

## Advanced Colorimeter

### • Construction Glazing & Building-Integrated Photovoltaic (BIPV) •



Marie Courtant<sup>1</sup>, Elie Flahaut<sup>1</sup>, Antonin Faes<sup>1,2,\*</sup>, Raphaël Margueron<sup>1</sup>,  
Nicolas Fürst<sup>2</sup>, Paul Rémondeau<sup>1</sup>, Aïcha Hessler-Weyser<sup>1</sup>, Fabio  
Manzini<sup>3</sup>, Christophe Ballif<sup>1,2</sup>

<sup>1</sup> PV-LAB, Ecole Polytechnique Fédérale de Lausanne (EPFL), Neuchâtel, Switzerland

<sup>2</sup> CSEM, Sustainable Energy Centre, Neuchâtel, Switzerland

<sup>3</sup> GMP, Renens, Switzerland

## Buildings In The EU

40% EU energy consumption

36% GhG emissions

## Nearly-Zero Energy Buildings

by 2030 (ZEB by 2050)

Energy Performance of Buildings Directive

– European Parliament & Council [1]

Energy perf. of building:



- primary energy consumed
- share of energy requirements supplied from Ren. Energies

Art. 2

## Building-Integrated Photovoltaic (BIPV)

nature reviews clean technology

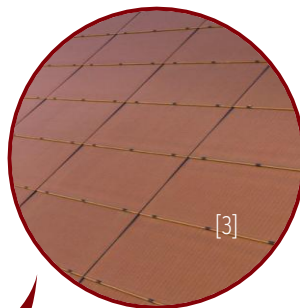
<https://doi.org/10.1038/s4359-025-00059-9>

Review article

Check for updates

## Building-integrated photovoltaics

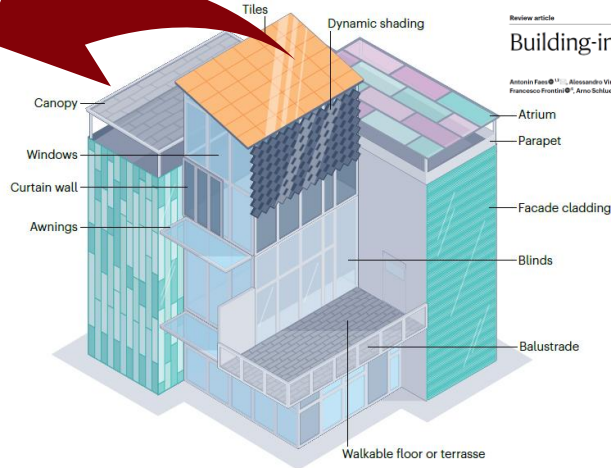
Antonin Faes<sup>1,2,\*</sup>, Alessandro Virtuani<sup>1,2</sup>, Hugo Quest<sup>1</sup>, Lucas Mattar<sup>1</sup>, Alessandra Scognamiglio<sup>1</sup>, Francesco Frontini<sup>1</sup>, Arno Schuster<sup>1</sup>, Laura-Martin Chivard<sup>1</sup>, Angèle Reinhard<sup>1</sup> & Christophe Ballif<sup>1</sup>



[3]

Energy and Buildings  
Volume 314, 3 July 2024, 114253

Colouring solutions for building integrated photovoltaic modules: A review



## Color characterization tool

- Color design – R&D
- Quality control – Prod.
- Degradation – Field

[1] [https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings\\_en](https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_en)

[2] Faes, A., Virtuani, A., Quest, H. et al. Building-integrated photovoltaics. Nat. Rev. Clean Technol. 1, 333–350 (2025). <https://doi.org/10.1038/s44359-025-00059-9>

[3] Borja Block, A. et al. Colouring solutions for building integrated photovoltaic modules: a review. Energy Build. 314, 114253 (2024). <https://doi.org/10.1016/j.enbuild.2024.114253>

## Small-beam commercial tools

A - Colorimeter [4]



B - UV-VIS Integrating sphere spectrometer [5]



