# Gloss goes 2.5D: Comparison of gloss printing in 2D and 2.5D

Donatela Šarić[1,2,*], Tanzima Habib[2] and Aditya Suneel Sole[2]

[1]Fogra Research Institute for Media Technology, Einsteinring 1a, 85609 Aschheim b. Munich, Germany
[2]Norwegian University of Science and Technology, Teknologivegen 22, 2815 Gjøvik, Norway

**Abstract**

In the field of graphic technology, the need for high-quality print reproduction is an ongoing research activity. Gloss reproduction plays a significant role in determining the quality of the printed products. In this paper, we investigate reproduction of specular gloss properties of prints produced using the traditional 2D printing method and the evolving 2.5D (elevated) printing technology. The changes in the specular gloss (60°) across colour patches of the Media Wedge, which are printed with different tone values and combinations of CMYK in 2D and 2.5D prints are compared. The results show a significant differences in specular gloss (60°) changes between the two printing methods, especially for colour reproduction using low tonal values. A simple correction is applied to the printing methods to reduce these differences and obtain a 2D proof for the time consuming and expensive 2.5D (elevated) printing technology.

**Keywords**

2D printing, 2.5D printing, specular gloss, appearance



## 1. Introduction

In graphic technology, the quest for improved print quality is an ongoing research topic. As continuous advancements redefine the possibilities of print production, the interaction between various factors, such as ink application, substrate properties, and finishing techniques, becomes increasingly critical for a better appearance.

Print houses expand their print quality, not only in terms of colour management and reproduction but also in the reproduction of other appearance attributes, such as gloss, texture, and translucency. The expansion to other appearance attributes enables the creation of more realistic images and replicas, while also expanding design possibilities and enhancing visual appeal. Gloss, in particular, plays a significant role in determining the quality of a product [1]. Gloss is defined as an *optical property of a surface, characterised by its ability to reflect light specularly* [2]. In conventional printing, gloss is strongly influenced by factors such as the smoothness and porosity of the print substrate and the reflective properties of the ink or coating applied [3]. The manipulation of gloss appearance can significantly impact the perceived texture, depth, and colour of printed images and objects. By strategically modulating gloss, printers can achieve desired visual effects, ranging from a high gloss finish to a matte appearance, but also add luxury value and special effects to the printed image. [4] These enhancements not only enrich the visual experience but also broaden the creative scope for designers, offering new avenues for innovation and differentiation in printed products.

2.5D printing, also referred to as elevated printing, is a technique that incorporates depth and texture into two-dimensional prints, thereby creating the illusion of three-dimensionality. In contrast to traditional 2D printing, 2.5D printing involves the deposition of ink or other materials in a manner that results in creation of elevated or recessed areas. This process enhances the visual appeal of the printed image by imparting depth and tactile quality, thereby creating a more realistic and engaging visual presentation. By varying the amount of material deposited and the height of the layers, 2.5D printers can produce intricate textures and designs with precision [5]. However, the colour management of

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*Corresponding author.
saric@fogra.org (D. Šarić); syeda.t.habib@ntnu.no (T. Habib); aditya.sole@ntnu.no (A. S. Sole)

such printed objects is more complex than that of 2D printed objects, due to the influence of surface orientation on both colour and gloss appearance [6]. In addition to these factors, the texture of 2.5D printed objects plays a significant role in their overall appearance. As gloss and texture are directly related attributes, it is necessary to control both colour and gloss, which expands the management of colour into a comprehensive appearance management system. [7, 8, 1, 9].

