System Control Framework for Green Furniture Design Based on Systems Theory

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Abstract Based on Systems Theory, this paper elucidated the necessity of building a control system for the green design of furniture. By carefully studying the structure of a team for developing a product and its task allocation, the author proposed a framework of the control system and then clarified its characteristics and the functions of its "workgroups". A study on this framework aims to bring green furniture design under systematic control. This will help to apply concurrent engineering to the design practice and pave the way for assessing the cost and establishing an evaluation system in green furniture design.

Keywords Concurrent engineering • Furniture • Green design • System

1 Introduction

China is faced with many urgent and serious problems, such as resource shortages and environment deterioration. The 18th congress of CPC advocated ecological progress and initiated to strive for "a beautiful China"; it also stipulated the guiding principle of "giving high priority to green, sustainable and low-carbon development and building a resource-saving and environment-friendly industrial structure, mode of production and way of living". The core of these ideas is the same as the concept of "green design".

This paper sets about to building a framework of control system for green product design. Academic works concerning this field in China mainly fall into two schools. One is more theoretical, such as the exploration of the definition, importance, basic principles and methods of green design. For example, Cheng-

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duo Hu (2012), based on the definition of green design, concluded the design contents and predicted its future. The other focuses on a specific type of products and studies the methods of green design (Cheng-duo Hu 2012). For instance, Jing-guo Pan (2012) elaborated the influence of green design concept on contemporary simplified package design (Jing-guo Pan 2012). However, an extensive research, with the application of Systems Theory, on the constraints of and solutions to green design is scarce, which fails to meet the requirements of China's environmental protection, and thus deserves more attention.

Green design is to develop environmentally benign products. A well-established and sophisticated control system is a channel to achieve the goal. But, of course, contents of a control system for consumer-oriented products are definitely different from that for technology-oriented products. This paper is mainly targeted at the former, a field in which relevant researches are sorely needed.

2 Systems Theory and Its Application in Green Furniture Design

A system is an integrated whole that is formed by a set of interacting or interdependent components. Systems Theory is theoretically and practically applicable to the green design of furniture.

2.1 Importance of the Systems Approach

Yong-xiang LU, president of the Chinese Academy of Sciences, says: "Contemporarily, it is not so much the one or two fields in science that push forward the technology development but the interdisciplinary researches. (Hua-bin Wang 2012)" So, when more and more professionals are involved in the completion of a complicated task, a management method will be needed to coordinate the interrelations among the professionals and make the team function better. Systems Theory will contribute to solving this problem. It focuses on the general modes, structures and rules of a system, with systematic thinking being its core value. Green furniture design is also a giant system perplexed by the interrelations between technology and arts, men and the environment and material civilization and spiritual civilization. The systems approach will help to tackle problems of such a sophisticated system as green design.

2.2 The Necessity of Building a Control System

In the system of green furniture design, there are multiple interdependent subsystems. In terms of morphological structure, furniture consists of many components,

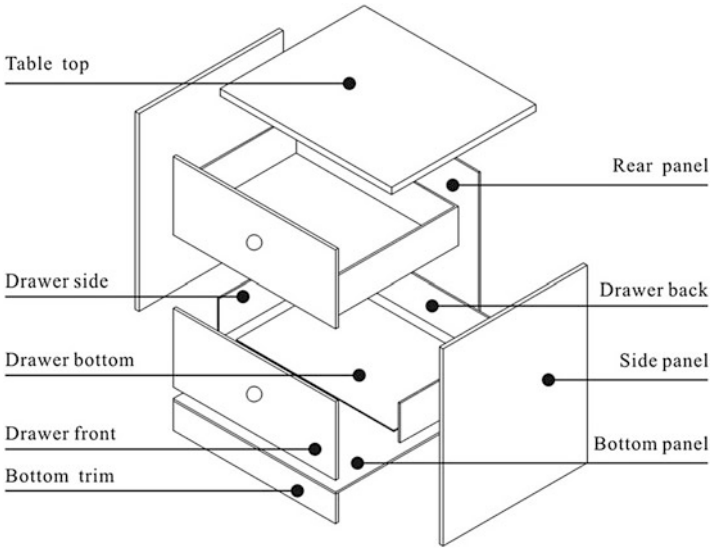

Fig. 1 Components of a bedside table

as is shown in Fig. 1 (Yan-hong Yang 2009). In terms of knowledge that guarantees successful green furniture design, it is interdisciplinary and involves domains such as humanity and social science, arts, engineering technology and ergonomics. In terms of procedures of product development, the process of developing a furniture product involves idea generation, product design, design appraisal, detail engineering and product manufacturing. Each procedure also has its own subsystems and requires the cooperation between various departments.

