Paper-based 3D printing industrialization for customized wine packaging applications

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Abstract

To take advantages of 3D printing technology in personalized wine packaging production, taking the paper-based 3D printing process as an example, three keynote issues including model designing, manufacturing process and quality evaluation, were analyzed and characterized to explore feasible solutions and specific rules from given cases study. Based on one Chinese wine brand, four original customized wine packaging models with different remarkable features were designed and compared by quantitative tests between the Cutting-Bonding Framework and printing time for each specimen. Considering specific supply chain of printed customized wine packaging models, the principles for marketing quality evaluation were mainly focused on surface color consistence and fragility, and corresponding evaluation frameworks were developed for printed wine packaging models. According to test results of designed cases for paper-based 3D printing, three practical solutions including models design rules, process optimization strategy and printing quality evaluation workflow were offered respectively and illustrated to contribute promising industrialization of the paper-based 3D printing technology in customized wine packaging applications.

1. Introduction

Recently, 3D printing process was praised as one of most promising technology, and applied widely in the customized manufacturing and culture creative fields [1~3]. Based on all forming principles, industrialized issues with special features are obvious concerns for existing 3D printers, especially for printing size and integrated surface appearance reproduction. Given inherent advantages including unique color reproduction and environmental protection, the first paper-based 3D color printer was distributed in Germany since 2012 [4], which developed by the Mcor technology company, full color 3D printing with papers was really appeared into public view. Given principles of layer manufacturing, paper-based 3D color printing should belong to a rapid prototyping (RP) technique [5]. For existing paper-based 3D printer, there are two main special stages: colorization and model forming. The colorization is a detachable stage that both sides of A4 office paper are printed by the Epson 310N ink-jet printer, while the model forming stage is used for delivering printed pages orderly to forming base for contour cutting and next single piece bonding layer by layer.

Customized wine packages have become more and more popular among Chinese wine markets, as along with increasing market size. For customized wine package, it usually requires much time and labor consumption based on the traditional manual methods. Meanwhile, the consistency of those same customized products is a big challenge for manufacturing factories. Many automatic visualization methods for customized wine packaging applications were indirectly developed by domestic manufacturers with rapid drafted model and sparse post-finishing process, while they can not directly combine powerful creative packaging models and wine packaging production as an integrated process chain. Since color 3D printing technology is good at creative 3D models implementation, feasible and practical solutions based on color 3D printing processes with paper-based substrate were developed partially [6]. It is important to develop the completed framework and key parameters for customized wine package implemented by the paper-based color 3D printing process.

For 3D printing applications in modern product packages, current hot topics had been discussed from material property to customized function property for printed packaging objects [7]. For plastic-based 3D printing process, it had been used for packaging containers production to obtain the effects of printing materials and new supply chain on physical and functional features of printed models [8]. For views of packaging industry, 3D printing processes were introduced and analyzed with significant guides for feasible container shapes and useful substrates [9]. 3D printing processes applied into gift packages were also proposed by the analysis of customized design rules and emotional demand [10]. However, various useful completed frameworks of 3D printing applications in customized packaging were still eager for formal guides or standards for process optimization and 3D color model design principles. In this article, an integrated framework for paper-based 3D printing applications in customized wine packages were gradually demonstrated by given tested cases with specific personalized wine packaging brand and models. The following sections were focused on the analysis of three core issues including specific model designing, manufacturing process and quality evaluation, as well as practical solutions for the paper-based color 3D printing industrialization for customized wine packaging applications.

2. Three core issues analysis of paper-based 3D printing applied into customized wine packages

Currently, 3D printing technology was commonly applied into various traditional manufacturing industries with fast printing speed and ranges of cheap printed substrates development, so individual industrialization of each 3D printing process was gradually explored from lab test product to market applications. Paper-based 3D printing process was a powerful technology that providing full color and fine gradient color, which was firstly applied into the cultural and creative industry. To some degree, all color 3D objects without requiring transparent features can be printed accurately by the existing paper-based 3D printers with limited high price. So it is suitable for small batch production for brand products by controlling print process workflow to reduce cost and improve efficiency. The personalized wine package production is a new matching industry which required more and more individual needs. Then paper-based 3D printing process applied successfully in customized wine packages, guided formal framework and standard process principles were an useful and efficient way to expand its industrialization scale. Considering the production and market of customized wine packages, three core issues including packaging model design, printing process control and quality evaluation, were described and analyzed with special examples and principles.

