Permanence and Color Stability in 3D Ink-jet Printing

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Abstract

In recent years, the possibility of color three-dimensional printing has been introduced. The process described in this work is by ZCorporation, and is currently the only process enabling full color printing. The basic materials are in the shape of powder and binders, clear and/or colored. In order to obtain final mechanical and surface properties, 3D prints are almost always post-processed with a selected infiltrant. Since color printing was made possible, the use of 3D printing was further broadened to specific application areas, e.g. AEC, archeology and cultural heritage preservation, fine arts and design, spatial planning and public-display of models. As the application in these emerging areas requested potentially more durable 3D prints than in the native RP/CAD applications, the color stability, an integral part of the prints permanence properties, was raised as a topic of interest for both, the researchers and the users of 3D technology. This work will discuss emerging research issues in 3D printing for selected applications, as well as describe and present examples of our current and developing work on permanence and color stability in 3D ink-jet printing.

Introduction

3D printing is classified as an additive rapid prototyping process, producing objects from the powder material which is fused by ink jetting the binder [1]. 3D printing technology described here is based on conventional ink-jet printing, with powder and liquid binders as basic build materials. Due to the use of colored binders, in CMY or CMYK combinations, it is currently the only RP method capable of producing objects in full spectrum color. Therefore, it is possible, to some extent, to study it using standard and modified methods for research of conventional prints, especially in the area of color properties and reproduction. 3D printing process, its characteristics, object production and issues relevant to specific applications has been researched in number of studies; mainly form mechanical engineering, product development and specific applications (bioprinting, medicine) perspective. The issue of color in 3D printing has also recently started to emerge in some studies [2, 3], though there is still limited amount of literature and published data available.

3D printing is inherently a RP process, with first and most important applications in mechanical design, concept modeling and visualization models, thus the question of permanence of 3D prints has not been a key issue. Since then and especially after the addition of color, the applications of 3D printing have been also in areas such as AEC, GIS and spatial planning [4, 5, 6], preservation of cultural heritage and archeology, and, quite recently, in fine arts and design [7]. This has opened the question of longevity of 3D prints, of which the color stability is an integral part. The work presented uses selected standard ink-jet prints measurements methodology for studying 3D ink-jet printing color and stability.

Basics of 3D Color Printing

3D printing is an additive RP process, with basic materials being in the form of powders and water-based liquid binders. The process is based on ink-jet printing; using a method of jetting the binder material in a form of controlled droplets which join the powder particles together. CAD model of the object that is being printed is sliced in layers, which are then consecutively being built. For the each layer, the powder material is evenly distributed over the printing surface at the desired thickness and then selectively joined by jetting the binder material on the predestined locations, slices of the CAD model. The build bed is then lowered and the process is repeated until the object is completely built. During production, the object is supported by the surrounding non-printed powder. Upon completion of the process, the printed object is cleaned from the unbound powder and most often finished with the selected agent.

In the case of 3D color printing, the colorants make part of the binder solution. The binders are water-based liquids, somewhat similar in composition to the ink-jet inks. 3D printing process reproduces color, as in standard ink-jet printing, on the basics of subtractive color mixing, meaning the primary printing colors are cyan, magenta and yellow binder. Recently, the machine which also employs the black ink binder was introduced. The systems use 2, 4 or 5 printheads to distribute the binder, depending on the printer model. Due to several reasons, the colored binder is applied only to the surface area of the prints, approximately in last 10 layers. Higher or lower shell saturation ratio, which relates to the amount of the binder applied to the specific location, can also be selected. Color 3D prints need to be infiltrated in order to obtain the final color properties [8].

Color Permanence and Stability for Relevant 3D Ink-jet Printing Applications

As mentioned, due to the emerging application areas of color 3D prints, permanence and color stability of 3D prints has recently started to be an issue. In such applications, 3D prints are expected to last for specific amount of time, with their properties, including mechanical, surface and thus color, remaining acceptable to all relevant users. The open questions are the color reproduction possibilities of 3D color printing, possible better control to obtain maximum of achievable color output and, most recently, 3D prints permanence, especially lightfastness and color stability, including the development of the appropriate measurements methodology, description of aging mechanism and characterization of properties of 3D prints. The evident nature of 3D prints, the fact they are three-dimensional also leads to the possible issue of color appearance being different on various sides and geometry of the object and varying color stability, as the amount of light intensity which specific sides of the object are being exposed to could lead to them not reaching the same level of fading.

