# The Quick Design Method for the Big and Complex Products based on Function Disassembling

Xianying Yang[1, a], Weizhan Li[1, b]
[1]*Chongqing Jiaotong University, Art Design Collage, Chongqing 400074,China*

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Abstract: This paper gave out an analyst the condition, disassembling and unfold principle of module concept with the function planning and relationship, developed the process with the sample of leveling machine. It got the idea plan of the product, put forward the action of function disassembling and transit into the design by the quick industrial design sketch and rendering method, improved the efficiency of concept design. It get conclusion the modularity and disassembling method will guiding the designer and give a reference on the large and complex product function defining and design.

## 1 BACKGROUND

Simplified conceptual design is usually adopted to start the creative process first in the early stage of product development, because of massive components of big and complex products. These products are characterized by large size, complex design, high technical standard, and strict requirements for the adaptability in actual working environment (Jungmin Yoo, Minjung Park, 2016). In simplified methods, the modular design concept is universal in this kind of products design, and it is the study object of traditional design. Previously, the team of foreign scholars Browning. T.R and Wei XP proposed multi-level evolutionary design theories and methods for complex products to improve the intelligence of complex product design, aiming at the multidisciplinary coupling integration of complex product design. Liu FY studied the key technologies of complex customized products development and design. Lin ZQ studied the digital design of complex equipment. Zhang SY studied the theory and method of engineering semantic expression, transmission and driving in product design based on fuzzy interaction modeling technology for product design information of engineering semantics. Feng YX researched the principles, methods and applications of complex mechanical product design intent (Lei Zhang, Xuening Chu, Deyi Xue, 2019; CHEN Mengyue, et.al, 2016). Based on the above methods, this paper put forward research on the product form design from further function disassembling and unfolding process of modularity, to obtain a creative method that is easier for designers to control.

## 2 DEFINING MODULES BY PRODUCT FUNCTION

Module is a relatively independent and replaceable component in a product system or service system, which is also a function unit of modular system. In mechanical products system, module is a group of combined elements with the same function. Modular design is a way of disassembling and reorganization. It is a method of integrating and innovating based on product system design by exchanging and transplanting innovative ideas. The purpose is to improve the demand of system diversity, plurality, economy and standardization. According to the relevant demand information of the product system, considering the correlation between the product modules, the product function re-design module can be identified according to the output efficiency of product core function, after determining the importance of each module by using QFD (Quality Function Deployment) matrix and fuzzy evaluation method (CHEN Mengyue, et.al, 2016, Chen, L., A. Macwan, and S. Li, 2007). In the module construction and combination of ideas, the module is



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a bit fuzzy, which needs to be sorted and determined according to the design goals and research methods.

Taking automotive products as an example, the body structure is a large and complex system. Soon after the birth of the first production line, Ford Motor faced consumer demand to cars diversification, and thus produced a variety of models by determining the core modules. Toyota launched a global framework to improve the common use of component layers whose versatile rate increased from around 20% to 80%. In addition, domestic and foreign automobile enterprise introduced different types of modular platforms such as MLB, MMB, UKL, MFA and MRA to improve the common use of design and increase differential controllability. At the same time, the platforms number of cars were reduced by modular design. For example, the number of Ford Motor car platforms was reduced from 27 to 8, and its utilization rate of core modules was greatly increased. In today's highly competitive marketplace, the development team of automotive manufacture enterprises introduce modular design ideas in automotive construction system, to reduce production risks and costs, increase production flexibility, and improve production acumen. The car body is divided into several modules according to the specific function, and the module is disassembled hierarchically from the model, the body, the units, the components, the parts, etc. And then the modules are combined according to the produced models. The production adaptability and R&D production efficiency are greatly improved by this form of production organization. As shown in Figure. 1, from left to right is the module layer subdivision of automobiles. Automobile companies form a variety of models through multi-layer module combination, which meets the needs of consumers' meticulousness and greatly improves the efficiency of supporting production.

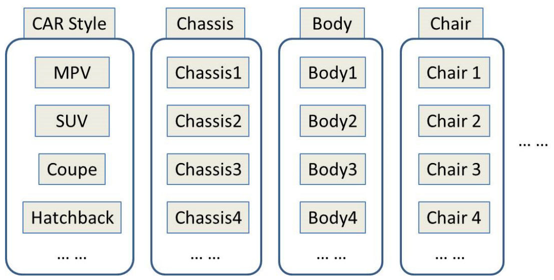


Figure 1. The Module Layer of Car Body.

# 3 PRODUCTS MODULARITY FUNCTION DEPARTING

## 3.1 The Condition and Demand

Modular design is a special design idea and the designers need to consider factors such as using conditions, economy, and necessity of demand. The design team analyzes the system factors such as the conditions and requirements of the design object, and understands the modular advantages of the design object function. Through the analysis and evaluation, the modular design method is determined.