2.1. Paper-based 3D printing principles

Paper-based 3D printing process is originated from the laminated object manufacturing with paper sheet substrate, and later added the single inkjet printing nozzle compared with four primary color inks to the forming system by Mcor technology. Currently, this 3D printing is the first 3D printer provided ICC profiles to achieve color management function for fine gradient color reproduction. While used primary color inks with similar composition structure of traditional inkjet inks, then color gamut of paper-based 3D printer is common smaller than the original model design profile within RGB color space, which is an concerned issue for high-value antiquities reproductions.

Figure 1. From the left to right, the pics are Mcor IRIS SliceIT, IRIS 3D printer, Aqueous adhesive and Office A4 paper, printed wine package model respectively.

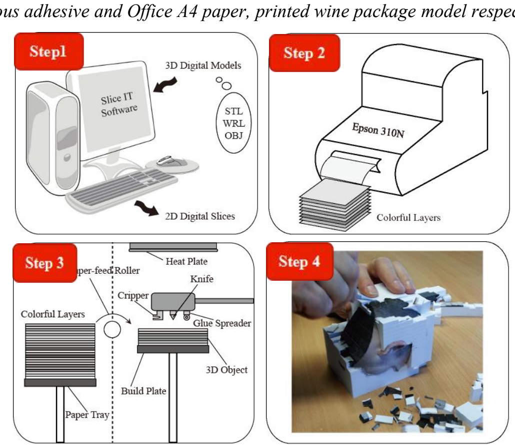

Figure2. Paper-based 3D printing workflow: slicing phase, colorizing phase, forming phase and fixing phase.

The principle of paper-based 3D printing process is shown in the Fig.1, it is easy found that office A4 paper used as printing substrate, and aqueous adhesive used as layer bonding. All 3D models are sliced automatically with Mcor IRIS SliceIT which can compute and show the whole time of sliced models before sending formal order to 3D printer. When all printing files were prepared well with color calibration, then printing process can be illustrated with below workflow in Figure 2 [11]. There are four dispersed stages: slicing phase, colorizing phase, forming phase and fixing phase. Slicing phase is to provide sliced files from original models. Colorizing phase is to print the color contour ring layer by layer with location marker. Forming phase is to cut contour and bond previous layer sheet. Fixing phase is to remove excess waste sheet and improve surface by manual post-processes which including waxing or impregnating approaches. Sawtooth effect of printed model is a troublesome phenomenon in local sharp surface area.

Another limitation of existing paper-based 3D printer is its maximum build size (256×169×150 mm) which one fatal factor influenced on the its industrialization in customized wine packaging applications before the 3D-CBF strategy proposed in large-size 3D model implementation [12]. This is a method that combine the cutting technique in additional design phase and the bonding technique in later fixing phase with integrated strategies including cutting angle and layout design.

2.2. Customized wine packaging model design

Since printed wine packaging model was consist of paper sheet, ink and adhesive, which all can not contact and store directly wine. So for customized wine packages, paper-based 3D printing are available for displayable packaging model and auxiliary packaging model. The displayable packaging model is referred to the packaging model considering comprehensively display property and transport property for upgrading current wine package production based on thick cardboard box or decorative wooden box under different skilled workers. This type is good at complex creative wine packages with different combination of hollow, abnormal and connective features coupled with less cost shown in Figure3. Auxiliary packaging model is defined as the packaging model to display and protect wine container with aesthetics property and functional property, which its size is usually bigger than displayable packaging model. In addition, the customized wine packaging models can be printed with irregular curved details from thousands of personalized demands.

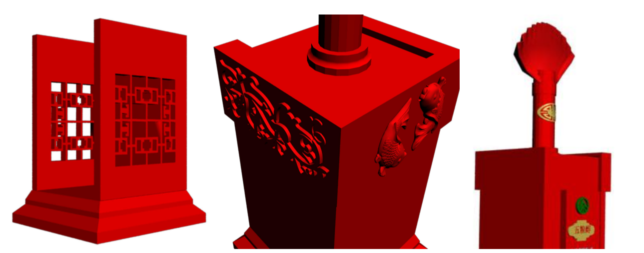

Figure3. Displayable packaging modes with hollow,abnormal and connective features respectively.

