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ORIGINAL ARTICLE

Web-service-based parametric design reuse for parts

Yi Xu · Li-Chen Hu · Wei Zeng · Bo Jin

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Abstract Design reuse of parts plays an important role in product design. In this study, we present a parametric design reuse framework for parts design based on web service. The proposed framework borrowed the ideas from component model of software reuse, such as reuse service, separation of interface, and realizing procedure. The reuse framework for parts can be divided into three layers: the design interface layer, the design service layer, and the design result layer. Firstly, we built parametric templates for parts design using software integrated technology (e.g., iSIGHT). The parametric, automatic, and integrated design for parts can be accomplished through the templates. Then, we deployed parametric templates for parts design using web encapsulation technology (e.g., EASA). Finally, we developed a design reuse prototype system using heat pipe exchanger design reuse for demonstration based on the proposed framework.

Keywords Design reuse · Web service · Parametric modeling

Y. Xu (✉)
Department of Computer Science and Engineering,
Dalian University of Technology,
Dalian 116024, People's Republic of China
e-mail: tenghf@dlut.edu.cn

L.-C. Hu · W. Zeng
China North Vehicle Research Institute,
Beijing 100072, People's Republic of China

B. Jin
School of Innovation Experiment,
Dalian University of Technology,
Dalian 116024, People's Republic of China

1 Introduction

Design reuse of product is vital for industrial design. Much more effort has been devoted to this area now [1–5]. Generally, the design problem solving process consists of four phases [6]: problem clarification, conceptual design, embodiment design, and detailed design. As the final stage of product design, detailed design (mainly referring to parts design) has an important impact on the product quality [7]. Recently, most methods of detailed design reuse concentrated on the following design aspects: detailed design data store [8], database construction, feature extraction techniques and geometric data similarity evaluation [9], standard languages for detailed design description, and product modeling [10]. Shahin et al. [11] proposed a flexible design reuse method to generate the 3D model through CSG tree. Ong and Guo [7] described a web-based detailed design reuse system where the clients could generate a new model by altering the parameters of the existing model.

On one hand, most of the aforementioned detailed design reuse researches focus on the reuse of geometric modeling and do not discuss other issues for design process, such as engineering analysis and optimization in detail. Thus, the current detailed design reuse systems need further study in order to fully meet the design requirements for parts; on the other hand, there are few papers discussing the design reuse framework that can guide the construction for detailed design reuse system. Furthermore, current small- and medium-sized manufacturing enterprises (SMMEs) cannot support large commercial computer-aided design (CAD)/computer-aided engineering (CAE) software system due to their limited level and scale. Thus, low-cost web-based CAD/CAE service has become one of the trends in current CAD/CAE technique [12–14].

For these reasons, we proposed a web-based parametric design reuse framework for parts design and discussed several key technologies. The proposed design framework is enlightened by the component model of software reuse. Users could complete the design tasks (e.g., geometric modeling, simulation analysis) on web-based design reuse system just by giving out design parameters of proposed issue without mastering the knowledge on CAD/CAE software. In this way, the training costs of the CAD/CAE software would be cut down and design difficulty would be effectively reduced for the SMMEs.

Taking heat pipe exchanger design reuse for example, we have developed a parametric design reuse prototype system to demonstrate the efficacy and efficiency of the proposed framework.

2 System architecture

2.1 Design process

Detailed design is the final stage of product design, which mainly includes [6] structure design, simulation, optimization, etc. As shown in Fig. 1, the structure design phase consists of parts selection, design computing, and variant design; the simulation and optimization phase consists of finite element analysis, dynamic analysis, thermodynamic analysis, and fluent analysis.

