Sustainable Design of Curved Wood Rice Barrel with Healthy Considerations

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Abstract: The impacts of plasticizers on the human become a controversial topic, avoiding the effects of plasticization is one of the demands of wood barrel design. Through the green design and the bentwood forming skill, we consider the environmental factors in the design stage. By collaborating with bentwood manufacturers, we emphasizing on humidity and insect prevention and design bentwood rice barrel for the small household. The proposed rice barrels have the following features: using of green materials, reducing the environmental impact of processing, providing options for appropriate size by modular design. During humidity test, a curled wood and an equivalent plastic rice barrel were chosen and checked their difference on humidity absorption. High relative humidity (65%) was observed within the plastic barrel. The absorption performance of bulk wood is better than that of plywood. Based on measurements, we will refine design by combining the advantages of materials in future.

1. Introduction

Excessive unsustainable consumption of resources may cause considerable damage to the environment. Sustainable design is a design process [1] in which the designer, in response to possible environmental cost to reduce the impact of a product in the design phase by considering into the material, transportation, processing, and use of the product. The green design enables designers to look detail to adopt the proper concept of reducing the impact of the environment. "The green design reflects the reflection of the environment and ecological damage caused by modern science and technology culture, as well as the return of the designer's moral and social responsibility." Based on this view, we incorporate bentwood forming technology [2, 3] in the design process so that both environment and health concerns can be met. The three objectives of this study are:

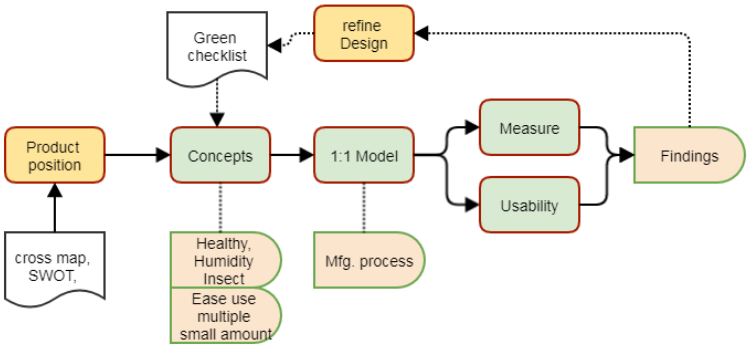

Figure 1. The research flow.

1. To design a rice barrel using bentwood based on scenarios for a small, healthy household. The emphasis of the design is on humidity prevention and insect prevention, and a proposition fit the target household's need;
2. Measure humidity absorption performance of rice barrel prototype model. We select an equivalent plastic rice barrel, and check their difference on humidity absorption, and evaluate humidity absorption performance of bulk wood and plywood;
3. Based on measurements, we refine design concept by combining the advantages of materials.

Figure 1 indicates the research flow of this study.

The intention is to involve scientific data in the design process. Designer can test the system and implement the required improvements. In re-design phase, we acquire new idea to address the finding during the test. After that, some details regarding the usability are provided. The notion of design-based research has been introduced by Collins [4], who described design experiments as a way to advance design and practice. Based on collaboration among designers and practitioners in real-world settings, we adopted this iterative evaluation-driven design-based research approach.

2. Literature

2.1. Green design

Green design is also known as eco-design, environmentally friendly design. Although the argument behind each name is different, the content is consistent. The basic idea is: environmental factors and pollution prevention measures are taken into account in the design stage; the objective of performance parameters are set as the product design goals and the starting point and strive to decrease the product's environmental impact. In [5], authors pointed out that the green design has the following characteristics: safety, reducing materials or using renewable materials, and avoiding improper ecological pollution. Also, Rebecca Proctor [1] pointed out that the sustainable environmental design has the following characteristics: biodegradable, fair trade, local materials, low energy/ waste, and no toxins.

2.2. Bentwood technology

Composite wood assembled with smaller pieces of wood glued together. Wood bending is a specialized technology [6]. After an extended period of development, varieties of shapes successfully developed with anti-moisture, anti-torsion ability. In bentwood process, two kinds of sliced wood are bent and stack; place into the steam tank, softening it by using a hydraulic bending machine, and proceed with compress. The wood bending stereotypes usually divided into dry and high-temperature treatment types, such as high-frequency drying and microwave drying [6]. Stacking bending and high-frequency drying are utilized in the present study.

