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Recreating the Relief of the Temple of the Jaguars: Exploring Digital and Analogue 2.5D Printing of Mesoamerican Imagery

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Abstract

Digital and analogue printing methods are studied for reconstructing a Mayan decorative relief from the ancient temple of the Jaguars. Height maps, image files encoding height information as intensity values, were produced in commercial image editing software from early 20th century photographic records. Physical height was generated in different materials through analogue printing processes including casting and embossing from photo exposed polymer plates, and digital processes including 2.5D elevated printing and stereolithography. The surface geometry of the outcomes from the analogue processes was recorded using photometric stereo to obtain feedback on the translation of the grayscale range onto relief. 2.5D prints produced with Canon Elevated Printing and stereolithography were used for comparison and qualitive assessment. Differences, parallels and sustainability of the processes are discussed.

Introduction

The geometric concepts for 3D design, are exchangeable from one application to another, nevertheless, there is still a gap when it comes to surface appearance, as most printers have limited capabilities for appearance reproduction. For designing a virtual surface, it is possible to apply layers of physical effects as texture maps (roughness, height, diffuse). Diverse software programs, such as Blender and 3DsMax allow the user to create and render geometry and physically based surfaces, while Substance Painter allows the creation of the appearance of procedural materials and painting directly on mesh. 3D printers face the challenge not only of colour reproduction, but also of surface appearance like gloss and translucency which influence colour perception, when it comes to physical reproductions of these digital files.

2.5D printing is an approach to appearance printing by generating a physical relief in addition to the colour, texture and gloss of a surface. 2.5D printing can be achieved by commercial digital 2.5D printers and has a long history in traditional printing and photomechanical reproduction [1].

2.5D and heritage

A remarkable application of modern digital 2.5D printing in the reproduction of heritage, was achieved by Factum Arte and Canon Production Printing (CPP), in the reproduction of the Tomb of Seti I [2]. The data from different recording systems, Lucida, FARO scanners, and photogrammetry/panoramic photography, were used to create a facsimile and a virtual tour. Relief panels printed by CPP were the basis of plaster reliefs, while the colour was printed on flexible skins made from elastic fabric and fitted on top of the plaster casts. Some of the missing colour information was recovered from the watercolours painted by Giovanni Battista Belzoni in 1817. The purpose of making full sized facsimiles of temples is to allow visitors to explore the *aura* of an original [3] while protect them from the damage caused mainly by humidity and pH changes derived from the presence of numerous visitors [4].

Printed reproductions allow the public to engage with accurate replicas of ancient artefacts [5]. When the original no longer exists the missing information has to be gathered from different sources and put together to approximate an interpretation either artistically [6] or algorithmically [7-9]. Recreations then can be made either manually [10], digitally [11] or in a hybrid process [12-13].

This study uses the hybrid approach to 2.5D printing aiming to narrow the gap between digital and analogue technologies in the 21st century through the recreation of an outstanding example of Mesoamerican art and world cultural heritage, lost in real life, but preserved in image archives. The Lower Temple of the Jaguars is one of the most significant buildings of the archaeological site of Chichen Itzá, located in Yucatan, Mexico. Chichen Itzá has the greatest richness in iconographic representations of the Mayan area and Mesoamerica in general. A large number of artistic reliefs covered walls, columns, pillars and boards, exterior and interior, like tapestry. Originally, these reliefs were covered by a very thin layer of stucco and were painted with a whole range of colours, such as burnt red, green, yellow, black and Mayan blue. The soft limestone that was chosen for most of these works facilitated on the one hand the sculpting of very fine details but, on the other, it also led to its destruction by water, abrasion and internal chemical processes. Only few reliefs with their original painting and colouring remain, mostly on specimens that have been kept buried or in some way protected from the weather [14].

The iconography embodied in stone, has helped archaeologists to understand the history of its inhabitants, their art, their vision, their achievements and their complex rituals. The walls of Chichén Itzá depict 500 years (600-1100 AD) of history. Being an ancient centre of pilgrimage, Chichén is today a significant cultural heritage site for all cultures of Mesoamerica and modern Mexico. It was declared world heritage site by UNESCO in 1988 [15].