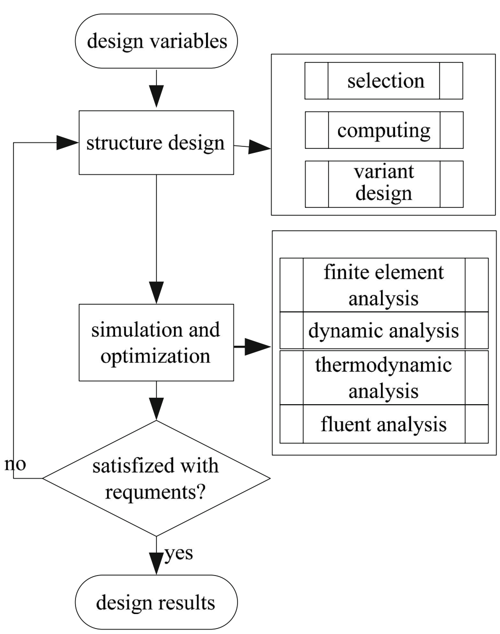

Fig. 1 Detailed design process

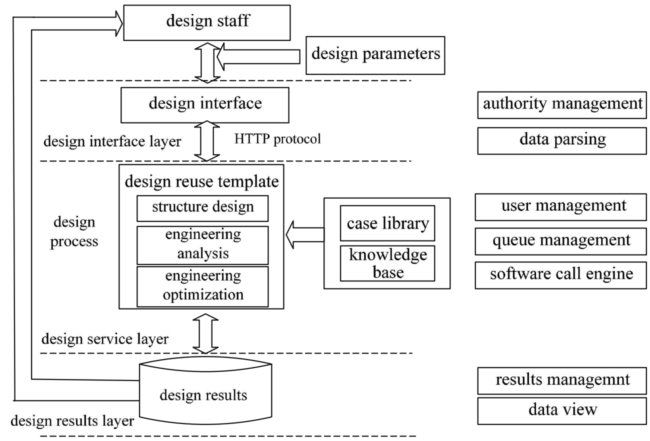

Fig. 2 Parametric design reuse system

2.2 Component model reuse

Design reuse of products is a dynamic technology realization procedure of "weak theory and strong experience." It is difficult to describe the design process with a formal language. Design reuse of software have been studied in the field of software engineering [15, 16], and some successful reuse models have been proposed. For example, the component model in software is "an independent, distributed, and reusable set of services" [17]. Each component has a number of interfaces which play certain attributes or methods. Users can access service modules to accomplish certain logic function through these interfaces. The service modules are distributed and independent. With code reuse technology, component model has the advantages of process encapsulation, logic shield, and knowledge reuse. Component model is widely used in software engineering. In this study, we employ the idea of component model in the literature [17] for parametric design reuse framework.

2.3 Reuse framework

As shown in Fig. 2, the proposed parametric design reuse framework includes three layers: the design interface layer, the design service layer, and the design results layer.

Design interface layer includes the abstract data structures and the service functions. Each design reuse service template provides a collection of design interface to users. Users can complete design tasks through design interface, with no need to understand the implementation procedure.

Design services layer provides design reuse service templates for users. Design reuse template is the combination of design process and design results based on the practice tested and repeated use processes, such as experienced formula, experienced data, solid models, simulation models, and optimization models. This layer interacts with users through interface and completes design task according to design parameters given by users.

Design results layer is the sets of reusable CAD models, engineering analysis, and optimization data. This layer provides the version management function and so on.

The proposed framework of parametric design reuse provides a solution of integrated, parametric, and rapid parts design. Its features are listed as follows: (1) The design reuse template is encapsulated by web and deployed on the server. Clients can share design software through web service. (2) The system shields detailed technology of parts design and eliminates redundant duplications of design information. (3) The separation of design interface and design realization process makes design reuse template to be easily used and effectively deployed.

3 Key technologies

In this study, the realization of parametric design reuse process within the proposed reuse framework includes two steps: Firstly, design reuse templates for parts design are deployed on the application server with software integration technology (e.g., iSIGHT). Therefore, it would be possible to accomplish an automatic integrated parametric design process though the software integration technology. Secondly, web packaging technology (e.g., EASA software) is used to capsulize and manage the parametric design templates. There are several key technologies for realizing and packaging the parametric design templates.

3.1 Design parameterization

Design parameterization is to automatically complete new parts design through changing the parameter value of the existing design results.

In this study, the realization approach of design parameterization is based on feature-based parametric model [18]. Generally, a solid CAD model is the combination of some features (such as holes, fillets, and chamfers). Users can alter the parameters (i.e., length and location) of CAD model to generate a new model [19–21]. In this study, design parameterization is based on CAD software. Taking Pro/E for example, there are two methods that can realize parametric design. One is to program using software package provided by CAD software. The other is to create the script files of CAD models. Figure 3 shows a partial script file of a cylinder model generated by Pro/E. Users can modify the two design parameters (the diameter and the height of the cylinder) in the script file and then call Pro/E in command line to complete design reuse.

