Green Material Characteristics Applied to Office Desk Furniture

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The rational application of green materials is a necessary step for the development of environment-friendly industries and a circular economy. However, the popularity and practicality of the sustainable development of office furniture companies in China still lags far behind the world's leading companies. To gain a deeper understanding of the application of green materials in the Chinese office furniture industry, a questionnaire survey for enterprises in response to relevant issues was conducted based on an extensive review of the relevant literature. The research comprehensively analyzed the application status of green materials in Chinese and overseas office furniture companies, and the environment-friendly materials selection strategy of the main materials, and packaging materials for office desk furniture was proposed according to the current situation. The results showed that China has vigorously begun guiding and supporting the green development of furniture manufacturing enterprises, but there is imperative need of a range of upgrades in the enacting or revising of laws and regulations pertaining to green manufacturing and manufacturing technology. Furniture enterprises should seize the opportunity to promote the application of clean energy and improve the recycling mechanism of waste furniture with an aim to maximize the benefits of sustainable development.

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INTRODUCTION

Faced with the deteriorating ecological environment, national and international authorities have been continuously promulgating environmental strategies. China has established that green and low-carbon development is necessary for enterprise development, which is related to the quality of high-quality economic development, the nature of ecological environment conservation, and the most inclusive people's livelihood (Tang 2019). The development of the green furniture industry has become an inevitable trend, and green furniture manufacturing has become an important direction for the future reform of China's furniture industry (Xiong *et al.* 2017). However, in terms of the current operating conditions of China's office furniture companies, the penetration of the concept of sustainable development is not comprehensive enough, and there is a lack of a complete green manufacturing technology system for the furniture industry (Xiong *et al.* 2020). As the material basis of the system, green materials are a key step to achieve sustainable development. This paper starts from the perspective of green materials and discusses its application path for office desk furniture. The aim is to provide ideas for the improvement of the green manufacturing technology system of the furniture industry.

The concept of green material was first introduced at the first International Conference on Materials in 1988. Green material was designated as an environmental-friendly material with basic performance characteristics that will not have a negative impact on the environment after it has been manufactured, utilized, and discarded (Wang *et al.* 2019; Xiao 2021). In the category of furniture, green materials can generally be divided into four categories: natural materials, recycled materials, low environmental load materials, and environmentally functional materials (Zhu and Wu 2013). With the passage of time and technological progress, the materials that are used in desks have gradually expanded from a single natural material. Many materials can be used in desks, such as wood, metal, plastic, and leather. This is because the need for desk function gradually increases, causing more materials to be needed to support the function. Such functions of an office desk may include a lifting system for adjusting office posture, a screen for protecting privacy, and the cable management of the desk for organizing the desktop computer (Fig.1). But it is undeniable that wood is still the main material of desk furniture, and the environmental research on wood materials is still the focus of the future (Wu 2021).

Fig. 1. Various office desk usage pattern: a) height adjustable office desk, b) fabric screen of the desk, and c) cable management of the desk. (Picture source: https://www.lamex.com/zh-hans/product/duplex)

In recent years, most Chinese office furniture companies have begun to pay attention to the application of green materials, especially among high-end brands such as Aurora Furniture, Sunon, and Onlead. Green materials that are used in the whole line of products can basically contain minimum or no harmful chemical components, and the utilization rate of degradable materials is high. Medium and low-end brands may be limited by capital, do not have a complete furniture processing and production chain, and cannot strictly control the product supply chain. The materials that are used in medium and low-end brands are not highly degradable and the degree of environmental performance is relatively low. Overall, there is still a big gap between Chinese and overseas leading office furniture enterprises in aspects of the popularity and practical operation of the green concept.

The penetration and implementation of the concept of sustainable development for world leading office furniture enterprises are generally high in companies such as Herman Miller, Steel Case, and Haworth. The materials used in these products have basically passed the authoritative certification such as GREENGUARD and ISO 14001. In addition to the material itself, the processing equipment, the energy supply, the product service life, and the product recycling have been systematically planned. This also benefits from the guidance of national policies. The furniture industry in the world's mainstream countries has high standards for the selection of environmental-friendly materials. One of the main reasons is the early and high degree of implementation of relevant regulations regarding

green development (Huang *et al.* 2017). In the late 1960's, the book "Design for the Real World" by American design theorist Victor Babanak put forward the concept of green development and promoted the transformation of the concept of industry development (Leng and Teng 2013). A series of environmental rules and regulations, such as the basic law on countermeasures against public hazards implemented in Japan in the 1970's, are already preparing for green development (Liu and Sun 2016). In 2009, the United States and the United Kingdom repeatedly stressed that the development of a green economy should be a priority (Li and Li 2011). Therefore, with the investment and support of the government, the transformation speed of enterprises has greatly improved.