The relief and polychromy of the Lower Temple of the Jaguars, were only preserved in hand-tinted photographs. The original still can be seen in a deteriorate state but the surface has lost all the coloured stucco. The archaeologist Alfred Maudslay photographed in black and white, and the painter Adela Breton coloured the photograph with watercolours to add more detail and colour. McVicker [16] suggests it was Alfred Maudslay who first requested that Breton make copies of the murals found at Chichén Itzá. She would travel then to the site to copy the colour of the wall [17]. The reproduction of the polychrome frieze of the Palace of Stucco in Acanceh is another example of artistic work from Adela Breton where she traced and coloured a 13x2 m relief in full scale [18].

The history, cultural achievements, and resilience of Mesoamerican heritage in present day culture, is continuously reinterpreted and discussed. Although until the early 20th century many of the ancient sacred sites, such as the ones of the Maya Area, were in decay and just about to be erased by the harsh weather, the 20th century brought technological advancements for recording, as well as public awareness of the need of preserving, rescuing and systematically studying the material traces of the Mesoamerican realm prior to contact with western cultures. The range of tools and materials for design, fabrication and imaging, open opportunities to decode or creatively exploit the early approaches to represent and preserve what today is human heritage, even though those representations do not fulfil present-day Cultural Heritage standards.

Methods

The coloured photograph of the east wall of the Lower Temple of the Jaguars is held by the Bristol Museum and Art Gallery (cat. Ea8494) and was provided as a digital file for this study.

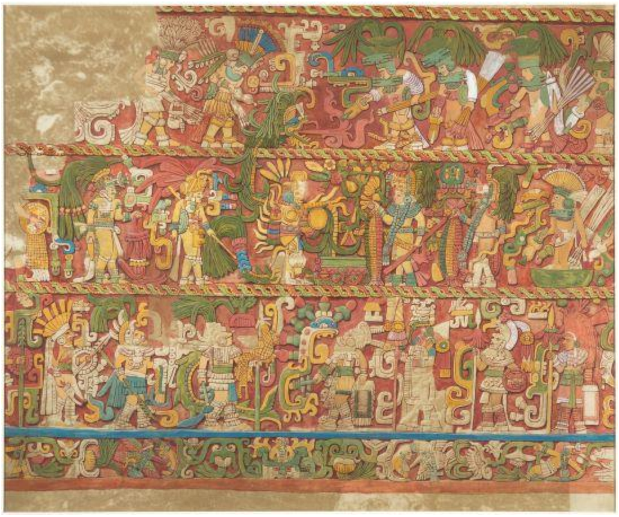

Figure 1. *The Lower Temple of The Jaguars by Alfred Maudslay and Adela Breton (cat. Ea8494) © Bristol Museum & Art Gallery*

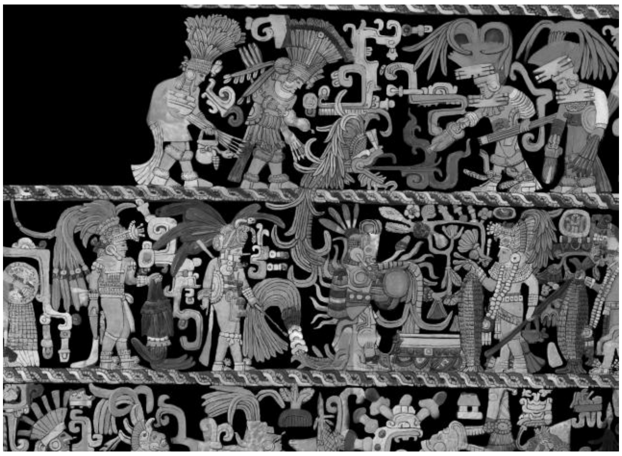

Figure 2. *Section of height map from Ea8494, where the background is the darkest area*

For this work a height map that resembles the relief of the original stucco was digitally made. A height map is a 16bit grayscale image where the intensity values correspond to height values. The darkest areas represent the lowest height and the clearest ones correspond to the highest areas. The colour image was manipulated in Photoshop to separate the figures from the background. Knowing that the image represents a relief where the characters are salient, the procedure for separating lower parts from higher consisted in an initial rough selection of the background based on colour similarities using the 'Colour Range' tool, followed by a fine manual selection of the background areas not included in the selection due to missing colour, and deselection of areas that were initially selected but belonged to the salient characters. The final selection is then obscured, and the image is converted to grayscale. The contrast is increased to enhance the difference in intensity between foreground and background. The texture or luminance intensity variations in the clearer areas of the relief were expected to produce additional microgeometry in the printed surface [19]. Fig 2. shows the file produced after this process. The transference of a height map to physical surfaces has been tested using three methods: Analogue printing using embossing plates, elevated printing, and 3D printing (SLA).

