Design Knowledge and Process Management Method Based on 3D CAD System

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ABSTRACT: *With the diversification of customer needs and the widely use of 3D CAD systems, in order to make the 3D CAD system truly become the best carrier of professional technologies and realize the accumulation and reuse of enterprise design knowledge and design process, a design knowledge management method based on 3D CAD system is presented. In this method, a Design Navigation system based on 3D CAD system is researched, which can build Design Navigations for different products with language engineers are familiar with, and make product design visualized and processed. The mechanism of knowledge classification, management and reuse is also established for Design Navigation, design model, standards manual, formula, charts, drawings, and so on. This method was applied in piston design, and was approved to be effective in design knowledge accumulation. With this method, design experiences of senior staff can be accumulated within the enterprise in forms of parameterized features, standardized design process, precise rules and verified methods. Finally, design efficiency and quality of modularized and serialized products were improved, and the accumulation of design knowledge and design process was strengthened.*

Subject Categories and Descriptors
J.6 [Computer-aided Engineering]: Computer-aided Design (CAD); **I.5.2 [Design Methodology]**: Feature Evaluation and Selection

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1. Introduction

In modem product development, there is more and more knowledge in enterprise's management and operations, and they are embedded within products and product development processes. For product-oriented enterprises, their main assets exist in the products and product development processes. Nothing is important more than the accumulation and reuse of their wisdom and know-how. Engineering designers are often challenged to reusing the design knowledge from previous completed projects in a current one [1-3]. Furthermore, knowledge loss, inappropriate replication, and errors are all-too-common issues encountered when attempting to reapply existing but incomplete knowledge to a new design [3, 4]. Therefore, knowledge plays an important role in product design, and design knowledge reuse has attracted much attention from the engineering design community in recent years [1, 6-8].

At present, most enterprises are using 3D CAD system for product development. Although commercial CAD systems are good at building geometrical data and models, it is widely acknowledged that they are ineffective to help designers manage design knowledge for reuse. Three typical problems occur in the application of the current 3D CAD systems: (1) the potential of 3D CAD systems has not been fully exploited and CAD is computer-aided design, rather than simply computer-aided drawing or modeling [9]; (2) technical know-how is ongoing loss along with the retirement or resignation of excellent technical staffs; (3) the old staffs are well versed in product design, new staffs are good at 3D CAD manipulation, there is no combination of both advantages. In order to solve these problems, many researchers studied on professional CAD platforms, and customized design platforms for multiple products [10-12]. However, most of them have defects like: there is large workload in platform development, applicable scope is limited, and the staffs need to spend more time to learn the new platform except general CAD systems.

In order to find the best strategy to take full advantage of design knowledge and 3D CAD systems, we analyze the characteristics of the current design process, and attempt to develop a design knowledge and process management system based on SINOVATION which is a general 3D CAD system in China. Using user familiar language, this system closely integrates professional knowledge, advanced design methods, and CAD system. It can instruct designers to design products, make 3D CAD system truly become the best professional and technical support.

2. The Analysis on Product Design Process

With the diversification of customer needs as well as the application of 3D CAD systems, product design process gradually exhibits features of parameterization, repeatability, feature-driven and information integration.

2.1 Parameterization

Because of the widely use of standard parts and general parts in product design, parameterization is focused on and parametric design method appears in 3D CAD systems. Parametric design is defined by Shah as "a *process of designing with parametric models in a virtual surrounding where geometrical and parameter variation are natural* " [13, 14], which can greatly improve the design speed and quality for products with same topology and similar structure. Parameters here include both numerical design parameters (such as length, width, etc.), but also include descriptive features (such as diesel application environments including ship, engineering machinery, automobile, etc.).

2.2 Repeatability

Research shows that 75% of products are designed based examples, and even in the design of new products, about 40% of the parts are designed to reuse the past, about 40% of the parts have been designed to make some modifications, but only about 20% is a totally new design [15, 16]. Moreover, the product design process in a certain enterprise is a gradual process for product model generating, and product design methods or ideas will be embedded in the process. Therefore, the product design process model once formed is repeatable and continuously available.

2.3 Feature-driven

Features are high-level geometric constructs used during the design process to create shape configurations in the model that are usually related to the intended functionality of the designed product [17, 18]. The design approach with feature-driven can simplify complex product design to meet the needs of high-level abstract description, which can improve design efficiency, promote enterprises to summarize the industry experience, and extract more regularity knowledge.

2.4 Knowledge integration

Product design process requires the integration of existing feature-based parametric design method, and needs to combine CAD modeling with standardized product design process, engineering calculations, design specifications, rules and other design knowledge. Therefore, design process is a process with knowledge integration.

