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Editorial

Advances in Conceptual Design Theories, Methodologies, and Applications

Dongxing Cao,[1] Shengfeng Qin,[2] and Yu-Shen Liu[3]

[1] *School of Mechanical Engineering, Hebei University of Technology, Tianjin 300130, China*
[2] *Department of Design, Northumbria University, Newcastle upon Tyne NE1 8ST, UK*
[3] *School of Software, Tsinghua University, Beijing 100084, China*

Correspondence should be addressed to Dongxing Cao; dongxingcao@gmail.com

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Conceptual design lies in the early stage of a complex product development process, requiring not only considering the product's function and structure but also its social and environmental impacts. The design and decision made at the conceptual design stage have a significant influence on the success of the product development. Thus, exploring advanced conceptual design theories and methodologies and their applications has been considered as an important stage of a new product development, and it is currently a hot research topic in the engineering design field. The existing design methodologies have achieved extensive applications in engineering design, such as axiomatic design, collaborative design, agent-based design, and nfused design. Computer-aided design is widely seen as an enabling technology for supporting the scheme evaluation, geometric modeling, and structural feature design of new product development. Furthermore, within the industry engineering areas, there are strong commercial drivers to reuse and extend existing methodologies. Sometimes they are often undertaken in a highly coupled manner for a specific product design. However, as the complexity of product system and the diversity of product functions increase, the need for advanced design methods and tools becomes stronger. Therefore, conceptual design, as a rapidly changing field, developing new and advanced theories and methodologies dedicated to product innovation is required.

This special issue of Advances in Mechanical Engineering is dedicated to exploring the conceptual design theories, methodologies, and applications. We invite investigators from different countries and regions to contribute to this special issue with the original research articles as well as the review articles on engineering design.

This issue aims to stress the importance of using conceptual design and advances in the conceptual design theories. This special issue contains thirteen papers dealing with theories, methodologies, and applications of conceptual design in mechanical engineering. We hope that it is valuable to readers for their own research work.

The papers in this issue represent multifaceted contributions as well as the availability and usability of conceptual design in new product development. Three taxonomies, including theories, methodologies, and their applications, are differentiated. A brief overview of each paper as follows.

Firstly, R. Gaha et al. presented a literature review of different works based on feature technology to ecodesign products in their paper "Ecodesigning with CAD Features: analysis and proposals". Environment has become an important factor for product design, especially for a kind of devices of producing gas against environment. They divide ecodesign into two parts. The first one concerns CAD-Life Cycle Assessment, such as methodologies, prototype tools, and the second one implements feature technology to reduce the environmental impact of one life cycle stage, such as material selection and manufacturing.

Secondly, advanced conceptual design theories are proposed by five research papers. The first paper by Y. and Chakrabarti "Physical realizations: transforming into physical embodiments of concepts in the design of mechanical