Analogue printing using embossing plates

Water-wash photosensitive printing plates were used for casting a relief in plaster and water-based resin. Depending on their hardness, thickness, and base material (metal or film), photopolymer plates have diverse applications such as general printing, tag, label, textile, varnish, offset, embossing and pad.

The process for generating prints via photo-embossing is indirect as it involves producing an inverse relief on a photopolymer plate cured with UV light, and using the plate to cast a positive relief in other curable materials, such as silicon, Jesmonite or even ceramics. For hardening the plate to the desired level of relief, the intensity of UV light is regulated by the height map printed on a transparent film and placed between the photopolymer and the UV lamp (Fig 3.b). The varying opacity of the heightmap regulates the thickness of cured material and the relationship can be determined quantitatively by measuring opacity and the height for a given intensity of UV light. Flexo-photopolymer plates are often cured in industry in a digital process. We chose to work with the analogue process as it does not require to having an IR engraving unit for direct printing on the plate.

To get a negative relief on the plate, it is masked from the back with the negative height map, in which higher areas appear darker. The deepest depression is produced in the darkest regions of the grayscale mask. To obtain a negative height map the image is inverted in the editing software.

Canon Elevated printing

2.5D printing adds relief (elevation, height) to a 2D print. Canon Elevated Printing Technology uses UV curable ink to create 2.5D prints[20]. Elevation is created by superimposing successive UV ink layers. Each layer is 4 – 40um thick. After each layer the ink is cured. Elevation is build up with one or more ink colors. In default setting all colors are used resulting in blackish elevation layers. The build up elevation is covered with a white layer . On top of the white cover layer color is printed to create a full color print. Canon Touchstone is an application for Canon Arizona flatbed printers. It offers Elevated Printing up to 1mm height. Within Canon Production Printing facilities in Venlo, the Netherlands printing up to 5mm or higher is possible on prototype printers.

Input file formats to create Elevated Prints are 3D mesh files (like .STL, .OBJ) or a height map. A Canon raster imaging processor converts color and heightmap files into slices, containing elevation, white and color data, that can be printed automatically.

Conversion of height map into geometry

The positive height map was used to generate a mesh in 3DsMax software by the following procedure. A planar mesh surface and its material are created. The heightmap is then plugged into the displacement slot of the material. The material has a parameter where is possible to change the minimum and maximum height. A minus sign in the displacement level creates depression and a positive sign extrudes a positive surface. The displacement within the material is used to get live feedback of the level of relief, once achieving a convenient the level of displacement a displace mesh modifier is added to the model which enables "baking" the parameters into the plane altering its topology. The number of polygons in the mesh affects the resolution of the image. The mesh can be saved as .STL or .OBJ file suitable to be used in 3D printers.