Literature Review

The focus here is on environmental-friendly desk furniture in design and manufacturing, normal use, and waste recycling. The aim is to improve the greening of desk materials in line with the scope of enterprise development benefits. In fact, back in 2013, relevant studies showed that most consumers were willing to buy goods produced by materials and technologies with a low negative impact on the natural environment and are willing to bear more costs (Shabani *et al.* 2013). This has had a positive impact on the green transformation of enterprises. In the process of enterprise operation, customers' willingness to tolerate a somewhat higher prices of green products can directly reduce waste and environmental costs in their business, while maximizing returns. Customer collaboration combined with internal green supply chain management is considered as the most effective way to improve economic performance (Azevedo *et al.* 2011). But there are limits to the extra costs that consumers are willing to pay for green products. A survey conducted in Europe and the United States showed that more than 70% of consumers are willing to pay an additional 5% for green furniture products, but if a premium exceeds 25%, only about 10% of consumers are willing to buy them (Kucher *et al.* 2019). That is to say, if the premium of green furniture products leads to the loss of market competitiveness, then more enterprises will tend to abandon the route of sustainable development and continue to choose non-environmentally friendly materials and production methods to the environment. Therefore, government intervention is necessary for enterprises in implementing green manufacturing, and compliance with regulations remains the largest single driving force for implementing green manufacturing practices (Bumgardner and Nicholls 2020).

For the desk furniture itself, in order to show an environmentally friendly green nature in the whole life cycle, it is necessary to organize each functional unit to conduct effective communication and coordination in the early design and development stage (Boks 2006). In addition, 90% of the production costs can be controlled by product design (Cordero *et al.* 2010). For example, the ESCC model fully integrates effective resources upstream and downstream of the supply chain, thus effectively reducing the consumption of materials, water, and energy across the entire supply chain (Susanty *et al.* 2020). The design decision of desk furniture needs to consider the processing energy consumption, service life, recyclable utilization and other indicators into consideration, so as to make decisions on the type of material of the material, the geographical location of the material supplier, the service life of the product, the recycling of products or parts, and the processing mode of materials (Chen *et al.* 2019). It is worth noting that the desk reuse system is better than the recycling system or life extension system, because the product must have simple design and component materials. Otherwise the recovery cost is too high. If the product cycle is long, then the company may lose in product sales (Besch 2005).

However, this is only a comprehensive consideration of the enterprise's economic performance and environmental performance, and it does not mean that the recovery of products or parts is not important. On the contrary, that part of the abandoned resources is still valuable. In terms of the current market environment, companies limited to producing waste and ultimately using waste will suffer from a lack of integration of certain factors. These factors include waste collection and transportation, the scale of business, the industrial sector where the company operates, the amount and type of waste generated, environmental regulations, and the level of development within a particular country. Thus, the recycling system still needs to be further designed (Nemli *et al.* 2007).

EXPERIMENTAL

Target Respondents

A specially developed questionnaire was sent to 10 randomly selected Chinese office furniture enterprises through an Internet-based questionnaire survey, covering northern, southern and central China.

Questionnaire Design

The questionnaire was distributed to the relevant staff of office furniture enterprises through the questionnaire star platform. The respondents have certain practical experience in furniture production and relevant knowledge of furniture design.

The questionnaire used in this study was divided into three parts.

The first part of the questionnaire collected basic data of the respondents, such as the province of the company, the name of the company, the scale of the company, my position, etc.

The second part of the questionnaire, the respondents were asked to choose the main materials and decorative materials of their company's desk products, so as to understand the current material application trend of desk and the application trend of decorative materials.

The third part of the questionnaire evaluated the disassembly of desk components and the recycling of desk parts, auxiliary materials, and packaging materials. These factors reflect the utilization status of desk materials in use and after abandonment.