2.3. Wood and humidity

Wood is a hygroscopic material; it naturally takes on and gives off water to balance out with its surrounding. Wood can absorb large quantities of water before reaching moisture content levels [7]. Moisture content (MC) is a measure of how much water is in a piece of wood relative to the wood in oven dry. Dry wood's moisture content is less than 19%. Fiber saturation is the level of moisture content where the cell walls are holding as much water as they can. Decay can get started if the moisture content of the wood is above fiber saturation (28%). Below this, the water content in the cell cavity will not affect the dimension of the wood [7]. Wood will reach equilibrium moisture content (EMC) that yields no vapor pressure difference between the wood and the surrounding air. The timber used indoors will eventually stabilize at 8-14% moisture content which allows the wood to function as a natural humidity controller.

2.4. Rice storage

Relative humidity and temperature of the storage environment are the most critical factors affecting maintenance of seed quality during the storage period. Of these two factors, relative humidity is most important because of its direct relation to seed moisture content [8]. The airtight storage means that the store is sealed to prevent air exchange with the ambient atmosphere. For large amount storage, container or storeroom was popular for a long period and less frequently access. In rural areas, hermetic storage is a cost-efficient and chemical-free insect control [9, 10]. Although plastic package can achieve hermetically; it cannot maintain airtight once open the seal.
Maintenance of relative humidity in a storeroom substantially lower than the ambient condition successfully enhanced with a moisture vapor barrier in walls, floor, and ceiling. Moisture vapor diffuse caused by a difference in pressure or relative humidity. The small size of H_2O molecular makes it difficult to stop the water vapor diffusion. The possible approach is O-ring combine with pressure on the cap.
In [11], an airtight storage of brown rice with low moisture content was tested and evaluated as an alternative to refrigerated storage. Brown rice samples (500 g each) at 16.2- 11.0% moisture contents (m.c.w.b.) were stored in plastic bottles for 6 months at 25° C. It was found that germination rate with 16.2% m.c.w.b. at 25° C declined from 97% to 27%. Low-moisture-content storage could be as effective as low-temperature storage. In [12], the storage's oxygen concentration dropped to 2.7% within 30 days, and carbon dioxide rose to 9.1%. The change in gas composition was caused by insect respiration. Hence, insect prevention is also important.

3. Design of Rice Barrel

Many creative techniques have been practiced in concept generation stage. At the beginning of the design, the divergent thinking was used to identify the possible concepts. After the initial direction was found, the convergence of thinking can be used in order to avoid too much information to interfere with the design.

3.1. Positioning and affinity analysis

Positioning analysis help designers to determine the relationship between existing products correctly, and find own opportunities according to the material, functional structure, shape, etc. Figure 2 shows the location of wood barrel by positioning analysis. The existing commercial barrels have a large volume; some are not easy to classify or stack. In order to meet the habits of modern life, the bentwood barrels with healthy considerations will be our target domain.

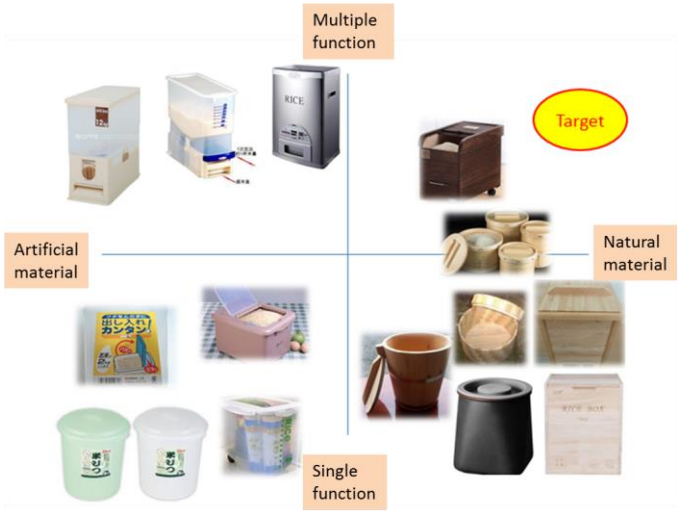

Figure 2. Cross positioning analysis of rice barrel.