An example of these application areas is production of architectural, landscape and especially city models for display purposes, usually in places like city halls, museums and other various public spaces. 3D prints here serve as semi-permanent or permanent models which need to maintain the required appearance for specific duration of time. One of these examples if the city of Zagreb, Croatia, whose area has been digitalized and 3D virtual model was created using photogrammetric mapping of rooflines and Digital Terrain Model (DTM). The center urban area was then printed as a 3*3 meters large color 3D model, Figure 1, which was procured by the Zagreb government for their department of spatial and urban planning and was publicly displayed, in transparent casing with open top, in the Zagreb City hall. The model which is currently exhibited consists of 120 panels, which are a part of about 500 panels that were made [9]. The model is intended to be further broadened by assembling together printed panels of other areas of the city and should be exhibited in one of museums. This example covers some of the mentioned issues with color and stability of 3D prints, such as the variation of color output, which infiltrant has been used, based on achieving adequate mechanical and best available color and permanence properties, under what conditions, light, casing, temperature, humidity will the model be display, at what time span will the additional panels be added to the original model and for how long is it expected that the model will be used.

Figure 1. *3D printed model of city of Zagreb, © Ib-procadd*

Other example of using 3D prints as public display models is the model of the Sečovlje Salina, Slovenia, which is one of the largest such models in the world. The 3D model was printed from the digital model based on digital relief model (DMR) and digital orthophoto (DOF) of saline, and is 4.5*3.5 meters in dimension, assembled from 172 panels, Figure 2. It was finished with epoxy based infiltrant, and later further protected by employing polyurethane-based UV varnish on top. The 3D model is displayed, un-covered, as a central object in Multimedia Centre in Sečovlje. Other than the large 3D model, a smaller model, measuring 1.05*1.25 meters in dimension, for visually impaired people was also produced, containing Braille's writing [10]. This is of possible interest since the model is therefore going to be more handled by visitors, introducing another element to the issue of durability.

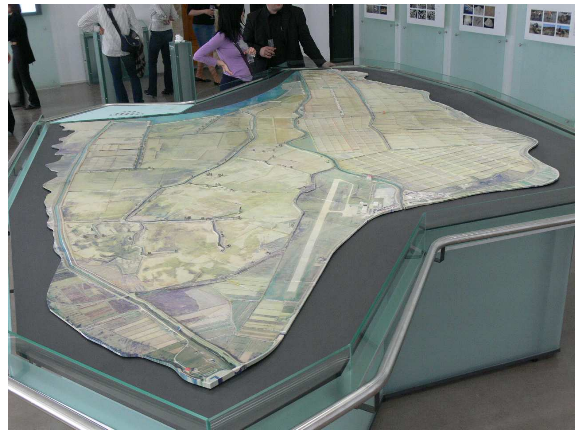

Figure 2. *3D printed model of Sečovlje Salina, © Ib-procadd*

Other example of this kind is also the 3D model of settled part of Šaleška Valley, Slovenia. The 3D digital model was created on the basis of digital panoramic photographs, digital relief models and other archival written documentation and images, measures 1.5*1.5 meters in dimension and contains 30 panels. The 3D color printed models was as well infiltrated with epoxy-based finishing agent and glazed with polyurethane-based varnish, mounted on a vertical board and is publicly displayed outdoors, near the hayrack in town Gaberke in Šaleška Valley [11], Figure 3. The displayed model is placed in glass casing, and turned in such position that it is not under the impact of direct sunlight. This application of 3D models is interesting due to the fact that the 3D printed object is displayed outdoors.

Figure 3. *3D printed model of Šaleška Valley, displayed at the site near town of Gaberke, © Ib-procadd*

Color, permanence and stability are potentially also relevant to the application of 3D prints in preservation of cultural heritage, especially for reproduction of replicas of specific works of art and other artifacts, which could be used for either presentation or education purposes. This application already uses the 3D scanning and its use is further increasing as a method for digitalization of objects for preservation, so 3D printing of such obtained digital models could be the next step. Other application area is fine arts and design, where the 3D printed objects are regarded as an author works of art and are often exhibited in galleries, museums, various exhibition places and in some cases could also be displayed in open places. The question which is additionally raised here is how important is permanence as the object could be easily reproduced again when it changes in its properties above the specific end point. But, if digital methods of object production are regarded as just a mean of expression and creation, it could be said that reproducing the object again interferes with that concept, although it is up to the author to decide on how to treat this production process.

3D Prints Color Properties and Stability Research Examples

Our current research in color, permanence and stability in 3D ink-jet printing can be roughly divided into topics of color measurement methodology, lightfastness and color stability measurement methodology and related color and permanence properties of 3D prints themselves.