Data Collection

The questionnaire title setting widely refers to the relevant literature using the same research methods at home and abroad, and increases, decreases and modifies the questionnaire title according to the relevance of the research content to ensure that the questionnaire is rigorous and effective. Then the questionnaire was placed on the Questionnaire Star platform to collect information. A total of 60 target respondents answered the questionnaire within 3 days.

Data Analysis

The data from the questionnaires were compiled and tabulated using Microsoft Excel to facilitate analysis. The analysis of data was conducted using the Statistical Package for the Social Sciences (SPSS IBM, USA). A total of 60 questionnaires were distributed and 56 were recovered, including 54 valid questionnaires, with a questionnaire recovery rate of 90.0%. The coefficient alpha of Cronbach was 0.708, which

comprehensively shows that the data reliability quality was high and able to be used for further analysis.

RESULTS AND DISCUSSION

Necessity of Applying Green Materials

As a major branch of furniture products, the annual consumption of office furniture in China is very large. According to the analysis report on market prospect and investment planning of China's office furniture industry in 2020, the production of office furniture in 2019 was highly concentrated in eight countries that accounted for 78% of the global production, of which China topped the list (Fig. 2). Moreover, China is also the leading office furniture exporter at a world level, which increased its share from 35.9% in 2012 to 38.5% in 2021 of the global exports (CIFF 2022). Therefore, in the context of such a large amount of production and export, the green development of China office furniture is imperative. Moreover, the transformation from a linear economy model to a circular economy model is also beneficial to enterprises, as it can improve their cost efficiency and competitive advantage and reduce the negative impact on the environment and society (Hartini *et al.* 2021).

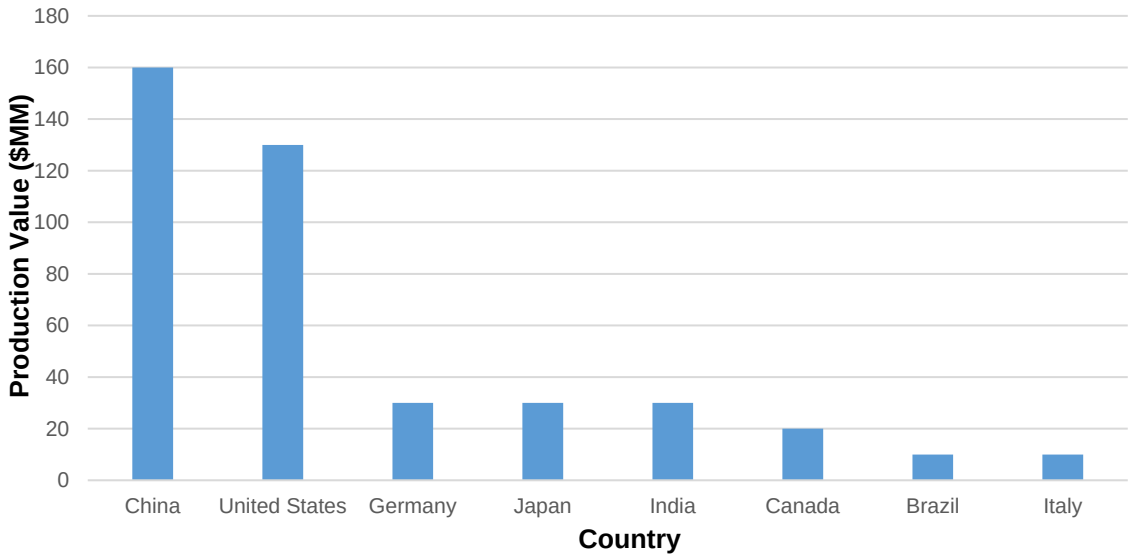

Fig. 2. The production value of the major office furniture production countries in 2019

The application of green materials in office desk furniture should be considered from two aspects. The first aspect should be the greenness of the primary construction materials used for the desk furniture, where materials should be considered from the whole life cycle of products, namely the raw material preparation, the product processing and manufacturing, the utilization, the recycling, and the waste disposal. The second aspect is the greenness of the related materials for the desk furniture, which refers to the packaging materials and the protective materials for transportation, in addition to the main construction materials for the desk. The quantity and nature of these packaging materials are closely related to the main design of the desk.

