

Converting instrument readings into visual plausible colour measurements

A blue banner for the ICC Color Experts Day event. On the left, the text "ICC COLOR EXPERTS DAY" and "MAY 24, 2019" is displayed in white. Below this, it says "Hosted by Barbieri Electronic". In the center, the text "Colour Management for Wider-Format Printing on Non-Paper Substrates" is written in white. To the right of this text is the ICC logo, which features a stylized eye with "ICC" written above it, surrounded by a circular color spectrum. Further right is a photograph of a modern, curved white building with a grid of small holes, identified as the HQ of Durst Phototechnik AG in Bressanone, Italy.

ICC COLOR EXPERTS DAY
MAY 24, 2019

Hosted by Barbieri Electronic

Colour Management for
Wider-Format Printing
on Non-Paper
Substrates



HQ Durst Phototechnik AG
Bressanone, Italy

Agenda

1. Fogra - Exploring | Testing | Certifying
2. Colour measurement could be so easy
3. But, practically ...
4. Summa

1. Fogra - Exploring | Testing | Certifying



Fogra -
Serving the print industry
for over 60 years

Applied Research

Expert opinions

Testing & Certifications

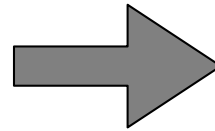
Standardisation

1. Fogra - Exploring | Testing | Certifying

Building setups for measuring fluorescing inks



1. Fogra - Exploring | Testing | Certifying



Providing basis for managing transparent media



2. Colour measurements could be so easy

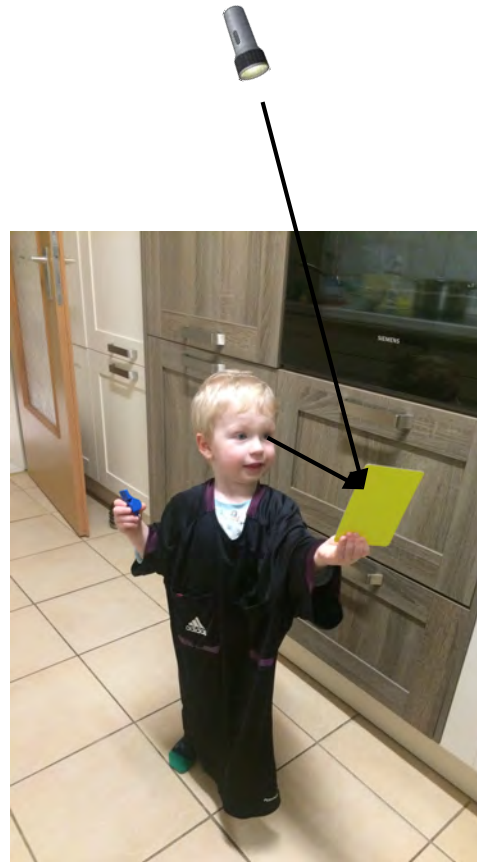
Make sure that you:

Measure as you see!



2. Standardized geometries work fine

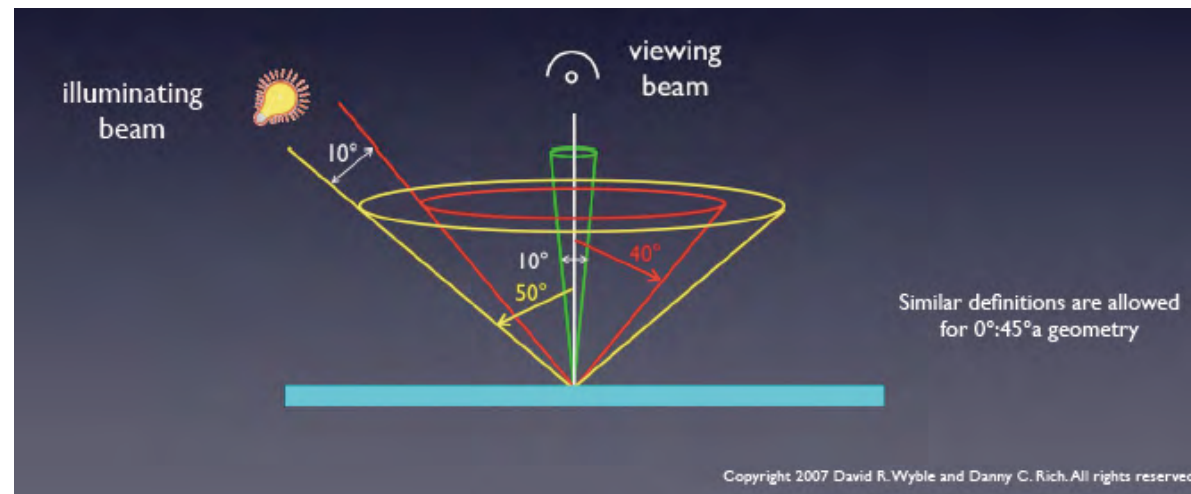
And the best average for actual viewing is (some sort of) directional illumination and (glare free) viewing under 45° → 45°/0°