movements" represented a kind of the method of concept generation, which could be used to support designers to systematically search for physical objects from a given input in terms of simplified functional, spatial, and mechanical movement requirements. Although it is similar to traditional method proposed 20 years ago, it is an effective means for resolving simple input/output and multi-input/output. Ying-Chieh Liu and Amaresh Chakrabarti proposed a method of conceptual generation to come up with possible physical embodiments to offer to designers for exploration and evaluation. They investigated the issue of how to transform a variety of possible initial solutions to the specified problems in terms of abstraction of mechanical movements and the synthesis of possible generic physical embodiments and report an implemented method that could automatically generate these embodiments. The underlying principle of this method is to make it possible to link common attributes between a specific abstract representation and its possible physical objects. The second paper by D. Cao et al. "Port-based ontology modeling for robot leg conceptual design" proposed a method of port-based ontology modeling for product conceptual design. It is an advanced design method, different from the existing design theories, such as axiomatic design QFD, to be conducted to model the process of product conceptual design. It can not only be used to model the early stage of product design, but also to implement embodiment design. D. Cao et al. considered that a port can be assumed as a real or virtual interface of the component which can exchange information with its outer environment, and it is the basis of the component concept and configuration generation. In this paper, they give a port-based ontology representation for robot conceptual design. Component knowledge and the primitive concepts are presented on the basis of port ontology. The taxonomy of port-based ontology is built to map the component connections and interactions to cluster functional blocks, and the semantic synthesis is employed to describe component ontology. At the same time, an approach is proposed for computing semantic similarity by mapping terms to function ontology and by examining their relationships based on port ontology language. Furthermore, the construction process of port-based ontology concepts is described, and its elements are related to the similarity values between concepts. The third paper by K. Li et al. "Research on SDG-based qualitative reasoning in conceptual design" reported a SDG-based qualitative reasoning for concept generation. The main task of conceptual design involves the generation of concepts to fulfill required functions and the evaluation of these concepts to select the most promising ones for further development. K. Li et al. adopted the signed directed graph (DSG) to reveal the inherent causal relationship and interactions among the variables, and find qualitative interactions between design variables and design purposes with the help of causal sequence analysis and constraint propagation. In the case of incomplete information, qualitative reasoning, which has the function of qualitative behavior prediction, can improve conceptual design level aided by the computer. To some extent, qualitative reasoning plays a supplementary role in evaluating scheme and predicting function. Next paper by Y. Kang and D. Tang "Matrix-based conceptual solution generation approach of multifunction product" puts up with a matrix-based conceptual generation method. It is an effective approach for matrix modeling design concept, such as axiomatic design, incidence matrix, and QFD. Y. Kang and D. Tang proposed a matrix-based conceptual solution generation approach to integrate two single-function products to a multifunction product. In the approach, the functions are represented by the functional basis and are used to construct the function model of the single-function product. The function similarity matrix of two single-function products is constructed based on the quantified similarity index of two subfunctions. Also the function-component matrix of each single-function product is constructed. The component-component matrix of two single-function products can be acquired by the function-component matrix multiplied by the function similarity matrix. There are three kinds of the component relationships in the component-component matrix: no-correlation, simple-correlation, and complex-correlation. The components of two single-function products are, respectively, removed, modified, and reserved according to the different correlation relationships. The design solution of a new multifunction product can be obtained by combining the reserved and modified components. The final paper by Y. Feng et al. "Equilibrium design based on design thinking solving: an integrated multicriteria decision-making methodology" used an integrated multicriteria decision-making methodology for concept evaluation. Y. Feng et al. proposed a multi-criteria decision making model to acquire the optimum one among different product design schemes. VIKOR method was introduced to compute the ranking value of each scheme. A multiobjective optimization model for criteria weight was established. In this paper, projection pursuit method was employed to identify the criteria weight set which could keep classification information of original schemes to the greatest extent, while PROMETHEEII was adopted to keep sorting information. Dominance-based multiobjective simulated annealing algorithm (D-MOSA) was introduced to solve the optimization model.

Thirdly, different methodologies have been used to improve the process of conceptual design, such as customer preference modeling, knowledge-based reasoning, and generic algorithm. They have different features and have achieved the expected results. We collected four papers to be used to represent conceptual design. The first paper by D. Cao et al. "Customer preference-based information retrieval to build module concepts" proposed customer preference information retrieval method to model concepts. How to obtain the new concepts from users' requirements and design information? How to deal with these documents? They are the fundamental work for generating alternative design concepts. D. Cao et al. viewed preference as an outer feeling of a product and also as a reflection of human's inner thought. It dominates the designers' decisions and affects people's purchase intention. In the paper, a model of preference elicitation from customers is proposed to build module concepts. The attributes of customer preference are classified in a hierarchy and make the surveys to build customer preference concepts. The documents or catalogs of design requirements, perhaps containing some textual description and geometric