These characteristics of product design directly affect management way for product design data and design process. To this end, leader companies in the development of CAD systems augmented their top-end CAD products with parametric design, feature modeling, modeling approach like top-down, and KBE capabilities. For example, PTC introduced the Behavioral Modeling toolkit for Pro/ENGINEER 2000i, which allows methods to capture rules to steer the CAD engine. Siemens PLM Software acquired the KBE language Intent!TM which was integrated into NX as the Knowledge Fusion tool. Dassault Systemes sinks ICAD and exploits KTI expertise to develop the KBE add-on's (Knowledge Ware) of CATIA V [19, 20]. In China, we also present a design knowledge management method based on the domestic three-dimensional CAD system SINOVATION, which we call Design Navigation. It introduces a different way for knowledge management based on CAD systems. Next we will introduce the functions of Design Navigation, and discuss the management structure of design knowledge.

3. Design Navigation Based 3D CAD System

The formation of Design Navigation for a certain product is a process developing from nothing. If totally dependent on programming by the designers, there will be a huge workload and take a long time. Therefore, to simplify the definition process of Design Navigation and improve the efficiency of the system customization, a quick and easy customization process for Design Navigation is presented based on the basic function of 3D CAD system SINOVATION, and it includes design process recording, command editing, information adjusting, and Design Navigation performing four steps, shown in Figure 1.

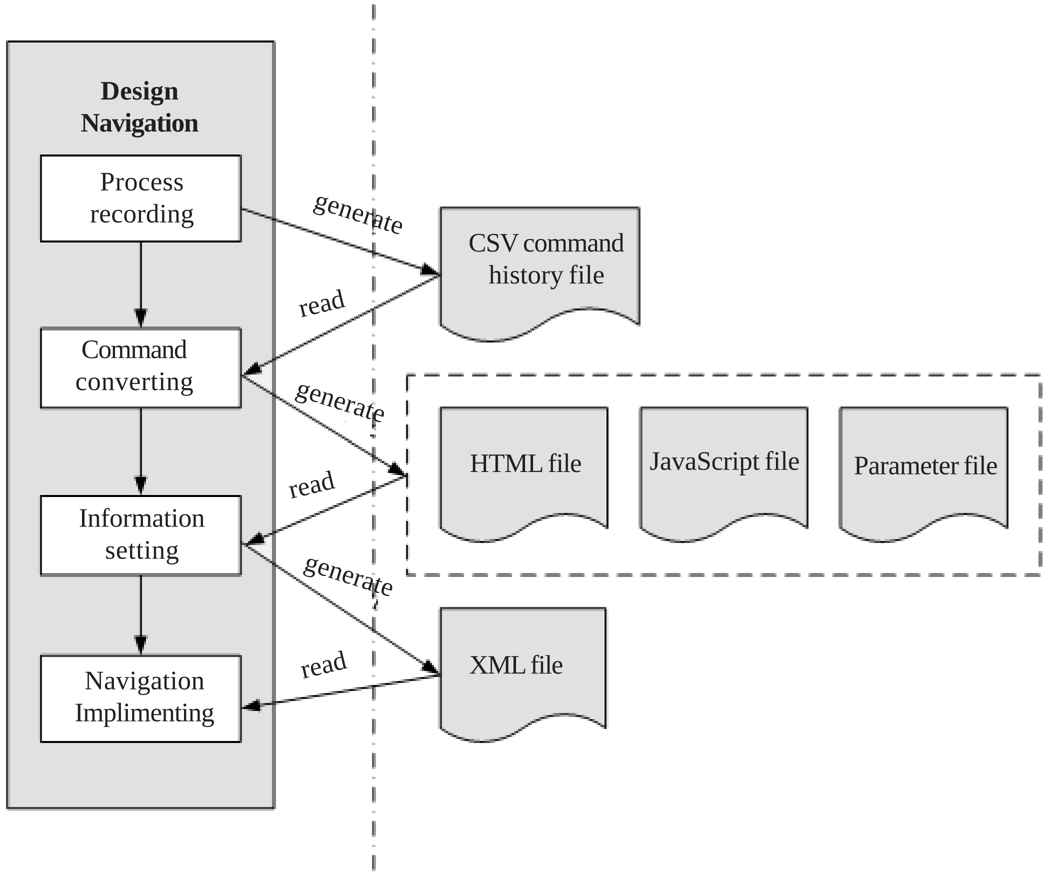

Figure 1. Customization process for Design Navigation

(1) Recording design process to generate command history file which is called CSV (Command of System Video). Design experience of senior designers is particularly valuable, and their operation in design process is an important reference for Design Navigation. In the design process, parametric design method based on features will facilitate the subsequent Design Navigation customization.