2.3. Specific 3D printing parameters setting

Paper-based 3D printing process is consist of work stages by integrating different printing materials and parameters setting. For current paper-based 3D printer, the whole printing time of designed model is easily varied from fine structure scale to lager size scale, as well as the quantity of once printed model. Thus considering flexibility and efficiency of process control, three core parameters including cutting angle, layout strategy and impregnation index. Generally, the center of biggest face of objects is selected as the symmetrical cutting center. The cutting angle is defined as the angle deviating from the normal vector of the cut face of specimens. For removing the additional waste easily, the layout methods also need to be limited. For this reason, according to the cut face distributions, two kinds in vertical plane and one kind in horizontal plane were introduced and compared. In the vertical plane, the cut face distributions are same-direction and opposite direction. The cut face distribution is just reversed in the horizontal plane. Cutting strategy and layout strategy both influenced the number of whole sliced layers and printing pages, and their quantitative relationships were analyzed and discussed in our own proposed 3D-CBF strategy tests. Impregnation index is to improve the color reproduction local or global surface areas by adjusting infused material and time.

2.4. Quality evaluations of printed 3D model

For paper-based 3D printed models applied into customized wine packaging industry, there are some general necessary requirements for manufacturing products and special standards for wine packages. Taking manufacturing requirements for example, quality evaluations were mainly concentrated on surface property, color reproduction, mechanical strength and chemical stability and so on. Surface properties were to improve smoothness and continuity of printed models, especially on retarding the Sawtooth effect of market product by adjusting the slicing method. Color reproduction evaluation is to measure the color stability and color difference of printed models with limited color gamut and improve color within complex images or textures reproduction. Mechanical strengths refer to targeted behaviors required in transport procedure and user experience. These are pointed to compressive strength, tensile strength and brittleness. Chemical stability mainly focused on resistance to the movement of harmful substances into wine even though all the printed models are eco-friendly. For 3D printing service provider of customized wine packages, the color reproduction accuracy and brittleness estimation are two core concerns that demanding feasible and practical evaluation guides for various potential customers, which also illustrated in below cases test.

3. Cases test and practical solutions

Most factors influenced on the adaptability and market scale of paper-based 3D printing applied into customized wine packages had been analyzed with above detailed issues. To demonstrate how acquire the optimized process parameters for manufacturers, design principles of printed models were tested and summarized by four specific specimens with regular features, hollow features, abnormal features and connective features. Based on these tested specific models, feasible quality evaluation methods and practical principles were proposed respectively.

3.1. Tested packaging models design principle

For customized wine package, it should behave the brand value of wine company with amazing package model for attracting targeted consumers. Then wine packaging model design can be fast determined by the dynamic balance between whole shape and color property. For Chinese customers, given shape property should care about domestic national cultural elements implemented by various structure forms including hollow feature, abnormal feature and connective feature. Secondly, the location and amount of all those elements designed on the main part are sensitive to printing quality and time. Generally it is best for no more than two types of above mentioned elements are used for a specific packaging model. It should reduce the long or curve hollow features inside packaging model to protect a completed product in fixing phase, while surface with short and medium-size hollow features are encouraged to meet more individual demands. Next, too big saturation color of printed model surface was difficult to achieve with the output color gamut limitation. Thousands of color can be used for image with fine gradient color. For example, Chinese red is a native color preference with high saturation which need complex post-process to achieve. Based on above principles, further four tested packaging models including regular type, hollow type, abnormal type and connective type, were designed and shown in Figure 4, respectively. It should be pointed out that whole size of each type model were similar with same scale to keep inside maximum build size of current paper-based 3D printer.

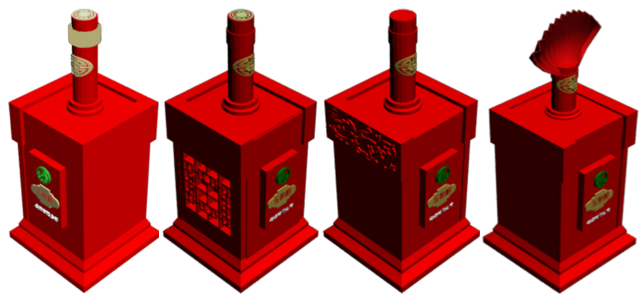

Figure 4. Four tested packaging models from left to right, regular type, hollow type, abnormal type and connective type.

