STUDY ON THE DESIGN OF TENON AND MORTISE JOINTS FOR NEW TYPE SUSTAINABLE EXPRESS PACKAGING BASED ON THE CONCEPT OF INTEGRATED CYCLING

Xue-ying Wang
No. 5 Jinyuanzhuang Road, Shijingshan District ,Beijing, P.R. China, school of Architecture and Art, North China University of Technology, email: 357289336@qq.com
Jiao Yi
No. 5 Jinyuanzhuang Road, Shijingshan District ,Beijing, P.R. China, school of Architecture and Art, North China University of Technology, email: 730430254@qq.com

1. INTRODUCTION

With the growing prosperity of e-commerce in China, the logistics industry has made considerable development, especially the express delivery industry has achieved rapid growth. The monitoring data of the E-Commerce Research Center (100EC.CN) shows that in 2017, the business income of China's domestic express was RMB 276 billion yuan, with a year-on-year increase of 35%. With the rapid development of the express delivery industry, express packaging has become an indispensable material carrier in people's consumption process. However, while consumers are enjoying the convenience and excellent shopping experience brought by the express packaging, a surge of garbage appeared due to the large amount of discarded express packaging boxes. According to statistics, the proportion of plastic and paper wastes in domestic garbage has increased significantly in recent years. Based on the calculation by the National Post Office, more than 1.5 billion express parcels were sent during the promotions of "Double 11" period in 2017, and most of these express packages were directly discarded, resulting in tens of thousands of packaging wastes. Even with conservative calculations based on the usual standard of 0.2 kilograms per package in the industry, 1.5 billion express packages produced at least 300,000 tons of garbage. Throughout the whole year of 2017, the amount of garbage generated by express packaging was as high as 8 million tons. [1] The resulting waste of resources and environmental pollution is breathtaking. Under the current situation of thriving supply and demand, how to reduce the pollution of express garbage, improve the recycling rate, and control excessive emissions has become an urgent necessity in China.

2. DESIGN STANDARD FOR THE SUSTAINBILITY OF EXPRESS PACKAGING

On February 6, 2018, the General Administration of Quality Supervision, Inspection and Quarantine and the Standardization Administration of China officially issued the National Design Standards for the "Packings for express service", including three parts: the enveloping, the packaging box and the packaging bag. This standard was implemented on September 1, 2018. The release and implementation of the national design standards for express packaging has brought the express industry into a new stage of development. First, it embodies the idea of sustainable design based on technological development. The relentless pursuit of rationalization, recyclability and greenization of express packaging through minimization has been made to reduce the consumption of packaging materials, thus reducing the comprehensive cost of packaging and transportation. Secondly, an effective system for recyclability has to be established and perfected for recovery and recycle of express packaging materials to improve recycling utilization rate of materials, extending the life cycle of packaging to ensure the recycling of express packaging. Finally, waste of resources and environmental pollution of packaging waste are reduced during production and processing to ensure degradable treatment and achieve environmentally friendly packaging that meets the true standards of sustainable packaging design. [2]

2.1. Minimization

Packaging minimization is to facilitate the recycling, that the designer shall adhere to the guidelines of pursuing reasonable and appropriate properties of packing in designing product packaging on the premise that the design can fulfill the basic purpose of packing and functions of protection, operation, delivery and dissemination of information, minimizing the use of various materials to reduce the resource consumption in the manufacturing process and the energy consumption in the logistics process, meanwhile discarding the use of rich colors to achieve a reduction in the weight and volume of the package. For example, when the weight is the only factor to be considered, for packing the plastic bottle of the same volume, the plastic packaging material is calculated as 1, the aluminum is 1.5, the composite board is 2, and the glass is 13.5.[4] The correct selection of packaging materials can achieve the purpose of minimization.

2.2. Greenization

Innovative design promotes sustainable transformation of the economy and society, opening up a brand new "deep green" design approach to achieve the transformation of degradable and pollution-free packaging. Specific cases include: SF Express green packaging (green packaging of sticking envelope for secondary use, tape-free carton, and ordinary woven bags replaced with canvas bag in transit depot); paperless system in 1st shop warehouse; logistics box recycling at Suning logistics (supply chain + express delivery, localized distribution of package production).