(2) Converting CSV files which store user operation command into JavaScript files, HTML files, and parameter files. Design Navigation is displayed in the form of Web pages, which provides convenience to set controls and modify parameters.

(3) Setting procedures, parameters, interactions between them in Design Navigation, and generating XML file for the navigation. This step is the key to Design Navigation customization. It will filter and adjust the design recording, clear sequence of steps for each operation (including feature selection, feature positioning, assembly sequence, etc.), determine interaction method between Design Navigation and designers, define the types of design parameters (CAD input, Design Navigation default, parametric equations or geometric constraints) and so on.

(4) Reading XML files of Design Navigation, and being executed by the designers. The design navigation for certain products can be repeatedly used in the design of similar products.

During the process of defining and executing Design Navigation, function modules like modeling, engineering drawing, and assembly will be called and interacted continuously, and it is also possible to use internal or external data sources like various parameters, rules, functions, and so on. Meanwhile, the Design Navigation should support a variety of complex secondary development. Therefore, the Design Navigation is not an independent module, and the interactive relationship is shown in Figure 2.

4. Management method for design knowledge

Different products, different Design Navigations. In a certain enterprise, there will be several types of products and at least thousands of parts, so the number of corresponding Design Navigations will also increase exponentially. In order to manage various Design Navigations and the complex relationships between them, a design knowledge management module is developed, and it can be integrated with PDM/PLM systems to ensure the accuracy and uniqueness of enterprise data. It is helpful to design knowledge (such as manuals, formulas, drawings, charts, standards) reuse and workload reduction. Furthermore, it is essential to make potential knowledge explicit, which was tacit as experience and transferred orally in the past. The corresponding management method of design knowledge management module is shown in Figure 3, and it is composed of category management, object management, business activity and data warehouse.

