2013 and Fig. 1) represent examples, which can substantially benefit from solid-surface hybrid models and related hybrid modeling commands. Typical modeling operations of a hybrid solid-surface environment are comprised of the extraction of surfaces from solids, the conversion of surfaces into bulk or sheet solids, and the interoperability between the two different types of models, using, for example, surfaces to cut solids and vice-versa. However, in order to successfully apply such kinds of modeling operations, some basic geometric requirements must be preserved. Unless the hybrid model is geometrically sound, it is impossible to proceed further toward more specialized models to be used for analysis and simulation.

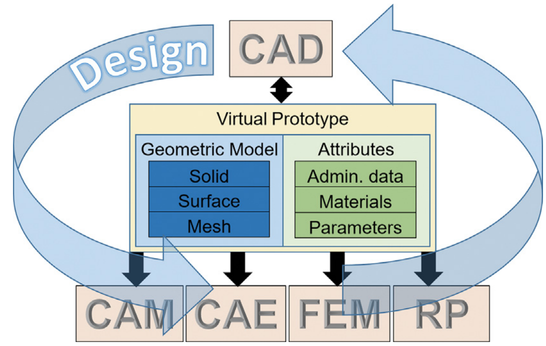

Fig. 1. The geometric model and virtual prototype in the context of product engineering.

From an educational point of view, teaching hybrid geometric modeling is a challenging task, because it implies the integration of solid modeling concepts with the surface-based approach to 3D modeling. Especially, while dealing with surfaces, concepts such as appropriate sewing among different patches, surface curvature, surface continuity, and the impact that such geometrical and topological properties have on further modeling commands, are not so easily understood by novices.

Quite commonly awareness of deficiencies introduced into CAD models by the implementation of an inappropriate strategy arises too late to avoid critical situations and serious errors. A typical situation where this happens is during the shape engineering process, when the external (aesthetic) layer, the so-called *skin* of an object, is first modeled as a surface and then transformed into a solid shell with thickness, to which appropriate features will be added with a typical solid modeling approach, in order to obtain the final geometry of a component. If the skin surface was not modeled with the correct degree of accuracy and with the geometric properties required, the commands aimed at adding thickness to the model will fail. In such a context, novices are not able to proceed with the modeling process and have no knowledge on how to recover. In such cases, most of the time novices do not have any hint as to why they failed or where the error occurred.

2.2. Objectives and research outline

For product engineering, CAD education requires a curriculum design and teaching approach that are beyond the sum of standard lectures on surface and solid modeling and the exemplification of guide lines and best practice for those fields. One central part of the learning outcomes is aimed not only at the development of domain knowledge and general geometric modeling skills, but foremost at competency building on how to create and manage usable hybrid geometric models. In particular, students need to develop knowledge and understanding of shortcomings and errors that can turn a geometric model during the creation and editing process into a model unusable for successive tasks, and they must also be able to recognize and subsequently avoid modeling situations that most likely lead to the introduction of such model deficiencies and errors.

Therefore, the objective of the proposed approach is to integrate traditional methods that are based on positive knowledge with aspects related to negative knowledge, to facilitate the development of situation awareness and knowledge on how not to select inappropriate actions, and to avoid critical situations.