# Smart lighting with luminous tiles in the H2020 LUMENTILE™ Project

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www.lumentile-project.eu

This project has received funding from the European Union's Horizon 202o for research and innovation programme under grant agreement No 644902.

# Outline

- The **LUMENTILE Project**: facts sheet
- **Objectives** & **Products**
- **Photonics & Electronics Technologies**
  - Light sources
  - Light management
  - Printed, large-area electronics
- **Other Technologies**
  - Tile-to-tile connection
  - Tile-to-tile communication
  - Materials integration
  - Towards large-scale production
- **Conclusions**

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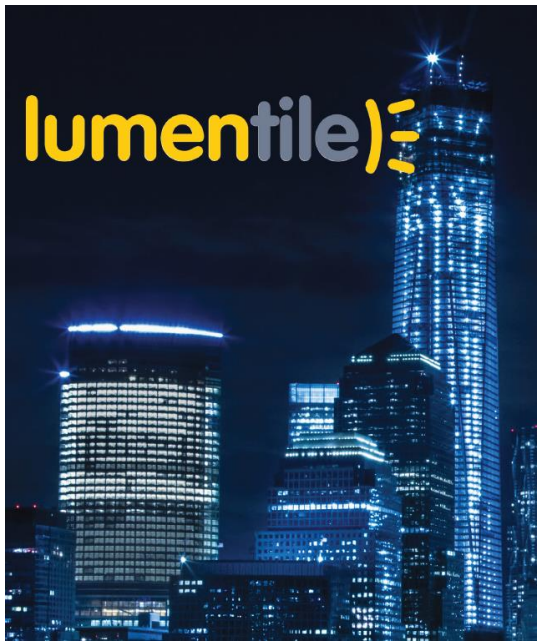
# The LUMENTILE H2020 Project




- **Partners**

| | | |
|---|---|---|
| University of Pavia | www.unipv.eu | Italy |
| Teknologian Tutkimuskeskus (VTT) | www.vtt.fi/ | Finland |
| Eclexys SAGL | www.eclexys.com/ | Switzerland |
| Julight SRL | www.julight.it/ | Italy |
| Keraplan SRL | www.keraplan.it/ | Italy |
| Siarq Advanced Solar Design | www.siarq.com/ | Spain |
| Knowledge Innovation Market (KIM) | www.kimglobal.com | Spain |

## Facts sheet

- **Title**: **LUM**inous **E**lectro**N**ic **TILE**
- **H2020 Call**: TOLAE
  (Thin Organic Large Area Electronics)
- **Funding**: 2.47 M€ EC + 0.50 M€ Switzerland
- **Duration**: 36 Months
  Mar 2015 → Feb 2018
- **Contact**: *guido.giuliani@unipv.it*

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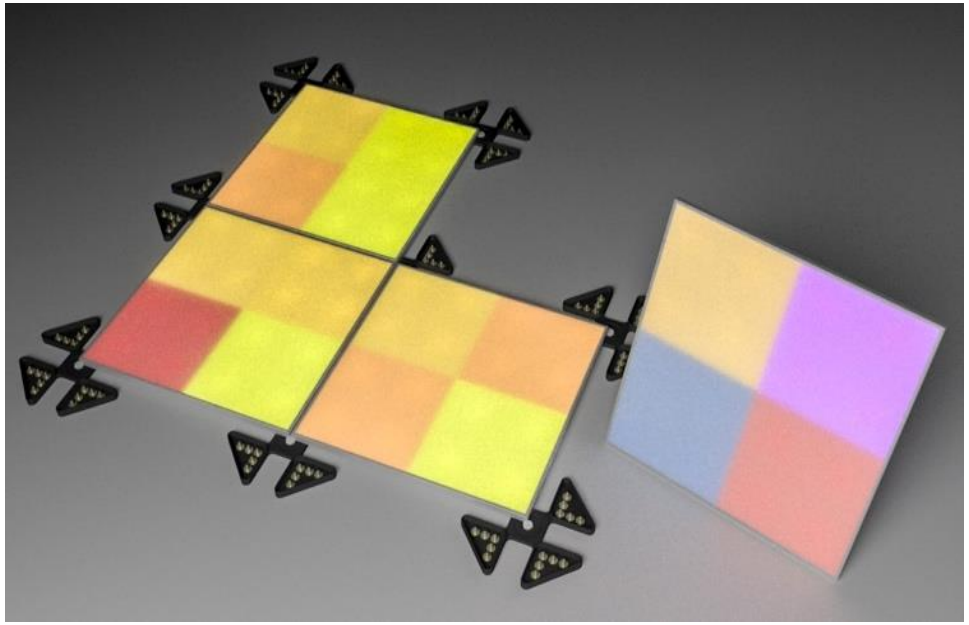
# Overview