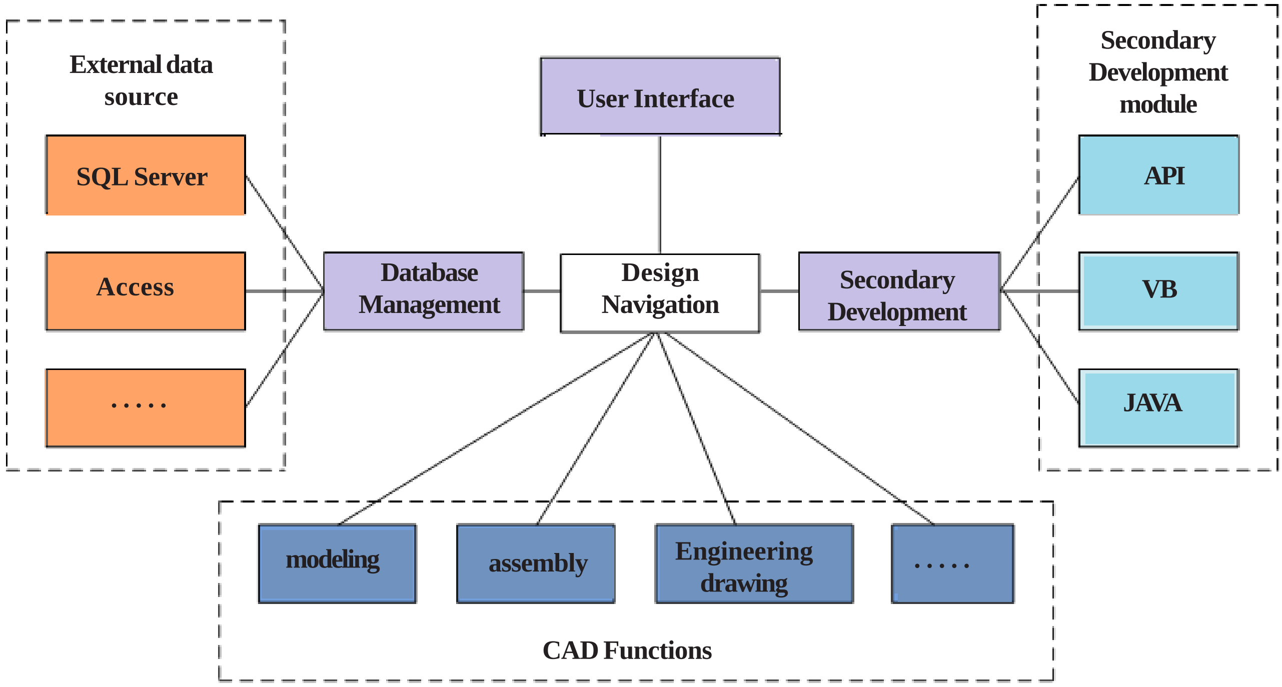

Figure 2. Interactions between Design Navigation and function modules

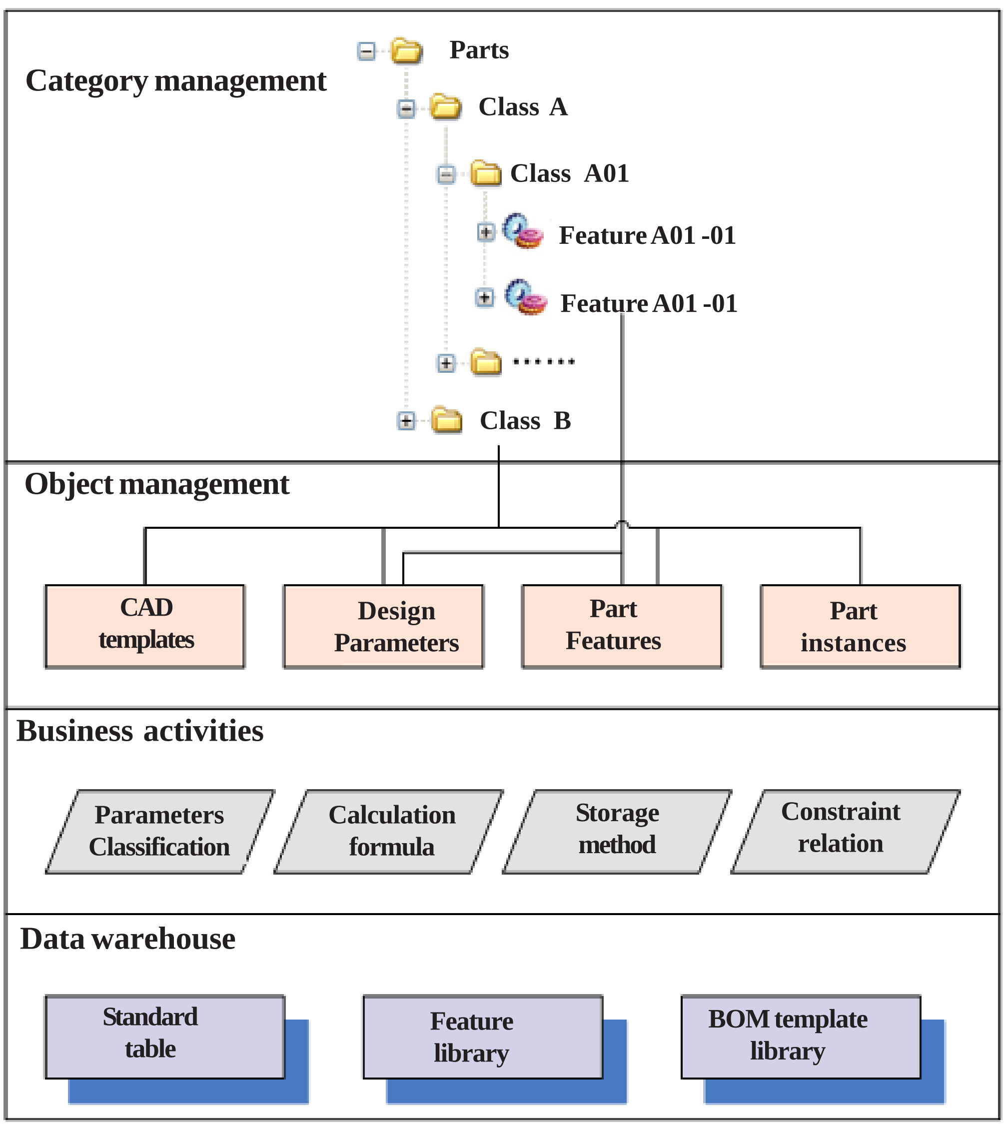

Figure.3 Knowledge management method of Design Navigation

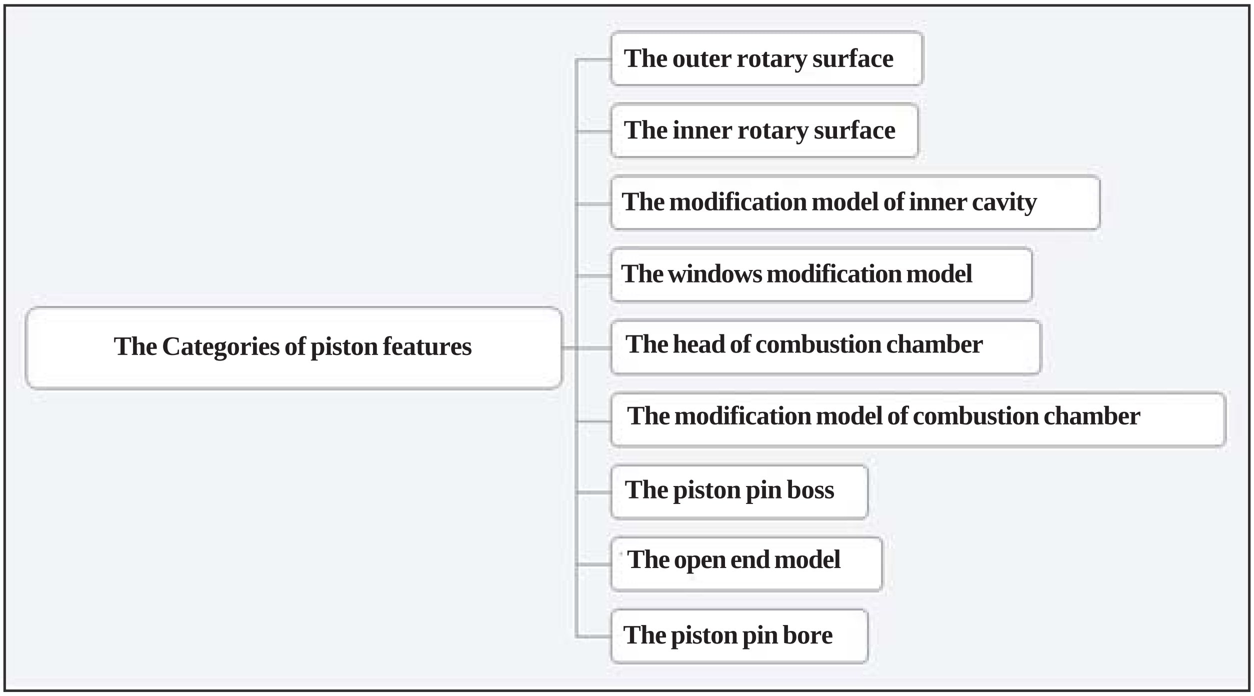

Figure 4. Categories of piston features

4.1 Category management

Different products, parts and features have different classification, and it will form the homologous category tree following certain classification criteria, such as function, structure, shape, process method, or a combination of the above. The leaf of this tree describes a specific part or feature category which inherits all the attributes and methods from parent class. The object–oriented method is used here to organize and describe complex relationships between various objects, which take full advantage of class inheritance and generalization.

4.2 Object management

CAD templates (such as scale drawing, assembly drawing, etc.), design parameters, part features, part instances are extremely important for product design, so they should be managed effectively. Therefore, according to the category tree above, four object types are defined for each part or feature class. Attributes between classes and sub classes have inheritance relationships, especially in design parameters. That is to say subclass inherits attributes from parent class automatically while sub class has its own attributes.

4.3 Business activities

In design knowledge management module, parameter classifications, calculation formulas, storage methods, and constraint relations are significant to the above four kind objects, which determine the management quality and efficiency of Design Navigation. So they should be defined and managed in this section, especially in the most complex design parameters.

4.4 Data warehouse

It is the data management layer for the other three layers, and provides basic data for design knowledge management module, like standard table, feature library, BOM template library.

5. Design example of a piston

Piston is a key component of the engine, and has characteristics of complicated structure, poor work conditions, and design difficulties. With traditional design methods, it requires repeated test, trial production, and continuous revision to finalize the design. But for the piston design and production enterprises, after decades of accumulated research and development, they have formed a series of products; have accumulated a wealth of experience and processes in design requirements, structures, feature selection, performance analysis, and so on; have a great deal of successful examples in piston skirt, combustion chamber, cavity and other structures which are difficult to design. Therefore, it is representative to select the piston design as an application object for Design Navigation and design knowledge management, which has significant economic value.

Before the customization of Design Navigation based on features and parameterization, we should extract the typical features of piston structure, take structure analysis of various features, and establish the parameterized constraint relationships to ensure the linkage between every feature. In piston design, combustion chamber, cooling oil chamber, and piston pin boss all have a variety of structures. Besides the standard features (like cooling channel, piston ring, etc.) recognized across the industry, characteristic features of piston are subdivided into nine categories which are the basis of product modeling, shown in Figure 4.