It is far from enough, therefore, to study only a few aspects of the complicated system of green design. On the contrary, the systems approach must be applied to bring thoroughness and scientificalness to the designing activities and help ensure the green quality of furniture.

3 Control System for Green Furniture Design

According to Systems Theory, all components of a system must be closely integrated because the high efficiency of only a few components may not guarantee the success of the whole (Xiu-yun Liu 2012). Likewise, in developing green furniture, all factors throughout the product life cycle must be considered. For example, green design must comply with the "3R" principle (reduce, reuse and recycle). Also, ideas from previous researches should be taken into consideration, like the G-DMMPM theory (an acronym for green design, material, manufacturing, packaging and marketing) (Yan-li Huang et al. 2012). Based on these ideas, the author is to build a framework of system control and introduce the structure of the framework.

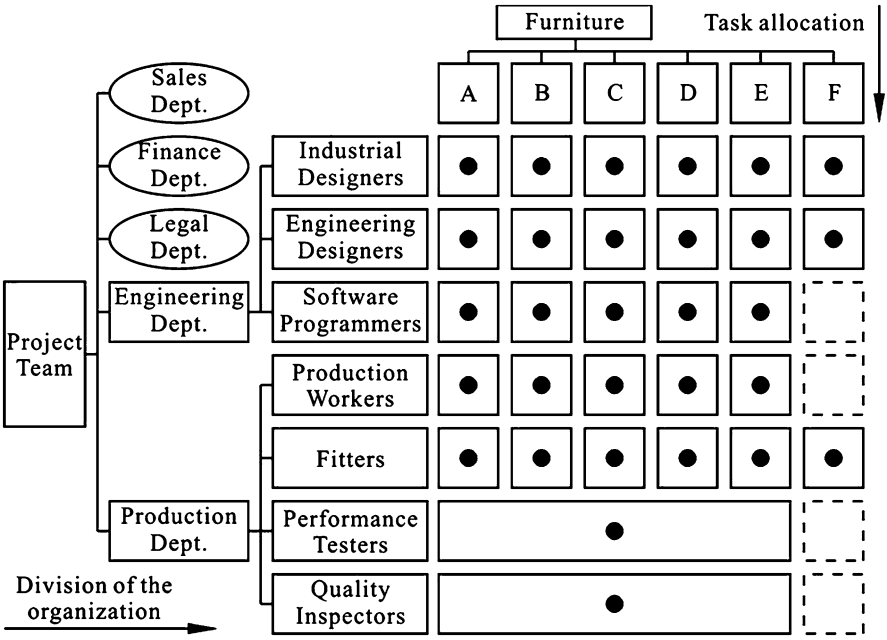

Fig. 2 Framework of the control system for green furniture design. *A* stands for designing product form; *B* for choosing materials; *C* for manufacturing; *D* for sketching product structure; *E* for packaging; *F* for recycling; • for workgroup

3.1 Task Allocation of the Design Activity

The soul of green furniture design is "greenness". In another word, every step like selecting materials, production, packaging, distribution and recycling has to be harmless to the environment. According to the basic process of product development, the author divides the design task into several manageable actions, thus forming a vertical tree diagram in Fig. 2.

To be specific, manageable actions include designing the product form, choosing materials, sketching product structure, defining manufacturing techniques, designing product package and recycling. Of course, those actions can be further divided if necessary, and they are not performed separately; the "green" concept ties them together. For example, when choosing materials, the purchasing agent should consider not only whether the materials are environmentally favorable but also whether they will incur pollution in subsequent actions such as recycling.

3.2 Division of the Organizational Structure

Organizational structure allows the allocation of responsibilities between different entities such as departments, workgroups and individuals, as is shown in the horizontal tree diagram in Fig. 2. A business can be structured in many different ways, depending on its objectives. The key in this process is to define clearly the specific tasks and responsibilities that a department should take. In furniture development, those entities who are concerned with the designing task are engineering department and production department. The former is responsible for developing new products or modifications to existing ones, including engineering designers (such as product structure engineers), industrial designers (for aesthetic design, ergonomics design and user interface design) and software programmers; the latter mainly includes production workers, fitters, performance testers and quality inspectors. Moreover, the sales department, finance and legal advice section often assist the designing process. With the collaboration of all staff, a team for new product development comes into being (You-dan Guo 2009).