The design conditions and requirements of the modular design are often the requirement of multi-function, multi-purpose, and variable function, such as the space variability requirements of product combination, requirements for high frequency switching of storage and placement functions, multi-function requirements for both home and outing.

To determine the use time and condition of modular product design, we can observe the product's operating conditions, core functional components, and maintenance needs, it can be observed in terms of product use conditions, core function components, and maintenance requirements.

## 3.2 Function Layer Disassembling

The modular concept facilitates the complex product functions disassembling. The function output of the product system can be disassembled into constituent units to determine the core modules and non-core modules of the modular layout. Module functions can be disassembled from the following layers:

### 3.2.1 The Whole Product

This layer mainly focuses on products serialization and product group differentiation. The serialization of products is targeted at the function disassembling of modules. Take construction machinery - leveling machine as an example, product group and system composition layers can be classified from the function requirements. The core function module can be divided into four basic modules: power unit, operation unit, cockpit and frame platform (Chen, L., A. Macwan, and S. Li, 2007). By product modules disassembling, the multiple combinations of product serialization extension are provided, as shown in Figure. 2 below.

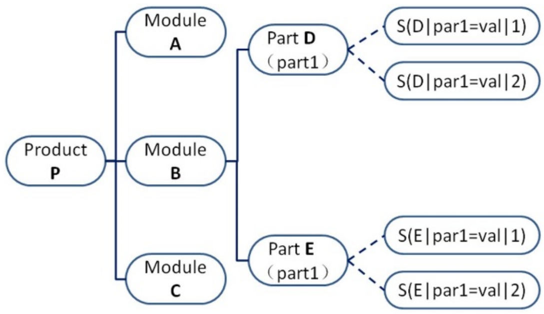


Figure 2. The Product Model of Leveling Machine.

### 3.2.2 Parts Layer

Components are independent modules that make up a product, which is also the layer of the most common modular design applications. Different configurations can be obtained by modularizing the components, with obvious modular design traces and visual elements. The structural connection between the component modules affects the basic direction of the exterior form design. According to the algorithm of module division under design structure matrix (DSM) architectural constraints, Wei et al. adopted the modularity $Q$ function as the optimization target of module division (Wang, Y., Cho, H, 2012).

### 3.2.3 Components Layer

Part modularization is the basic module element layer division in product design category. The modules are combined from the basic functions, and then the overall form is designed, based on the consideration of product serialization. According to the modular design idea of the leveling machine structure described above, the chassis components are further subdivided into basic component module elements (Smith, S., G. Smith, and Y. T. Shen, 2012), such as transmission, frame and suspension, to form a new combination scheme. Then, the holistic design of the new combination is made.

The module elements are divided from the perspective of function flow disassembling of the components level. The form of function flow is divided into material flow, energy flow and information flow. The disassembling or aggregation of product functions is made by the module division based on function flow, through materials, energy and information flow. And then, the product module is qualitatively divided. Through the static and dynamic relation between components, the correlation between function input and output is established, such as the input-output relation matrix of a certain parameter. Where, each matrix element $s_k(I_i, O_j)$ is the correlation degree of the j function input to the i function output when the k parameter is considered. If the input and output functions are listed separately, $s_k(I_1)$ is the input function and $s_k(O_1)$ is the output function. When observing the correlation degree, it is assumed that there are correlation degree indexes of M categories of indicators and parameters for analyzing functions. Among them, the influence coefficient of the correlation degree of category k parameter on the total correlation degree is $W_k$ . Since the sum of product functions is set by the goal, the sum of the influence coefficients of various parameters is equal to 1, as shown in equation (1).

$$\sum_{k=1}^{M} W_k = 1 \tag{1}$$

## 4 FUNCTION PLANING

After the decomposition of modularization, a preliminary layout plan can be obtained through the graphic arrangement of functional layout, that is, the function modules are simplified into blocks to show the basic construction system of modular design and the basic logic relationship of the product is expanded. For example, the function modules of a product are divided into four parts: P1, P2, P3 and P4, among which P1 is determined to be the core module and cannot be replaced, while the other three modules can be replaced according to the application. The basic combination scheme of P1+ P2+ P3+ P4. It can also be divided into P1+( P2+ P3)+ P4 combination scheme according to the function application frequency. In addition, it can be divided into P1+( P2+ P3+ P4) combination scheme, that is, P1 is the core module, P2, P3, P4 is the component or part module, can be replaced, as shown in the lower part of Figure. 3. By dividing in this way, different combinations are formed. After the basic plan is determined, differential exploration of the detailed modeling for the certain plan is obtained, such as the differential combination of the basic combination scheme. Then the detailed decomposition form is obtained, thereby forming different structure prototypes and appearances.