In this paper, we investigate the reproduction of specular gloss (measured at 60°) using traditional 2D printing and the new evolving 2.5D (elevated) printing technology. The specular gloss was measured according to the ISO 2813 standard, at 60° due to the fact that this angle offers a balanced sensitivity to both specular and diffuse reflections, thereby providing a comprehensive assessment of surface appearance. [2] Some research that has been done before in the field of gloss and gloss appearance shows that in the high gloss range, measurements at 20° and 60° yield similar values, while 85° predominantly captures diffuse reflection and thus underrepresents high specular gloss. Therefore, specular gloss measured at 60° is the most representative angle for accurately evaluating gloss in the context of this study. In addition, we propose a simple correction method to reduce the specular gloss difference between the two printing techniques. [10, 11] This correction method aims to align the gloss levels more closely between traditional 2D and 2.5D prints, ensuring a more uniform appearance across different printing technologies.

## 2. Methodology

In order to get a better understanding of the gloss appearance of the two printing technologies, two sets of samples were created. The first set of samples represents 2D printed samples, while the second set represents 2.5D printed samples.

The 2D set of samples includes the Fogra Media Wedge CMYK v3, which contains 72 colour patches printed with different tone values (TV) and different combinations of the primary colours (CMYK). [12] The Fogra Media Wedge is read by almost all evaluation and measurement software and is therefore selected as the media wedge to be printed. The substrate on which the media wedge is printed must be suitable for reproducing a range of glosses, from matte to high gloss. Accordingly, CGS Pear Proof semi-matte paper was used. The measured specular gloss (60°) of the paper was 27.7 GU, which falls within the semi-matte category. The Media Wedge was then printed onto the paper in six copies. On top of each copy of the printed media wedge, different tone values of varnish were applied, particularly 0% (no varnish), 20%, 40%, 60%, 80%, and 100% TV of varnish. The 2D set of samples was printed on a Roland Versa UV LEC2-330 inkjet printer, given that this particular model is capable of printing varnish in a range of tone values.

The printing of the media wedge was done with 720x1440 dpi resolution and 32 passes. This high resolution and multiple passes enhance the accuracy of colour representation, which is crucial for creating a reliable media wedge that serves as a reference for colour consistency. In contrast, the varnish on top was printed with a resolution of 720x720 dpi and 16 passes. Since the varnish layer primarily serves to protect the printed media and enhance its gloss, it does not require the same level of fine detail as the media wedge. After printing, each colour patch's specular gloss (60°) was measured. The gloss measurements were performed with the Canon Surface Reflectance Analyzer SRA-532H. The device is equipped with a built-in camera, which is essential for accurate positioning, particularly given the proximity of the multiple patches to one another. [13] Each colour patch was measured three times by slightly rotating the device in a different direction to control any irregularities in print, like gloss bending on varnish. Gloss bending refers to the irregularities on the surface when applying ink and/or varnish, as a result, lines in the print head movement direction are visible. These irregularities lead to an uneven or distorted surface leading to a surface that appears uneven or distorted. [14, 15] The final specular gloss (60°) was calculated as the average of the three measurements.

**Figure 1:** Fogra MediaWedge CMYK v3 printed in 2D print on a semi-matte paper (left). The applied tone values of varnish are: (from left to right) 0%, 20%, 40%, 60%, 80%, and 100%. On the right is the Fogra MediaWedge CMYK v3 printed in 2.5D print with different print settings and types of varnishes categorised as 1-1, 2-1, 2-2, 1-3 and 2-3