2.3. Recyclability

Recyclability of packaging means that a single packaging material is used for product packaging as much as possible to facilitate sorting and recycling. Without affecting the quality of the packaging, the materials with high recoverability should be selected for packaging and transportation [5]. At its core, whether for use or recycling, what we do at each stage has a positive interaction with the natural environment, and such interaction is beneficial to the Earth's ecosystem and environment. The most typical is the repeated use of packaging, which means the packaging can be reused many times. It is the most environmentally friendly practice today. [6] The development of new materials continues to change the exterior of the packaging and provides a new way to protect the product. Reuse allows the available resources to be fully utilized, which not only extends the life of the product, but also limits the increase of wastes.

3. THE CONCEPT OF INTEGRALLY CYCLED PRODUCT

The realization of the products, especially the integrally cycled restorative products with ecological restoration function, will surely become an important powerhouse for leading a new round of development of human civilization. Judging from the development of packaging in China's express delivery industry, it obviously followed the pattern of the traditional extensive economy. The traditional extensive economic development mode has caused a series of problems such as resource shortage, environmental pollution and global ecosystem destruction, and the integrally cycled products become the strategic trend of common concern. [7] As shown in Fig. 1, the concept of integrated circulation of sustainable express packaging consists of three cores:

Materials. How to select renewable or recyclable materials to ensure efficient economy of raw materials through improving integrated circulation and recovery, reuse and control of biodegradation of target applications is the cornerstone and primary task of the integrated cycle of express packaging, helpful to reducing the demand for non-renewable resources and contributing to environmental protection.

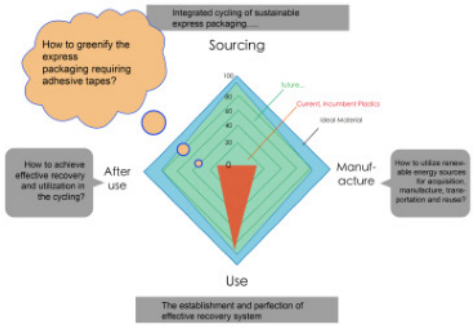
Manufacturing. In this process, how to obtain renewable energy for manufacturing, transport and reuse, and use clean production techniques and best practices for manufacturing determines whether the product so manufactured meets market standards for performance and cost, and whether the entire manufacturing cycle is beneficial, safe, healthy, and cyclical to individuals and communities. Green design and manufacturing should further strengthen the ability to deal with complex and systemic problems, especially to further develop common technologies such as methods, tools, software, integration and evaluation of green design. [8]

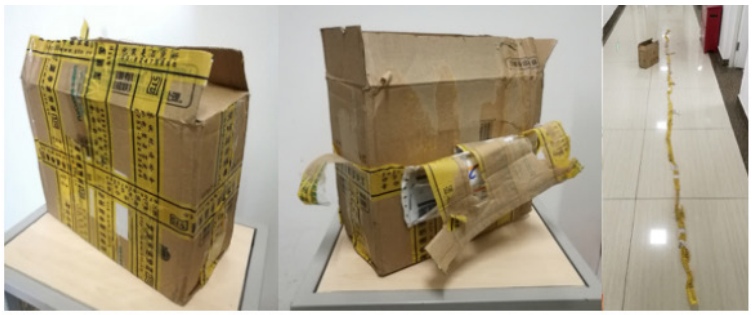
Recycling and reuse. The questions that designers need to consider include how to effectively recycle and utilize the packaging after it has been used and what happened to the packaging after it was discarded. Material waste degradation and decay, resource recycling, regeneration recycling, and sorted recovery, etc [9] are the first principles of the integrated cycled product, thoroughly improving the economical quality of recycling and reducing circulation loss. The lifecycle of packaging process application is extended by establishing and improving an effective recycling system.

4. PROBLEMS IN THE TRADITIONAL DESIGN OF EXPRESS PACKAGING

The express packaging waste accounted for a considerable proportion in urban domestic waste, which began to impose a heavy burden on the social environment. Taking Beijing as an example, in 2017, China's express delivery industry consumed 9.9 billion packaging boxes, 8.26 billion plastic bags, 16.95 billion meters of adhesive tapes, and 2.97 billion buffering pads, which can wrap the earth 425 rounds, as well as 182,000 tons of corrugated paper, equivalent to felling 1547 hectares of forest. [10] Therefore, the main problems of the domestic traditional express packaging design lie in disposable express packaging, overpacked, low quality packaging, plastic tape is used in large quantities that give rise to concerns such as environmental impact, product safety and so on.