White foil + top glass



0

3.2 mm

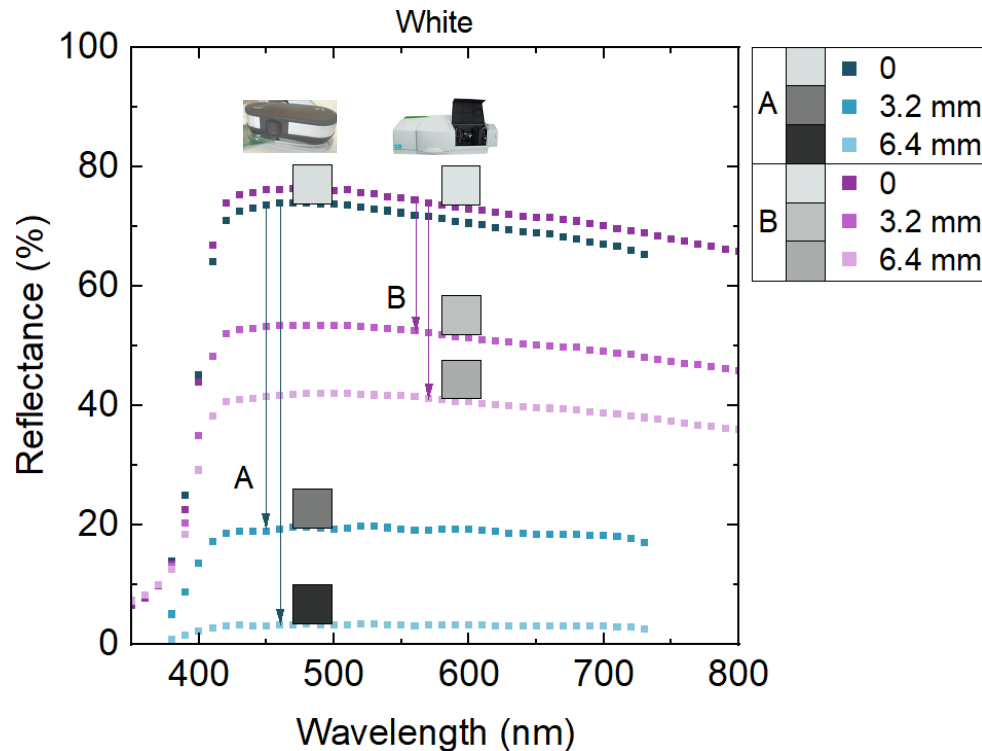
6.4 mm



## Color characterization tool

- Color design
- Quality control
- Degradation

Why not use  
**EXISTING**  
device?



## Small-beam commercial tools

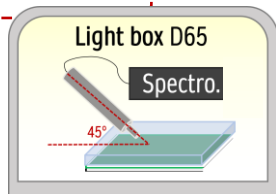
A – Colorimeter [4]



B – UV-VIS Integrating sphere spectrometer [5]



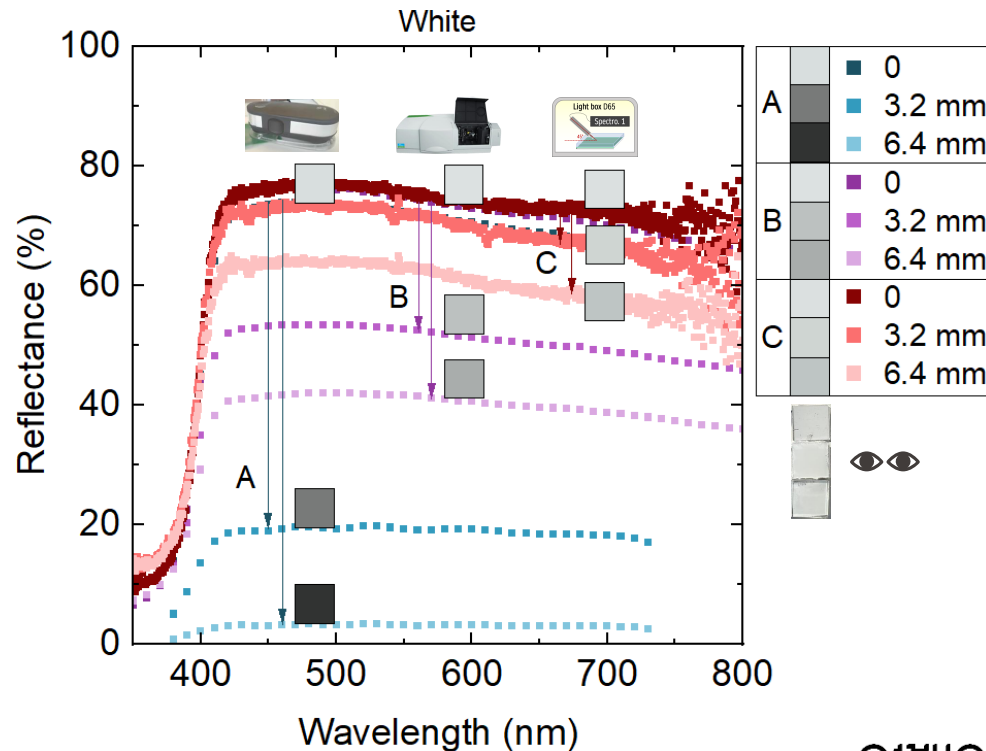
C – Proof-of-concept: **Broad-area irradiation** [6]



