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Topology Optimization Design of Biology Wooden Furniture

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Abstract

Reducting weight and exploring new structure, is an important issue that should be addressed as prerequisite in the design of furniture structure prior to the practical application of the Additive Manufacturing in furniture manufacturing. For the weight reduction and optimal material distribution with specific requirements on external loads and appropriate constraints, the topology optimization methods is most widely used. In this paper, by using Solid Thinking Inspire topology optimization software via simulation in terms of effective load and reasonable constraints on the 3D model of the chair, six different chair concept structure prototypes are obtained, which are then used to deepen the product scheme and to facilitate the Additive Manufacturing. Optimal topology optimization results are associated with the loads and constraints that applied. The actual use of the furniture should be also considered when apply topology optimization in designing furniture covering the load and constraints. Study results indicate that the topology optimization is an effective way to innovative furniture structure and design methods, which then provide new ideas for the development of new products. Besides, applying the correct external loads and constraints is the key for the optimal topology design, and is also the challenges for studies.

Keywords: Furniture structure; topological optimization; additive Manufacturing; load; constraint; Solid Thinking inspire

1. Introduction

Additive Manufacturing technology is one of the advanced technologies that achieved numerous progress in last 30 years, which can used for manufacture of almost all component freely and quickly and has been widely used in various fields[1].The furniture structure with light weight, reasonable material distribution and excellent mechanical properties are the prerequisites for the application of the Additive Manufacturing to the furniture manufacturing. While the topology optimization design is an effective way to reduce the mass and innovative design methods of furniture. For optimization of furniture, many researches have focused on Finite Element Analysis and optimization [2-3], which optimize the furniture to some extents, however only in terms of the section size of furniture products or the size and position of the fittings and without the use of topology optimization. Moreover, the products based on such kind of optimization can not fit with Additive Manufacturing. Other researches involved the topology optimization on furniture parts and has made some achievements [4,5], but provide no explanation on the external loads and constraints on 3D model, which leads to ambiguity and limitations. Loads and constraints applied in topology optimization in this paper strictly refers to ISO7174.1-1988. The seat surface vertical static load is 1470 N, the back vertical static load is 410 N, with balanced load 1100 N in seat surface, straight down the back static load is 735 N, with balanced load 1100 N in seat surface [6].

Ergonomic factors analysis of chair

1.1 Seat surface

In normal use, the maximum static load that the seat surface of a chair bears is the body weight. According to GB10000-88 China adult body size , the design should select a larger body weight with baseline of P95 (95%). For Chinese adult male, the age of 26-35 years, the weight at P95 is 74kg and 78kg, respectively. Therefore, the value of 75kg (735N) is selected for the study. While research take into account special circumstances, such as a seat is used for two people, the load value will increased to 1470 N, which falls in the level 3 and level four defined in State Standard.

1.2 Back

In practice, people will lie their back against the back of chair with a force approximate to 270N. However, the force varies due to variousl sitting posture and the body weight [8]. In situations when the chair is wrongly used, people may sit on the chair back with foot on the seat. In this case, the vertical maximum load will increase to 735 N. Therefore, according to the State Standard, a force of 735 N on loading points of midpoints is simulated in the study, considering the vertical downward static load; similarly, a force of 1100N preventing tipping the balance placed on the seat surface template loading point is simulated as well. The back-rest chair, a chair without armrests, mainly comprise of the seat surface, the backrest and chair legs. In the topology optimization , the main loads considered are load for the seat and the back. The force load are provided in below Table1.

Table 1. Force and load of chair

Parts	Load	Mechanical property	Using condition	Misuse
Seat surface	Vertical static load	Strength of seat surface and leg	Normal seated person's weight	Standing sitting surface, beyond one person's weight
Back	Vertical static load	Strength of back	Sitting back by force	Backing too much
Back	Vertical downward load	Strength of back	Person or good's weight	Sitting on back with leg on seat surface

This study is starting from the basic form of a chair, and then applying simulation on topology optimization software-SolidThinking with load and constraint conditions based on mechanical properties tests to explore the rudiment of furniture with new structures, and finally to provide preliminary work for deepening product scheme and Additive Manufacturing.

2. Methodology

Optimization method used in this paper is the topology optimization method. Topology Optimization is a method of structural design which driven by load. It intends to help designers in the initial stages of design to find out optimal material distribution meeting specific loading conditions and constraints [8]. The method is more advanced method than the one concentrating on the size and shape, since it considers both the topological structure of the connection and the internal boundary shape of the structure. General steps for topology optimization are as follows:

Step 1: Creating original 3D model of chair.

Step 2: Importing the model into topology optimization software and applying selected loads and constraints.

Step 3: Setting optimization goals (such as maximum stiffness or minimum mass, optimization proportion, vibrational frequency, considering gravity or not) and solving the equation.