As it has been long studied, the research on color permanence and stability in standard printing, especially in the areas of digitally printed photography and conservation of printed matter, has been presented in vast number of studies, books and other literature sources. The procedures of testing in this area are more or less standardizes, and also described in work of, for instance Wilhelm Imaging Research, which does extensive work on stability and preservation of both traditional and digital photographs and digital prints [12, 13]. Next to that, there are a large number of institutes, universities, other organizations and individuals active in this field which do specific research on the topic of permanence of printed matter. Lightfastness properties are dependant primarily on type of colorant used, type of substrate and properties of light that the material is exposed to, and also to factors such as area being solid or half-tone, color density, properties of coating if is present. In addition to that, 3D prints are most often infiltrated, with the infiltrant being usually present either just in the surface area of specific depth or penetrating through the whole print structure. Color 3D ink-jet prints which are discussed here can be considered as a system comprising of powder, binder, with the colorants making part of the binder, specific infiltrant and additional varnish or coating that can sometimes be applied on top. Therefore, research of both color and permanence properties of 3D prints opens possibilities and questions on the specific measurement methodology and 3D prints properties.

Color properties of 3D prints were studied using graphic technology based methodology, which proved adequate for characterizing the 3D printed output. Determination of basic color reproduction possibilities of 3D color printing and impact of finishing method on the final 3D printed output color properties was studied, along with the determining the most adequate color measurements methodology. For the purpose of the work, both standard ECI 2002 V, with just profiling part of it being used, and custom made test charts were employed. The 3D test plates were created by applying the mentioned test charts on 3D models of constructed plates as textures. The color properties were measured using sphere geometry spectrophotometer, GretagMacbeth (X-Rite) XTH. The impact of specific infiltrants on achieved color was discussed and it was found finishing method is detrimental to the final color and surface appearance. Other than 3D test plates, our work in collaboration with University of West of England, Centre for Fine Print Research, also included development of custom 3D color test object, which enabled the reproduction of colors on different sides to be studied.

The permanence and color stability has, for now, been focused on some preliminary work in the subjects of lightfastness test methodology and lightfastness properties of 3D prints. The current work has included some preliminary accelerated aging by exposure to xenon-arc light, in Xenotest, and natural aging testing.

The accelerated aging procedure was used in order to study the impact of light on differently finished samples, as they would be exposed to when displayed indoors, behind window glass. Xenon-arc based light was used for accelerated aging since it, when used with appropriate filter systems, simulates window-filtered daylight better than some other light sources used [14]. Xenon-arc light source is therefore routinely used in various industries for accelerated aging, but not that often in the lightfastness testing of standard ink-jet prints, although relevant standards exist, e.g. ASTM D3424 – 09 Standard Practice for Evaluating the Relative Lightfastness and Weatherability of Printed Matter and ASTM F2366 – 05 Standard Practice for Determining the Relative Lightfastness of Ink Jet Prints Exposed to Window Filtered Daylight Using a Xenon Arc Light Apparatus. For the color stability measurements custom developed color 3D test plates were used, consisting of selected basic colors patches, with 20%, 40%, 60%, 80% and 100% ink coverage of C, M, Y, K (obtained by mixing CMY), R, G and B inks. The samples were measured using a spectrophotometer with sphere geometry, GretagMacbeth (X-Rite) XTH. The effect of light on the color behavior has been evaluated by using instrumentally assessed color change of initial and exposed samples. Figure 4 shows an example of initial sample and sample that was exposed to filtered xenon-arc light, cyanoacrylate based infiltrant.

Figure 4. *Example of initial (top) and exposed (bottom) samples*

Figure 5 shows the ΔE color differences of C, M and Y colors for all samples, 100% and 40% ink coverage patches. The ΔE color differences were calculated from L*a*b* values obtained from spectral data. The difference between specific colors is noticed, also between patches with different amount of ink present, and the samples finished with different methods. For the infiltrated samples, the finishing agent used has specific aging behavior which than affects the overall color stability properties of the 3D prints. As there is variation in color stability of primary printing inks, the colors which are printed by mixing will also be affected. The results of the comparative testing show some of the basic properties of color stability and can be further used in defining parameters for continuing research, resulting in development of methodology for predictive testing for specific uses of 3D prints.