2. Standardized geometries work fine

Geometry	Old	New	Definition
bidirectional	45/0	45°x:0°	incident at a single azimuth angle
		45°c:0°	circumferential (partial annular)
		45°a:0°	annular illumination
hemispherical	d/0	di:8°	diffuse illumination, specular included, 8° detection
		de:8°	diffuse illumination, specular excluded, 8° detection
		d:0°	used only when detection is at the normal

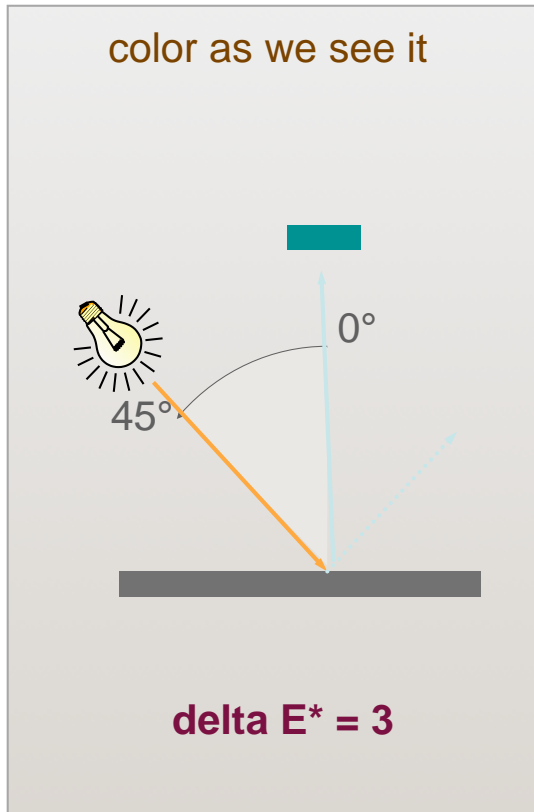
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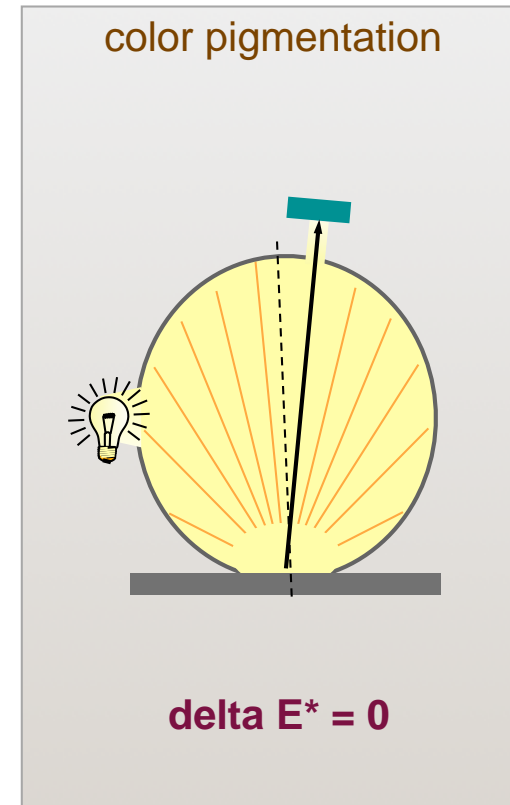
for objects that reflect „normally“ (no lateral diffusion), but with the need for small apertures (no real estate on the prints for control elements ...)