The LUMENTILE project aims to **fill the gap between a simple construction element and a luminous surface element**, by developing a cutting-edge technological module - **the luminous electronic tile** - that is capable of **displaying lights, colors and images,** that can be used as a chameleonic display to be employed as a skin for horizontal (floor) or vertical (wall) applications. The possibility of integrating **embedded sensors** in the tile further increases its potential allowing, for example, the **detection of people walking** onto each tile of the floor.



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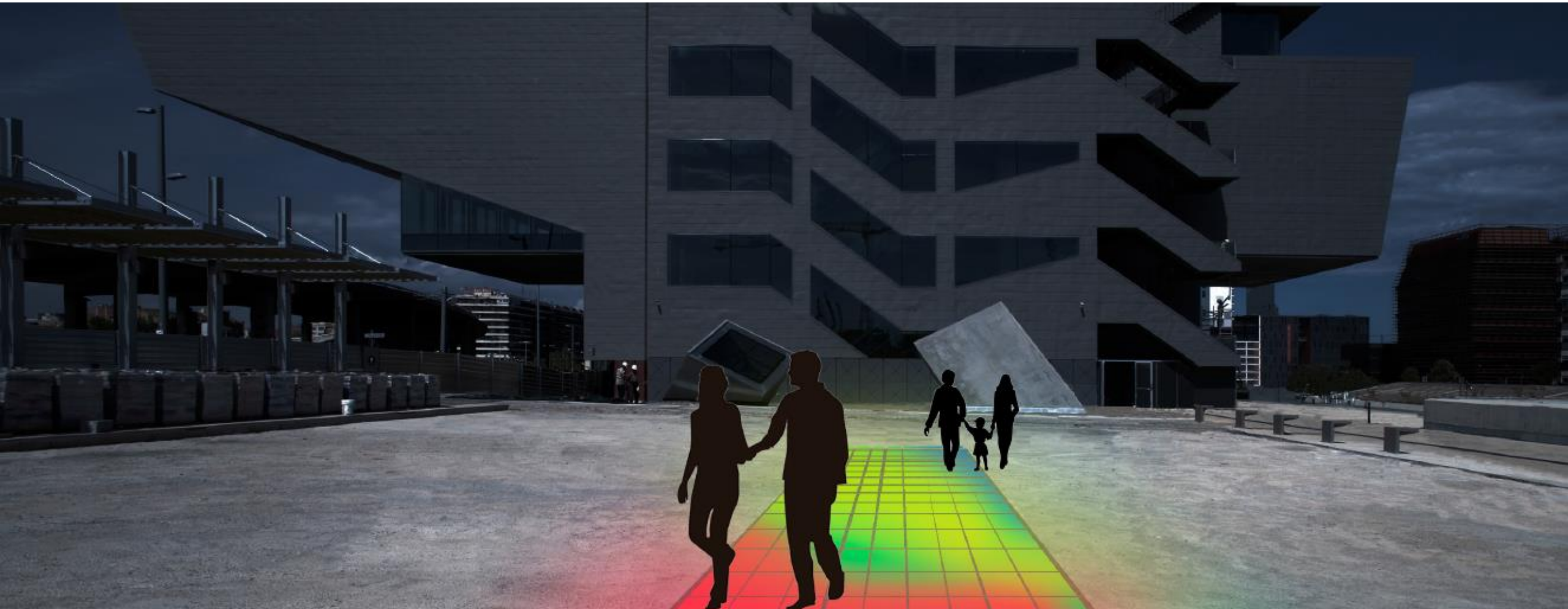
# Applications

- Define active luminous paths in public spaces like hospitals, airports, shopping malls.
- Safety / Security: detect (elderly) people lying on the floor / track people movements in a vaste area
- ? Integrate LiFi functionality

