3D PRINTED LITHOPHANE

Jure Klokočovnik , Deja Muck iD

University of Ljubljana, Faculty of Natural Sciences and Engineering, Ljubljana, Slovenia

Abstract: *Lithophane is a transparent plate on which, with the help of the different thickness of this plate, an image is formed. Light that passes through the plate from the back side of the plate shows a clear gray image on the front side of this plate. The strength of the transparency is determined by the material of the plate and the light source coming from behind. Without backlighting, the subject on the lithophane cannot be seen.*

Lithophanes in the form of porcelain vases were discovered in China long before the technique made its way to Europe. In Europe the origins of lithophanes date back to the early 19th century in France. Europeans perfected the technique and also used it to reproduce famous portraits and paintings.

Today, the production of lithophanes is experiencing a renaissance with the advent of 3D printing technologies.

In the research paper, the process of making lithophane using 3D printing is presented. First, 3D printing technologies are presented, more specifically the technology of extrusion of materials or thermoplastics modelled by joining layers. Then, the materials used for 3D printing with the mentioned technology are presented. Next, the procedures for 3D acquisition and reproduction of reliefs are described, and at the end, the lithophane itself is presented. In the practical part, the whole process of making lithophane is presented. For the creation of the lithophane model, the 3D modelling program Blender was used, and the lithophanes in physical form were made with the Creality Ender 3 3D printer using PLA filament. Droplet and electrophotographic printers were also used to produce colour lithophanes. The influence of LED and halogen lamps on the final impression of lithophane reproduction was also compared. Lithophanes produced with different print settings and different colour reproductions were compared. The results showed that the best wall thickness is one millimetre, and the layer thickness is the smallest value allowed by the printer. The orientation of the lithophane during printing has a great influence on the final image of the design. The best orientation is upright. Color reproduction is best when using electrophotographic printing in combination with acrylic varnish. Lighting research showed that LED is better than halogen lamps. The finished lithophane was of satisfactory quality and could be used as a decoration for the home or to organize an art exhibition with a large number of coloured lithophanes reproducing various artworks and motifs.

Key words: lithophane, coloured lithophane, 3D printing, relief reproduction

1. INTRODUCTION

People are constantly creating and designing new works of art and objects. In the technological age, these creations can be transformed from the real world into the computer world and back into the real or material, physical world. We do all this to preserve art and cultural heritage, duplicate certain objects, render creations for easier presentation on computer screens and for many other reasons (Elkhuizen et al., 2019; Horne & Hausman, 2017; Koontz, 2003).

One of the ways to reproduce works of art is to convert them into a relief form and make a high-quality lithophane. Lithophane is a transparent plate on which an image is formed with the help of different thicknesses of this plate at certain points. Light traveling from the back of the panel through the panel displays a pure grayscale image on the front of that panel. The strength of the transparency is dictated by the material of the panel and the light source coming from behind, so called backlight. Without illumination from behind, the motif on the lithophane is unrecognizable (Lavelle, 2020).

The beginnings of lithophanes date back to the early 19th century in France, where Baron Paul de Bourguignon of Rubelles produced the first lithophane in Europe in 1827. They also discovered lithophanes in the form of porcelain vases in China and conclude that this technique was used in China long before it came to Europe. Europeans, however, later perfected this technique and used it more often, also for reproductions of famous portraits and paintings. They also used hand-cut porcelain and later developed a method of moulds combined with the use of wax, and these moulds were suitable for about 20 rapid reproductions (Yuan & Bourell, 2013).

The production of lithophanes experienced a revival in the 21st century with the entry of 3D printers into domestic households. To make lithophanes, we do not need much proficiency, however knowledge of 3D modelling and printing is required. 3D printing enables the production of lithophanes, as it can form a relief layer by layer. Also, current software allows the transfer of any 2D digital image into a 3D model which is suitable for printing. These software are based on the grayscale values of a coloured photograph. They change the coloured photo to grayscale, then invert it, and thereby obtain the values of the filament application. Imaging programs perceive this as values from 0 to 255, and a 3D printer perceives this as the height of a certain point on the lithophane. When looking at the lithophane with the eyes, the black colour is physically closer to the eyes and white is the opposite (Zukas & Zukas, 2015). Currently, the production of monochrome lithophanes dominates, but we have set ourselves the goal to also produce coloured lithophanes, as not much has been researched in this area.

