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Product design-optimization integration via associative optimization feature modeling

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ABSTRACT

This paper addresses an important problem of integrating structural optimization into a traditional CAx system and therefore, realizes an integrated product design-optimization system. Specifically, structural optimization has been embedded as an independent module of most commercial CAx systems. It mainly communicates with CAD but can only have the STL-based CAD geometry as input. The knowledge-level information transfer is not supported which causes the optimization intent not fully captured. The consequence could be quite negative that the optimization process generates unsatisfactory or even useless design solutions and tedious manual efforts are required to modify or even redesign the immature solutions, which reduces the overall design efficiency and quality. To fix this issue, this paper proposes an integrated product design-optimization system by enabling the complete information transfer between CAD and structural optimization modules. Interfacing rules have been defined to enable the complete information transfer and the associative optimization feature concept is proposed to manage the transferred information for the structural optimization module. Furthermore, knowledge based reasoning is performed to capture the full optimization intent in order to create a fit-for-purpose optimization model, including both the optimization problem formulation and the solution strategy. For technical merits, this integrated product design-optimization system robustly ensures the timely and high-quality product design delivery which is superior to the existing commercial systems. Effectiveness of this proposed system has been proven through a few case studies.

1. Introduction

Industrial products are embedded of increasingly rigorous and complex design requirements which make the product design process difficult and time-consuming. To meet the challenge, increasingly more design tasks are solved through structural optimization algorithms and the structural optimization tools are gaining the popularity. Generally speaking, structural optimization algorithm performs the finite element analysis to evaluate the structural performance and accordingly, calculates the sensitivity result to decide design changes. This process is repeated till convergence and the derived design solution is at least close to the global optimum which can hardly be achieved through the traditional trial-and-error approach.

A flow chart of the feature-based product design process involving structural optimization is demonstrated in Fig. 1. We can see that structural optimization plays a major role during the embodiment design phase which effectively generates the design solution from a conceptual idea or an existing product model.

After introducing the background, this paragraph will disclose the remaining research issue that structural optimization is not fully embedded into the feature-based product design process; in other words, the structural optimization module is not a well-integrated part of the CAx-based product design system. As indicated in Fig. 1, structural optimization starts by extracting geometry from a conceptual CAD model or an existing product model. All the attached semantic information is just removed and their importance is ignored. The semantic information is generally a reflection of design intent which supports the product related high-level reasoning, e.g. functionality and manufacturability evaluations. Conventionally, a major principle of feature-based design is to keep the information consistency in order to avoid design intent violations. However, the geometry extraction procedure definitely violates this principle, which in fact isolates the structural optimization module and makes it a standalone tool. The impact of ignoring the attached semantic information is quite negative that, the optimization process would generate less optimal or even

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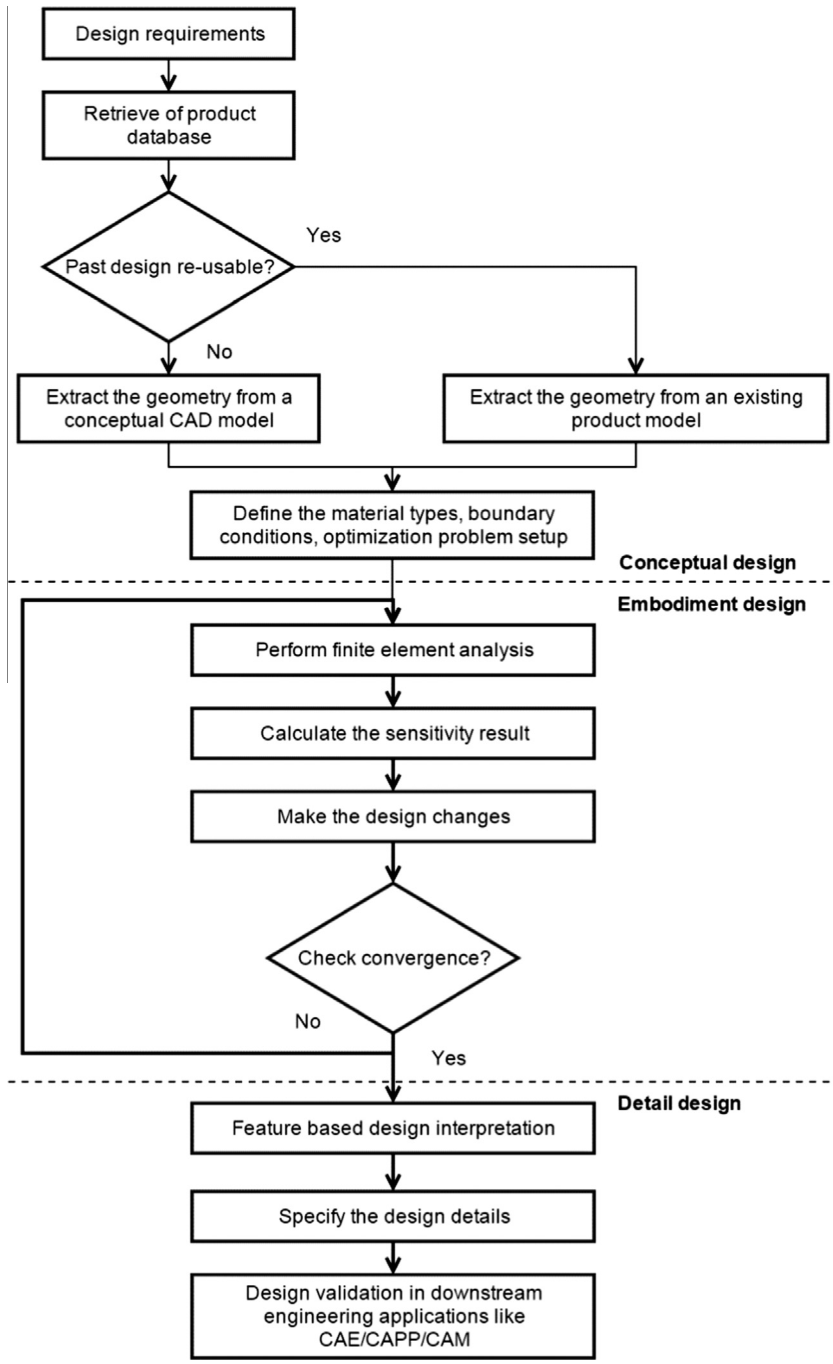

Fig. 1. Feature-based product design process involving structural optimization.

useless design solutions and afterwards, tedious manual efforts are required to modify or even regenerate the solutions.

An example is demonstrated in Fig. 2. External profile of the pipe gripper is generated as a conceptual idea and the internal ribs are to be designed through structural optimization. The semantic information attached indicates the injection molding manufacturing method. Then, if only the geometry is imported into the structural optimization module, it will generate the solution as presented in Fig. 1b; in contrast, if the attached manufacturing information is also received and properly interpreted, the optimal solution will satisfy the constant rib thickness requirement as demonstrated in Fig. 1c which employs much better manufacturability. In summary, embedment of the structural optimization module into the CAx-based product design system is not well realized because of the incomplete information transfer.

To fix this issue, the paper proposes an integrated product design-optimization system which supports the complete information transfer between the internal modules. The framework is presented in Fig. 3.

This system consists of four main components: associative feature modeling, information transfer, associative optimization feature modeling, and optimization intent capture. The associative feature concept was proposed earlier by the authors (see Fig. 4) [26,28]. It effectively supports the sematic information creation and management, and therefore, is adopted as the core part of the information management mechanism in CAD module.