As shown in Fig. 2, the structural strength of the traditional express packaging largely depends on the toughness of the adhesive tapes, and the excessive use of the tapes makes the recycling and reuse of the packaging box of corrugated board difficult, and the tape that is difficult to tear off virtually increases the difficulty and cost of recycling and reusing the corrugated paper. While the excessive use of tapes is related to the violent loading and unloading practice in the express delivery industry, because the seller would rather wrap more tapes and bubble films round the goods than bear additional losses and risks, lest the packaged goods sent by the seller be damaged in the violent loading and unloading by the couriers. However, the excessive use of tapes also adversely affects the consumption experience, although it provides consumers with a sense of security. Sometimes it is not so convenient to take apart the package from the seal as to open a hole in the box with a key to take the goods out, causing heavy pollution to the environment and failure of recycling and reuse.





[Figure 1] Diagram of the concept of integrated cycling economy. [Figure 2] The unpacking and tape issues of traditional express packaging

5. NEW DESIGN OF EXPRESS PACKAGING REQUIRING NO TAPE

5.1. Resolution of the problems by the new express packaging

From the perspective of the integrated recycle, the new sustainable express packaging design vigorously aims at eliminating waste during the design phase and achieving sustainable utilization of resources through the "cycle to cradle" circular economy practice. In addition, consideration must be given to the protection of the goods contained inside packaging, materials, and costs, as well as conditions that consumers are unaware of, such as being transportable, easy to use and recycle, etc. [11]

On the basis of the above conditions being met, the " mortise-and-tenon joint structure" of new sustainable express packaging has a foothold in low carbon and environmental protection. Minimizing the use or abandoning the use of tapes is the best solution to achieve the sustainability of express packaging from the design phase to lengthen the service life of express packaging as much as possible, fully exploit the sustainable value of express packaging; continuously improve the robustness of express packaging and recycle to the greatest extent possible; provide solutions to reduce tape usage and lower down resource waste and environmental pollution of express packaging.

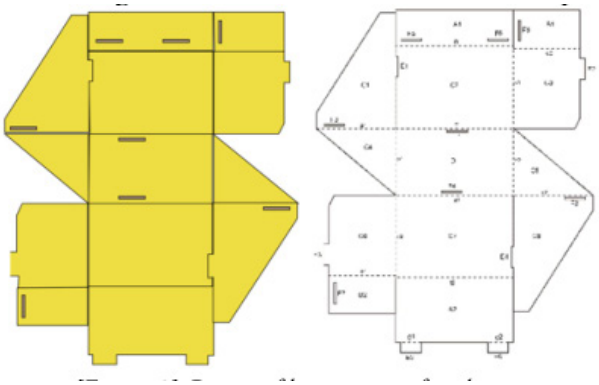
The new express packaging design adopts the concept of avoiding excessive use of tape, exploring the sustainable concept of using mortise-and-tenon joint technology, and promoting the closed loop relationship between input and output of express packaging in future, which is conducive to the cycle of symbiosis of the enterprises and the ecological environment. Firstly, the existing traditional express packaging structure has to be changed: the sides of the package are designed as movable surfaces, and the sides are fixed in a form of rabbet, thereby reducing the surfaces to be sealed from two to one, so that even if one openable surface needs tape sealing, it will save more than half of tapes used in the conventional form, providing a solution to the problem of excessive use of tapes and packaging boxes discarded after being used once in the express delivery industry.