2. METHODS

The structure of the process is shown in Figure 1 below. It shows how we started the work and how the steps follow one after the other. First, we devoted ourselves to the comparison of monochrome lithophanes with different parameters, and only then did we also analyse coloured lithophanes.
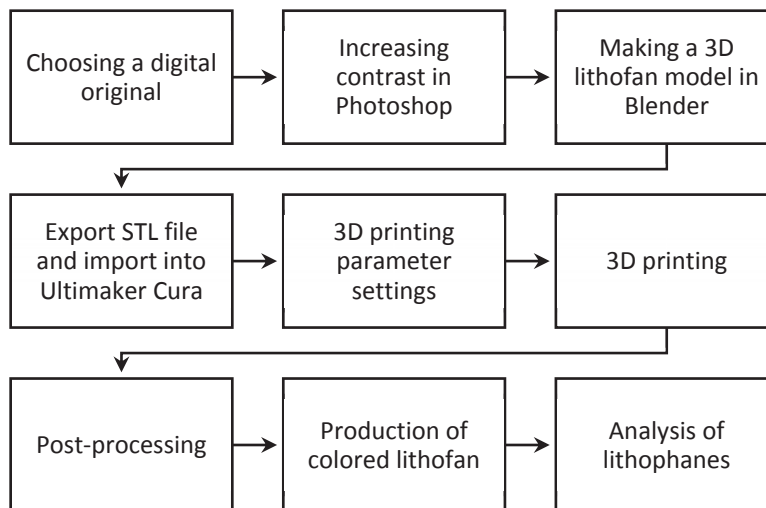

Figure 1: Procedure of experimental work

2.1 Lithophane motif and materials

We chose the painting The Starry Night by the painter Vincent van Gogh for reproduction, as it represents a well-known painting where contrasting colours, yellow and blue, are used. Due to the pronounced contrast, it was easier to analyse the colour reproduction on the lithophane. Also, the painting itself expresses a certain relief, which will be additionally expressed on the final lithophane. On the other hand, there are certain parts in the image that are quite detailed, which is a test for the quality of our 3D printer and for different print and design settings.

In the research we used: Creality Ender 3 3D printer, HP desktop Inkjet printer, HP desktop electrophotographic printer, desktop computer, Adobe Photoshop 2020, Blender 2.8, Ultimaker Cura, PLA filament, acetone, acrylic clear varnish, LED and halogen lighting.

2.2 Changing the contrast

We recommended to process the selected original digital image before further use for 3D printing. We can remove unwanted artifacts or change certain parameters to give us a higher quality final lithophane. It is typical for lithophanes that they work on the principle of contrast or the ratio between light and dark points in the image. Therefore, we also increased the contrast of the image. This way, the finished lithophane will be more embossed and the differences between the light and dark parts of the lithophane will be more visible. It should be emphasized that changing the settings depends on each motif separately. Figure 2 shows the original motif and Figure 3 shows the modified and edited version of the same motif.

Figure 2: Original motif

Figure 3: Edited motif

2.3 Making a 3D model of a lithophane

We decided to use the free program Blender version 2.8 to make the lithophane. This program allows the creation of 3D objects, which in our case, the lithophane is. The process of making a lithophane model is quite demanding. It is mainly based on mathematical transformations. In this way, the coloured image is converted to grayscale, and on this basis the program gets data on the value of each pixel separately, numbered between 0 and 255. Based on this, the height of a certain pixel on the motif is calculated. With the help of certain settings in Blender, we created a motif that is no longer in 2D form but is in relief. Light points are located lower than darker ones. Then we added thickness to the lithophane, as this is necessary for the final production with a 3D printer. At this point, we made a lithophane in the form of a square tile, which was ideal for our research. Finally, we just determined the axis directions, and then exported the 3D model file in .stl format.

2.4 3D printing settings

We set ourselves the goal of studying the influence of three different parameters on the printing process and quality, or usability of the finished lithophane. First, we devoted ourselves to monochrome lithophane, where we tried to find out the best settings for quality reproduction. We decided to use the Ultimaker Cura program to change the settings, as it offers all the functions we need and is also user-friendly.