SWOT analysis helps reveal of Strengths, Weaknesses, Opportunities, and Threats in competitive markets which identified by the external and internal environment. We will pay attention to the modern people focus on health trends, natural materials to development of small capacity barrel with flexible storage. High-quality design can increase the product market penetration and improve consumer acceptance. Bentwood products need to invest in high manpower, resulting in higher production costs. On the Weaknesses hand, if consumers are unfamiliar with the new product, the product receives less attention. The existing low-cost plastic products (lower-left of figure 2), we cannot rely on low price to get competitiveness.

KJ method is known as Affinity Diagram. It is a way to sort out ideas from complex factors and organized to find a solution to the problem. From the KJ analysis in figure 3, there are three tasks to fulfill namely, healthy, elegant design, and sustainability. The main design issues are the use, the cost of manufacturing, and the environmental assessment considerations. In-depth understanding of the production and promote benefit of natural material are important.

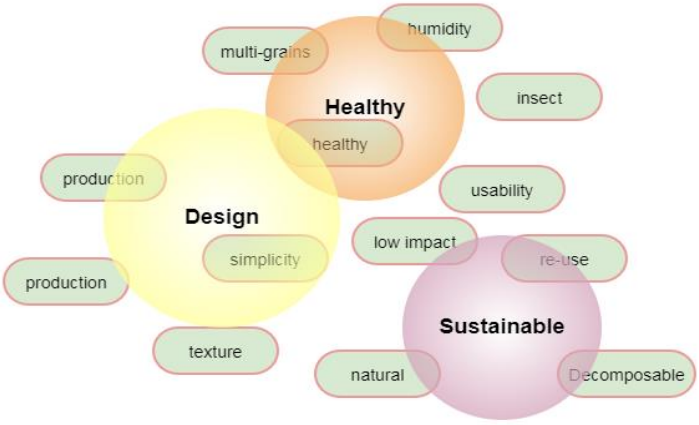

Figure 3. KJ analysis of bentwood barrel.

3.2. Design implementation

After confirming the design direction, we carry out the design steps such as concept development, sketching, and model making. Eating habits shifted to less amount, as well as more variety of grains mixed. We also considered the small packaging capacity with several choices. To reduce processing steps, we chosen simplicity elements (square, rectangular, round shape). The modular and stackable design reduces space required for transportation. The transparent window can be included to identify the internal contents quickly. The module has the same cross-sectional area, and the height of bentwood is changed to allow different capacity.

Prototype model (shown in figure 4) was made in the Canstar a local expertise on bentwood [3]. The barrel bottom uses cypress for pest control and enhances the aesthetic quality. Choosing faster growth wood (beech or birch wood) causes less environmental burden. It can be single barrel or a three-tier structure that allows different rice or grain storage. If bentwood processing can be standardized, the modular design can enable mass production. The consumers are free from plastic barrels, which may have plasticizer ingestion concerns.

Figure 4. Rice barrel during utilization.

3.3. Manufacturing consideration

Prototyping stage was carried out in Canstar. To increase the strength of the curved joints and manufacturing yield, engineer arranged the length of the wooden layers. The joining surface progressively terminated from inside to outer layers (10-degree skew). In figure 5, we found laminated wood joint traces run smoothly on the inner and outer walls (as shown in the tags). Through the thickness compensation, they built a constant thickness wall after the hot pressing process.

(a) (b)

Figure 5. The junction regions of wood barrel (a) inner surface, (b) outer surface. Notice the offset between the junctions of two sides (indicated by 2 tags).

4. Humidity Test

4.1. Compare plastic and wood barrel

We adjusted the moisture content of the white rice to the same level, by placing in the base floor for two days. It is summer time; the average temperature was 32◦C. Then we put rice evenly into plastic and wood barrel. During usage, the cover lid is not fixed. For comparing with the same situation, the caps of a plastic barrel are placed without clamping two sidebars (figure 6).

Firstly, we placed both samples in the living room with proper ventilation. After one day, we moved both samples to underfloor without ventilation. The relative humidity (RH) is recorded using four Onset data loggers. The sampling rate is 20 min each. For comparison, four data loggers were placed (figure 6-left) within two rice sample barrels, the rice surface, and the ambient.

Relative humidity was measured according to the method as specified. Figure 7 is moisture change during three days. Researchers observed high relative humidity (65%) within the plastic barrel. In the wood barrel, it is 62%. According to the environment, relative humidity is high (above 67%) in the evening and low (50%) during the day. There is several hours' response delay within the barrel. It suggested that low-moisture storage could be as effective as low-temperature storage [13]; hence the wood performs better.