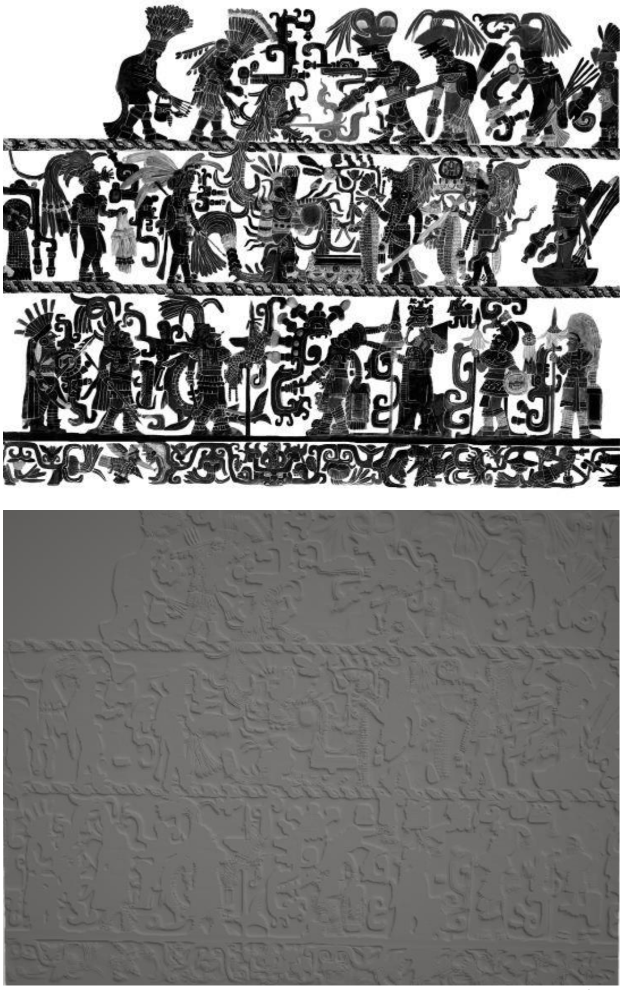

***Figure 3.** top: negative heightmap, bottom: 3D mesh extracted from positive height map*

Stereolithography

Stereolithography (SLA or SL) is a resin-based 3D printing based on vat polymerization [1] A Formlabs 3 SLA 3D printer was used to print the relief produced as described above. SLA's UV light source is a laser, precisely controlled by rotating mirrors to "draw" out each layer being printed.

Experimental conditions and materials

Photo- embossing with polymer plates

Variable depth is generated in a photo-sensitive polymer by exposing the surface to a variable distribution of UV radiation. The plate is masked with film with a grayscale image. The variable opacity of the grayscale regulates the exposure. When exposed to UV light, the polymer cures in depth in proportion to the incoming light. Height differences in the plate are revealed when the uncured polymer is washed-off with water. When casting the surface of the plate with a curable material the depression in the plate is transferred as positive.

Photopolymer plates

Water-wash photosensitive printing plates were used for casting a relief in plaster and water-based resin. For this project, Toboyo Printight® plates (cat. No. KF95GC) mounted on transparent mylar film were used. The photopolymer has a spectral sensitivity between 300-400nm, a resolving capability of 150-200 lines/inch, a minimum dot image of 0.10mm in diameter (0.004"), and a minimum line image of 0.03mm in width (0.0011"). The material has a hardness of 67' shore degrees, a thickness of 0.95 mm which allows a relief depth of 0.68 mm [25].

Exposure

The photo-sensitive polymer plate is masked with the negative height map (Fig 3. Top) printed on film and is exposed to UV radiation. The exposition to light between 300-400 nm, cures the plate, hardening the photopolymer in proportion to the irradiance received by the surface. For revealing the height differences the uncured photopolymer is washed-off in water at 40 degrees Celsius.

Exposures were made in a Natgraph self-contained exposure unit. The optimal exposure time for making embossing plates preserving details was found to be 200 units (High). According to a calibration made in November 2021 this is equivalent to an integrated intensity of 645.38 mJ/cm^2_measured in the UVA region (340-390nm). To continue curing the plate after washing-off the uncured polymer, the plate is dried thoroughly and exposed to another 500 units or 1450.284 mJ/cm^2.

***Figure 4.** Photopolymer plate after exposure and washing-off, in the final stage of curing.*

Casting

The plates were varnished with sandarac varnish and left dry for a day to make them water resistant. Jesmonite AC100, a water-based resin and silicon Smooth-Sil™ 960 were used for casting the surface of the plates according to the supplier instructions. A cardboard box was adapted to provide walls to the plate. Afterwards, a reusable wooden frame was built for durability.

The purpose of making a silicon cast is to preserve the detail of the surface for future analysis and reproduction, given that the exposed plates bend and become stiff after several days of being made. A second cast from the relief in silicon is taken in the same material. This cast has the same indentation and depression as the plate. Relief copies in clay have been made by press moulding using the silicon negative cast to explore whether the relief is preserved and visible after biscuit fire and glazing.

Canon Elevated Printing

For Canon Elevated prints, once a 3D model of relief or a heightmap exists, the printer will create the target height distribution given a maximum height set by the user. The minimum and maximum height in the prints correspond to the whitest and darkest values of the heightmap. Elevated technology is capable of printing relief in colour. It creates the colour in the upper layers by halftoning process.

Stereolithography with Formlabs printer

A 3D model of the Temple of the Jaguars was made in 3DsMax from the original height map. A 14x14 cm square section was prepared for printing. It was necessary to add thickness to the mesh otherwise the printer would cure a single layer and the surface would not be continuous. The mesh was uploaded to PreForm software. Supports were generated automatically and the plate was printed diagonally. Layer thickness was 0.05 mm in grey resin V4. Printing time was 19 hours 35 minutes.

Results

Figures 5-8 show the results from each method.