The second set of samples is the elevated samples created by using 2.5D print technology. Similarly to the 2D printed samples, 72 colour patches of Fogra Media Wedge CMYK v3 were printed on a substrate, i.e. a di-bond sandwich panel of aluminium-plastic-aluminium, using a 2.5D UV curable inkjet printer. The 72 different colour patches of size 1.5cm x 2.5 cm were printed flat. First, a layer of white deposit is printed and then a layer of ink is applied using halftoning. Each layer is 35 microns in thickness. Then a layer of varnish is applied on top, such as matte, glossy, or high-gloss varnish, in order to create different levels of gloss. Five sets of 2.5D prints of 72 colour patches on each with varying gloss were created. They are named as 1-1, 1-3, 2-1, 2-2 and 2-3. In 1-1, colour patches are printed using a particular default print setting (Print setting 1). In 2-1, colour patches are printed using another default print setting (Print setting 2). In both cases, no varnish has been applied and the gloss in this case is due to the ink layer itself. Print setting 1 creates glossier colour patches than print setting 2. In 2-2, colour patches are printed with print setting 2 and then a layer of matte varnish is applied that decreases the glossiness. In 1-3, colour patches are printed with print setting 1 and then a layer of satin varnish is applied that increases the glossiness. In 2-3, colour patches are printed with print setting 2 and then a layer of high gloss varnish is applied that brings the gloss units (gu) to be greater than 80 when measured at 60° specular angle. Specular gloss was measured the same way as the 2D prints were measured, by using the Canon Surface Reflectance Analyser [13]. Each colour patch was measured three times in different directions, and the final specular gloss (60°) value was determined by averaging these three measurements. The Fogra MediaWedge CMYK was scaled for both sets of samples (2D and 2.5D) so that the patches were big enough to measure the gloss of each colour patch. The printed samples are shown in Figure 1. Due to time and money constraints, only five variations were completed for the 2.5D set of samples. These were selected to represent a meaningful range of conditions for our study, ensuring that the results are both representative and achievable within our available resources.

## 3. Results

Our investigation focused on several key aspects, including the manipulation of gloss with different tone values of ink and varnish in 2D printing and the manipulation of gloss with different tone vales of inks, print settings and types of varnish in 2.5D printing. The comparison of measured specular gloss (60°) is shown in Figure 2 together with the standard deviation for the three measurements in different directions. The standard deviation did not have any great significance for any of the measured colour patches, which shows that the prints were printed uniformly without any gloss bending, texture or artefacts on the surface of the print. This is important because there is no difference in gloss and no