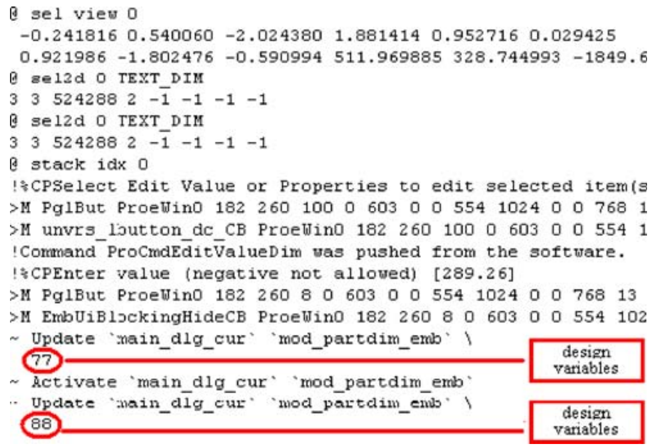
```
@ sel view 0
 -0.241816 0.540060 -2.024380 1.881414 0.952716 0.029425
 0.921986 -1.802476 -0.590994 511.969885 328.744993 -1849.6
@ sel2d 0 TEXT_DIM
3 3 524288 2 -1 -1 -1 -1
@ sel2d 0 TEXT_DIM
3 3 524288 2 -1 -1 -1 -1
@ stack idx 0
!%CPSelect Edit Value or Properties to edit selected item(s
>M PglBut ProeWin0 182 260 100 0 603 0 0 554 1024 0 0 768 1
>M unvrs_button_dc_CB ProeWin0 182 260 100 0 603 0 0 554 1
!Command ProCmdEditValueDim was pushed from the software.
!%CPEnter value (negative not allowed) [289.26]
>M PglBut ProeWin0 182 260 8 0 603 0 0 554 1024 0 0 768 13
>M EmbUiBlockingHideCB ProeWin0 182 260 8 0 603 0 0 554 102
~ Update `main_dlg_cur` `mod_partdim_emb` \
 77
~ Activate `main_dlg_cur` `mod_partdim_emb`
~ Update `main_dlg_cur` `mod_partdim_emb` \
 88
```


Fig. 3 Script file of CAD model

Most CAE softwares also provide the secondary development interface and the function of recording analysis modeling process. Taking ANSYS (the finite element analysis software) for example, there are two methods for simulation analysis reuse. One is to change parameters (e.g., geometric parameters and mesh parameters) in the data file with the APDL language of ANSYS. The other is to alter directly the parameters in the script file and then call ANSYS in the command line.

In this study, we adopt the method that modifies the script file and call CAD/CAE software in the command line for the realization of design parameterization.

3.2 Design template

Design template is used to integrate several parts design processes into one design unit.

Typical process of parts design generally includes CAD modeling, CAE analysis, etc. Design template can be used to format different design processes into one individual design unit. In this study, we use iSIGHT software to realize the design template.

iSIGHT is a desktop solution that provides engineers with a suite of visual and flexible tools for creating simulation process flows consisting of a variety of applications, including commercial CAD/CAE (e.g., Pro/E, ANSYS) software and internally developed programs. It can integrate multidisciplinary design software and provide optimization algorithms. Figure 4 shows the flowchart of typical integrated design process based on iSIGHT. Users can establish parts design flow through function module of iSIGHT such as process integration and task management. iSIGHT will read and alter the design variables in the script file and then drive design software to complete the new design task. Finally, iSIGHT will read out target design variables in output file to evaluate the results according to the requirements.

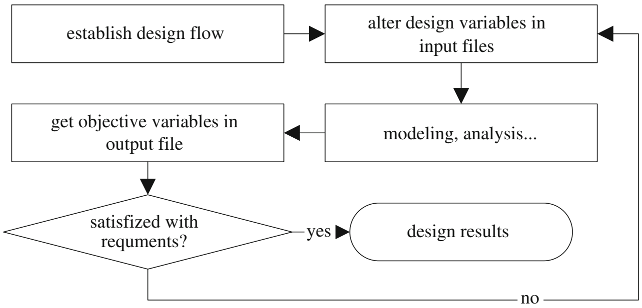

Fig. 4 Flowchart of typical integrated design process

3.3 Template encapsulation

The template encapsulation is developed for deployment, reuse, and management of the design templates. It provides the web service for users. In this study, we use EASA to realize encapsulation and management of parametric design templates.

