# Workflow for Colour Visualization of Building-Integrated Photovoltaics (BIPV)

**Janina Willmann[1], Aravind[1], Dr. Helen Rose Wilson[1], Dr. Bruno Bueno[1]**

[1]Fraunhofer Institute for Solar Energy Systems ISE, Freiburg, Germany

Presented at the 43rd European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC 2026), Rotterdam, the Netherlands

## 1 – Motivation

- Coloured BIPV modules based on interference coatings often change appearance with illumination and viewing direction.
- **The International School in Copenhagen** illustrates how architectural visualizations can differ from the built façade.
- Renderings based on angle-resolved colour data can support better-informed façade design decisions.





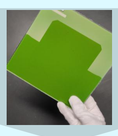


## 2 – Method

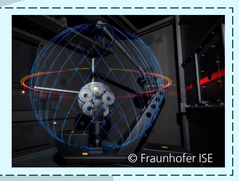
- Successive measurements with three colour filters capture the angle-resolved reflection behaviour of coloured BIPV samples for varying incident directions.
  → three-filter bidirectional reflectance distribution function (BRDF) data
- The data are transformed to XYZ colour space for ray-tracing visualization.
- Three matrices $\boldsymbol{M_i}$, each for a different colour region, are derived from the reflectance spectra of 99 reference colours.

### Rendering Workflow

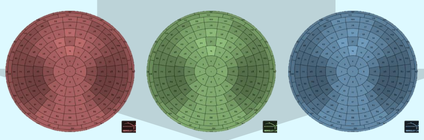
coloured module



BRDF measurement with 3 colour filters → $f_a$ $f_b$ $f_c$ & conversion to Klems format



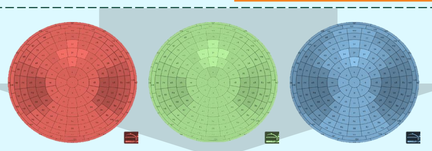

three-filter Klems BRDF



Transformation from device-specific filter colour space to XYZ

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \boldsymbol{M_i} \begin{pmatrix} f_a \\ f_b \\ f_c \end{pmatrix}$$

XYZ Klems BRDF

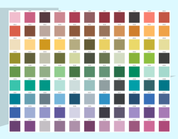


Rendering the scene with a raytracing software e.g. Radiance




### Determination of Transformation Matrices $M_i$

99 colours (reflectance spectra)



Calculation of filter responses




Calculation of reference XYZ values




$$\boldsymbol{F_i} = \begin{bmatrix} f_{ak} \cdots f_{am} \\ f_{bk} \ddots f_{bm} \\ f_{ck} \cdots f_{cm} \end{bmatrix} \qquad \boldsymbol{X_i} = \begin{bmatrix} X_k \cdots X_m \\ Y_k \ddots Y_m \\ Z_k \cdots Z_m \end{bmatrix}$$

Transformation matrix $\boldsymbol{M_i}$

$$\boldsymbol{M_i} = \arg\min_{\boldsymbol{M_i}} \|\boldsymbol{F_i}\boldsymbol{M_i} - \boldsymbol{X_i}\|_F^2$$

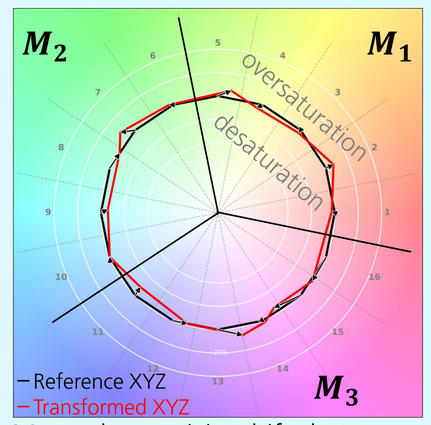
with $i \in \{1, 2, 3\}$

→ $\boldsymbol{M_1}$ $\boldsymbol{M_2}$ $\boldsymbol{M_3}$

## 3 – Results

### Evaluation of the Transformation Matrices $M_i$

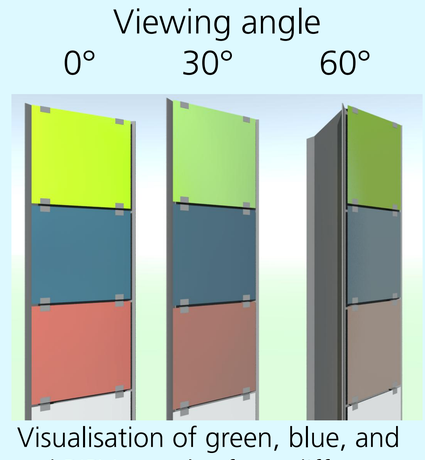
- Transformed and reference XYZ values are compared for 99 reference colours.
- The colour-vector graphic shows mean chromaticity shifts – hue shifts and de-/oversaturation – for 16 colour bins.
- As the same 99 reflectance spectra determine $\boldsymbol{M_i}$, the differences are residuals, not independent validation.




Mean chromaticity shifts between transformed and reference XYZ values for 16 colour bins.

### Application of the Rendering Workflow

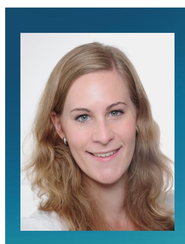
- Green, blue, and red BIPV samples with interference coatings were rendered using sample-specific XYZ Klems BRDF datasets in Radiance `rtpict`.
- The visualization shows viewing-direction-dependent changes in apparent colour under illumination conditions for Freiburg, Germany, on 2 February at 13:20 CET.




Visualisation of green, blue, and red BIPV samples from different viewing directions

## 4 – Conclusion and Outlook

- The workflow converts three-filter BRDF data of coloured BIPV samples into XYZ Klems BRDF datasets for architectural visualizations.
- The visualization shows viewing-direction-dependent colour changes.
- Independent validation with outdoor colour measurements is planned.
- Future work will provide a design tool to facilitate application of the workflow by planners.



Janina Willmann

Solar Building Envelopes
Fraunhofer ISE
Tel. +49 761 4588-5885
janina.willmann@ise.fraunhofer.de

Hong, G., Luo, M.R. and Rhodes, P.A. (2001) 'A study of digital camera colorimetric characterization based on polynomial modelling', *Color Research & Application*, 26(1), pp. 76–84. doi: 10.1002/1520-6378(200102)26:1<76::AID-COL8>3.0.CO;2-3.

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Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101135299.

Project funded by

Schweizerische Eidgenossenschaft
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