Application of main materials and decorative materials for desk

According to the questionnaire survey, the investigation results of the main materials and decorative materials of the desk can be seen in Fig. 3. Most of the main materials of the current desk are wood-based panels and metal materials. Materials such as solid wood, bamboo, rattan, and cloth are utilized relatively less. The decorative materials are primarily wood veneer and decorative paper, and a few are decorated by coating and polyvinyl chloride (PVC) decorative film.

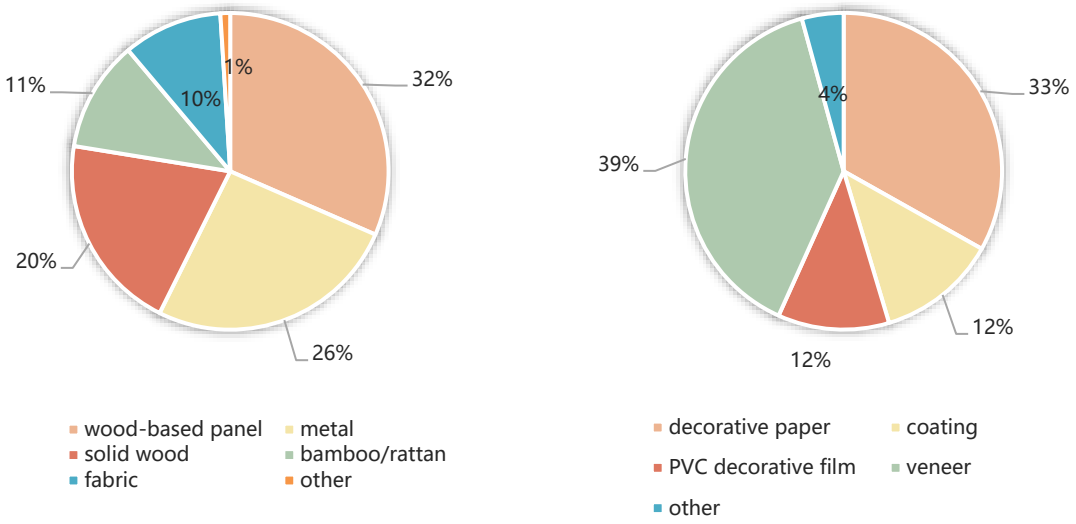

Fig. 3. The use of structural materials and decorative materials for office desks