EASA is developed for engineering software encapsulation and industry knowledge share. EASA provides a straightforward, codeless methodology for creating professional, web-based applications. It is also frequently used to build and publish applications that function as "wrappers" around legacy or "green-screen" codes and databases, eliminating costly rewrites and removing deployment issues.

As shown in Fig. 5, the proposed parametric design reuse prototype system is based on EASA. The data parser exchanges data with design reuse templates. Users can establish different design reuse tasks in different computers with EASA builder. EASA server provides concurrent user management, design task queue management, results version management, authority management, and other functions. The design reuse tasks are deployed and managed with EASA server. User can use EASA client to customize different input interface for different design tasks.

4 Experimental details

In the experiment, we establish a reuse prototype system to demonstrate the design reuse framework using heat pipe exchanger design.

4.1 CAD model simplification

The CAD model of heat pipe exchanger consists of condensing tube, straight fin, evaporation pond, thermal source, etc. In the experiment, the purpose is to optimize structural parameters of the heat exchanger (e.g., the heat pipe radius, the number of straight fin, etc.) for better heat exchange performance and better resistance performance while avoiding changing the overall size of the heat pipe exchanger [22]. For the sake of description, we simplified the CAD model of heat pipe exchanger into a 2D model (Fig. 6).

4.2 Constitution of parametric design template

In this study, we employed iSIGHT as the optimization tool for parametric design template. Firstly, users set up the design objective, variables, and constraints in iSIGHT. Then, iSIGHT will call other software (such as Gambit and Fluent) to deal with the design tasks, including geometric modeling, mesh generating, solving setting, numerical calculating, and post-processing. The whole design optimization process will be integrated.

GAMBIT is Fluent's geometry and mesh generation software that has single interface for geometry creation and meshing. Therefore, most Fluent's preprocessing technologies will be brought together in one environment. In the experiment, Gambit is used to build geometric modeling and mesh generating of heat pipe exchanger. Fluent is used to solve the parameters of mesh data. iSIGHT is used to integrate Gambit and Fluent and obtain the final result.

4.3 Web encapsulation

The web encapsulation process of the prototype system is realized with EASA where the interface customization, the input confirmation, the file assignment, the operating implementation, and the export setting are encapsulated. Users can set up three optimization elements (design objectives, variables, and constraints), the simulation boundary conditions, and the optimization results reporting format through the web interface.