# Applications

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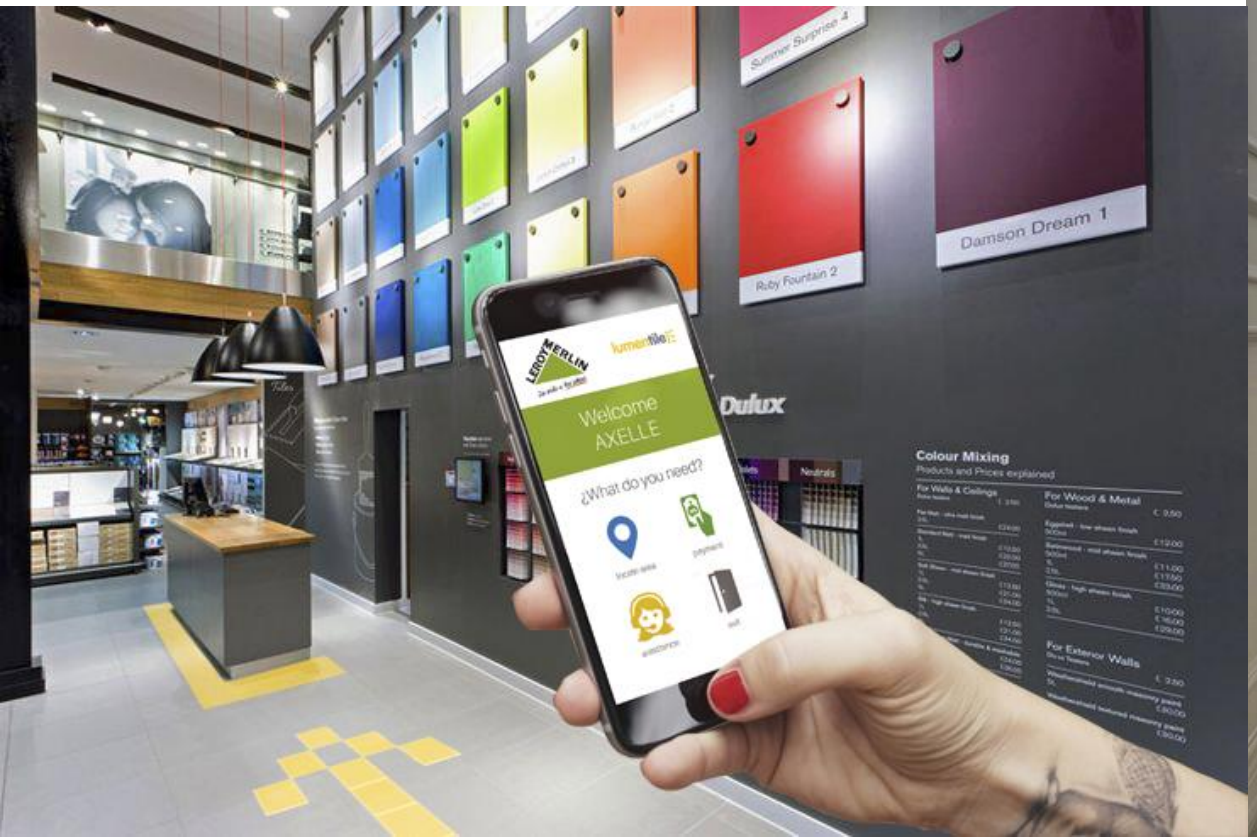
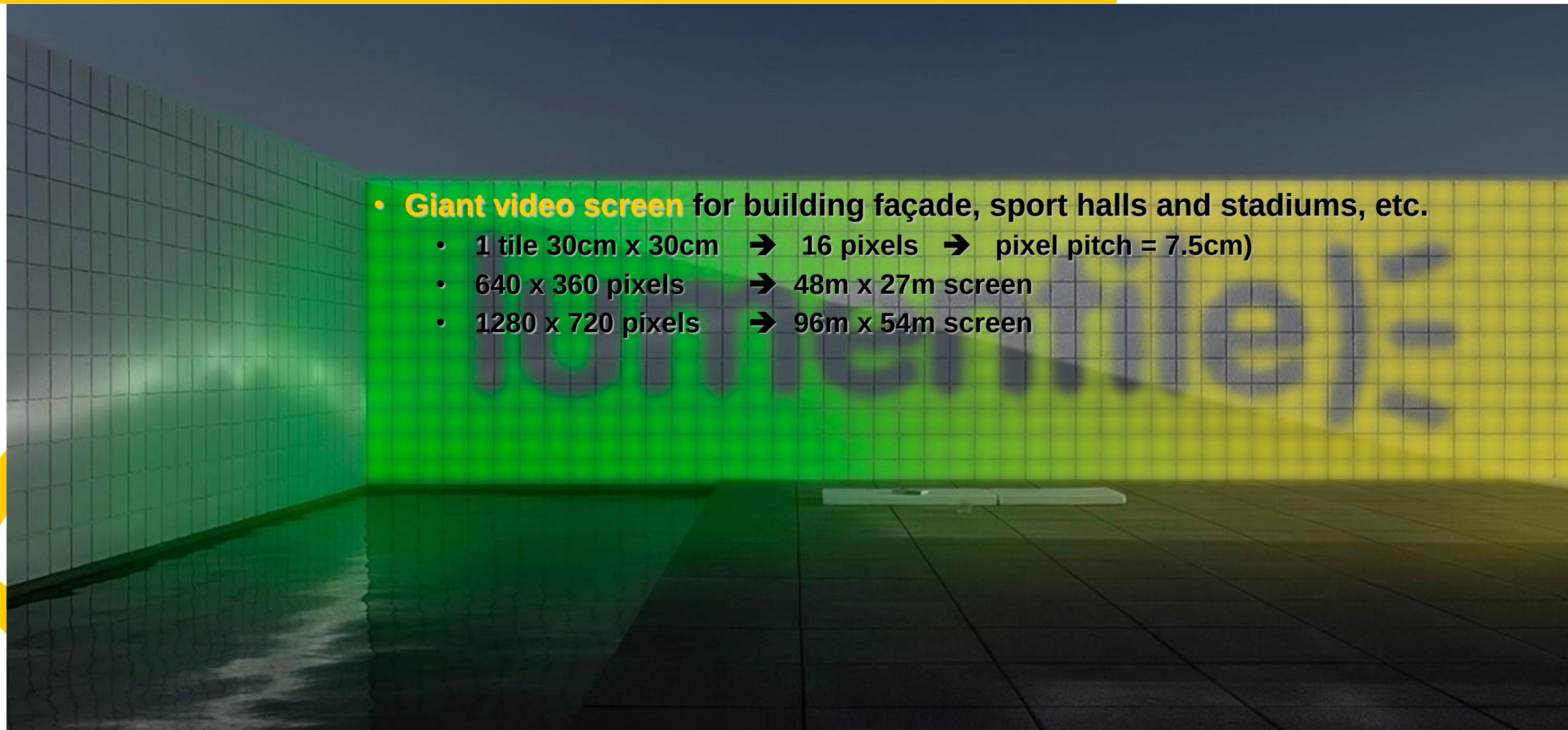
# Applications