2. Take care what to measure

45°x:0°

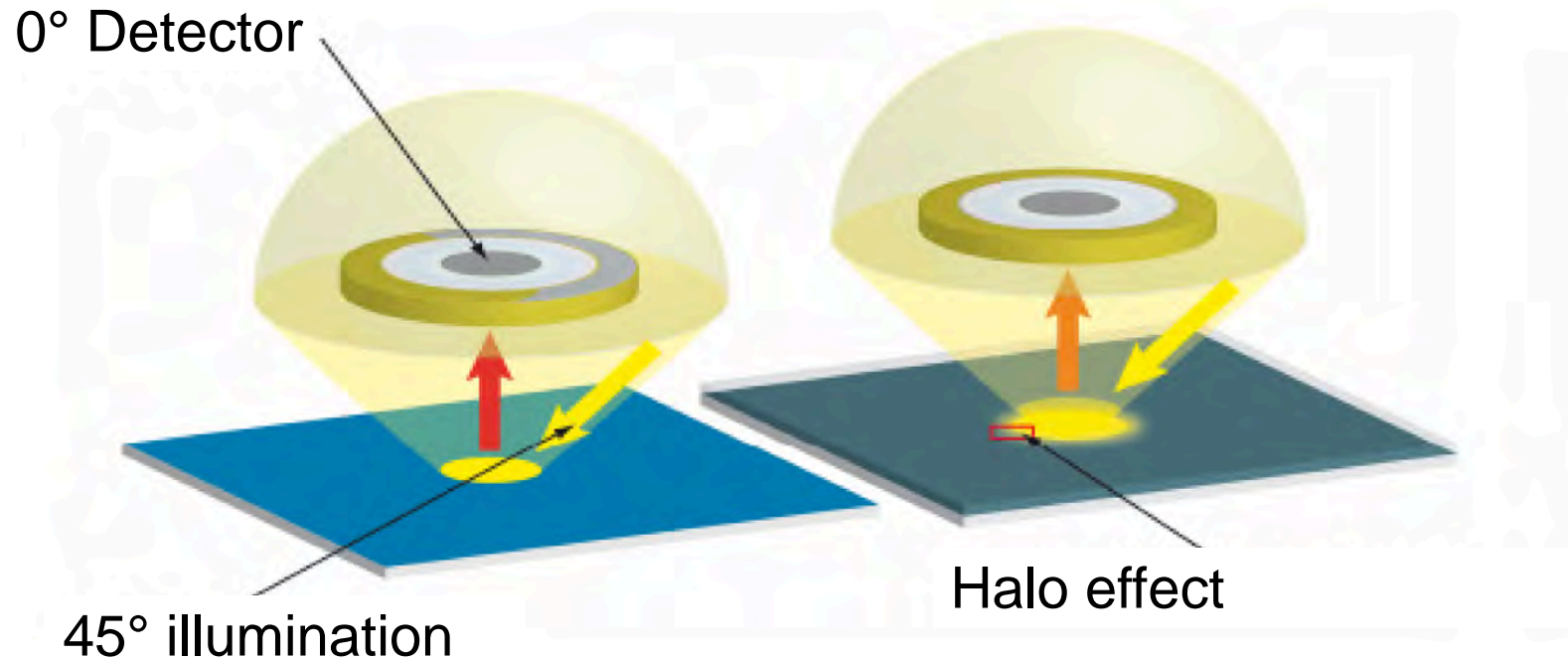


di:8°



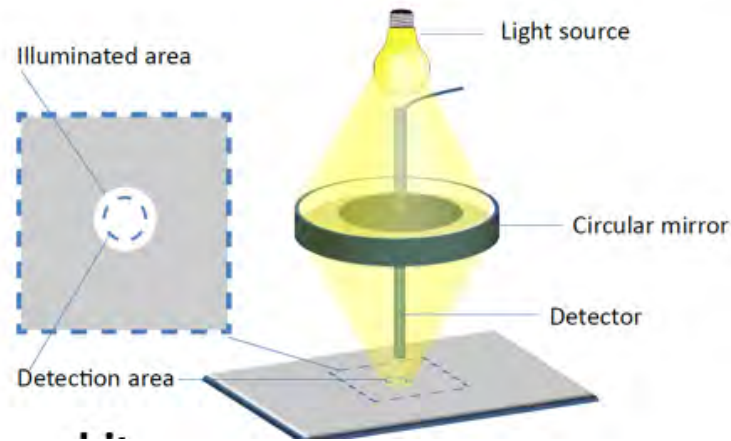
* Specular Included

2. as long as samples are not translucent

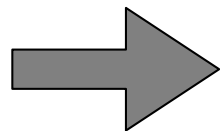


- effect called:
- translucent blurring
 - lateral diffusion
 - subsurface scattering

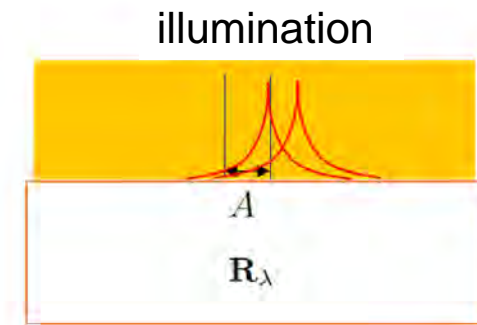
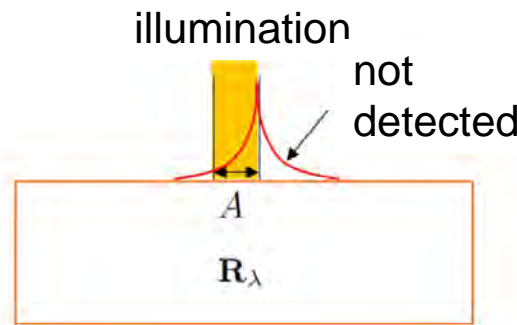
2. ISO 13655 defines over- and underfilling



ISO 13655:2017 cites ISO 5-4 and requires: “the realised boundary of the larger of the illuminator region and the receiver region shall be outside the boundary of the smaller by at least 2 mm.” & opaque reference materials.