## Color characterization tool

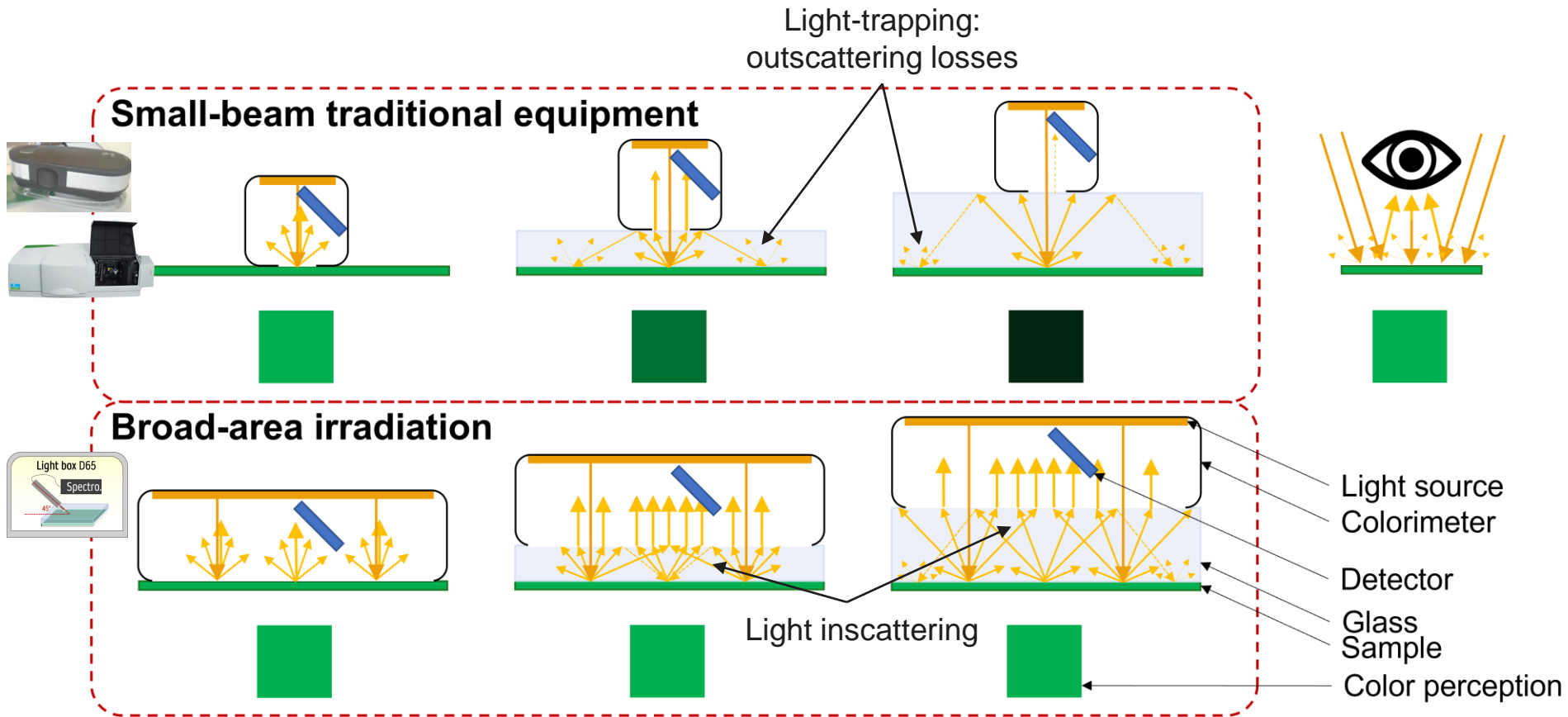
- Color design
- Quality control
- Degradation