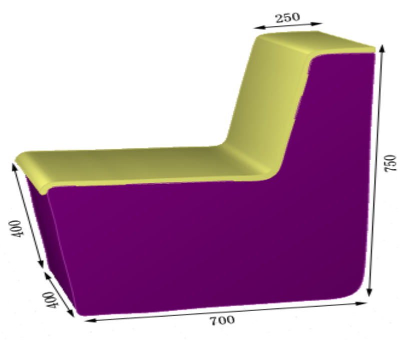
Step 4: Reconstruction of 3D model based on the results of topology optimization.

2.1Creating original 3D model of chair

Building 3D models of products is a prerequisite for topology optimization. For topology optimization, a 3D model includes the design area and non-design area. For design area, only a basic outline is built as a constraint boundaries to topology optimization design.

The basic 3D Model used for the chair in this paper is established by the SolidThinking Evolve, and is saved as STL (a common format of Additive Manufacturing). Then the model is imported optimization software SolidThinking inspire. The basic parameters of the model as shown Figure 1.

Fig 1. Basic parameters of chair 3D model



2.2 Importing model into topology optimization software and applying loads and constraints

The topology optimization software used is SolidThinking inspire with solver of Hyper Mesh for solution. The software can automatically mesh, which requires less knowledge of finite element than other optimization software such as Optistrut etc, making it more suitable for designers. The simulation for load and constraint of 3D model is conducted by application of structural simulation module. According to the static load test method and the number of the chair legs, six different load conditions are applied for simulation, and then six effective optimization initial schemes are obtained, shown as Fig. 2- Fig.7.