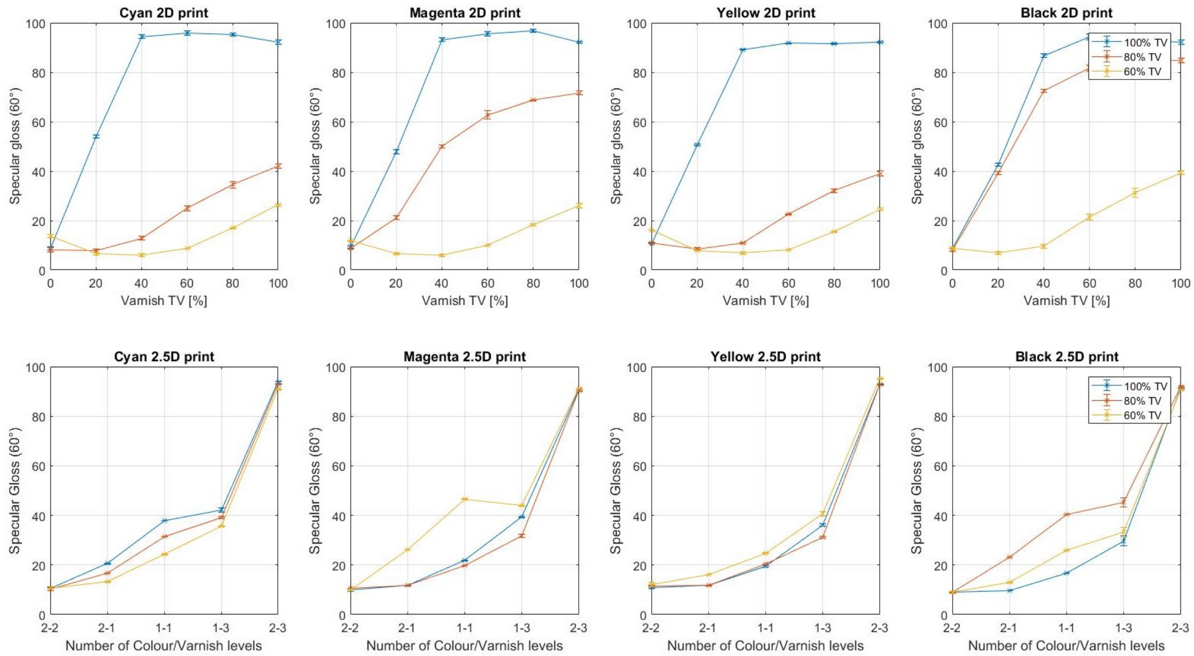


**Figure 2:** Comparison of specular glosses (60°) of the colour patches containing the four process colours (CMYK) reproduced with a) different varnish tone values on colour patches of 100%, 80%, and 60% TV of ink (2D set of samples) and b) different print settings and varnish types (2.5D set of samples)

texture which can happen due to the printer instability. All measurements have been visually inspected and confirmed. For easier visualisation, only the 100%, 80%, and 60% TV of Cyan, Magenta, Yellow, and Black (CMYK) are shown. The 2.5D samples are arranged according to their increasing specular glosses (60°) as follows, 2-2, 2-1, 1-1, 1-3, 2-3.

From Figure 2, it can be confirmed that the specular gloss (60°) does not change in the same way for the two examined printing techniques. In the case of 2D printing, the specular gloss (60°) is consistently the highest when the full tone is printed. This implies that as the tone value of the colour increases, the specular gloss (60°) also rises. In contrast, in 2.5D print, the gloss is similar at all tone values of the colour patch. An exception to this is the magenta and black colour patch where with different print setups, the gloss of the 60% M and 80% K have higher specular gloss than full tones.

Furthermore, in 2D printing, applying 20% and 40% TV of varnish on top of brighter colour patches (60% C, M, Y or K) slightly decreases the specular gloss (60°). This has also been the case in previous work by Samadzadegan et al. [16], but also in the work from Karlovic and Novakovic, where the gloss would decrease with large amounts of applied varnish due to the roughness [17]. In the work from Samadzadegan et al., an almost monotonic relationship was found between the 60° gloss measurements and the varnish coverages for printed full tones. Both sets of samples exhibit a notable increase in specular gloss at a specific point. For the 2D set of samples, the effect on gloss varies depending on the primary and its associated tone value. To illustrate, the greatest increases are observed in the full tones for all CMYK fields. The increase is significantly lower for CMYK reproduced with lower tone values. For the 2.5D set of samples, there is a slight increase with the first four print combinations and the increase is significantly higher when applying high gloss varnish. In light of these findings regarding the primaries, we sought to examine the behaviour of gloss for other colours. To this end, we analysed the specular glosses of secondary colour patches (RGB), given that printing with two or more colours is a more common practice in the printing industry. Furthermore, to extend the investigation, we plotted the specular glosses (60°) of the white colour patch (paper white in 2D print). The results of the measurements can be seen in Figure 3.