Why not use  
**EXISTING**  
device?

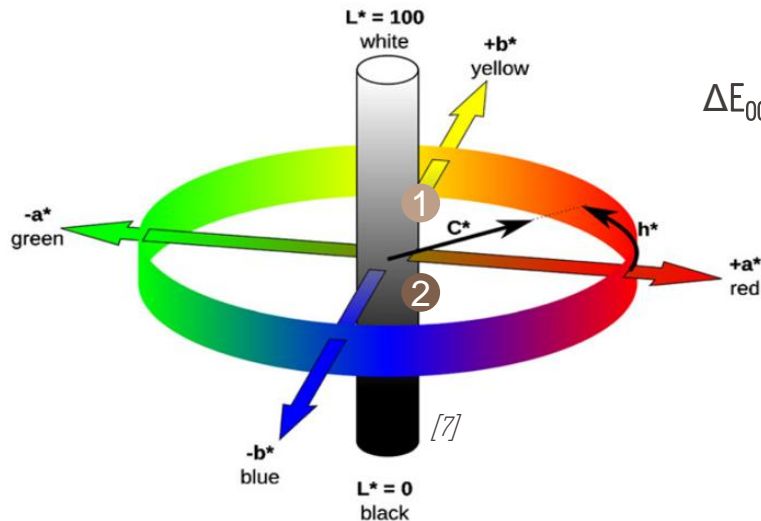


[6] A. Borja Block, et al, Accurate color characterization of solar photovoltaic modules for building integration, *Solar Energy*, Volume 267, 2024, <https://www.sciencedirect.com/science/article/pii/S0038092X23008617>





CIELAB → 3D color space, most complete (e.g. of other color space = RGB)



$$\begin{array}{c} \textcircled{1} \quad L^*_1 \quad a^*_1 \quad b^*_1 \\ \updownarrow \Delta E_{00} \\ \textcircled{2} \quad L^*_2 \quad a^*_2 \quad b^*_2 \end{array}$$

$\Delta E_{ab}^*$	1)	2)
1		
2		
3		
4		
5		
6		
7		

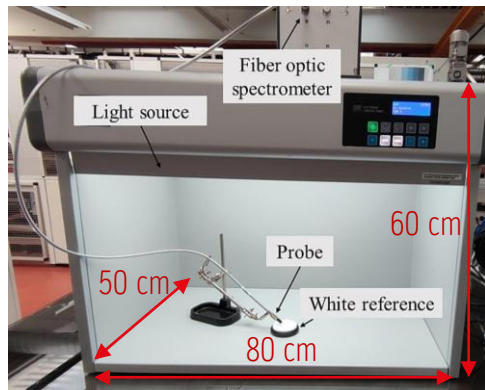
$\Delta E$ : Perception of **color differences** between **two** sets of **coordinates** ( $L^*$ ,  $a^*$ ,  $b^*$ ):

- $0 < \Delta E < 1$  – No difference is noticed
- $1 < \Delta E < 2$  – Only experienced viewer notices
- $2 < \Delta E < 3,5$  – Difference can be noticed by all
- $5 < \Delta E$  – Two different colors

[8]

[7] M. Bertalmío, "Colour representation and colour gamuts," in *Vision Models for High Dynamic Range and Wide Colour Gamut Imaging*, pp. 131–155, Elsevier, 2020.

[8] N. Kirillova, et al., *New perspectives to use munsell color charts with electronic devices,* Computers and Electronics in Agriculture, vol. 155, pp. 378–385, Dec. 2018.