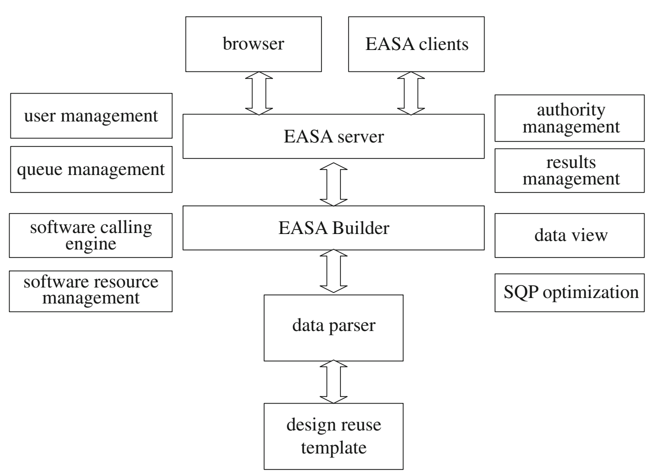

Fig. 5 Template encapsulation with EASA

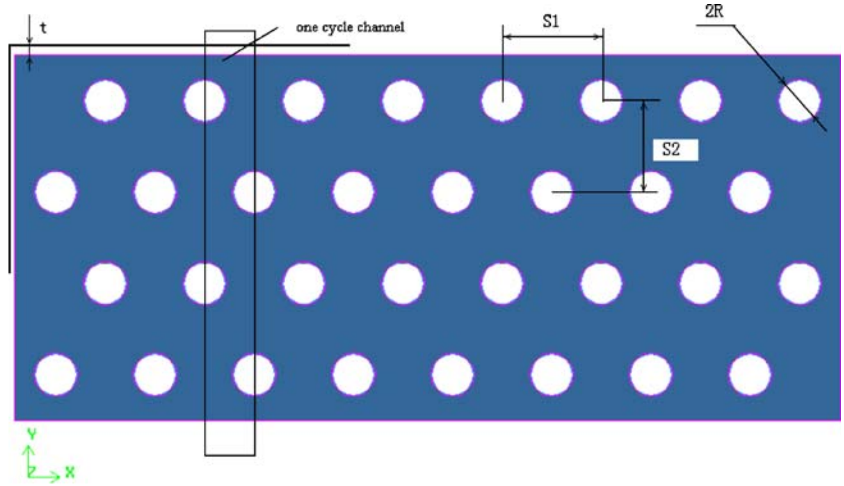

Fig. 6 Simplified model of heat pipe exchanger

Figure 7 shows the parametric input interface for heat pipe exchanger. Users can input the initial values and boundary values on the right side of the interface according to the sketch map on the left side. Figure 8 shows the input interface for optimization of heat pipe exchanger. The left side of the interface shows the model of heat pipe exchanger. Users can input the parameters of elastic modulus, thermal conductivity, objective heat dissipating capacity, and average import wind flow on the right side of the interface.

Generally, it takes 2–3 days for an experienced designer to accomplish the whole design of the heat pipe exchanger. Using the design reuse prototype system in this study, it takes about half an hour for a designer to finish the same design issue. What is more is that the proposed approach can reduce the training costs of the CAD/CAE software and design difficulty effectively.

Meanwhile, it should be noted that the design works of the design template and the software packages are not very complex and difficult since iSIGHT and EASA are