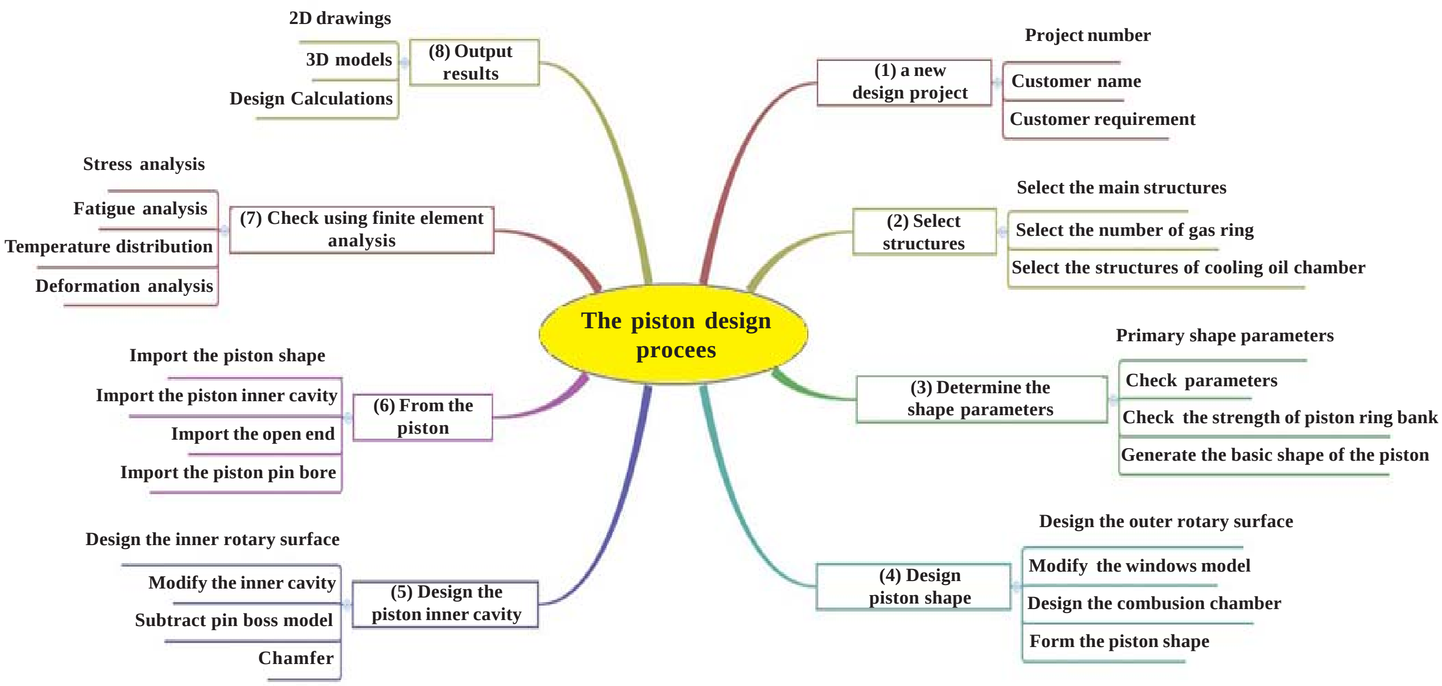

Figure 5. The piston design process in SINOVATION

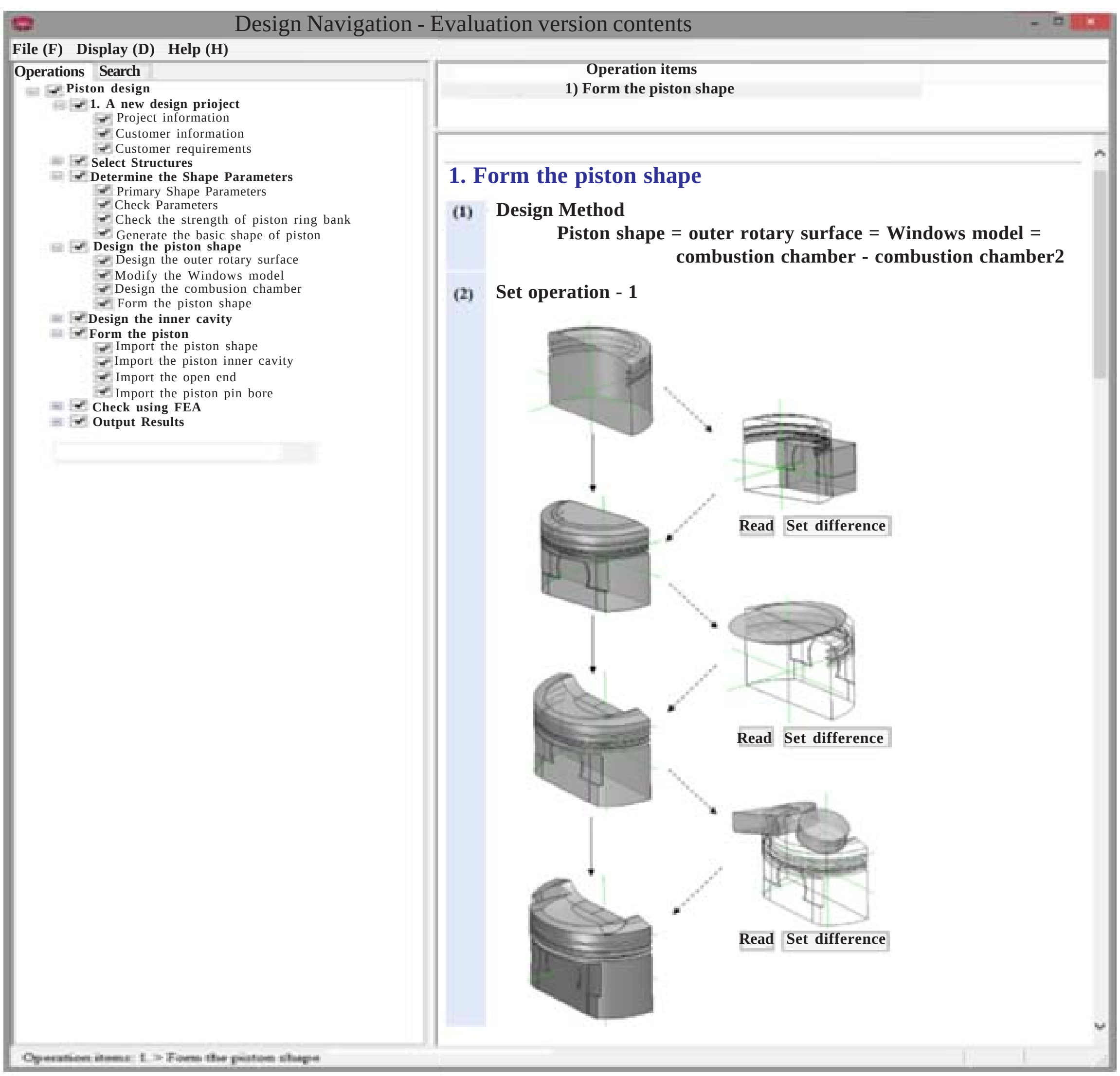

Figure 6. Design Navigation: form the piston shape

According to the category management of piston features, relationships between the features are defined, and a feature-based parametric 3D solid model of the piston will be gradually formed after topological operations of the features. This process should be a standard process of product design, and each steps of this process are recorded in SINOVATION to be the basis for subsequent Design Navigation editing and execution. Based on this recorder, in information set stage, various parametric design features, design calculations, experience and rules are defined in Design Navigation, and the sequence of product design steps can be adjusted according to the actual situation. This process is gradually improved and enriched realizing design knowledge accumulation and design process precipitation. Through this method, with a kind of piston products as an example, a piston Design Navigation process is established as shown in Figure 5, the main function of each step is described below.

5.1 A new design project

Each time the piston Design Navigation execution corresponds to a design project, and customer requirements input here will drive the subsequent product design.

5.2 Select piston structures

According to user needs, choose an appropriate piston structure type, determine the number of gas ring, and select the structure of cooling oil chamber.

5.3 Determine the shape parameters

Choose shape parameters for each part of the piston in the way of manual inputting or experience recommending, check the parameters to meet the design requirements, and determine the strength of piston ring bank. Finally, piston shape is generated.

5.4 Design the piston shape

The outer rotary surface, the windows modification model, and the combustion chamber are the core of this design. Several alternative structures of these three parts are established for designers to choose, and the corresponding structure selection basis and conditions are provided as references. Note that, due to the complex structure of the piston combustion chamber, the design of combustion chamber is divided into two parts in Design Navigation, the head of combustion chamber and the modification model of combustion chamber. Therefore, the piston shape = the outer rotary surface - the windows modification model - the head of combustion chamber - the modification model of combustion chamber, it is Boolean operation between the four models. The Design Navigation in SINOVATION is shown in Figure 6.