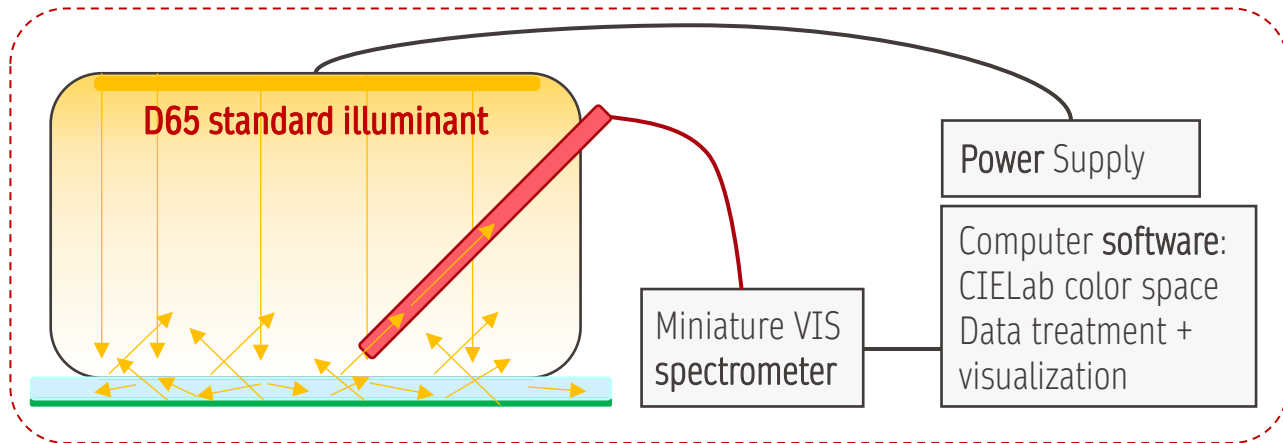
Goal: Build a **portable Broad-Area Irradiation** (BAI) colorimeter  
 → Perception of color difference  $\Delta E_{00} < 2$

### Proof of concept

A.Borja Block, et al, 2024,  
 doi: 10.1016/j.solener.2023.112227

#### ➤ Limitations:

Huge lightbox (80x60x50 cm<sup>3</sup>)  
 Large and heavy spectrometer



### Front-End

- Small
- Light
- Portable
- User-friendly
- Easy-to-handle
- Easy to move around