data, are normalized by using semantic expressions. Some semantic rules are developed to describe low-level features of customer preference to construct a knowledge base of customer preference. Designers' needs are used to map customer preference for generating module concepts. The second paper by D. Karayel et al. "Integrated knowledge-based system for machine design" integrated knowledge for mechanical product design. When a method is used to a general product design, it is certain to be of the merits and demerits. An effective measure is to develop the merits and avoid the defect by integrating and combining them together. D. Karayel et al. developed an integrated design system (IDS) approach to various stages of the mechanical design process including rapid prototyping. The system consists of design, analysis, calculation, rapid prototyping, and library modules, and it blends artificial intelligence methods, CAD-CAM, and technical computing packages into a single environment. The third paper by C. Hu et al. "A simulation model design method for distributed/cloud-based simulation environment" sets up simulation environment to model design process. A variety of simulation models have been developed in specific organizations or enterprises to conduct the design process. However, they are difficult for reuse in the process of design. C. Hu et al. proposed computer simulation as a valid tool for the conceptual design of complex products involving multiple disciplines. The paper provides a simple implementation of simulation model reuse for distributed/cloud-based simulation environment and creates the simulation models' meta-model and ontology for the universal description. They proposed four rules to design/reprogram a simulation model into service-oriented form for its interoperability and established the ontology of service-oriented simulation model. The fourth paper by P. Gao and S. Yan "Fuzzy dynamic reliability model of dependent series mechanical systems" developed a reliability model for mechanical system. As the difficulties in describing the strength degradation process of components under fuzzy load and considering the failure dependence between different components in a system, conventional static fuzzy reliability models cannot be directly extended for dynamic reliability analysis of mechanical systems. To deal with these problems, P. Gao and S. Yan proposed fuzzy dynamic reliability models of mechanical systems in terms of stress and strength. The proposed models can be used to represent the dynamic characteristics of fuzzy reliability and analyze the influences of the variation in the parameters of fuzzy stress and strength on the failure dependence of components in a system and the dynamic behavior of fuzzy system reliability.

At last, the application of conceptual design theories has achieved a great success in industry engineering areas. We collected three papers to represent the applied results. The first paper by J. Li et al. "Conceptual design of deployment structure of morphing nose cone" adopted genetic algorithm to obtain the deployment structure of morphing nose cone. For a reusable space vehicle or a missile, the shape of the nose cone has a significant impact on the drag of the vehicle. J. Li et al. proposed the concept of morphing nose cone to reduce the drag when the reentry vehicle flies back into the atmosphere. The conceptual design of the structure of morphing nose cone is conducted. Mechanical design and optimization approach are developed by employing genetic algorithm to find the optimal geometric parameters of the morphing structure. The second paper by Z. Li and D. Cao, "Conceptual design of compliant mechanism based on port ontology" applied port ontology to conceptual design of compliant mechanism. Port-based ontology (PBO) is used to represent and organize product design information and support product conceptualization. Port is used to map and link components together. It plays an important role in capturing component information. Z. Li and D. Cao established a design method of compliant mechanism based on port ontology. The paper constitutes coding rules and constructs PBO knowledge base of compliant mechanism, which includes stiffness-base and inherent frequency-base of flexible cells. The incidence matrix is built to denote the relationship of components, and the schemes are generated by adopting the genetic algorithm based on incidence matrix. The scheme populations for training neural network (NN) are generated by parameters distributing, and the preferential scheme is to be selected via the trained NN. The third paper by M. H. Shojaeefard et al. "Optimum design of 1st gear ratio for 4WD vehicles based on vehicle dynamic behaviour" adopted optimum approach to obtain the gear ratio for 4WD vehicles. M. H. Shojaeefard et al. presented an approach that allows optimizing gear ratio and vehicle dimension to achieve optimum gear transmission. Augmented Lagrangian multiplier method, defined as classical method, is utilized to find the optimum gear ratios and the corresponding number of gear teeth applied to all epicyclical gears. This method is able to calculate and also to optimize the gear ratio based on dynamic of 4WD vehicles.

The emergence of increasingly newer theories and methodologies of conceptual design will constantly be proposed with the development of sciences and technologies. The more mathematic tools and algorithms will be applied to the stage of conceptual design, even to some specific case studies. We believe that this special issue is valuable to readers from engineering design field. We would like to acknowledge all authors and all reviewers anonymously contributed to this special issue. It is that your efforts make this special issue possible. We would be interested to receive any comments either to the members of Editorial Board or to any readers.

Dongxing Cao
Shengfeng Qin
Yu-Shen Liu