5.5 Design the inner cavity

Similar to the piston shape, the piston inner cavity also need to complete three parts, the inner rotary surface, the modification model of inner cavity, and the pin boss. Finally, the inner cavity = the inner rotary surface - the modification model of inner cavity - the pin boss (as shown in Figure 7), and complete chamfer.

5.6 Form the piston

After the completion of the piston shape and the inner cavity, the open end and the piston pin bore are designed subsequently. Then, the piston = the piston shape – the inner cavity – the open end – the piston pin bore, as shown in Figure 8.

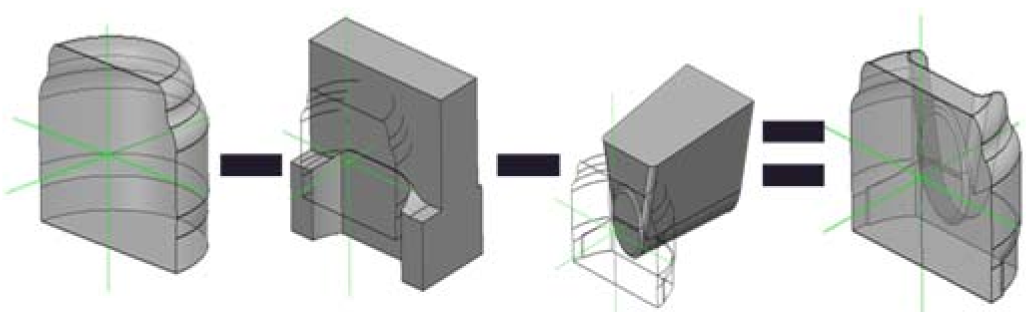

Figure 7. The process of the inner cavity design

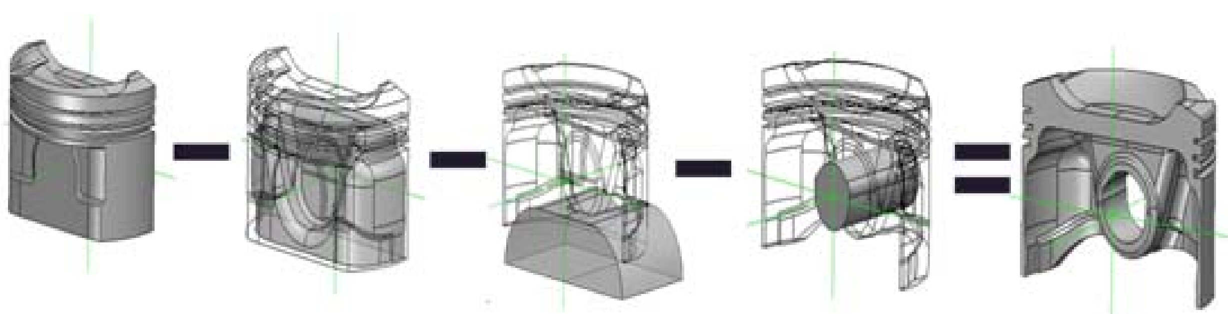

Figure 8. The process of the piston forming

5.7 Check using Finite Element Analysis

Stress analysis, fatigue analysis, temperature distribution, and deformation analysis should be taken to ensure the design quality. SINOVATION not only provides CAE capabilities to meet the general structure analysis, but also integrates third-party CAE software to output results.

5.8 Output results

According to the final design results, 2D drawings, 3D models and design calculations can be output accurately.

During the execution of Design Navigation, various characteristics and structures can be established with the navigation default methods, and also can be designed in the way of parameter adjusting and structure modification according to actual cases. Moreover, the Design Navigation keeps continuous interactions with CAD modeling, such as the selection of boundary lines and constraint lines, surface fitting in combustion chamber modeling process. This approach is more flexible, which can ensure designers understand the product design process whenever they need, and the design process can be constantly revised in accordance with the design results.

6. Conclusion

Through the analysis of design process characteristics, a Design Navigation system based on 3D CAD system is planned, and a corresponding method of design knowledge management is presented in this paper. This approach simplifies the definition process of Design Navigation, improves the efficiency of the system customization, and helps enterprises accumulate and reuse design knowledge. The application in piston design process verifies the feasibility and practicability of this approach. It can integrate existing knowledge with product design process, improve enterprise product design process with the advantages of features and parameters-driven mechanism, and also can ease the drawbacks of knowledge gaps because of the staff replacement.

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