non plausible colour values



3. Some materials show lateral diffusion

60x magnified halftone on Polycarbonat

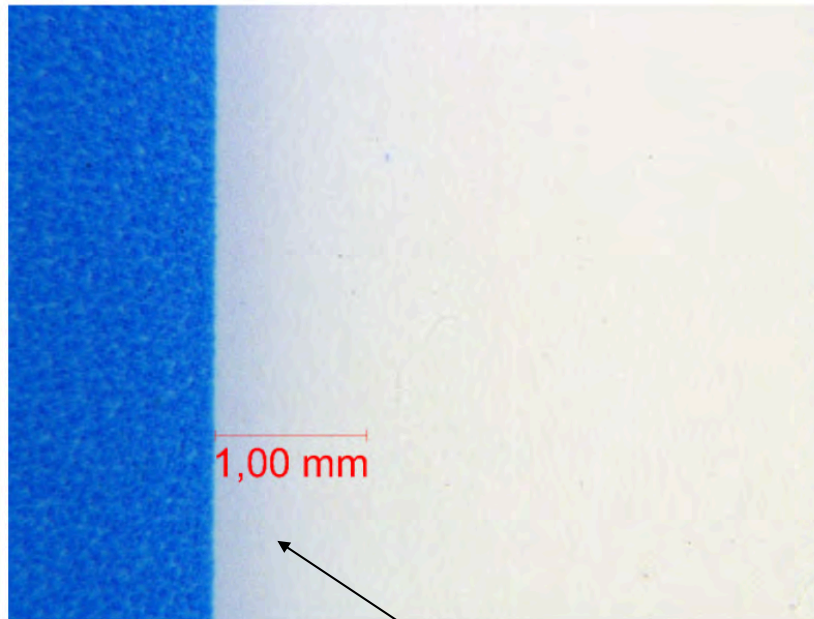


No lamination

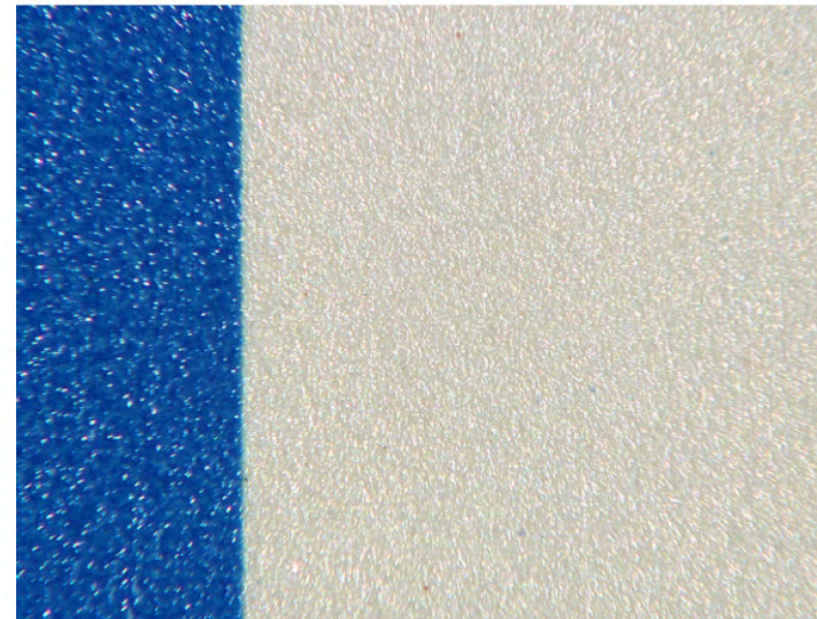
200 µm think Polycarbonat-
Overlay film

3. Some materials show lateral diffusion

60x magnified solid on Polycarbonat



200 μm think Polycarbonat-
overlay film