## Hotels

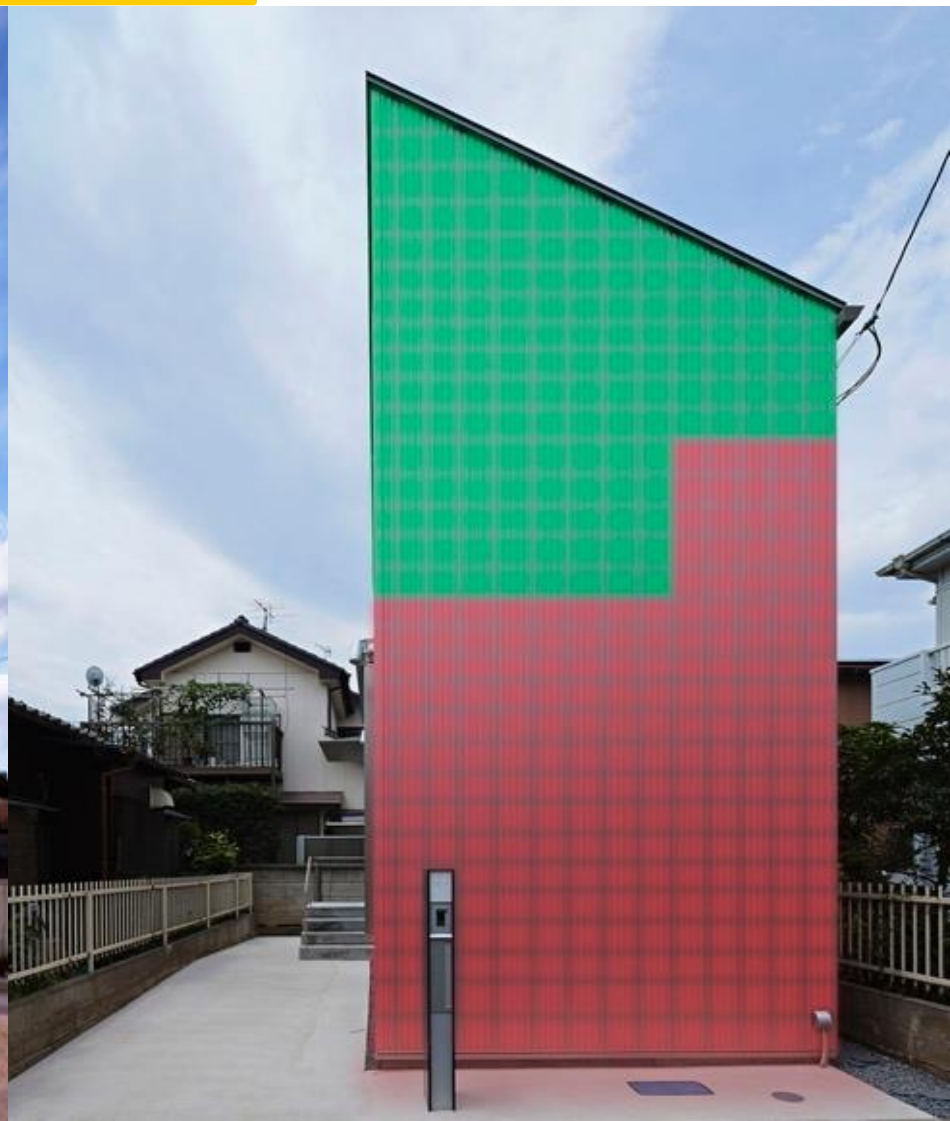
## Stores



# Applications



# Applications

# New products

- **Luminous tile for interior/exterior design (floor/wall)**, capable of changing colour and luminosity, adapting itself to the needs and will of the Designer

  *Size: 30cm x 30cm ; Number of sub-pixels: 4 ; Sensors: pressure (floor), gesture/presence (wall)*

- **Illumination tile**, for **smart/dynamic lighting** of interiors through a structural element that can be embedded into the wall or ceiling, does not require a specific wiring, and can be **LiFi-ready**

  *Size: 30cm x 30cm ; Sensors: gesture/presence ; Luminous efficiency: >50lm/W*

- **Video tile**, where each tile defines **pixels of a giant screen** to display videos using structural elements that cover the wall of a building, of a sports stadium, of a shopping mall…

  *Size: 30cm x 30cm ; Number of sub-pixels: 16 ; Illuminance: >2000 lux*

The luminous tile **remains a ceramic tile**
that can be installed using **conventional techniques**, and has the **ruggediness** of traditional tiles!