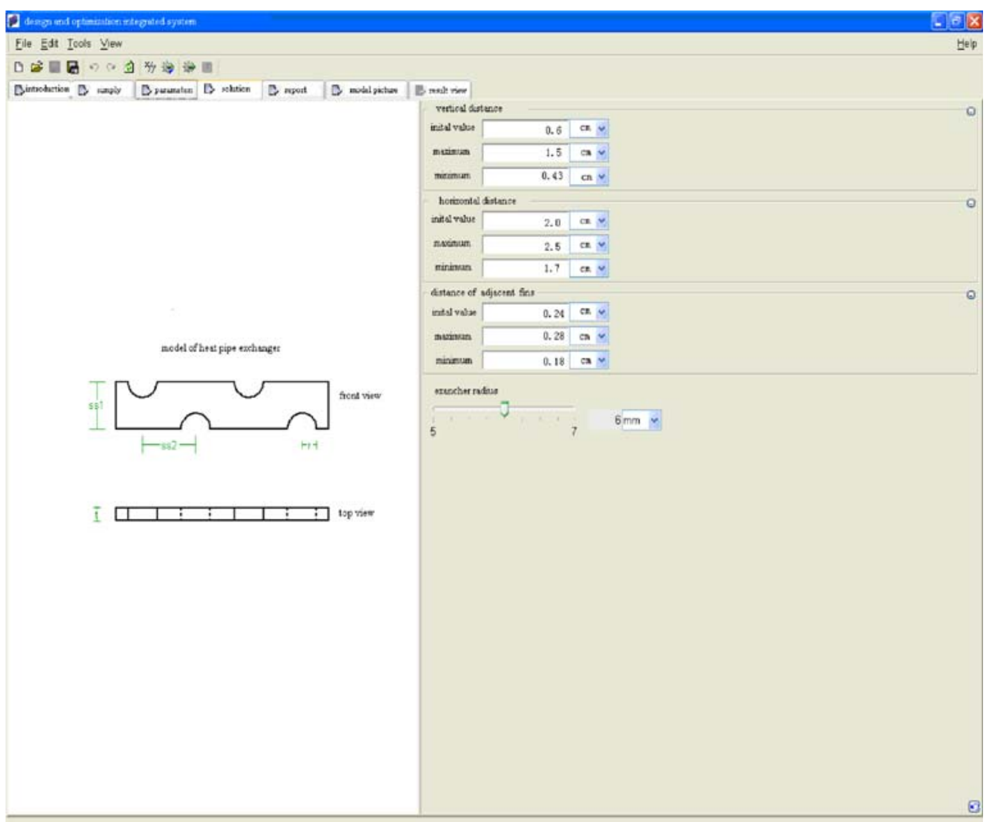

Fig. 7 Interface: parameters input

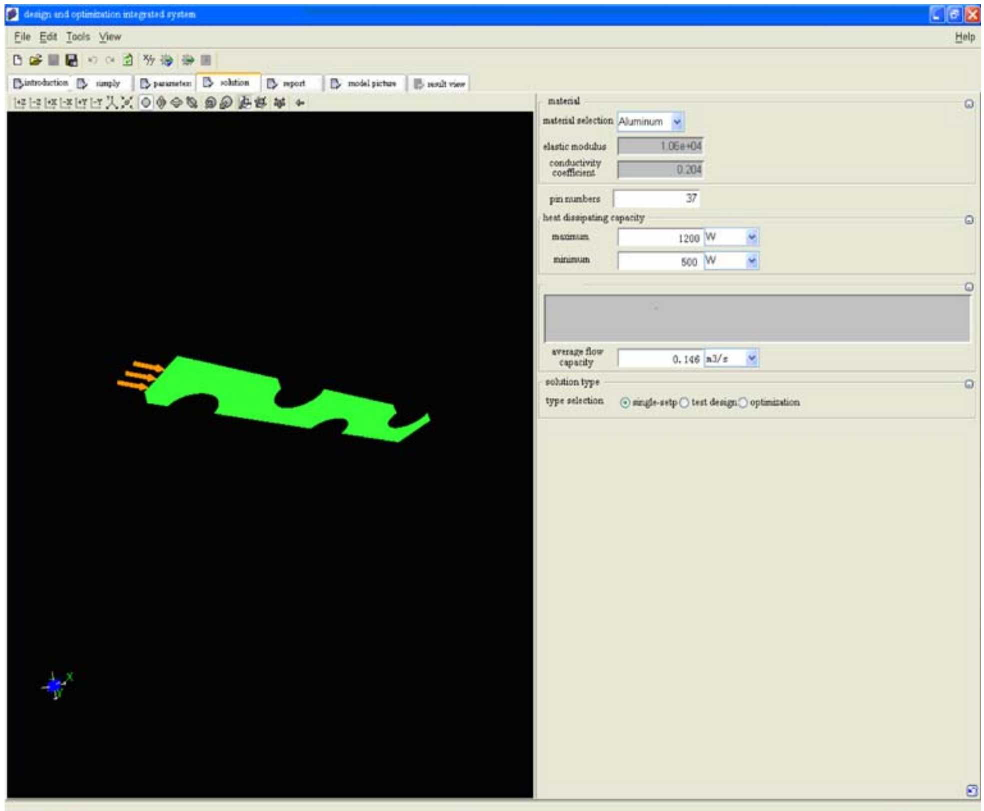

Fig. 8 Interface: optimization parameters input

widely used in many enterprises currently. In general, a designer skilled with iSIGHT and EASA would finish the aforementioned design works within 2 days. Certainly, the prices of EASA and iSIGHT are not cheap, but when the proposed system is realized, it cannot only save the design efforts and time but also can take full advantage of the license of the software and reduce the training costs of these softwares. From this point, we can say that the proposed system for design reuse is more suitable for the SMMEs that lack economy and technology strength.

5 Conclusions

In this study, we proposed a web-based service parametric design reuse framework for parts design and discussed several correlative key technologies. The framework is enlightened by the component model of software reuse. The framework would be used in the enterprises to encapsulate the detail design process of parts, including the simulation models, the optimization models, etc. Taking the heat pipe exchanger design reuse for example, we present a prototype system based on the design reuse framework that has web interface and can be safely used by the staff of SMMEs on web even if they have no experience on the CAD/CAE software. The application of prototype system showed that the proposed design reuse framework cannot only improve the design efficiency but also reduce design difficulty.

This study is expected to contribute to the design reuse in the following aspects: (1) A web-based parametric design reuse framework is proposed to accomplish detail part design and (2) the key issues on realizing design reuse framework are solved. The core of the proposed web-based parametric design reuse framework includes three aspects: (1) The design reuse framework is effective to reuse and share the whole design process (i.e., the solid modeling, simulation, and optimization); (2) the design reuse framework integrates the prior knowledge and experience, shields the detail technology, and eliminates the duplicated design; and (3) the parametric design templates are deployed on web server and the clients are used to share engineering design software for users.

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