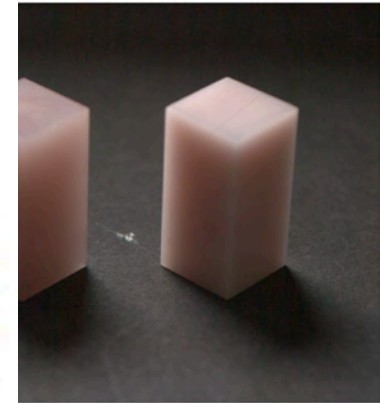
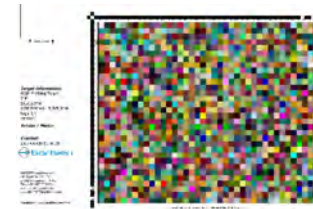


No lamination

Blue shadow ...

3. Also for 3D printing materials ...

pulver and polyjet printing,
which require even more overfilling
3D softproof requires
colour beside 45°/0° (BRDF)
translucency assessment

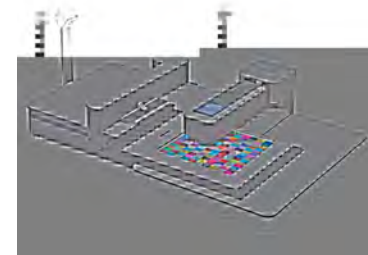
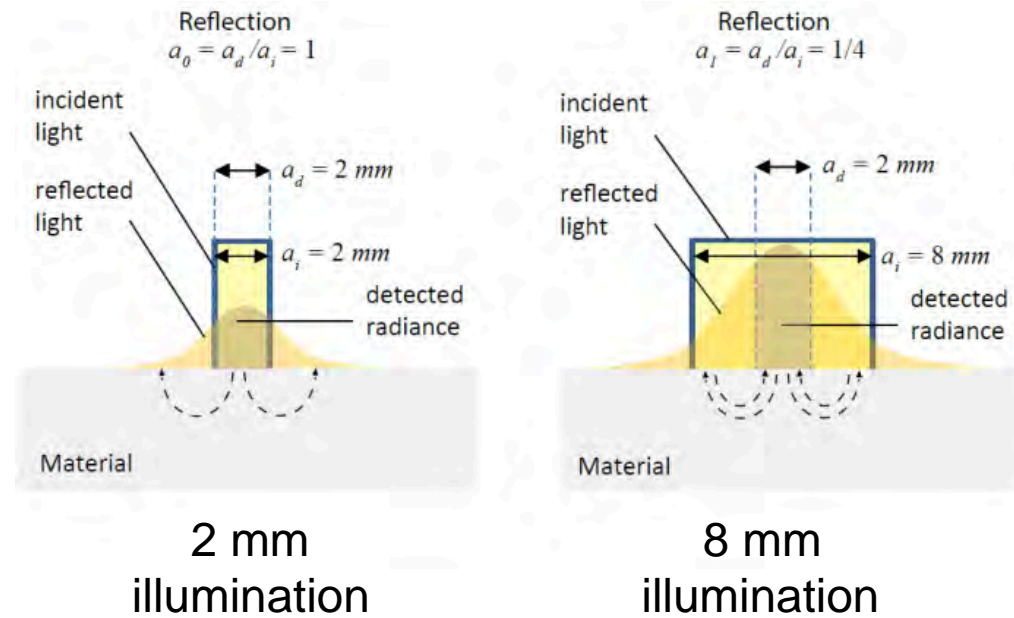