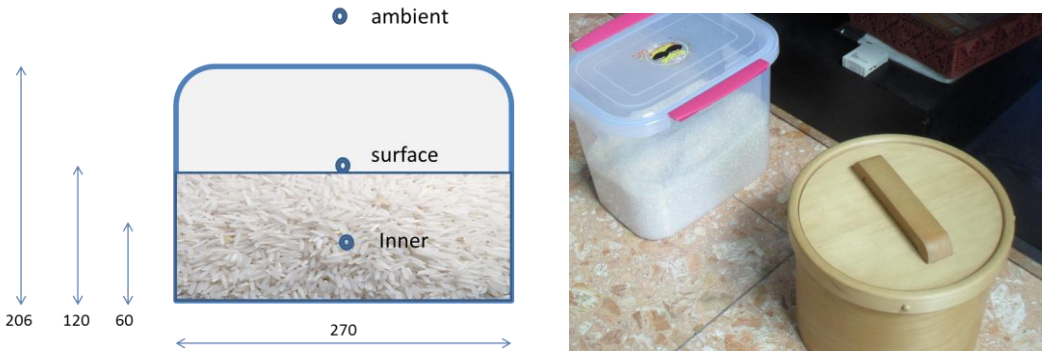

Figure 6. Relative humidity: (a) measurement setup, (b) comparing plastic and wood barrel.

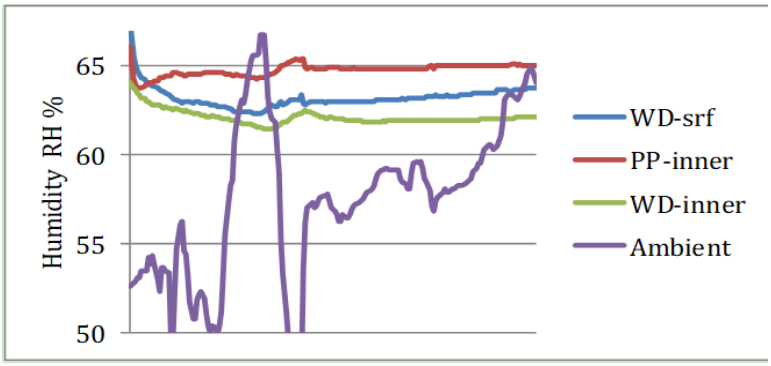

Figure 7. Relative humidity measured results.

4.2. Compare buck wood and plywood

What is the difference of absorption between different wood materials? The curved wooden barrel is made up of two parts, the cylinder is bentwood, and barrel's bottom and lid are solid wood. Are there any differences in the water absorption characteristics of the bulk and the plywood?

Experiment 2 compares the water absorption characteristics of these two materials. Because the plastic bucket has a sealed feature, so we put rice into the plastic bucket and then insert two pieces wood into the rice. After researcher closed the lid, the wood will absorb the moisture in this confined space. We placed the bucket on the basement floor, the solid wood and plywood were placed individually (shown schematically in Figure 8). The period for measurement is 30 minutes, and sampling interval is 20 seconds. Figure 9 shows the change in the moisture content of barrel during 30 min. We can see the gradual decline in the humidity for the solid barrel (with 6% difference). While we put the plywood into the barrel, the humidity decreased slowly (with only 1.5% difference). We can imagine that when the stack of the laminated process, viscous glue is used between different layers with pressure, so the adhesive decreased the permeability of wood, resulting in moisture absorption ability to drop.

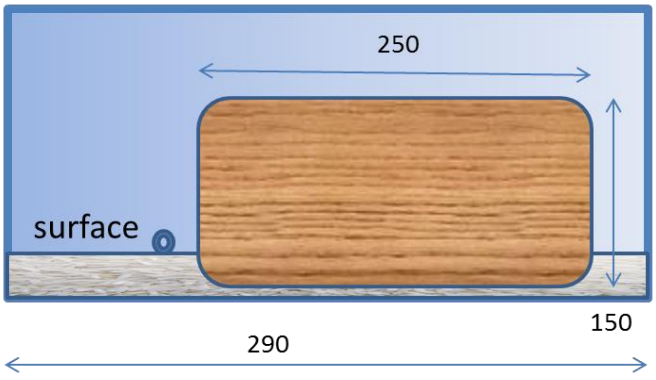

Figure 8. Schematic arrange of water absorption test of two materials

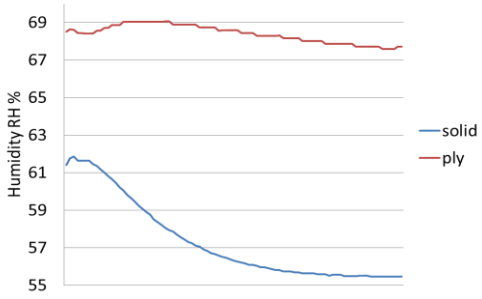

Figure 9. The moisture adsorption curves for bulk wood and plywood.