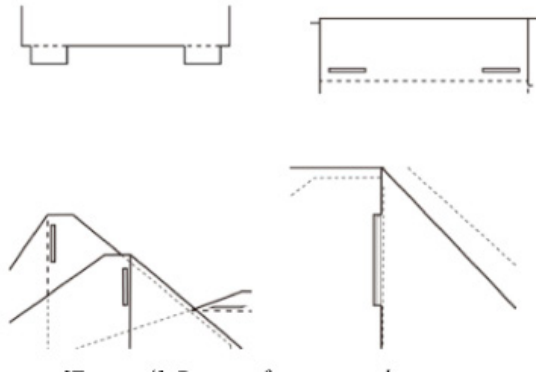
It is found, through research and practice, that the interlocking structure of corrugated paper can achieve the required strength for express packaging and get rid of the use of a large amount of tapes. Such structure not only makes consumers feel safe, but also allows consumers to enjoy a fast unpacking experience. And the structure of the box is not destroyed after the box is opened. The packaging box is only made up of corrugated paper and courier receipt, which is more convenient for recycling of the package, or the package can be directly sent to the paper mill for beating and remaking, reducing the link in the cycle process and the cost of the cycle.

5.2. Layout view of the new packaging

The layout of traditional express packaging box is a structure of connected lateral cardboard, with top and bottom sides left open, to be fixed and sealed with tapes. However, such structure makes the tapes a necessity for express packaging, otherwise the bottom side will have no load-bearing capacity, and the excessive use of the tapes increases the difficulty and cost of recycling the packages.

The new-type packaging structure adopts a crisscross structure in which the bottom cardboard is connected to the side cardboard and the side cardboard connected to the cover cardboard. This structure causes the ridges of the two lateral boards to be perpendicular to the main direction of force, leading to the reduction of the load-bearing and impact resistance of the bottom and sides of the entire box. As shown in Fig. 3, the new-type packaging structure consists of two cover boards: A1, A2; two dust-proof folding fins: B1, B2; eight lateral boards: C1, C2, C3, C4, C5, C6, C7, C8; six tenons: E1, E2, E3, E4, E5, E6; eight mortises: F1, F2, F3, F4, F5, F6, F7, F8; and fourteen folding lines: a1, a2, b1 B2, c1, c2, d1, d2, e1, e2, f1, f2, g1, g2. It has a diagonal triangular structure on both sides of the carton, so that each side has two boards and the ridges of the two lateral boards are upward vertical, which can withstand the tensile force and impact force in all directions and reinforce the lateral strength, as the added lateral boards are in within the maximum length and width of the layout plan, with the minimum consumables and without affecting the jointed board, while the utilization rate is improved, thus forming a structure that can greatly reduce the influence on the goods inside even if the box is impacted.

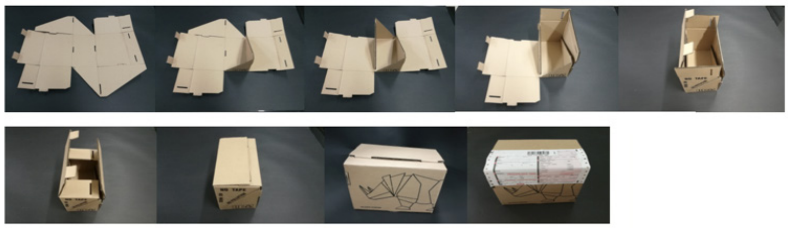




[Figure 3] Design of layout view of packaging [Figure 4] Design of mortise and tenon joint

5.3. Design of mortise and tenon jointing

As shown in Fig. 4, the method of rabbeted locking is inspired by the Chinese classical mortise and tenon joint structure. The protruding portion (tenon) at the bottom of the triangular side cardboard is fit into the mortise on the bottom board, so that the side cardboard can keep stable without relying on external force. The mortise on the triangular lateral board can be used to secure the square lateral board. This solves the problem that the crisscross structure is immediately scattered when the external force is lost after being closed, and all the lateral boards are interlocked and mutually fixed. The projection of the lateral board is about 2mm longer than the depth of the mortise, so as to counterbalance the elasticity of corrugated paper by means of folding. The protruding portion of the lateral board results in the notch on the lateral boards, which can make room for the protrusion of lateral boards after boards are jointed, increasing the strength in the middle of the sealing to ensure a firm closure.



[Figure 5] Steps of closing a box

5.4. Design of rapid box closing

The new express packaging structure adopts pure jointing structure design and application featuring both lightweight and convenience. As shown in Fig. 5, the folding process of the box is as follows: First, the lateral board is folded along the folding line so as to be perpendicular to the lateral board, and the lateral board is folded along the

folding line so that it is perpendicular to the bottom board, with the tenon inserted into the mortise; then the dust-proof folding fin is folded along the folding line so that it is perpendicular to the lateral board, and the box is closed.