<http://cappsit.s3cloud.de>

3. Proposing a method to measure „halo“

Method „edge loss measurement“ proposed:

based on:



3. Metric details

Optical Material Properties

- BSSRDF reproduction impossible → reproduce albedo color + translucency cues
- Input texture RGBA (already supported by various file formats, e.g. 3MF, OBJ, WRL, X3D)
 - three parameters for color (RGB, CIELAB)
 - one parameter for translucency (A)
 - signal is given on the surface

Measuring Lateral and Vertical Light Transport

Lateral light transport Vertical light transport

Barbieri Spectro LFP: Commercial reflection/transmission spectrophotometer Reflectance 45/0, Transmittance d/0

Defining A (Alpha)

Basis Radiative Transfer Equation:

$$\frac{dI_2(x, \omega)}{dx} = -a_2(x)I_2(x, \omega) - s_2(x)(I_1(x, \omega) - \int_{\Omega} I_2(x, \omega') p_2(\omega, \omega') d\omega')$$

varying (const for λ) varying (const for λ) isotropic

Measuring Lateral and Vertical Light Transport

Simulations of measurements for reference materials

- CAD design of the Barbieri Spectro LFP optical path
- Defined sample size (must be used also for real samples later)
- Solving the **spectral radiative transfer equation** for the reference materials and the viewing conditions
- We used the physically-based path-tracer Mitsuba
- Based on these measurements the Lookup table is created

Redefining A in RGBA: Towards a Standard for Graphical 3D Printing

Philipp Ulfarsson
Fraunhofer Institute for Computer Graphic Research IGD, Norwegian University of Science and Technology NTNU
Teges Madan Tankasale and Alan Brunton
Fraunhofer Institute for Computer Graphic Research IGD
Bui Minh Vu and Shigeki Nakazuka
Department of Computer Science and Engineering, Toyohashi University of Technology

Advances in multiresolution 3D printing have the potential to reproduce various visual appearance attributes of an object in addition to its shape. Since many existing 3D file formats encode color and translucency by RGBA systems mapped to 3D shapes, RGBA information is particularly important for practical applications. In contrast to color encoded by RGB, which is specified by the object's reflectance, selected viewing conditions and a standard observer (transparency) provided by A is neither linked to any measurable physical nor perceptual quantity. Thus, reproducing translucency encoded by A is not an interpretation.

In this paper, we propose a rigorous definition for A suitable for use in graphical 3D printing, which is independent of the 3D printing method and software, and which links both optical material properties and perceptual suitability for human observers. By deriving our definition from the absorption and scattering coefficients of virtual homogeneous reference materials with an isotropic phase function, we achieve two important properties. First, a simple adjustment of A is possible, which preserves the translucency appearance of an object if needed for printing. Second, determining the value of A for a real (potentially non-homogeneous) material, can be achieved by estimating a distance function between light transport measurements of the material and simulated measurements of the reference materials. Such measurements can be conducted by commercial spectrophotometers and in graphic arts.