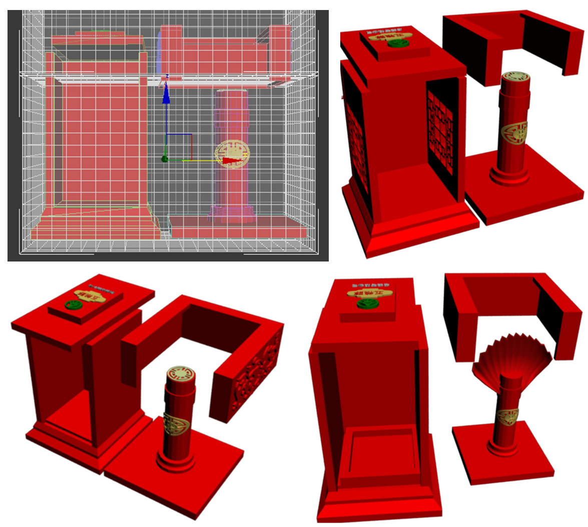

Figure 5. A specific layout case of four designed models in experiment group.

3.2. Printing time and layout strategy test

When original packaging models had been designed, then they were divided into detachable sub-parts based on user habits. Next step was to arrange those sub-parts based on given layout strategies before the slicing phase. In Figure 5, one specific layout case of four designed models was shown, while another control group case was not shown directly in this paper. Same sub-parts were re-arranged with different layout strategies in control group. The first one image in Figure 5 was shown the build space of current paper-based 3D printer and sub-parts of regular type together, and renamed R_e in the Table 1. Correspondingly, the second one, third one (bottom left) and fourth one in Figure 5 were marked as H_e, A_e and C_e, respectively. So in another control group, they were marked as R_c, H_c, A_c and C_c, respectively. It is noted that printing time of all tested models in Table1 were simulated by Mcor Color IT software, and did not contain post-process time.

In the Table1, it can be found that printing time of specific tested model was increasing with the complexity of customized elements. Contrast to original tested group, it also illustrated the rise of printing time of each type printed model with different rate in control group. However, it was still difficult to determine the quantitative relationships between printing time and layout design even though tested layout strategies maybe not the best case. So printing time optimization of customized wine packaging model can be trained and achieved by this guide test.

Table1. Printing time and layout design

Type ID	Printing time	Type ID	Printing time
R_e	30 hours	R_c	32 hours
H_e	56 hours	H_c	60 hours
A_e	48 hours	A_c	50 hours
C_e	42 hours	C_c	40 hours

3.3. Proposed practical solutions

Based on cases test method and core issues analysis, an integral guide were summarized for the industrialization of paper-based 3D printing technology in customized wine packages with following workflow items:

- The input of original customized packaging models;
- Determination and discrete of customized features;
- Application of 3D-CBF strategy and files preparation;
- Colorization, formation and contour waste remove;
- Post-process, evaluation, assemble and optimization loop.

For mentioned consistency evaluation of model surface color reproduction, it can be characterized by average CIE Lab values of six measured points of each model surface coupled with traditional classic spectrophotometer. For above brittleness evaluation of whole packaging model, it is recommended for the combination of dynamic trial method and experience estimation method even though so few practical database or standards can be accessed while collision machine are provided by big standard Laboratory.

4. Conclusion

The paper-based 3D printing process is ever a powerful tool for manufacturing customized products, and now applied widely into personalized wine packaging industry. By the analysis of three core industrialization issues including packaging model design, printing process control and quality evaluation content, an integral guide map was proposed for understanding and optimizing the practical paper-based 3D printing workflow and applications. Perfect wine packaging model should build the dynamic balance between customized elements and printing time of printed models. Currently, the feasible principles were provided for only printing quality implementation while the shortages including low printing efficiency and few transparency were further study to expand the market scale and depth of industrialization.

Acknowledgments

This work was financially supported by Students' Innovation and Entrepreneurship Training Program of Yuncheng University (Grant No. DC-2017167), Applied Basic Research Program of Foundation of Yuncheng University (Grant No. CY-2016012), National Natural Science Foundation of China for Youths (Grant No. 61301231), Guangdong Provincial Science and Technology Program (Grant No. 2013B010401007 and Grant No. 2013B090600060), Guangzhou Science and Technology Program (Grant No. 201607020045), State Key Laboratory of Pulp and Paper Engineering Project (Grant No. 2016C01).

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