### Measures

- Point-measurement
- Broad-area illumination
- Light source : D65 + stable

### Main equipment

Spectrometer  
Compact  
VIS range  
High SNR

Light Source  
D65  
Compact  
Stable  
Long lasting



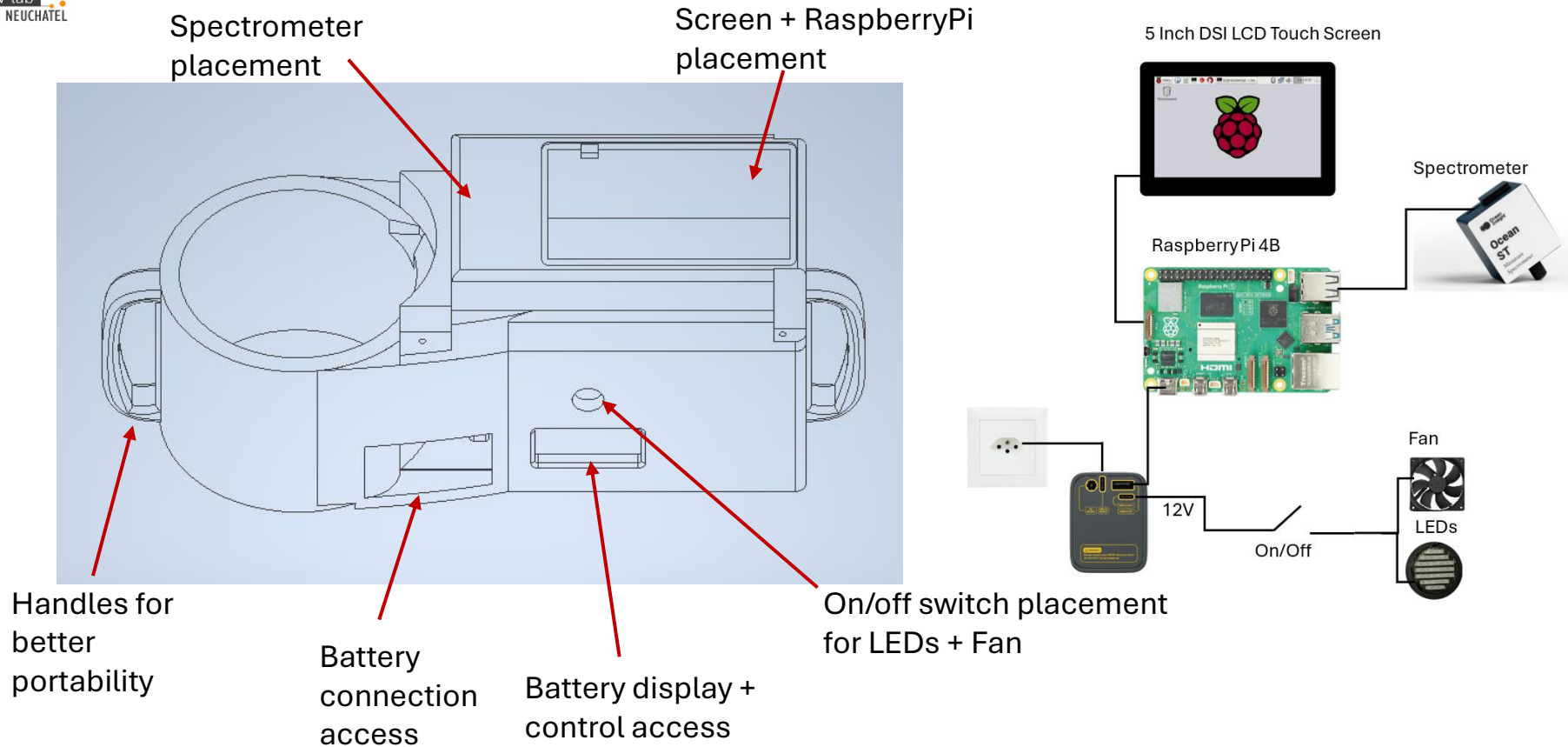
➔ *Avoid:*  
*Modern Sysphus... ..and the curse of the integrating sphere*



● High CRI LED D65

● VIS Microspectrometer

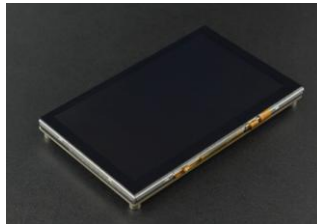
# Colorimeter 1<sup>st</sup> portable prototype + electrical setup



