Printed 3D coloured objects:
3D ink-jet prints colour properties and colour stability

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ABSTRACT: 3D ink-jet printing is an additive, powder-based rapid prototyping (RP) process. The 3D printing process described in this overview has been developed by ZCorporation and is based on an ink-jet printing technique. The 3D computer models, created by 3D scanning or in 3D CAD modelling software, are built layer by layer from the basic materials of powder and binders. Due to the basic build principle, it is currently the only RP process capable of printing in “full” colour, and uses clear binder with CMY or CMYK coloured binders.

The emerging areas of this 3D printing application has opened up opportunities for expressing new and creative ideas, but at the same time, has presented new challenges for material research. These issues include: the colour properties of 3D prints, the effect of materials and process properties on the achieved colour, 3D printed surface characteristics and methodologies for colour measurement. Furthermore, the question of the colour permanence and stability of 3D prints is a growing issue and considers which methods could be applied to study permanence and how long the prints will last.

1. INTRODUCTION: In the recent years, a new concept of 3D ink-jet colour printing has been introduced. It is an additive, powder-based method of rapid prototyping (RP) [1], and it is originally a mechanical engineering process. The 3D printing process described in this overview has been developed by ZCorporation and the process itself was patented by MIT in the mid 90s [2]. It is based on a digital printing technique ink-jet. The 3D computer models, which have been created by 3D scanning or designed in 3D CAD software, are built layer by layer from the basic materials of powder and binders. The powder is deposited and spread from a chamber or from a powder bed by a roller system. The liquid binder, clear or coloured is ink-jet printed by the print heads, very similar as in classic 2D ink-jet printing systems. The powders are, for example, plaster-based, while the binders are water-based solutions. Figure 1. is a typical example of a 3D printer system, which is the ZCorp. 650 machine. Figure 2 shows an example of a 3D colour print.
To build a 3D object the machine deposits and spreads a thin, usually a 0.102 mm (0.004 inch), layer of powder forward across the build platform. The carriage then moves across this layer, depositing binders in the pattern of the first cross-cut or layer of the 3D computer model. The binder reacts with the powder, thus solidifying it. The rest of the powder, which is not printed with binder, is left loose and dry, which at the same time supports the model that is being built. The piston below the build chamber then lowers the build bed for one thickness of a layer. The cycle is repeated until the model is finished [3]. After the printing, the printed 3D object is de-powdered and usually finished with a selected infiltrant. Due to the basic build principle being based on ink-jet process, the 3D printing process by ZCorporation is currently the only RP process capable of printing in “full” colour, and uses a combination of clear binder (to print “whites” as the powder is more or less off-white in colour) with CMY or CMYK coloured binders. In coloured binders, the colorants are a part of the binder solution. Binders can thus be considered as inks and powder as a layer of substrate in classical ink-jet printing.

3D printing technology has been used for a number of applications in industry, which includes the arts and cultural heritage. Some of application areas include manufacturing and mechanical engineering (for printing concept and functional prototypes, FEA models, packaging design, sales tools, moulds for casting...), architecture, engineering and construction (AEC), education, GIS, health care, entertainment industry, arts and historic preservation. The emerging areas of 3D printing applications open novel opportunities for expressing new and creative ideas, but at the same time, present new challenges for material research, for instance for the artist, especially sculptors, who have successfully started to explore and utilise 3D printing as a new method for creating art. However users have begun to question “How long will the prints last?”, motivating new researcher opportunities to study these issues. Other colour issues include, as for printing technologies in general, the discrepancy between 3D computer model colour and printed 3D object colour, the effect of materials and process properties on the achieved colour, and the basic issue of 3D prints surface characteristics and colour measurements. The utilization of 3D printing in arts and in other new applications is broadening the area of rapid prototyping to the area of production and therefore raises the need for further multi-disciplinary research.

2. COLOUR PROPERTIES OF 3D PRINTS: Colour 3D printing, as a part of RP, has undergone, until recently, only limited research [4]. Colour reproduction, colour measurements, colour consistency and colour permanence are some of the issues that are an integral part of both graphic technology research, and the printing industry. The methodology of quantifying, judging and controlling the colour output has been well researched and is constantly developing further. The question which is raised here is can the methodology developed for dealing with conventional ink-jet printing colour issues, and to what extent, can it be applied to the 3D colour printing [5, 6, 7]. These issues are of importance, as for some specific applications, 3D prints colour properties and stability is of equal relevance as for standard prints.