3.3 Identification of the Workgroup

In Fig. 2, each horizontal line of the division of the organization is called a row, and each vertical line of task allocation is called a column. Where a row meets a column, there forms a square, which contains a specific workgroup. A workgroup is a basic unit in the control system. Whether a workgroup needs to be subdivided into smaller entities depends on how complicated the action is. It can be seen from Fig. 2 that, every department has its own specific actions to fulfill; each horizontal row of workgroups makes up the series of actions for a department. Likewise, every action has its own responsible departments; each vertical column of workgroups makes up an organizational structure for an action. A workgroup's job ranges from making agenda, labor split, assessing the cost, evaluating a green design, deciding on a plan, to raising questions and offering solutions. A workgroup, therefore, is a rather important control point in green product design and the controlling force on it will determine the quality of the design.

4 Functions of the Control System

The control system has clearly divided the design task between workgroups and each group has been told to take the green concept as their soul. So, this system makes it possible to bring together the exertions of all professional groups and perfect the design by workgroups scrutinizing each others' ideas and practices.

4.1 Having a Systematic Control Over the Design Process

The control system contains many subsystems of different levels. Its controlling force is to keep the greenness throughout the entire design process. After the task was approved, the team's leading agent firstly has to divide the whole task into manageable actions; then, divide the team into departments and workgroups and pick up a head in each group; and finally, set the green norms. In this way, the task is clearly divided between entities. Besides, it encourages engineers, designers and administrators to be concerned about how to meet the ecological criteria, which is to be further discussed below.

First, in terms of specific actions, the greenness can be controlled from the following aspects:

1. *Product form:* be as simplified as possible. "Light, small-sized, thin and functional designs" are preferred; excessive decorations must be avoided to prevent resources from being wasted (Hui-ping Liang et al. 2011). Particularly, multifunctional and intensive furniture is environment-friendly and has a promising prospect. According to a report, the market share for multifunctional furniture will be up to 50 billion RMB in 2015.

   Furthermore, keep the product form up with the times and avoid waste from products falling behind popular trends and being discarded by the market (Xianglong Pan 2007).
2. *Materials:* improve the sustainability of materials and use recycled materials. For example, China has rich bamboo resource and our bamboo furniture export takes up 30 % of the world market. We have the largest bamboo coverage and should make fuller use of it.
3. *Manufacturing techniques:* improve the paint and coating raw materials to reduce emission of toxic gas; simplify the manufacturing process and take into account how to recycle the discarded articles without incurring secondary pollution to the environment.
4. *Product structure:* design product structures that are easy to assemble and disassemble; adopt modeling technology to cope with configurable products where changing a small part of a product can have multiple impacts on other product structure models.
5. *Packaging:* use materials that protect the environment; avoid excessive packaging.
6. *Recycling:* reuse the useable parts from discarded items and raise recycling rates.

Second, greenness can be reinforced by cooperation between workgroups. For instance, product form needs the collaboration of industrial designers, engineering designers, software programmers, production workers and fitters. And there is often a leader in each group who coordinates work among group members. Table 1 gives an example of staff involved in the design process.

Table 1 Staff in furniture design process

	Product form	Materials	Manufacturing techniques	Product structure
Designing group	L	P	P	P
Engineering group	P	P	P	L
Manufacturing group	P	L	L	P

L stands for leader; *P* for participants

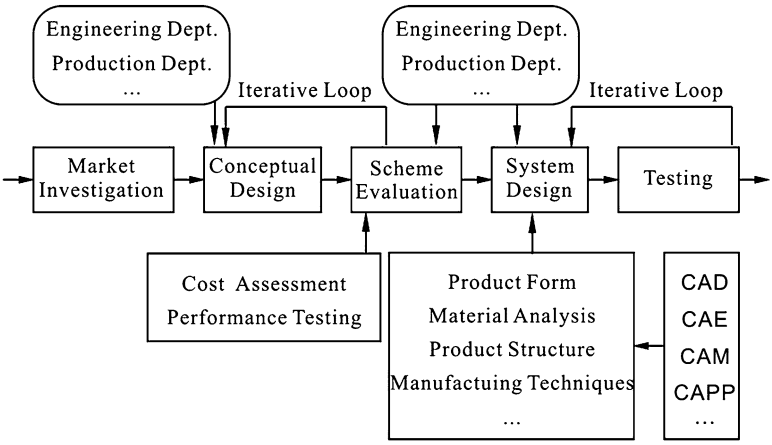

Fig. 3 Concurrent engineering in green furniture design

4.2 Applying Concurrent Engineering to Design

Concurrent engineering asks that all elements of a product's life cycle be taken into careful consideration in the early design phases. It requires that functions of all concerning departments be integrated to reduce the elapsed time required to bring a new product to the market (Long Zhang et al. 2012).