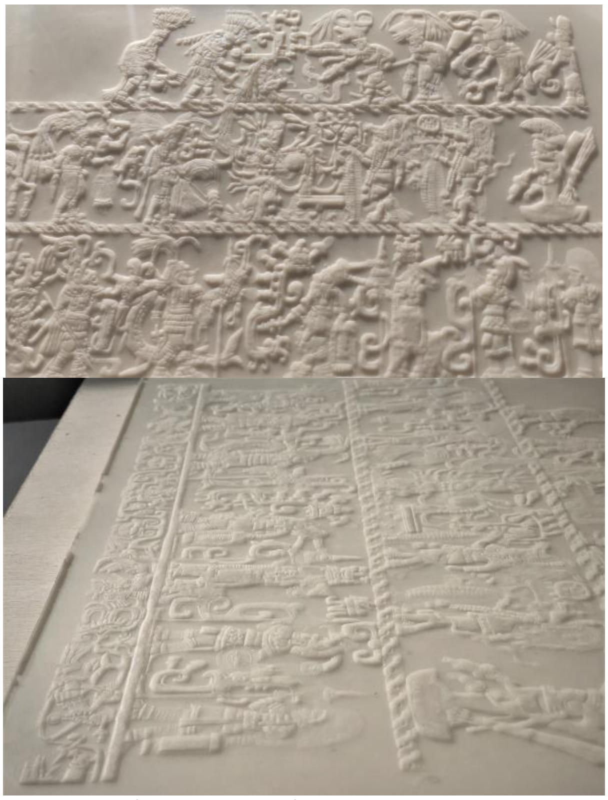

Figure 5. *Relief in Jesmonite cast from photopolymer plate.*

Elevated prints were supplied by Canon Production Printing. In this method, grayscale values are translated linearly into height values. The negative height map was corrected to guarantee an even distribution of values in the grayscale. Reducing the number of dark values in the histogram prevents the relief from appearing too flat at higher elevation. Manual correction was applied to the curves by the supplier correction of curves in Photoshop, these were set to 70 (input) =40 (output). The elevated prints were produced with colour with a maximum height of 1 mm and 2 mm for comparison.

Figure 6*. Left: grayscale after histogram correction, right: Relief print in colour produced by CPP*

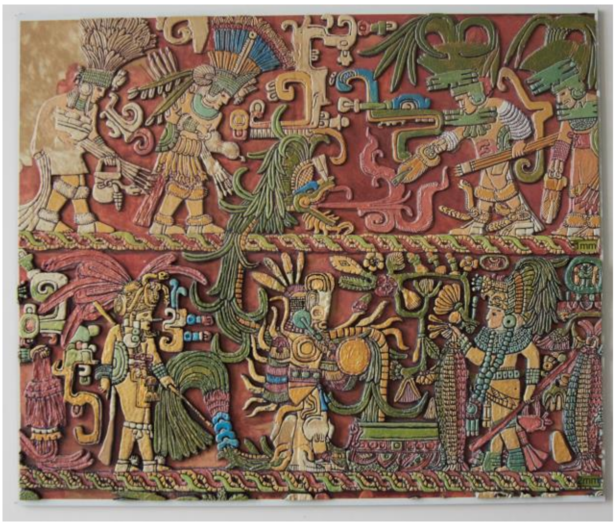

Figure 7. *Relief made by elevated printed in 1 mm and 2 mm height*

Figure 8. *Surface relief printed by stereolithography*

Photometric stereo

One of the reliefs in Jesmonite was recorded using photometric stereo (PS) to obtain feedback on the translation of the grayscale range onto relief in an analogue process. PS technique uses shading information to extract 3D information at per-pixel level. PS capture consists of photographing an object several times from a fixed position but illuminating it from multiple angles. The relief was captured using a custom illumination dome with 24 LEDs and a Sony A7RII camera fitted with a 50mm lens. Processing of the image set was done with the open-access software developed by Cultural Heritage Imaging [23] to recover surface normals and the Poisson formulation of surface reconstruction algorithm as in [24] to integrate into height field. Fig. 9 shows a fragment of the height information recovered with this method. The recovered height map differs visibly from the height map source. There is a cloudy appearance all over the image that resembles a noise pattern overlapped to the original image. The characters in consequence appear with more blur on the edges. When reconstructing the surface in 3D we observed that the borders are less sharp than in the original model (Fig b) and that medium contrast zones are more likely to generate lower relief. Higher contrast changes are made soft in the analogue between perceived grayscale gradients by the human eye and the actual opacity of the film.