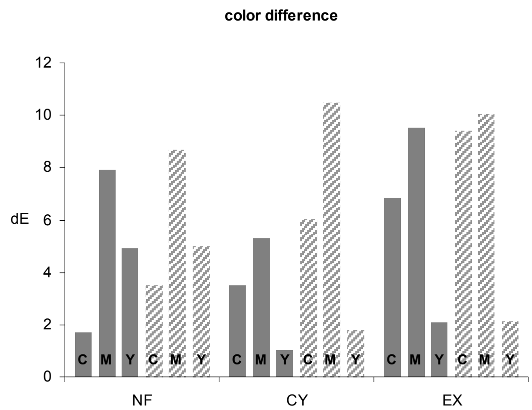

***Figure 5.** ΔE color difference of basic colors; 100% ink coverage patches filled, 40% ink coverage patches striped*

The natural aging of color 3D prints has also been conducted, where the same custom developed color test plates, with mentioned color patches, that were used for accelerated aging procedure, were exposed to various combinations of environmental factors, focused on different types of light sources and mixtures of light sources. In addition, 3D test plates were also printed with higher binder saturation ration, 115%, to observe potential impact of higher than usual amount of ink on color stability. Six sets of samples were printed, and placed in different conditions, varying in type of natural and artificial light prints were exposed to, temperature and humidity. The exposure was in duration of 6 months, from and including February to July. The color behavior after natural aging was again evaluated by using instrumentally assessed color change of initial and exposed samples. The measurements are still running, nevertheless the results are expected to show how combination of different specific environmental factors during natural aging affects the color stability, and give more insight on what are the detrimental 3D prints parameters for color stability.

Conclusions

The work presented discusses the emerging research in 3D printing for selected applications, in which the relevant 3D printed output properties may need to be retained for the specific duration of time, therefore color and stability could prove as an important issue. Examples of such applications are illustrated. It further describes and presents examples of our current and developing work on color and lightfastness in 3D ink-jet printing. The impact of process and material 3D prints properties and environmental conditions is being evaluated. The work uses methodology derived from standard ink-jet prints measurements.

The open research issues include color reproduction possibilities of 3D printing, obtaining maximum of achievable color output and 3D prints permanence, especially lightfastness and color stability, including the development of the appropriate measurements methodology, description of aging mechanism and characterization of properties of 3D prints.

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References

[1] Todd Grimm, User's Guide to Rapid Prototyping, (Society of Manufacturing Engineers, Dearborn, Michigan, 2004).
[2] C. Parraman, P. Walters, B. Reid, D. Huson, Specifying colour and maintaining colour accuracy for 3D printing, Proc. Electronic Imaging, (2008).
[3] P. Walters, D. Huson, C. Parraman, M. Stanic, 3D Printing in Colour: Technical Evaluation and Creative Applications, Proc. Impact 6 Conference, (2009).
[4] I. Gibson, T. Kvan, L. W. Ming, "Rapid prototyping for architectural models", Rapid Prototyping Journal, 8, 2 (2002).
[5] W. D. Rase, Visualization of three-dimensional GIS objects using rapid prototyping technology, GeoViz, (2009).
[6] S. Agrawal, J.P. Antunes, E. Theron, M. Truscott, D.J. de Beer, "Physical modeling of catchment area by rapid prototyping using GIS data", Rapid Prototyping Journal, 12, 2, (2006).
[7] P. Walters, K. Davies, "3D Printing for Artists: Research and Creative Practice", Rapport, 1, (2010).
[8] Z Corporation, Whitepaper: How 3D Printing Works, The Vision, Innovation and Technologies Behind Inkjet 3D Printing (Z Corporation, Burlington, MA, 2009).
[9] S. Franic, I. Bacic-Deprato, I. Novakovic, City Model and Scale Model of the City of Zagreb, Proc. ISPRS/COST-Workshop on Quality, Scale and Analysis Aspects of City Models, (2009).
[10] Ib-procadd, 3D Model of Sečovlje Salina In Multimedia Centre of Sečovlje Salina Nature Park (Ib-procadd, Ljubljana, Slovenia, 2009).
[11] Ib-procadd, Model Showing Settled Part of Šaleška Dolina around Year 1960 (Ib-procadd, Ljubljana, Slovenia, 2009).
[12] H. Wilhelm, A Review of Accelerated Test Methods for Predicting the Image Life of Digitally-Printed Photographs, Proc. Japan Hardcopy 2004, (2004).
[13] H. Wilhelm, A Review of Accelerated Test Methods for Predicting the Image Life of Digitally-Printed Photographs—Part II, Proc. NIP20, (2004).
[14] George Wypych, Handbook of material weathering (ChemTec Publishing, Toronto-Scarborough, Ontario, 2008).

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Maja Stanic (b. 1981) is currently a PhD student at the postgraduate study Graphic Engineering, at Faculty of Graphic Arts, University of Zagreb. She received a Dipl. Ing. degree in Graphic Technology, from the same university (2006). PhD thesis concerns the inner and surface structure properties, color issues and permanence of 3D ink-jet prints. Other research interests include novel printing techniques, developments in digital printing, print quality assessment and image analysis techniques in papermaking and printing technology.