The new express packaging design is intended to realized a mode of fast unpacking, fast taking in and fast taking out, with multiple interlocking rabbets to ensure the stability and supporting strength of the packaging structure, requiring no tape fixing and adhesive sealing, because the strength of this closure comes from the design that the rabbet on the triangular lateral board can fix the square lateral board, making the packaging more stable with higher compressive strength. It features high compression resistance, load-bearing capacity and resistance to heavy impact, in addition to quick unpacking and recyclable and reusable characteristics. What is more, when it comes to the basic role of express packaging, a very important point is to deliver the goods safely. The courier receipt at the seal is glued at the opening to ensure security and anti-theft.

5.5. STRUCTURAL STRENGTH TEST

5.5.1. Comparison of packaging opening and closing speeds

Traditional express packaging uses corrugated paper as the main material, reinforced with adhesive or metal nails, and sealed only with tapes. There is basically one type of packaging boxes, with upper and lower sides left open to be closed by winding a few turns of tapes. When unpacking, the tapes needs to be removed first. In case of excessive use of tapes, it may take more time. As shown in Fig. 6, the advantage proved in the new express packaging structure design test lies in that the physical performance of the traditional express packaging is guaranteed, while the packaging boxes can be quickly opened and quickly closed, safe in the transportation process and low at manufacturing and transportation costs. With the courier receipt at the seal torn off, the box cover will open. It can be easily opened, reclosed, and packed. The experimental results of the ease of opening of the traditional packaging and the new packaging shows that the unpacking speed of the new packaging is nearly 14 seconds faster than the traditional express packaging calculated from opening the box cover by hand, and the closing of new-type express packaging is 20.15 seconds faster, and different groups of people can easily use and intuitively open the box for a short time.

[Figure 6] Comparison of package closing speed

[Figure 7] Load bearing strength test. [Figure 8] Compression strength test of new express packaging structure

5.5.2. Load bearing strength test

The new express packaging is designed for transport packaging and logistics package, specific model is selected according to the weight and strength of the transport to test the load-bearing strength of the carton, containing eight kilograms of sand as a unit and thrown to the ground at a height of about 1 meter. As shown in Fig. 7, the result proves that the new tenon-and-mortise joint structure can withstand the impact during transportation, not easily broken, and can be recycled and reused as a resource.

5.5.3. Compression strength test

As shown in Fig. 8, The experimental results show that the tenon-and-mortise joint structure design is tested on the compressive strength of the corrugated packaging material, fully considering the factors of firmness and safe transportation of the express package. In addition, the new express packaging structure is designed like paper folding, which is used to increases the strength to avoid damage in the transportation.

5.5.4. Impact strength test

The most important feature of express packaging design, from the point of practicability, is safety, structurally stable, resisting to dropping and throwing force; Figures 9-10 show the different tests from the early development stage to the packaging strength and different damages occur from the same impact test on new and old packaging strength.

In general, express packaging will experience throwing, bumping, clashing, etc. during transportation. The diagonal triangular structure on both sides of the box provides two lateral boards on each side, and the two lateral boards are vertical in texture, which can withstand the tensile and impact forces in all directions and strengthen the lateral strength.

[Figure 9] Impact strength test [Figure 10] Impact strength test of packaging structure of the existing express market of new express packaging structure

6. CONCLUSION

From the perspective of integrated cycle, the new sustainable express packaging design proposes an innovative solution of a new integrated cyclic express packaging design that controls and reduces environmental pollution. Innovative research and development of tenon-and-mortise joint structure design is explored, which is the technique using mutual jointing and interweaving of cardboards by means of tenon and mortise joints according to the physical properties of the corrugated paper. This can ensure the stability of the structure without reliance on tapes, greatly reducing the amount of tapes used, the packaging boxes can be recycled within a limited times, increasing the recycling rate, beneficial to the popularization and realization of social sustainability, thus ushering in a development road to ecological benefits. At the same time, the entire life cycle is beneficial, safe and healthy to individuals and society. In the industrial cycle from cradle to cradle, efficient recycling and utilization can be achieved from the raw materials acquisition, manufacturing, transportation and recycling.

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