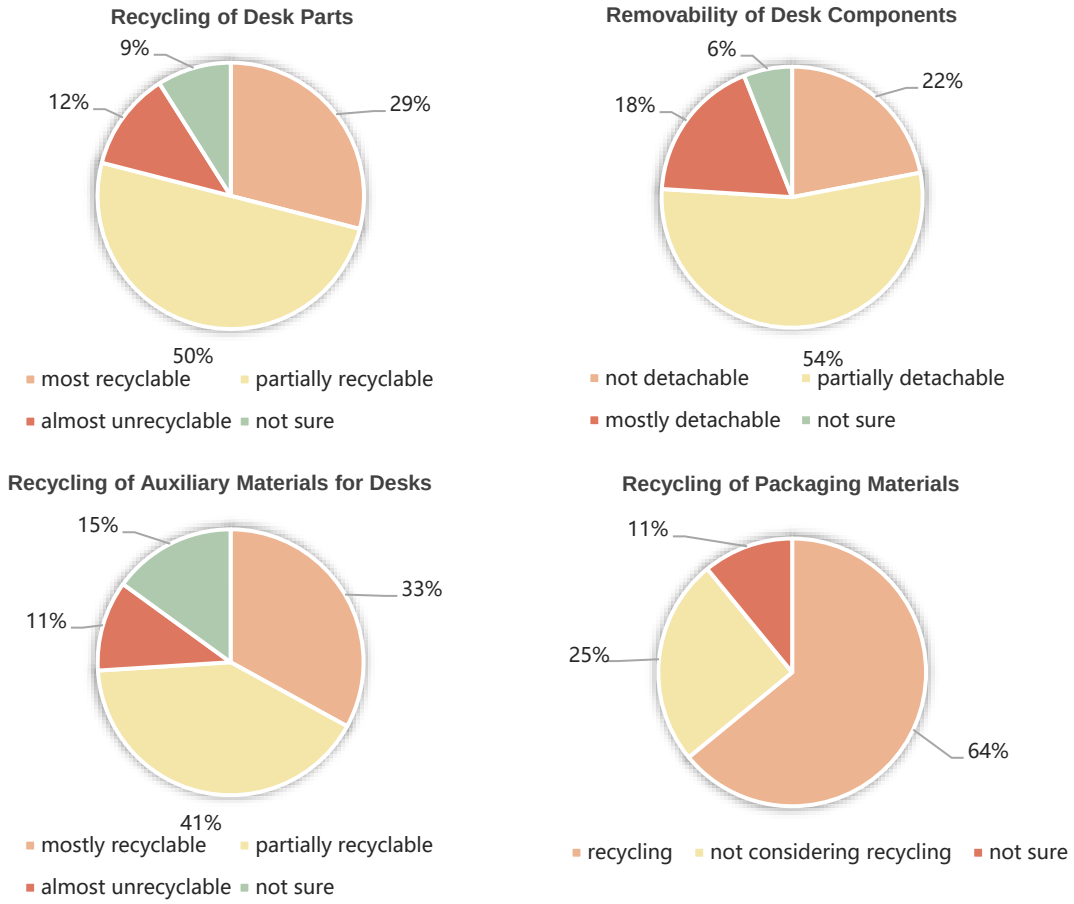

Fig. 4. The removability of desk components and recycling of desk parts, auxiliary materials, and packaging material

Use of work desk components, components, and packaging materials

The disassembly status of desk components and the recycling status of desk parts, auxiliary materials, and packaging materials are outlined below. As can be seen in Fig. 4, Chinese companies are aware of the recycling of furniture materials but the implementation is still less common, bringing most manufacturers to partake in partial recycling. Among them, 50% and 41% of the parts and auxiliary materials of the desk can be recycled respectively, and only 29% and 33% can reach the most recyclable category. In addition, for packaging materials, 25% of employees said that their enterprises had not considered the recycling of packaging materials. Therefore, it can be seen that some domestic office furniture enterprises have insufficient implementation of sustainable development. There are obvious defects in the R&D stage of furniture and the recycling stage of furniture and furniture packaging materials.

Analysis on the Selection of Main Materials of Desk Furniture

Structural materials

The structure of the desk is the organization or connection form of the parts to ensure the realization of the furniture design (Ke *et al.* 2014). The rationality of its design has a direct impact on the recyclability, replaceability, service life, and processing energy consumption of office furniture. The structural materials of environmental-friendly desk

can be considered through several aspects. It is important to increase the commonality of the parts in the desk (Hu 2020). Through the design adjustment, some parts can be standardized and generalized to the maximum extent, which can reduce the energy consumption of processing equipment and increase the interchangeability between parts (Zhang 2017). Materials that can be easily damaged should be replaced by materials having a long service life. The parts of the desk that bear impact load and cyclic load frequency can be replaced by metal or other materials with compression and wear resistance. The disassembly design and ductility design of the structure are considered with an aim to simplify the processing procedure and improve the reuse rate of materials (Ren and Wang 2018). Finally, it is important to consider the application of recycled materials and new materials. For example, the new type of ecological composite board made from wood-based panel compressed with sawdust, furniture boards made from crop residue, and wood plastic composite materials can improve the utilization rate and reduce the cost of the materials (Jiang 2018; Tian and Zhu 2020).

Decorative materials

The surface decoration material of the desk can keep the desk stain and warping resistant, protect the structural stability of furniture, and improve the service life of furniture through its characteristics of wear resistance, water resistance, heat resistance, and chemical corrosion resistance (Sun and Liu 2019). It is one of the indispensable materials for furniture production but at the same time hard to avoid the negative impact on the environment. Common decorative materials include coatings, decorative paper, thermosetting resin impregnated paper, high pressure decorative laminate, and PVC decorative film. With the continuous improvement of technology, there are many new decorative materials and decorative technology emerging in the market. For example, spinning cup electrostatic spraying technology and low-temperature powder electrostatic spraying technology on the surface of wooden products and plastic film-reinforced flexible decorative veneer preparation technology are new methods described by Peng *et al.* (2021). Upgrading the technology from the original decoration materials can help overcome the prominent problems of the original materials, simplify the processing procedures to a certain extent, reduce the release of harmful gases, and improve the environmental performance.