Fig 2.Original scheme#1

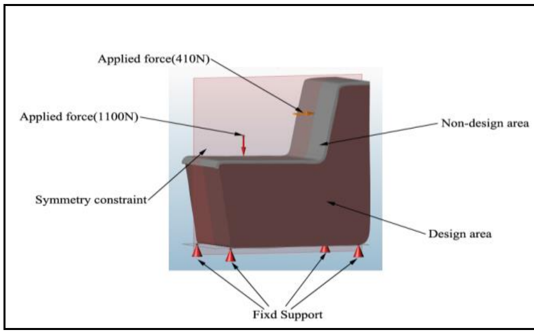


Fig 3.Original scheme#2

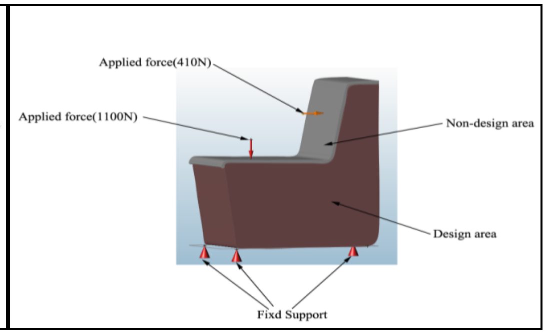


Fig 4.Original scheme#3

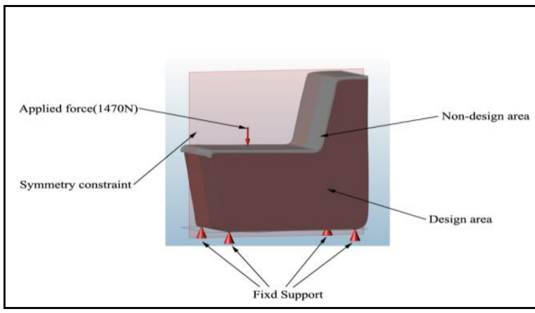


Fig 5.Original scheme#4

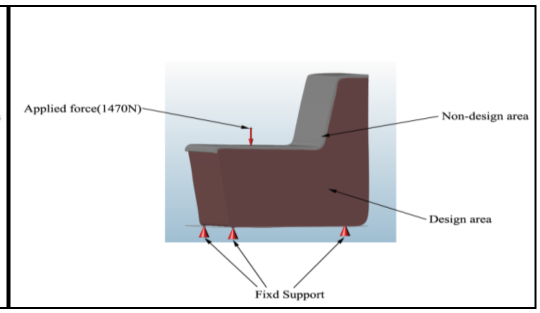


Fig 6.Original scheme#5

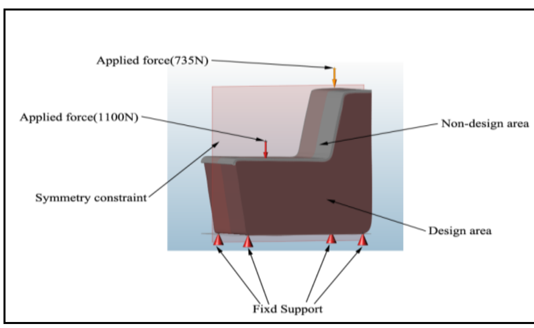
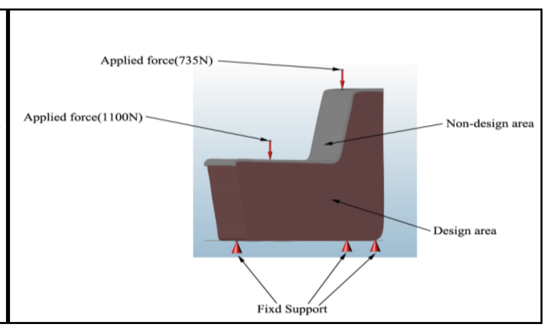


Fig 7.Original scheme#6



2.3 Setting optimization goals and solving

Setting the proper optimization goal is beneficial to the acceleration of the convergence of the topology optimization. According to the need of the design objectives, the following optimization objectives are set up and solved separately. Details are shown in Table 2.

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Table 2. The design objectives

Type	Parameter
Objective	Stiffness maximization
Mass objectives	30% of the total volume of the design area
Frequency constraint	None
Thickness constraint	7mm (minimum of 3.54 mm, maximum of 7.10 mm)
Accuracy	Medium
Contact	Sliding contact
Gravity	Without gravity
Loadcases	Depends on the specific schemes

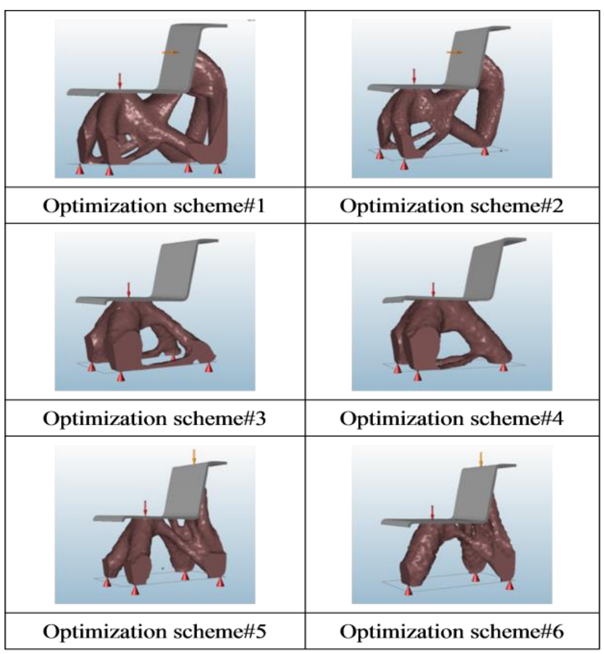
Notes:

It is generally believed that a volume fraction of 0.3 to 0.5 is in favor of better optimization results [9-12]. Chairs are not products used with periodic vibration, therefore the frequency constraints are not considered. Compared to the weight the user, mass of the products is neglectable, so the effect of gravity on the topology optimization is not considered in the optimization in this paper. Therefore the frequency constraints are not considered.

3. Results

It takes about 25 minutes for the solutions of the six different schemes, and the results obtained as follows in Fig 8.

Fig 8. Six different optimized schemes



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4. Discussion

The results of Optimal topology optimization are determined by the correct application of the loads and constraints. To satisfy this, designers are required to be familiar with usage of all kinds of furniture in practice. For #6 design, the fixed load is established as one in front and two in back on chair to guarantee the stability when person sit back too much, which is also close to its actual use. The design obtained by SolidThinking inspire topology optimization software can be saved directly as STL file, and then be imported other 3D model software for further optimization, finally, the product in compliance with the design is manufactured by the technology of Additive Manufacturing. Since the main points focused in this study are correct analysis on the load and its simulation and acquisition of conceptual design for a chair, the further optimization for the conceptual design and connections to Additive Manufacturing technology for production are not discussed.

5. Conclusion

Topology optimization is an effective way to reduce weight and for innovative furniture structure. It provides new ideas for the development of new products. Applying the correct loads and constraints on the 3D model of furniture is a prerequisite to obtain Optimal topology optimization results. In this paper, loads and constraints concerned are established based on ergonomic and furniture mechanical testing standards, which makes it close to its actual use, therefore appropriate degree of credibility is ensured. Based on this, six innovative chairs original design are derived , which is of great significance to shortening product development period , cost saving and resource saving. Only the design of a chair involving use of topology optimization is included in this paper, the limitation is existed, since the difference in terms of load and constraints are not negligible. Therefore, the correct parameters of load and constraints which are critical for the outcome of optimization must be determined case by case. Moreover, as a crucial element for producing designed products, the effect of material on the outcome of optimization is not considered in this study, and is to be further studied in future.

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