The infill density was the same for all versions of lithophanes, i.e., 100%. We decided this way, since lithophane is dependent on the reflection and transmission of light, which a lower value of the infill density would change. We chose PLA filament because of its quality properties and ease of printing, and it is also a biodegradable polymer. The filament is white coloured, because lithophanes must transmit light and this works best with white polymers. Using transparent filament would not give adequate results because there would be no separation of the dark and light parts of the subject.

When printing, it is also important to mention the temperature settings. Our chosen printing temperature was 200 °C. Which is the recommended temperature of Azure Film, the manufacturer of our PLA filament. The temperature of the printing bed was set to 55 °C.

Table 1 below provides an overview of all the different settings we used when printing lithophanes.

Table 1: Print settings we used in the analysis

Sample	Orientation	Back thickness	Layer height
1	Lying down	0.5 mm	0.12 mm
2	Upright	0.5 mm	0.12 mm
2	Upright	0.5 mm	0.12 mm
3	Upright	1.0 mm	0.12 mm
4	Upright	2.0 mm	0.12 mm
3	Upright	1.0 mm	0.12 mm
5	Upright	1.0 mm	0.20 mm
6	Upright	1.0 mm	0.28 mm

2.5 Colour reproduction

We also wanted to colour the printed lithophanes. We did this using three different methods. The first method involved Inkjet printing on plain office paper. We chose it mainly because of its simplicity and accessibility. The second and third methods are quite similar, where we printed the image also on office paper, but this time with an electrophotographic printer. These two methods were based on the transfer of toner from paper to lithophane. While the first method is simpler and did not require the transfer of colour to the lithophane, however just gluing the paper to the back of a lithophane. The colour was transferred once with acetone and the second time with the help of acrylic varnish.

2.6 Lighting

The lighting of lithophanes is a key part of depicting a subject. Without lighting, the motifs on the lithophanes themselves are not recognizable, as we only see the relief of the white polymer, but the motif we want to show cannot be seen. That is why we compared the two most common types of lighting. LED lamps and halogen lamps. Regardless of the type of lamp, the most important thing is to illuminate the lithophane from behind and not from the front, as this is the only way to see the final motif on the lithophane. The environment in which we light is also important, because in an environment that is too bright, we will not see the effect of the backlight. Therefore, it is recommended to view the motifs in darker rooms.

The used LED lamp emitted a neutral white light with approximately 4500 K to 5000 K, while the halogen lamp emitted a much warmer light with approximately 2700 K. We also chose these lamps because of the significant difference in colour temperature, as we wanted to compare the effect of colour temperature on the final depiction of the motif on both colour and monochrome lithophanes.

3. RESULTS

This chapter presents the results and findings obtained during and after the experimental part of the thesis. First, we will examine monochrome lithophanes and then colour reproduction, followed by the influence of light. We showed the results in the form of photographs, which were captured under controlled conditions in a dark room. The lighting in the first and second part (monochrome and colour lithophanes) was backlit by LED lighting. In the third part, we compared LED and halogen light on monochromatic and coloured lithophanes.

3.1 3D printing settings

Three different parameters have been compared. The first of these was the orientation of the lithophane during printing. We compared this first, as it is the most basic and fundamental setting. Lithophane was printed in both horizontal and upright positions. The final conclusions of this comparison are that, for high-quality and accurate reproduction, we recommend choosing upright printing rather than horizontal printing, as the differences are significant and should not be ignored. Personally, we find the horizontal