Auxiliary materials

The commonly used auxiliary materials of desk furniture include hardware connectors, plastic connectors, adhesives, *etc*. The life cycle assessment-based on auxiliary materials shows that the environmental impact caused by metal materials such as handles, guide rails and hinges are higher than that of other materials (Liu *et al.* 2019). Considering the high cost of hardware, the quantity and type of hardware shall be reasonably applied in the production and design of desk, and the recycling work shall be done well. But some parts such as plastic foot pads and plastic inset nuts are not easily recyclable, so it is recommended to ask suppliers provide degradable materials whenever possible (Zhang and Lou 2006). In addition, the impact of glue on the environment cannot be ignored, usually hot melt glue, multiple-use glue, white latex, and resin glue (Tong *et al.* 2018). According to the current application situation, formaldehyde synthetic resin adhesives cannot be completely abandoned in the Chinese furniture market, but the application proportion of environmental-friendly adhesives such as formaldehyde-free adhesives and biomass-based adhesives is expanding (Ma *et al.* 2020).

Analysis of Packaging Materials of Desk Furniture

Furniture packaging generally plays a role in protecting furniture and facilitating transportation. Green packaging is environmentally-friendly and it has certain publicity value. Relevant research shows that green packaging has a positive impact on consumers' purchase intention and behavior. In addition to satisfying customers' green consumption psychology to reduce the negative impact on the environment, green packaging also can enhance the enterprises brand image value and influence (Moorthy *et al.* 2021). The current office furniture packaging materials include internal cushioning materials and external wrapping materials. Based on the continuous improvement of preparation technology and material properties, the external wrapping material presents the trend of thin-walled and quantity reduced design (Li *et al.* 2018). The commonly used materials are corrugated paper, honeycomb paper, wooden frame, and plastic products, among others. The internal cushioning materials are also developing towards low cost and high utilization. The commonly used materials are air cushion, bead cotton, foam board, foam plastic, and wastepaper (Zhou *et al.* 2019). In addition, as green packaging research progresses, new applicable green materials continue to improve. Research by Li *et al.* (2021) shows that long-chain branched polylactide (LCB-PLA) foam is a completely biodegradable foam that is environmentally friendly, lightweight, and heat-resistant. Long-chain branched polylactide is an ideal substitute for non-degradable petroleum-based plastics. Alternatively, Allaf and Futian (2020) used wood waste to prepare green packaging composites and found that poly (ε-caprolactone)/sawdust-wood plastic composites (PCL/SD-WPCs) can potentially replace traditional plastic packaging applications.

The selection of office furniture packaging materials needs to consider many factors, one of which is the degradability and recyclability of the materials. Packaging itself is specially designed for the logistics and transportation of products, and most of them are disposable products with a huge demand. It is necessary to improve the recycling mechanism or select degradable green materials to make full use of resources and reduce the impact on the environment. Secondly, the rationality of packaging material protection is also worth considering. The basic purpose of packaging is to protect the furniture in the process of transportation, but also to avoid the waste caused by excessive packaging. Third, the environmental-friendly packaging materials cannot be ignored. Green packaging materials should be sourced from a variety of suppliers, have low energy consumption, possess easy recyclability and recycling efficiency, and have a minimal environmental impact in the preparation and disposal processes (Li and Sun 2019). Polystyrene films such as polystyrene foam as cushioning gaskets and wrapped products in furniture packaging have been banned or restricted by many countries for environmental reasons (Shi and Zhou 2018).

FINDINGS

Materials Serve Functions

The desk is a functional furniture piece, and the application of materials needs to serve the function. Since people began to pay attention to humanized design, the functions of the desk began to expand to include desktop lifting functions, timing functions, and screen lifting functions, among others. Subsequently, the materials of the desk are also gradually changing, from the original single material to a variety of materials (Fig. 5). Therefore, the application of desk materials should consider the changes of functional

trend. Currently, the office mode is affected by two main factors. One factor is the impact of the intelligent era (Wu *et al.* 2017).