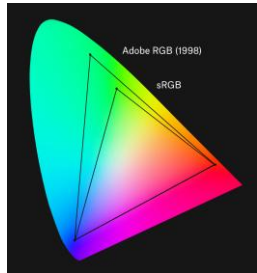
# Software Integration



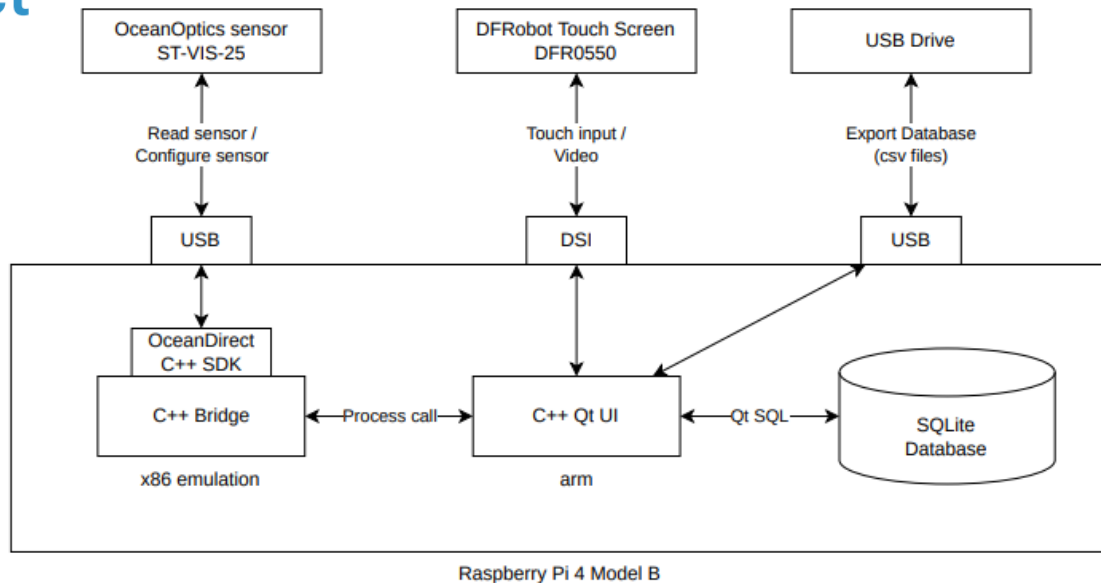
OceanDirect



Libraries:



Color Space



UI Framework



Language



**Goal** → assess tool perception of **apparent color** with & without frontglass



\*picture from scanner: difference btw glass and no-glass is greatly enhanced

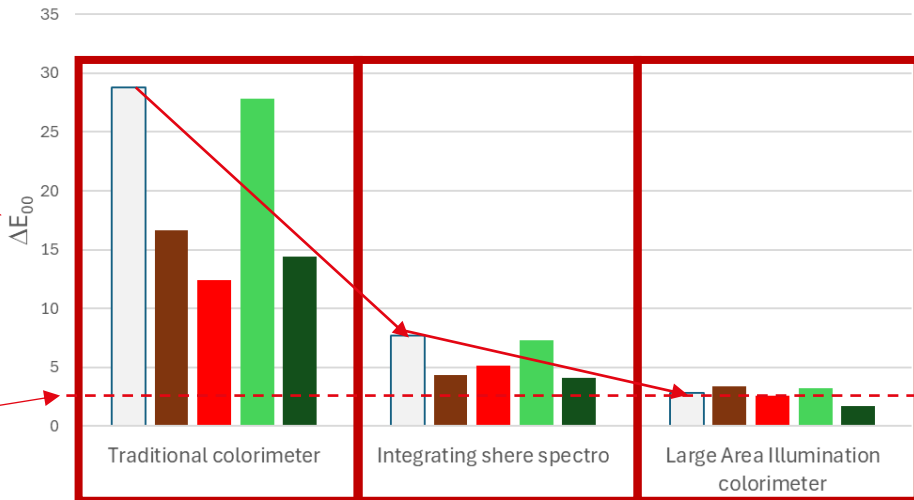


3.2 mm

White Brown Red Medium Green Dark Green

Metric  
Difference  
in color  
perception

Threshold  
human eye for  
no diff:  $\Delta E < 2$



From...



...to

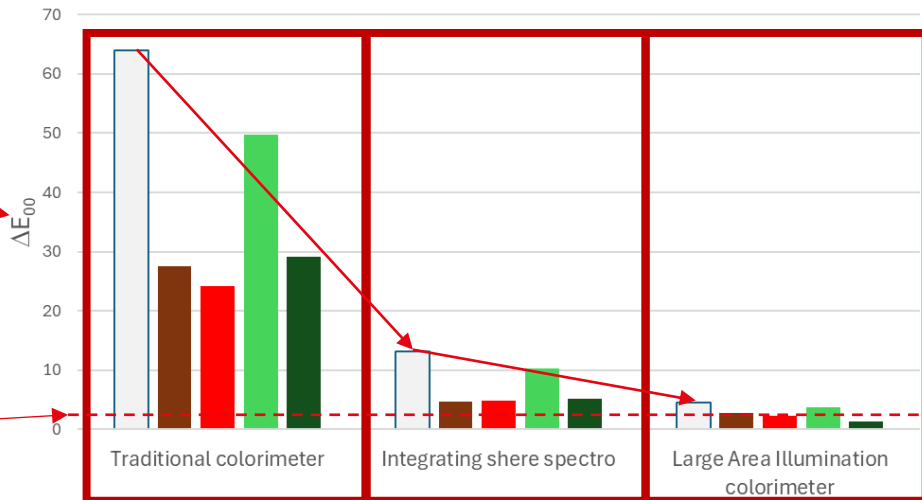


6.4 mm

White Brown Red Medium Green Dark Green

Metric  
Difference  
in color  
perception

Threshold  
human eye for  
no diff:  $\Delta E < 2$



From...