position interesting especially in terms of art, as it gives off its charm of a mosaic puzzle, which is interesting in its own way. We can find both lithophanes printed in different orientations in Figure 4 and Figure 5 down below.
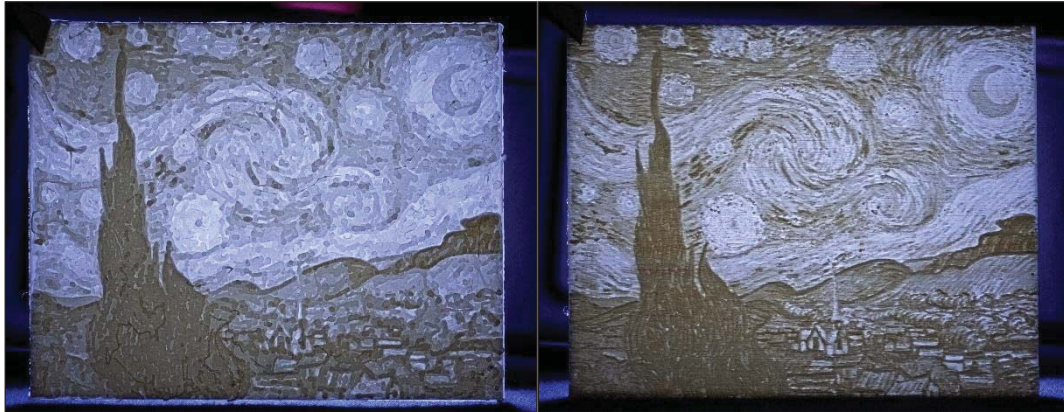

Figure 4: Horizontal print   Figure 5: Upright print

We continued by changing the thickness of the thinnest part of the lithophane or simply put, the thickness of the back. With this, we wanted to find out which thickness of the lithophane backing (0.5; 1.0; 2.0 mm) produces the best reproduction, quality and transparency of the lithophane. The back thickness is important, as the tile can quickly be too thin or too thick. The most obvious, immediately visible difference is the difference in the colour of the motif. The white polymer moved towards a yellowish or orange colour tone as the back thickness increased. This is due to the opacity of the white PLA filament, which, as the thickness increases, quickly begins to stop the light traveling through the polymer. The thinnest lithophane (Figure 6) did indeed transmit light the best and printed the fastest, but the tile was simply too thin for our 3D printer, as artifacts showed up because of the wall was too thin. The thickest lithophane (Figure 8) let in too little light and yellowed too much when exposed to light. Thus, the winner was the middle one (Figure 7) with a thickness of 1mm.

Figure 6: Back thickness 0.5 mm   Figure 7: Back thickness 1.0 mm   Figure 8: Back thickness 2.0 mm

The last comparison in this set was the comparison of different layer height settings and the quality of printing. We wanted to compare the layer height, as it is known that they can affect the quality of the prints, and we wanted to test at what level visible changes occur, or whether there are any changes in the motif at all. We were also interested in whether, at higher values of layer height, the printer would have any problems printing such thin structures. We compared layer heights of 0.12 mm (Figure 9); 0.20 mm (Figure 10) and 0.28 mm (Figure 11). The results showed that the best setting was the smallest setting i.e., 0.12 mm, as the larger two settings produced visible layers in the motif. Visible layers not only disturb the eye, but also degrade the accuracy of the subject. Not only the layers, but also the artifact in the form of a vertical line on the right side of the lithophane are disturbing. This is not noticeable on the smallest setting. The conclusion is that in our case 0.12 mm layer thickness gives the best results and it is not worth using the other two settings if we want a quality and accurate reproduction of the original image, especially in the details of the motif.

Figure 9: Layer height 0.12 mm　　　Figure 10: Layer height 0.20 mm　　　Figure 11: Layer height 0.28 mm

3.2 Colour reproduction

The results were somewhat in line with our expectations when we saw how poorly the paint transferred from paper to lithophane using the second method, using acetone. This is shown in Figure 13. Too little colour on the lithophane itself is manifested in the fact that the colour on the illuminated lithophane is not noticeable at all. Only a dark spot is visible on the left side of the lithophane, where most of the black colour has been transferred and makes it difficult for light to penetrate to the other side. The lithophane also deformed, as the reaction between acetone and polymer took place, which is why we do not recommend this method.

The simple first method showed a good result, considering the effort involved, compared to the other methods. Mainly in colour saturation. The stars and blue sky are very beautiful, but in the darker parts, the details are completely lost and the subject becomes completely unclear, as shown in Figure 12. Also, compared to the last method, the blue areas of the image are blended together and the white lines in the image do not come out in the final reproduction.