Fig. 5. Changes in the office. a) open office in the middle of the last century, b) modern open office, and c) modern joint office.
(Picture source: a) https://www.ma3office.com/news/632.html
b) https://www.isunon.com/space/index/1.html
c) https://www.lamex.com/index.php/zh-hans/product/pier)

Smart furniture is rapidly evolving in terms of technology and product intelligence, which provides unlimited possibilities for the development of office furniture in the future (Xiong *et al.* 2021). The second factor is the influence of the Coronavirus Disease 2019 (COVID-19). Affected by COVID-19, the introduction rate of telecommuting in worldwide enterprises has further increased, especially in Chinese enterprises (Cui and Jiang 2021). Telecommuting market of China is still in the enlightenment stage, unlike developed countries such as the United States and Japan, which have a certain market foundation. When forced by the epidemic situation, many enterprises and employees felt the benefits of the "on-site + remote" mixed office mode in the process, which promoted the rapid development of telecommuting market of China and showed a trend of normalized development (Jia *et al.* 2021). This means that the area of group office will be reduced to a certain extent, the number of home office will increase, and the office demand will change further in the future (Chen and Qi 2020). The application of green materials needs to follow the trend under the overall planning of green design, constantly explore new materials and meet the changes of functions.

Energy Conservation during Material Processing

In the furniture supply chain, one of the processes having the highest carbon emission output is the material processing (Chen *et al.* 2019). In addition to avoiding the use of heavy metals, fluorine-containing compounds, and other pollutants in the raw materials themselves, material processing equipment and facilities should also be adjusted to reduce the energy consumption and the output of pollutants. Many large furniture companies have started sustainable energy projects, such as Haworth's solar panel renewable energy project, Herman Miller's water recycling and reuse, and Sunon's solar photovoltaic power generation production. These projects have achieved considerable results in reducing carbon emissions and saving energy. Small enterprises do not have the ability to start large-scale environmental projects, so they need national policies to encourage and guide enterprises' independent innovation, strive to solve the coordination problems of technology introduction and technological innovation, and promote enterprises to complete green transformation (Liu and Zhang 2019).

Recycling of Waste Materials

Many studies have shown that, compared with new products, the remanufacturing operation of old goods can achieve the purpose of saving energy, saving cost and improving material efficiency (Abbey *et al.* 2015). As we all know, statically designed products will be eliminated in the process of continuous innovation and iteration. However, this cannot be defined as the elimination of materials. It can meet the needs of the current market through redesign and remanufacturing. At the same time, it also saves the material cost and processing cost for the company. Combined lifecycle evaluations of each component suggest that across the actual realized life of the constituent materials, multiple remanufacturing cycles in each case lower the total environmental impacts beyond what was achieved in the initial remanufacturing cycle; in other words, total environmental benefit increases with the number of remanufacturing cycles (Krystofik *et al.* 2017). For desk furniture, the service life is often longer than the enterprise that buys and uses it, so it has a high value of recycling and remanufacturing. For materials with a high degree of damage, they can be reused indirectly or used to generate energy (Luo and Xu 2016). For example, wood-based panels with a high usage rate can be used as raw materials for other panels such as recycled fiberboard or wood-plastic composite materials. Wood-based panels can also have potential industrial applications such as in the pulp and paper industry, and they can also be used as fuel for energy supply (He and Mu 2008).

CONCLUSIONS

1. As the material basis of the product system, green materials are a key step for office furniture enterprises to achieve sustainable development. With the global advocacy of the concept of sustainable development and the support and guidance of national policies, the popularity and practical operation of green concept in Chinese domestic office furniture enterprises are gradually increasing, and most enterprises are beginning to pay attention to the application of green materials.
2. Through the analysis of the implementation of the concept of sustainable development by worldwide office furniture enterprises, it is concluded that the Chinese domestic high-end office furniture brands have a high degree of implementation of green development, making the products contain very little or no materials that have a negative impact on the environment, which approaches developed countries such as European countries, the United States and Japan, where enterprises commonly have higher environmental consciousness and most of leading furniture enterprises can ensure that their products do not contain materials harmful to the environment. While the implementation degree of middle and low-end brands in China is relatively low, which cannot ensure the green of materials for the whole line of products.
3. The selection of structural materials, decorative materials and auxiliary materials of the desk should be comprehensively considered from the aspects of service life, recyclability and reusability in combination with the economic performance of the company, so as to achieve the situation of mutual benefit between enterprise development and ecological conservation. Most of the packaging materials of the desk are disposable products, which should be recycled and reused to protect the environment and save resources at the same time.

4. Desk furniture materials should keep up with the development trend. The new environmental-friendly materials should be constantly explored and developed together with the design innovation and technological innovation of desk products.

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