Colour test charts can be used to observe and monitor colour reproduction, colour gamut, colour differences or as colour visualization aids and can be universal, e.g. a Sample Color Chart from ZCorporation, or custom developed, depending on the application. 3D colour charts can be flat plates or complex 3D objects. Flat plates can be used for general applications, monitoring the reproduction of selected colours or for studying the colour differences. Flat plates, if well designed, are also easier to use when performing the spectrophotometric measurements. The Universal ZCorporation Sample Color Chart, (Figure 3) consists of 9 tiles with a total of 729 colour patches. For specific applications, custom colour charts can be developed, as they can contain specific number of patches and feature the selected colours. Some of custom designed and printed test colour charts in the form of plates are shown in figure 4. Flat test plates can also, for instance, be placed in different positions relative to the x, y and z axes, so the reproduction of colours on horizontal, vertical or angled surfaces can be observed, which is an issue in 3D colour printing.
Complex 3D colour test objects can be used for observing and examining the colour reproduction on both flat and curved surfaces, depending on their design. An example of one custom designed 3D object is presented in figure 5. The object can be coloured in the desired colour, some of which (R, G, B; C, M, Y, earth, sky, silver, gold, black, white) are shown. Printed objects can be infiltrated with different finishing agents, for e.g. showing the impact of the finishing agent on reproduced colours and the size of the object can be also scaled.

Due to the several operational and cost efficiency factors, coloured binders are printed on the approximately last 10 layers of an object. The 3D computer model can have colour applied in several ways: surfaces can be coloured directly or colour can be applied as a part of the texture (an image file, usually a jpg or tiff file type). The 3D digital data also needs to be saved as a type of file that can, in addition to the geometry information, contain the colour information, for instance as a vrml, 3ds, ply, zpr file. Other than in 3D CAD software, colour can also be applied in ZPrint, or more specifically in ZEdit Pro, ZCorporation proprietary 3D printing software, also by direct colouring of the surfaces or by texture application. If colours are applied directly, either in 3D CAD software or in ZPrint, they are selected from a palette or by their specific coordinates, most often in a RGB colour space. The colour charts can, in addition to their technical aspect of use, also be used as visualization aids for 3D technology users, such as designers and artists, allowing them to correctly pre-view the colour as it will look on the printed and finished prints. If the colour charts and objects have colour information (names, marks or colour coordinates) attached to the specific colour, they can also be used as a tool which
enables the users to select colour based on the obtained output, in a sort of colour reverse – engineering process. In order to use standard graphic arts methods and procedures for 3D prints colour measurements and monitoring, there are certain things that need to be respected. One of the issues is the surface of 3D prints, which differs in degree of roughness and has a specific texture as well, which is due to the object build process, printing mechanism and the structure of the basic powder material used. The appearance of colour depends on the surface structure and characteristics of the powder material, and there is also a certain difference in colour between variously finished 3D prints, as infiltrants have specific optical, chemical and physical characteristics and thus influence the print surface. Surface structure and variability also need to be taken into account when selecting the appropriate instrument and measuring geometry for 3D prints colour measurements. In our previous and on-going research, we have used a sphere spectrophotometer (d/8° measuring geometry) for measuring the colour of 3D prints. Sphere spectrophotometers are commonly used in industries in which colour is often measured on textured surfaces.

3. COLOUR PERMANENCE AND STABILITY OF 3D PRINTS: Colour permanence and stability of 3D prints is a current topic of our research and is an interesting area since the specific standards, procedures and prints aging behaviour, for the most part, still need to be refined and developed in more detail. The issue of the stability and permanence of prints and paper has been long explored, especially in archiving and ink-jet photo printing, a number of principles and methods for testing have been developed. Colour permanence of 3D prints is still being researched, so proper methods, based on the existing ones, need to be confirmed or defined. The colour longevity and stability of prints depend on a number of factors, such as light, humidity, temperature, exposure to ozone, gas, which, separately and/or in combination can influence the prints. Our current research includes testing of 3D prints permanence and stability by using accelerated light fastness tests and natural aging of prints, exposed to the various factors (light, humidity, temperature). The prints have been infiltrated with different finishing agents, so the impact of the finishing agent on the permanence can be examined as well. The colour test plates for these purposes have also been custom designed, as colour test plates and objects, as well as the visualization aids, is another area of our research.

3. CONCLUSION: The 3D printing colour capabilities, colour measurements methodology and colour permanence and stability were described and discussed. Based on the data presented in this overview, it can be seen that, for specific applications, colour issues in 3D printing are as equally important as colour issues in conventional ink-jet printing. Graphic technology methods developed for dealing with conventional ink-jet printing colour issues can, to some extent, be applied to issues arising in the recently developed field of 3D colour printing. 3D printing colour properties and methodology are currently more extensively researched and should be further broadened to study the permanence and colour stability topics.

REFERENCES: