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Editorial

Conceptual design: issues and challenges

Decisions made during conceptual design have significant influence on the cost, performance, reliability, safety and environmental impact of a product. It has been estimated that design decisions account for more than 75% of final product costs. It is, therefore, vital that designers have access to the right tools to support such design activities. In the early 1980s, researchers began to realize the impact of design decisions on downstream activities. As a result, different methodologies such as design for assembly, design for manufacturing and concurrent engineering, have been proposed. Software tools that implement these methodologies have also been developed. However, most of these tools are only applicable in the detailed design phase. Yet, even the highest standard of detailed design cannot compensate for a poor design concept formulated at the conceptual design phase. In spite of this, few CAD tools have been developed to support conceptual design activities. This is because knowledge of the design requirements and constraints during this early phase of a product's life cycle is usually imprecise and incomplete, making it difficult to utilize computer-based systems or prototypes. However, recent advances in fields such as fuzzy logic, computational geometry, constraints programming and so on have now made it possible for researchers to tackle some of the challenging issues in dealing with conceptual design activities. In this special issue, we have gathered together discussions on various aspects of conceptual design phase: from the capturing of the designer's intent, to modelling design constraints and solving them in an efficient manner, to verifying the correctness of the design.

S.F. Qin et al. begin this issue with the article "From on-line sketching to 2D and 3D geometry: a fuzzy knowledge based system" in which they look at the interesting research problem of capturing the user's sketching intentions and automatically generating the corresponding geometric primitives. The motivation of this work comes from the fact that most designers still prefer to express their creative design ideas through 2D sketches. It is therefore important for a computer-aided conceptual design system to allow sketched input. Qin et al. built a prototype system that allows 2D sketched input, interprets the input sketch into more geometrically exact 2D vision objects and, when needed, projects the 2D objects into 3D models. The system receives the sketched input data through a sequence of mouse button presses, mouse motions and mouse button release events. After that, the system attempts to identify each curve segments and generate a precise 2D primitive for the identified segment. For each pair of 2D primitives identified, a 2D relationship (connectivity, parallelism or perpendicularity) is inferred by the system. As the 2D geometry (primitives + relationships) slowly accumulates, the system continually checks to see whether it can recognize a 3D object or feature. Upon recognition, the 3D object/feature will be placed in 3D space and new features can be built upon previous ones.

Latif Al Hakim et al. approach the problem from the concurrent engineering perspective. Traditionally, design is a serial activity whereby reliability, manufacturability, maintainability, safety and other requirements are considered sequentially. In recent years, in an effort to increase competitiveness and reduce design life cycle, the concept of concurrent engineering is introduced. Instead of performing design-related activities in series, they are performed simultaneously. This approach greatly increases the complexity of the design process due to the highly interactive nature of the various design tasks. To support design activities adequately in such an environment, Latif Al Hakim et al. propose the incorporation of reliability with functional perspectives at the conceptual design stage. They use graph theory to represent a product and the relationships between its components. A product's components are represented as the vertices of a graph, while the edges of the graph represent the flow of energy between components. With this representation, it is easy to visualize energy flow between components and thus trace any loss of functionality. In addition, this representation allows one easily to take into consideration various constraints such as cost for further design refinement.

The third paper in this special issue points out the need for a suitable conceptual design representation scheme for smooth integration with downstream applications of the product development process. Brunnetti and Golob propose a feature-based representation scheme for capturing product semantics handled in the conceptual design phase. They believe that any computer-aided design system should accomplish two major goals. The first is to support the flow of information without loss along the product development process, and the second is to assist designers in

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developing a consistent design model by providing intelligent and intuitive computer support that minimizes the possible sources of engineering errors and maximizes the capability to map designers' creativity into corresponding mathematical models of the product. To this end, they propose the use of features to model the relationships between requirements, functional descriptions and physical solutions of a product. These features serve as information carriers to the downstream applications. In particular, they focus on the support for an early feature-based prototyping of different views to the overall product model.

Conceptual design activity is not complete unless we can verify that the design concepts satisfy the necessary functional requirements. The final article in this special issue, "Constraint-based functional design verification for conceptual design" by Y. M. Deng et al., looks at how design verification can be carried out automatically through the use of a constraint-based approach. Design verification is typically done either by directly calculating the attributes of interest, or by simulating the behavior of a system and comparing the simulated behavior with the desired behavior to determine the degree to which the functionality of a system is achieved. In Deng et al's paper, the authors propose an extension to the first approach through the use of constraint propagation and dynamic design verification based on graph. The input is the functional design model, which incorporates four aspects of functional design information: the working environment, the physical structure, the intended behavior, and the required function. Based on the input, the authors develop a framework that allows for the backward reasoning to the causes of system behavior. Design verification is achieved by identifying input and output design variables, developing a variable dependency graph, propagating constraints over the graph, and checking the values of the design variables against these constraints.

In summary, this special issue presents a selection of articles that cover a diverse range of issues in conceptual design, and show how computers and existing software technologies can be used to support conceptual design activities. It is fair to say that the current research and development in this area is still in its infancy. Further research will have significant practical impact on how designers carry out their design tasks. We hope that this issue will serve as a reference point and a motivator for readers to pursue research and development in this important and challenging area.

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