Finally, we conduct visual experiments comparing the method of constant stimuli and derive from them an embedding of A into a newly perceptually uniform scale of translucency for the reference materials.

Companion and Subject Descriptors:
General Terms: 3D printing format, translucency representation

1. INTRODUCTION

Advances in 3D printing allow the combination of multiple printing materials with different optical properties into a single object at a very high resolution. This allows the reproduction of not only the object's shape but also its visual appearance attributes such as color [Harrison et al. 2015], translucency [Hales et al. 2010; Dong et al. 2010] or glass [Hart et al. 2014].

Many existing 3D file formats encode spatially-resolved information of color and opacity of an object as a RGBA texture mapped to its 3D geometry. This information is widely used in rendering, where the RGB color information is typically mapped to device-independent standard RGB [Stamets et al. 1999] and A (also called α channel) as a blending or mixing parameter to produce transparent overlays in image composition assuming additive color mixture [Porter and Duff 1984]. Such an interpretation is common for 3D file formats, including the 3MF format, which is being pushed by many industry players as a standard for 3D printing. In the core specification [3MF Consortium 2015] the interpretation of A is left unspecified, whereas in the materials and properties extension [3MF Consortium 2018] additive blending is specified, which however also stipulates that the first color layer must be opaque. Thus, translucent objects can not be used at all according to this interpretation; it is purely a mechanism for additively mixing colors in a specified order.

Using an additive color mixture model is simple, computationally efficient and robust for on-screen display, but it has severe shortcomings [Fial 2017]: light is altered by matter subtractively and additively, i.e. many real transparent materials cannot be described by the model. As a result, rendering employing A as an additive mixture parameter are suitable for illustrative purposes rather than accurately simulating the appearance of real objects.

Nevertheless, it is highly desirable to capture perceived translucency of real objects within a single parameter, foremost because it allows the seamless continued use of existing image and 3D file formats, but also because the perceptual dimension of translucency is known to be small [Choudhury et al. 2013]. Therefore, in this paper we present a new interpretation of the A channel in RGBA for use in graphical 3D printing.

For the purpose of reproducing translucent objects by 3D printing, a few properties of A are desired:

- (1) A must be linked to a measurable quantity. Only then, it can be assigned to real materials via measurements and print material arrangements can be adjusted to preserve this quantity.
- (2) For print reproduction, a perceptually uniform scale for A is important, allowing to minimize perceived errors rather than physical ones. The viewing conditions for this scale must agree with the RGB conditions to ensure consistency of color and translucency. In color printing, the viewing/illuminating geometry (color-lighting) is specified by the International Color Consortium [ICC 2000] and is supported by color and spectrophotometric measurement devices employed in graphic arts [D50 Illuminant 2000], which are used to calibrate the printer. This rules out backlighting conditions for specifying the perceptual scale, even though translucency for materials possessing complex light transport properties may appear different for color and backlighting conditions [Khan et al. 2014].
- (3) If an object made of a translucent material is scaled (most commonly shrunk) for printing, it is desirable that average light transport distances can be adjusted accordingly to preserve perceptual translucency cues. Therefore, it should be adjustable to the print size in relation to the original object size as an intuitive, predictable and computationally efficient way.

3D Printing in English, Vol. 19, No. 4, July 2015, Publication date: March 2015

Paper, Data and Matlab- / Mitsuba-Code is Publically Available:

4. Take Home Message



- Since we print on anything which is not running away, there are more materials to come
 - plastics of all sort (including 3D prints)
 - ceramics
 - textiles
 - and many more
- Check your samples to be measured for visual plausibility
 - PSD Practical plausibility check
- Make a measurement as planned
- View that CIELAB value in Photoshop
- Proof that colour by means of a ISO 12647-7 conforming proofing setup
- Compare the sample with the rendering



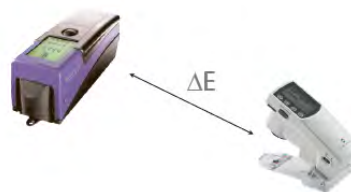
4. Summary

- Question all colour measurements
- Samples with no or less translucency can be measured as expected with 45°/0° geometry
- Use integrating sphere devices for matching physical objects (no appearance)
- Try to establish an uncertainty budget and judge your tolerances afterwards

Why not smaller tolerances?