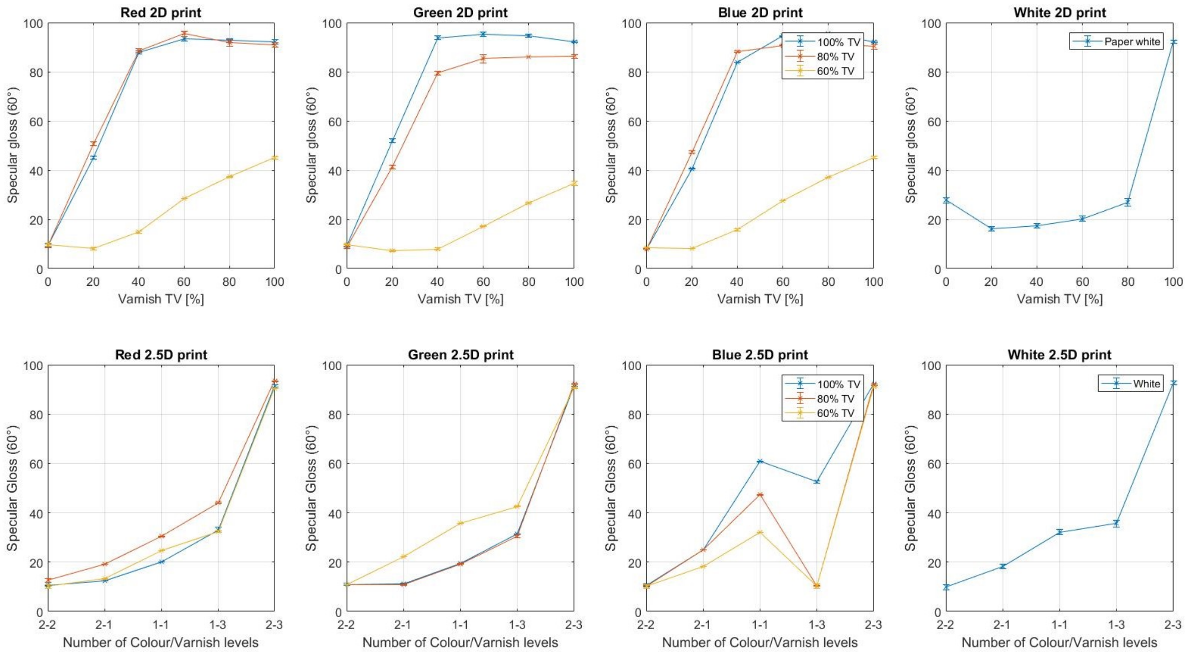


**Figure 3:** Comparison of specular glosses (60°) of the white colour patch and the secondary colours (RGB) reproduced with a) different varnish tone values on colour patches of 100%, 80%, and 60% TV of ink (2D set of samples) and b) different print settings and varnish types (2.5D set of samples)

On colour patches of full tones of red, green, and blue, specular gloss (60°) behaves similarly to the full tones of cyan, magenta, yellow, and black colour patches shown in Figure 1. The distinction lies in the colour patches printed with 80% TV of ink. In particular, in 2D printing, the gloss of colour patches printed with 80% TV increases rapidly with the applied varnish, similar to the full-tone colour patches. Colour patches printed with 60% TV in 2D have significantly lower gloss than colour patches printed with higher tone values. For 2.5D printed samples, the gloss of the secondary colour patches changes in a similar way as the primaries shown in Figure 2.