Concurrent engineering is characterized by the parallelization of tasks, i.e. performing tasks concurrently. This chimes in with the framework proposed in Chap. 3. On the one hand, the design task is divided into actions to be operated at the same time. Both product and process design occur in the same timeframe and all phases are closely coordinated to achieve optimal matching of requirements for cost and quality (Wei-jing Yuan 2011). On the other hand, members of every workgroup are from diverse areas like marketing, designing, manufacturing and engineering, and they put their strength together to constitute a cross-functional team. Decision making within a team depends on consensus. Under proper coordination, these teams will exchange ideas and information in time and help to improve products' general quality.

Figure 3 provides a simple process of concurrent product design. In the early phase of conception, industrial designers propose initial design plans based on data

collected in market investigations. Engineering designers also have to participate to give assistance and make preparations for product structure and manufacturing techniques. Then, professionals from different departments will evaluate the cost and greenness of the plans. After rounds of error detection and correction, the final design plan will be agreed. In the phase of system design, combined with elements of form, materials, structure and techniques, the concurrent engineering methodology and relevant software are to be applied to build a digital model. After repetitive testing and implementation, the design is finally settled and is ready for mass production.

4.3 Paving the Way for Cost Assessment

Product cost is one of the criteria for the superiority of a design plan. Green furniture design is of no exception. In the control system, cost assessment is based on the task allocation. The vertical tree diagram in Fig. 2 suggests that the design task is accomplished by many workgroups who have to purchase materials, tools and pay wages. The cost therefore is a total of the costs that all workgroups have paid in completing their actions. By this means, the cost assessment becomes easier and more accurate. In the early phase of conception, an accurate cost assessment is necessary for the evaluation of a design plan, and will help avoid the case in which high-quality furniture is produced at an excessively high expense.

4.4 Building a System for Evaluating the Greenness

The evaluation of green furniture aims to compare the greenness among alternative plans, find the right plan, detect problems and perfect the plan (Chun-peng Wang 2010). An evaluation system usually consists of three aspects: what to be evaluated, who to conduct the evaluation, and how the evaluation is to be conducted. The first two aspects correspond with the task allocation and the organizational structure in the control system. The framework in Fig. 2 shows that, product form, materials, product structure, manufacturing techniques, packaging and recyclability are the objects to be evaluated; representatives—from departments like sales, engineering and production—make up integrated product teams, who are not only participants of the simultaneous design process but also evaluators of the design plans. What's more, Sect. 2.1 of chapter "An Experimental Study of Drilling Small and Deep Blind Holes with an Abrasive Water Jet" of this paper has made it clear that the green norms are set before each workgroup starts their actions. The framework, therefore, automatically contains an evaluation system, which guarantees an instant and non-stop supervision.

As for evaluation methods, they are often grouped into two basic categories—quantitative, qualitative and the mixed method that combines quantitative and

qualitative techniques. In evaluating the greenness of furniture, qualitative evaluation (such as Delphi method) and the mixed method (such as the fuzzy evaluation) are usually adopted.

For example, referring to Fig. 2, we need to evaluate the greenness of four design plans using the fuzzy evaluation.

Firstly, we should choose evaluators from every professional department.

Then, we take product form, materials, product structure, manufacturing techniques, packaging and recyclability as the six objects and so we have an object set:

$$Y = \{y1, y2, y3, y4, y5, y6\}$$

Next, we agree on the final descriptions from which we can choose to describe a plan and get a description set:

$$X = \{x1, x2, x3\} = \{\text{Good}, \text{Fair}, \text{Poor}\}$$

Meanwhile, we have to fix the weighting coefficients for all objects and thus get a weighting coefficient set:

$$A = \{a1, a2, a3, a4, a5, a6\}$$

After two or more rounds of expert evaluation on the four alternative plans, an evaluation matrix is later gathered:

$$R1, \quad R2, \quad R3, \quad R4$$

And now, we can get the comprehensive evaluation of a plan:

$$Bi = A \bullet Ri = \{bi1\ bi2\ bi3\}$$

The best plan will surface by comparing the results of the four choices. Of course, important as greenness is, it is just one of the criteria for evaluating the furniture. The final evaluation of a plan must take into account other factors like quality and cost.

5 Conclusion

Green furniture design consists of a system of actions. To carry out the green concept thoroughly in every action requires the joint efforts of all departments. Based on the systems approach and combined with relevant theories, technology and methods of furniture design, this paper specified factors that may restrain products' greenness and proposed a framework for the systematic control of green furniture design. This research has theoretically explored the interrelations between elements in the control

system, analyzed the functions of the control system and pointed out its importance on cost assessment. The framework is hoped to provide a systematic and global tool for the analysis, design and evaluation of green furniture.

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