Inter-Instrument agreement



Inter-model agreement



Intra-model agreement

- Consult available guidance:
 - Technical report to come: „Assessment and validation of the performance of spectrophotometers and spectrodensitometers“
 - Fogra PSD handbook

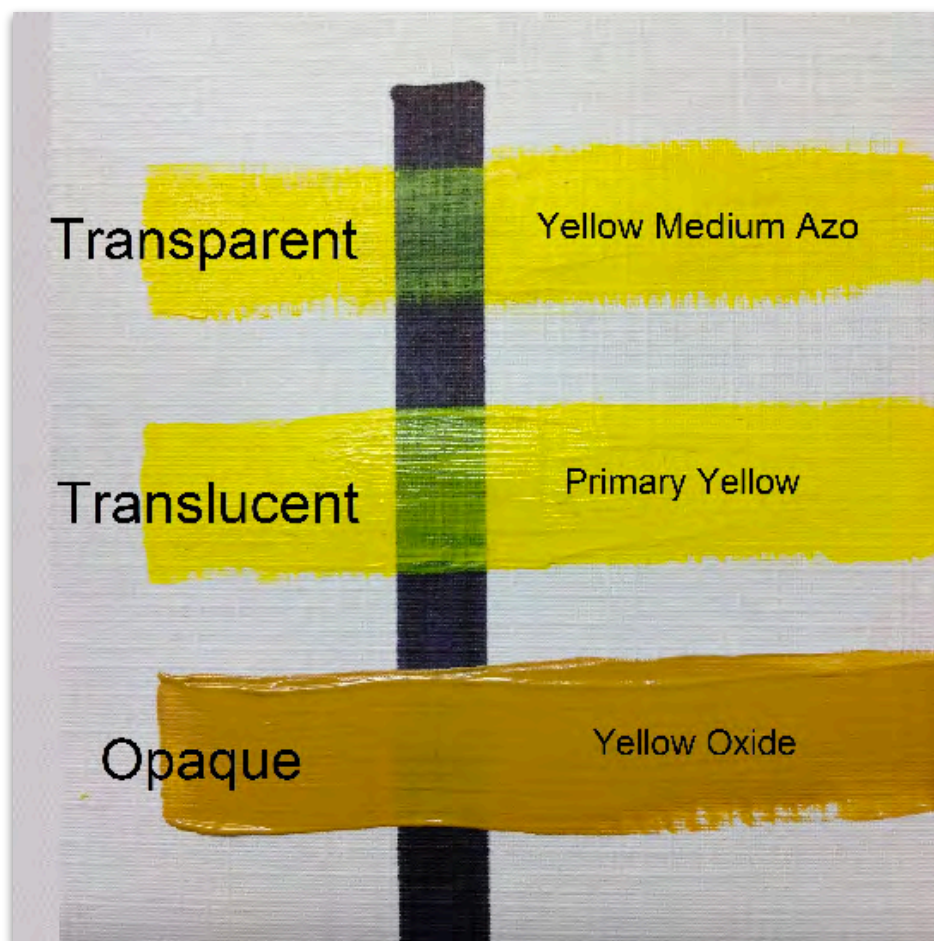
5. Resume

„When you can measure what you are speaking about and express it in numbers, you know something about it“

Lord W. T. Kelvin, Lecture to the Institution of Civil engineers, London, 3 May 1883



Backup



translucency, *n*—the property of a specimen by which it transmits light diffusely without permitting a clear view of objects beyond the specimen and not in contact with it.

translucent, *adj*—transmitting light diffusely, but not permitting a clear view of objects beyond the specimen and not in contact with it.

transparency, *n*—(1) the degree of regular transmission, thus the property of a material by which objects may be seen clearly through a sheet of it.

transparent, *adj*—transmitting radiant energy without diffusion. (1990)

haze, *n*—*in transmission*,
 (1) the scattering of light by a specimen responsible for the apparent reduction in contrast of objects viewed through it. (**D1003**)
 (2) the percent of transmitted light that is scattered so that its direction deviates more than a specified angle from the direction of the incident beam. (**D883, D1003**)