## 4. Discussion

In the section before it it shown that the gloss changes are not the same for the two printing technologies. The reason for this discrepancy of change in gloss can be due to how each printing technique reproduces different tone values. In 2D printing, colour reproduction relies on subtractive colour mixing, where the white light reflecting off the paper passes through the ink, subtracting specific wavelengths. Less ink means more light is reflected from the white paper, resulting in a lighter colour [18, 16]. In addition, the paper roughness may contribute to the gloss reproduction and as discussed in [19, 20, 21, 9], since roughness has a strong impact on gloss perception. On coated papers, less ink gets absorbed into the paper, leaving ink on top of the paper, thus generating a smooth film. With a smooth paper surface, more light gets reflected in the specular direction, making the surface more glossy [22]. This has been tested before by Preston et al. using laboratory UV-cured offset prints [23]. Their findings show that even though the paper substrates had similar gloss values before printing, after applying coating on them, due to the different paper's porosities, the final prints showed different specular gloss values. Graczyk and Mody [24] investigated the gloss in inkjet print with high loads. In their work, they tested different printers and different loads. The results reveal a big discrepancy in gloss between different printers and different colours. Since the machines used to create the samples in the work are from different manufacturers and use different RIP software for control, slightly different print setups were applied for printing, which can cause this discrepancy. It should be noted that 2.5D printing does not include a white paper substrate. 2.5D printing involves more complex interactions between primary inks and white ink/deposit, which serves as the base layer. This layer is printed first, after which halftoning is applied to create colour patches. To achieve lighter shades of colour, 2.5D printing can utilise a combination of ink layering techniques and the base layer's inherent properties. In 2.5D printing, lower tone values are reproduced in a manner similar to that of 2D printing. However, there is a key distinction: rather than light being reflected from the ink and white paper, as in 2D printing, light is reflected from the applied ink and the base layer, which is primarily a layer of white ink printed over the substrate first. The difference in materials (paper and white ink base layer) also affects the changes in gloss. As demonstrated by Baar et al., the time between the placement of the inks is an important parameter for the gloss appearance. [18] Since the creation of 2.5D prints is time- and money-consuming, a softproof is needed in the reproduction chain. Softproofing is a critical tool in the graphic arts industry for accurately controlling print properties such as colour, glossiness, and texture. It is widely used in 2D digital printing and allows users to preview and adjust colour before print. [25, 26] Softproofing in 2.5D and 3D printing is less common, and it requires surface appearance reproduction of non-planar surfaces. [6] Also, softproofing in 2.5D and 3D often requires special tools (measurement devices, software) and can therefore be extensive. [27] Given these challenges, it is important to develop practical and cost-effective methods for achieving accurate proof for gloss representation in 2.5D prints. Because of that, we aimed to make a 2D hardproof of the high gloss 2.5D print. Therefore, we tested if it is possible to recreate the gloss of the high gloss sample by adding a layer of white ink underneath. With the white ink underneath we would simulate the material that has been used to build the layers in 2.5D. We used the same semi-matte paper, printer, and printer properties to print an additional 2D test chart. On the paper, 100% TV white was first applied. The Fogra MediaWedge CMYK v3 was then printed on the layer of 100% white and then 100% TV of varnish was applied on top of the media wedge.

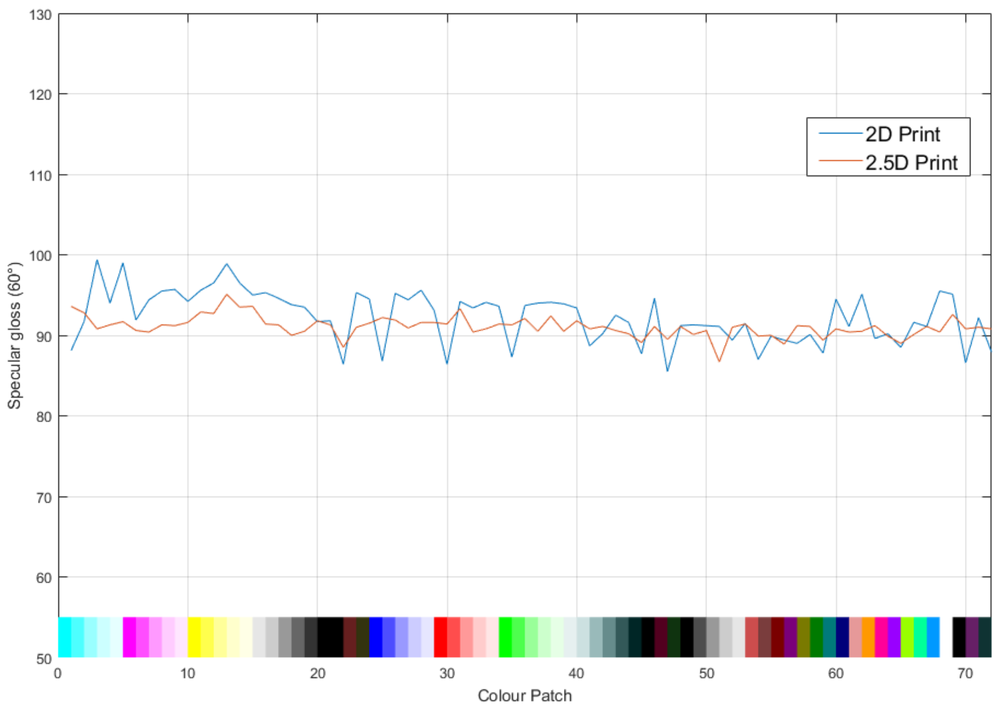


**Figure 4:** Comparison of the specular glosses (60°) of the Media wedge printed in 2.5D with the high gloss varnish (2-3) and the Media Wedge printed in 2D with an additional layer of 100% white underneath the colour patches (proof)