Figure 9. *Height map generated from photometric stereo.*

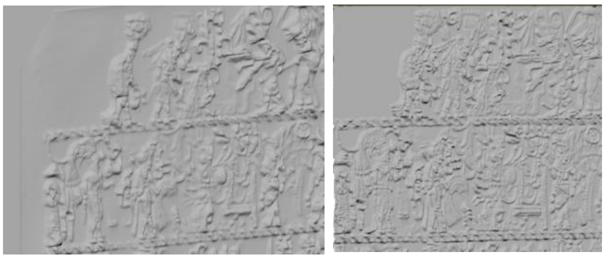

Figure 10. *a) 3D visualisation of height map from print. b) 3D visualization of source height map*

Discussion

We have employed three fabrication methods for the recreation of relief from heritage imagery, which allowed us to have an overview of the state of 2.5D printing for design applications. We have exploited the concept of height map using an analogue approach, where height is directly recovered in a photo-sensitive plate, and two digital ones: elevated printing and stereolithography in combination with a computer graphics program. In this way we compare a bespoke application for 2.5D printing with a 3D printing method.

Jesmonite is a material widely used by architects, manufacturers and the creative arts to make laminated structures or cast pieces. Relief casting in Jesmonite from a photopolymer plate is a viable application for art making and design given the detailed relief, finishing and resistance that is possible to achieve.

Analogue relief making, is an accessible technology since most printing workshops will have access to an exposure unit. However, this method has physical and digital variables (exposure parameters, optical qualities of the film, intensity values in image file, resolution) that make achieving the correct height scale given a target relief of certain physical dimensions challenging. So far, heightmaps have been generated manually from available records, making colour adjustments to the images. The resulting prints have a suitable relief effect, however, this is not necessarily accurate in relative scale.

The creation of the height maps from hand-tinted photographs required user intervention -in editing the images, darkening some areas to make them appear lower, manipulating curves, etc.-, which makes the process highly dependent on the user skills and decisions, and therefore poorly repeatable and transferable.

The aim at this stage, however, is not to recover the relief with accuracy but to understand how digital development, tools and materials can be combined. This paper considers learning through making and how design techniques and artistic methods incorporate industrial technologies in traditional printmaking practices. We have worked with hybrid methods for reproduction of imagery incorporating resources for imaging, in order to document and understand variables in the process of converting images into physical relief. We aimed to articulate physical aspects involved in printmaking techniques, to promote knowledge exchange between science and arts.

To improve transferability of the analogue method based on photo-embossing, future work will include the design of a digital pipeline to generate accurate height maps, which requires the characterization of the physical height of the prints as a function of the opacity values of the height map.

For improving the appearance of the prints produced by Elevated Printing technology, taking advantage of its capability to print relief in colour, we are investigating ways to model and print the characteristic roughness and texture of a stucco surface.

From the methods explored, stereolithography produced the result with less resolution in comparison with the analogue prints. Time required for printing with a resolution of 50 microns requires more than 19 hours for printing a surface of 14 x14 cm and 1 cm thick. It is possible to increase the number of polygons and resolution, but that would increase the printing time up to 27 hours. Table 1. presents an overview of the characteristics and requirements of the different methods.

Conclusions

Relief of the Temple of the Jaguars has been generated from images in a simple way using a combination of industrial resources and artistic processes to investigate how geometrical representations acquire meaning, overlap, or diverge when transferred from the virtual to the physical, and between the digital and the analogue, comparing what different methods have to offer. We explained different methods of generating relief and our insight on how to continue improving and learning from the hybrid digital-analogue approach. In terms of accessibility and cost, the analogue process has potential for continuing to be used as an accessible, artistic and educational approach to 2.5D printing.

Table 1: Comparison of methods

	Elevated printing	Analogue printing	STL
Printing in colour	Yes	No	No
Relief file	Height map/3D	Height map	3D
Resolution in area	400 dpi	only limited by resolution of film	Limited by 3d
Max. height	5 mm	0.6 mm	> cm
Materials	Inkjet photocura-ble ink	Photopoly mer plate	Photocura-ble resin
Device	Flat base printer	Nathgraph exposure unit or other UV source	3D printer
Cost	500 -1000 Euro per sqm up to 5 mm	£10 per sheet A4 £10 per litre of silicon £5 kg jesmonite	150 USD per litre

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