...to



- Improvements: smaller  $\Delta E$  closer to 2
- Fully autonomous (battery, integrated software & interface)
- Automatised data treatment calculation of  $\Delta E$
- Control of T(°C) thanks to the fan



- Develop the user interface
- Improve design ergonomoy, weight & size
- Test on different types of glass (Texture, gloss, pearlescent,...)
- Non-homogeneous colors
- BIPV samples – impact of metallization, degradation assessment

## Join us for testing on **GMP** booth H116!

PHOTONICS & MICROTECHNOLOGY

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**Contact:**  
Antonin Faes  
[antonin.faes@csem.ch](mailto:antonin.faes@csem.ch)



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Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

~90 peoples at CSEM SEC

~40 peoples at EPFL PV-Lab



Marie Courtant



Elie Flahaut



Dr. Aïcha Hessler-Wyser



Prof. Christophe Ballif



Fabio Manzini

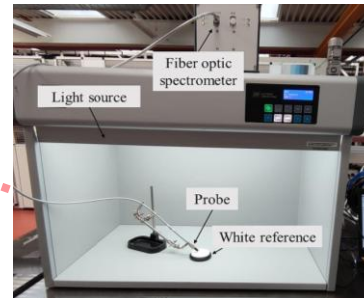
- [1] [https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings\\_en](https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_en)
- [2] Figure from: HZB Home [https://www.helmholtz-berlin.de/projects/baip/bipv\\_en.html](https://www.helmholtz-berlin.de/projects/baip/bipv_en.html)
- [3] Building in Zürich, Switzerland, with terracotta foil. 3S Swiss Solar Solutions AG
- [4] X-Rite Pro1 Colorimeter
- [5] Perkin-Elmer UV-VIS Integrating sphere spectrometer
- [6] A. Borja Block, et al., Accurate color characterization of solar photovoltaic modules for building integration, Solar Energy, Volume 267, 2024, <https://www.sciencedirect.com/science/article/pii/S0038092X23008617>
- [7] M. Bertalmío, "Colour representation and colour gamuts," in Vision Models for High Dynamic Range and Wide Colour Gamut Imaging, pp. 131–155, Elsevier, 2020.
- [8] N. Kirillova, et al., New perspectives to use munsell color charts with electronic devices," Computers and Electronics in Agriculture, vol. 155, pp. 378–385, Dec. 2018.
- [9] Data retrieved from I. C. on Illumination (CIE), "CIE standard illuminant a – 1nm and d65."
- [10] C. L. M. Costa, R. R. Vieira, R. C. Pereira, L. P. Souza, and A. D. Alvarenga, "Color rendering uncertainties of fluorescent light sources," 2013.
- [11] M. Courtant, et al., " Colorimetry of modules for building-integrated photovoltaic applications – Building a broad-area illumination colorimeter", Master's thesis, 2023.

**Metric**  
Difference  
in color  
perception

*Threshold  
human eye for  
no diff:  $\Delta E < 2$*

	Traditional colorimeter		Integrating sphere spectrometer		BAI proof-of-concept		BAI colorimeter	
$\Delta E_{00}$	3.2 mm	6.4 mm	3.2 mm	6.4 mm	3.2 mm	6.4 mm	3.2 mm	6.4 mm
White	28.83	63.96	7.77	13.03	2.77	6.62	3.64	4.50
Brown	16.61	27.6	4.3	4.7	5.9	6.78	3.38	2.69
Red	12.4	24.18	5.06	4.81	2.2	2.95	2.55	2.19
Medium Green	27.78	49.73	7.26	10.28	3.15	5.18	3.19	3.66
Dark Green	14.4	29.12	4.05	5.13	2.63	4.38	1.73	1.31

From...



...to