4.3. Design notice based on findings

How can we apply the findings of the experiment to the design? Since the wood and the wood are different in water absorption, so we can use their advantages. Curl wood can be used for the structural element; solid wood can be used in the internal support bar, the base, and the cover. We also need to pay attention; solid wood cannot be waterproof paint, to provide the original intention. For example, in the re-design phase, one can divide the rice bucket into three areas (white rice, brown rice, barley); then the partition board can be made with solid wood to reveal its advantages.

5. Conclusions

Health issue and the trends of diet lead habits of organic food and natural materials. Rice barrel of multiple usages was developed with curl wood. The design methods used in this study are parameter test and verification, KJ method, and SWOT. Through the design method and the mastering of bentwood forming technology, we considered the environmental factors and prevented the infiltration of pollution. We apply the green design checklists to evaluate its effectiveness. The possibility of technology application, design, and health can coexist.

The humidity test of moisture change during three days, high relative humidity (65%) was observed within the plastic barrel. There is several hours' humidity response delay within the barrel. For buck wood and plywood, there was 6% decline in the humidity for the solid wood and only 1.5% for the plywood. During the laminated process, the viscous glue used between different layers of wood decreased its permeability.

It suggested that low-moisture storage could be as efficient as low-temperature storage. Hence the wood barrel performs better than the plastic one. According to the findings of the experiments, curl wood can be used in curved structural parts; solid timber applied in the internal support bar, the base, and the cover. The future design will implement it to reveal its advantages.

6. References

[1] Rebecca Proctor 2013 Ecological design classic 1000- new eco designs and where to find them, Facebook group
[2] Jiang Haibo, Qiao Ying, Sun Hongbin 2008, Wood bending process research, forestry machinery and woodworking equipment, 2008, No. 36
[3] Dakun Quwood Furniture Co., Ltd. website, song introduction, website: http://www.kenstarwood.tw/html/index.html
[4] A. Collins, Towards a design science of education, New Directions in Educational Technology, E. Scanlon and T. O'Shea, eds., pp. 15-22, Springer, 1992.
[5] William Lidwell; Kritina Holden; Jill Butler Original, 2011 Design rule: 125 key laws affecting cognition, increasing beauty, making design better
[6] Zheng Shunfu 1989 Furniture Woodworking Ability Training Materials - Use of Special Press, Vocational Training Research and Development Center of China (PCF-CBM1103), Taipei.
[7] T. Genkawaa, T. Uchinob 2008 Development of a low-moisture-content storage system for brown

rice: Storability at decreased moisture contents, Biosystems engineering pp 515-522
[8] Al-yahya S A 2001 Effect of storage conditions on germination in wheat. Journal of Agronomy and Crop Science, 186(4), pp 273–279
[9] Moreno-Martinez E; Rivera A; Badillo M V 1998 Effect of fungiand fungicides on the preservation of wheat seed stored with high and low moisture content. Journal of Stored Products Research, 34, pp 231–236
[10] Thilakarathna B. Adhikarinayakea, 2006 Quality change and mass loss of paddy during airtight storage in a ferro-cement bin in Sri Lanka, Journal of Stored Products Research 42 pp 377–390
[11] De Lima, C.P.F. 1990 Airtight Storage: Principle and Practice, Food Preservation by Modified Atmospheres. CRC Press Inc, Boca Raton, pp 9–19
[12] Varnava, A., Navarro, S., Donahaye, E.J. 1995. Long term hermetic storage of barley in PVC-covered concrete platforms under Mediterranean conditions. Postharvest Biology and Technology 6, pp 177–186.
[13] Martha. Y. Quezada, 2006 Hermetic storage system preventing the proliferation of Prostephanus truncatus Horn and storage fungi in maize with different moisture contents, Postharvest Biology and Technology 39 pp 321–326.