# 5 QUICK CREATIVE DESIGN PROCESS

In this paper, a large-scale engineering equipment - leveling machine is taken as a design object for modular design process analysis and industrial design process study (Minjung Park, Jungmin Yoo, 2018; Daie P, Li S, 2016).

## 5.1 Function Decomposition and Developing

According to the previous function division principle, the following main function modules are determined: ① D engine cabin (Driving, red); ② H cockpit (Human, green); ③ P chassis and frame (Planning, orange); ④ M flat shovel module (Moving, blue); ⑤ I guide wheel set (Index, gray); ⑥ S supporting wheel set (Supporting, black),as the Figure3.

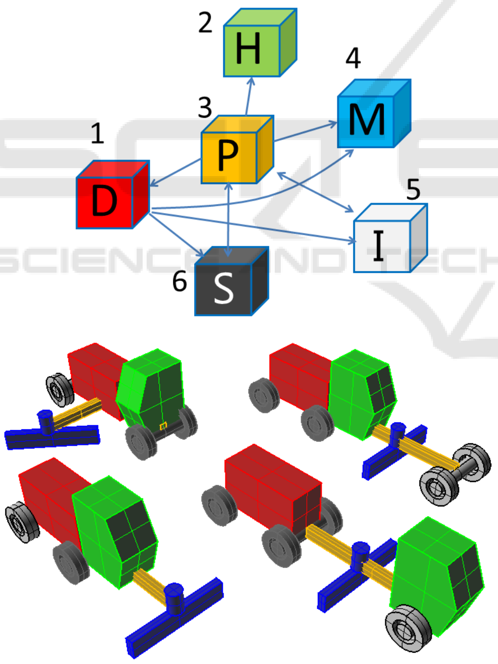


Figure 3. The Image of Function Relationship.

It can be seen that the chassis and frame are the main body supporting the engineering vehicle, and its shape is variable, according to the principle of function decomposition and interrelation. P supports and links each of the other modules, from the function input and output relationship. H cockpit is supported by the chassis and is not directly related to other modules. In the design process of it, care must be taken to maintain the open view of the cockpit. In the design process, it is necessary to ensure the wide operation vision of the cockpit. D engine cabin module is supported by P, outputting power to M, S, I and other modules, and the product function expansion is shown in Figure. 3. There are 8 unidirectional or mutual output - input relationships among the 6 basic modules of the leveling machine. At the same time, the M, S, and I modules must touch the ground at the same time, according to the body supporting and operation requirements. Through logical relationship analysis, creatives compile function relationship and use system software to rationally combine ideas.

## 5.2 Quick Creative and Rendering

According to the above combinations, the paper created a preliminary creative plan by divergent thinking and discussion. We evaluated and filtered the design schemes, according to the requirements of the engineering machinery products in the practical application, such as the operating range, the stability of the car, the steering stability, the passivity, the work efficiency, etc. Then, they obtained the more specific design schemes and drew detailed sketches. We continued to optimize the creative plans, and used CAR (Computer Aided Rendering) to elaborate the 2D plan design scheme and 3D data construction (Computer Aided Design, CAD) , as shown in Figure 4.

Figure 4. The CAD Picture of Leveling Machine.

## 5.3 Concept Evaluation

According to the 2D and 3D concept schemes completed by designers, explicit visual evaluation was made from the aspects of man-machine interaction measure, function range, assembly relation, maintainability and overall form. If detailed evaluation is needed, in-depth evaluation can be carried out based on 3D data, by methods of computer-aided simulation, dynamic analysis, structural performance, ergonomics, color survey

(Wei Wei, Xu Shaopeng, Liang He, 2016; Stone R B, Wood K L, Crawford R H, 2000), etc.

# 6 DESIGN EVALUATION

The industrial design method needs to be quickly evaluated in the conceptual design stage. Generally, the design evaluation is carried out from several aspects: the function realization effect, realizability, maintainability, sustainability, and overall appearance effect, which provides direction for later optimization. The corresponding evaluation mechanism and content should be established for each index. For example, Minjung Park has calculated the results of each evaluation index in the modular design by FAHP (fuzzy analytic hierarchy process). The design of color image has been studied by Daie P et al. based on mathematical evaluation for the evaluation of engineering machinery products color.

# 7 CONCLUSION

The big and complex device products design is meticulous, which is systemic and the link between the steps will affect the progress and efficiency of the next stage. Following the idea of modularity disassembling and function unfolding principle with a leveling machine as an example, this paper explored and found out the intuitive results in concept design stage by using the methods of function disassembling, function relationship and industrial design. The results would provide a reference for industrial design and research on the big and complex products. Due to the difference in production level and innovation, the role of industrial design in big and complex products needs to be improved, and further exploration of it is needed.

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