The best of all is the last method using acrylic varnish. The paint on the back side of the lithophane lets in just enough light so that the details are not lost. That is due to the paper being removed from the back in the last step pf the process. Although the colours are paler than with the first method, they are reproduced more accurately because they do not blend into each other as shown in Figure 14. Also, the third method allows viewing the image from the other side in daylight, which the other two methods do not allow, but it is true that this image is mirrored.

Figure 12: Inkjet LED　　　Figure 13: Acetone LED　　　Figure 14: Acrylic varnish LED

3.3 Lighting

From this experiment, we learned that LED lighting is much more suitable for lighting lithophanes than a halogen lamp and, consequently, an ordinary tungsten lamp. In principle, this applies to all lights, including LED lights, which have a colour temperature of around 3000 K. We have found that neutral white light is the most suitable, as it gives good results for both monochrome and coloured lithophanes and does not change the colour tone of the polymer or the applied colours. Also, LED lights do not heat up excessively, as halogen lamps do, and there are no problems with possible deformation of the lithophane during long exposure to LED lamps. Figure 15 shows a monochromatic lithophane being lit up from the front and not the back. This shows there is a big difference in being lit up from the front or the back of the lithophane. Figures 16 and 17 compare the monochrome lithophane being backlit by LED light or whit a halogen lamp. We can observe that there is a great difference in the colour tone of the motif. Figures 18 and 19 show the same comparison as the later one, but this time using coloured lithophane with the third method i.e., using acrylic varnish. Again the difference can be seen immediately.

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Figure 15: Monochrome- no backlight   Figure 16: Monochrome – LED   Figure 17: Monochrome - halogen

Figure 18: Coloured lithophane - LED   Figure 19: Coloured lithophane - halogen

4. DISCUSSION

It turned out that the final image of the motif was most affected by the orientation of the lithophane during printing, where the upright orientation proved to be better. The back thickness and layer height also significantly affect the final quality. Where the 0.5 millimetre back thickness presented minor problems when printing, the 2.0 millimetre thickness stopped too much light when exposed. At higher values of layer height, longitudinal lines started to appear, which negatively affect the image of the motif. The results show that the best parameters are the upright orientation, the back thickness of 1.0 millimetre and layer height of 0.12 millimetres. These parameters ensure stability during printing and the cleanest image where even the smallest details can be discerned.

Findings in colour reproduction show that the easiest method is the technique of printing on paper with a Inkjet printer and attaching the cut-out to the back of the lithophane. This gives satisfactory results, especially if the original image is lighter and brighter. The use of chemicals, on the other hand, is more complicated. The technique using acetone did not transfer a sufficient amount of colour to the polymer, which is reflected in the final result, which is not satisfactory and the coloration of the lithophane does not occur when illuminated. There was also deformation of the polymer at the edges where the lithophane curled. If we are not limited by time, electrophotographic printing in combination with acrylic varnish gives the best results. Here, the colour is well transferred from the sheet to the polymer, and thus the influence of the paper when light penetrates through the lithophane is eliminated. In this case, the image is the brightest, where all the details are visible, and sufficiently colourful.

The last experiment dealt with the influence of the colour temperature of the lights. We compared the LED light and the halogen lamp. It turned out that the halogen light emits too warm a light, thus causing the final motif to acquire an orange tone over the entire surface of the lithophane being observed. This can be used as an artistic approach, as you might do with a horizontal orientation when printing a lithophane, but especially for coloured lithophanes we do not recommend the use of a halogen lamp. Also, the halogen lamp emits a lot of heat, which can have negative consequences on the PLA polymer if the lithophane would be illuminated for too long. This could otherwise be prevented by using more temperature-resistant thermoplastics. Despite everything, the results show that the best reproduction of both monochrome and coloured lithophanes is achieved using neutral white LED lights. In both cases, we recommend lighting the lithophane in darker rooms if we want the motif to be seen as best as possible.

5. CONCLUSIONS

With the production of our lithophanes, we have shown that the 3D printer is a suitable tool for reproducing works of art in the relief form that is typical of lithophanes. With appropriate parameter settings (infill density, layer height, back thickness) in the printing process and upright printing orientation, we can produce high-quality lithophanes. As long as, after the 3D printing is finished, the lithophane is processed appropriately, e.g., with acrylic varnish, satisfactory colour reproduction can also be achieved when using a neutral white LED light.

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