In Figure 4, the specular glosses (60°) are shown for the 2D print with a layer of white underneath and 100% TV of varnish on top, and the 2.5D print with a high gloss finish (2-3 sample). On the x-axis, the colours of the MediaWedge are shown for easier visualisation. It can be noted that the gloss discrepancies between the higher and lower tone values are less expressed in comparison to the gloss changes when printing without a white layer (see Figure 2 and Figure 3). Overall, looking and visually comparing the samples, a match in the gloss appearance is achieved, especially since none of the colour patches exhibit a larger specular gloss difference than 9 GU (measured at 60°). The consistent gloss appearance across various tone values in both the 2D and 2.5D prints highlights the effectiveness of the applied techniques in achieving the desired gloss outcomes. However, the observed differences in specular gloss, particularly in colour patches with higher ink density, underscore the importance of considering ink application and substrate interactions in achieving a uniform gloss appearance.

In Figure 4, the specular glosses (60°) are shown for the 2D print with a layer of white underneath and 100% TV of varnish on top, and the 2.5D print with a high gloss finish. On the x-axis, the colours of the MediaWedge are shown for easier visualisation. It can be noted that the gloss discrepancies between the higher and lower tone values are less expressed in comparison to the gloss changes when printing without a white layer (see Figure 2 and Figure 3). There are still bigger differences in gloss in some colour patches, like the full tones of Red, Green, Blue, and Black printed with CMY. These colour patches exhibit a higher density of applied ink; therefore, the white ink does not contribute to the light reflection. Nevertheless, upon visual inspection and comparison of the samples, a satisfactory match in gloss appearance is achieved.

The focus of our study is the objective measurement of specular gloss (60°). However, the relationship between perceived gloss and specular reflections is a complex perceptual issue and a topic of many ongoing research projects. Specular gloss measurements quantify gloss by capturing light reflection at specific angles, which is related to visual gloss perception. Perceived gloss is influenced by many factors like colour, texture, Distinctness of Image Gloss (DOI) etc. Future research could integrate psychophysical studies with gloss measurements to gain a deeper understanding of perceptual gloss, providing valuable insights for applications where human gloss perception is crucial.

## 5. Conclusion

Our samples show that there is a significant difference in gloss reproduction between the conventional 2D printing technique and the 2.5D printing technique. The first difference is the gloss difference between colour patches with different tone values. When printing the same colour with varying tone values, the gloss will change since the gloss depends on the reflection from both the applied ink and the paper. In our work, we used semi-matte paper; therefore, the gloss was lower for colour patches with lower tone values than for colour patches printed in full tone. On the contrary, for the 2.5D prints, we did not observe such behaviour. For the 2.5D samples, the increase in specular gloss (60°) was constant for most fields, with more minor variations over the colour patches. This difference results from the different colour reproductions in the mentioned printing technologies. In 2D, the colours are reproduced on paper, and the paper's reflection greatly contributes to the final appearance. At the same time, in 2.5D, the inks are placed on a white layer with properties different from those of paper.

Lastly, since creating 2.5D prints is time and money-consuming, making a 2D proof can help reduce errors in 2.5D by overcoming them in the prepress phase. Therefore, we aimed to recreate the 2.5D print with the high gloss reflection. By adding a layer of 100% TV white ink underneath the printed Fogra media wedge CMYK v3, we decreased the discrepancy in specular glosses (60°) between the colour patches printed with different tone values. We increased the gloss overall to the maximum gloss of the printed media wedge, and, most importantly, had a good match between the two print technologies. For future work, this topic will be further investigated by matching different specular glosses (60°) in 2.5D printing, and not only concentrating on the high gloss level.

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