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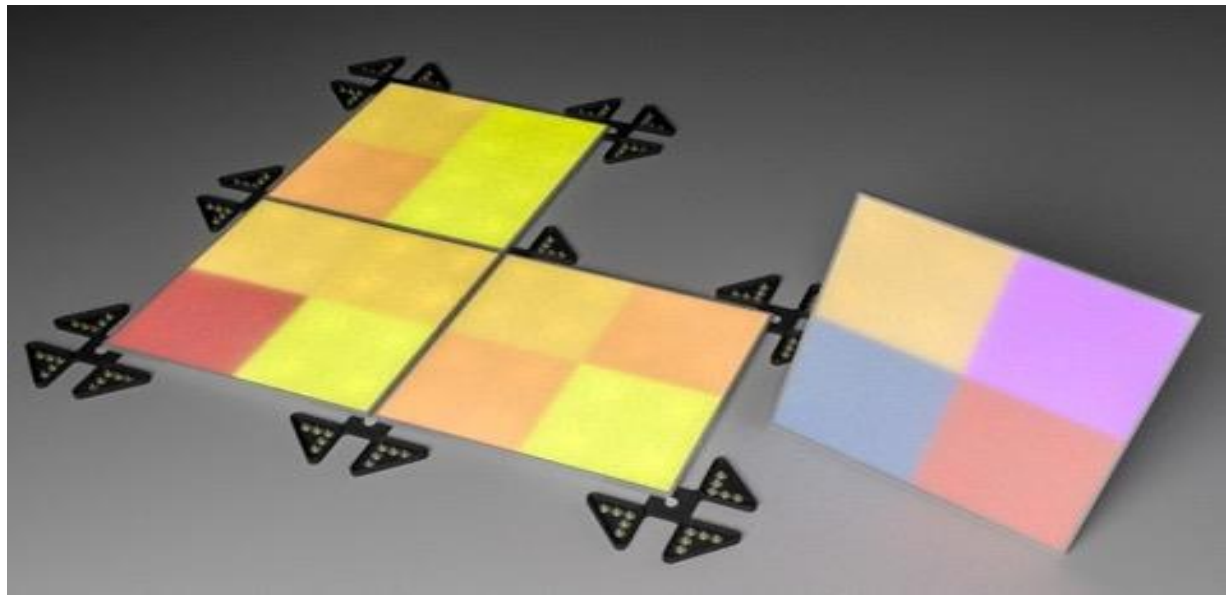
# Technical Specifications

- Power consumption: 2÷20 W
- Supply voltage: 24 VDC
- Size: 30cm x 30cm
- Colour depth: 12 bit
- Maximum light intensity: 500lux



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# Impact

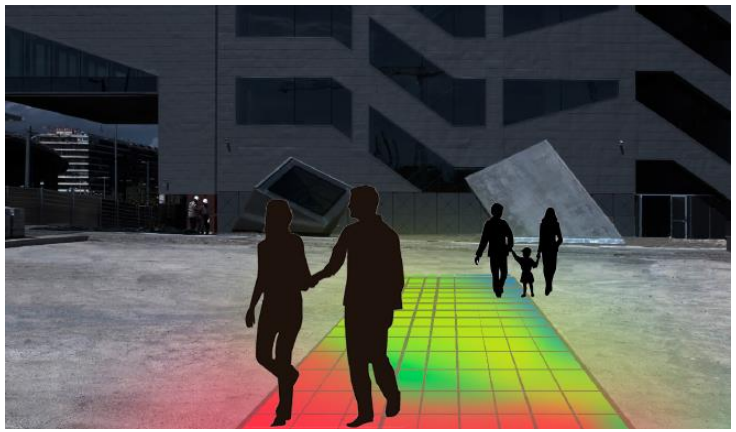
- **Project goals:**
  - bring research results to the market
  - start **pilot production line** (by 2019)

- **Production of very large area luminaries-type product**
  - 100,000 sqm of luminous tiles to be produced in 2020
  - **> 1,000,000 sqm** of luminous tiles to be produced in 2023 (> 1.2% of the total area of backlit LED TV sales worldwide*)
  - Revenues (in 2023): **300 M€** (at 300 €/sqm sale price)

- **Revolutionize the use of public spaces**

* Forecast: 250 mio LED TV units sold, with 40” average size

# Technological Objectives



- Development of a **high-efficiency luminous layer,** that integrates LED light emitters and electronic circuits for LED driving and tile intelligent management

  *GOAL: **uniform illumination** (for interior/exterior design)*

- **Smart technological integration** of large-area electronics/photonics with traditional ceramic material, towards mass production of the luminous tile.

  *GOALS: competitive price ; easy installation ; integrated, invisible electrical/electronic network*

- Development of **flexible and versatile luminous tile product/technology**, capable to respond to the needs of design-driven solutions and applications
- Development of **functional demonstrators** to be installed in **public spaces** to showcase the LUMENTILE to the general public and stakeholders (fall/winter 2017-2018)
- Definition of the **industrial production process,** for large-scale manufacturing

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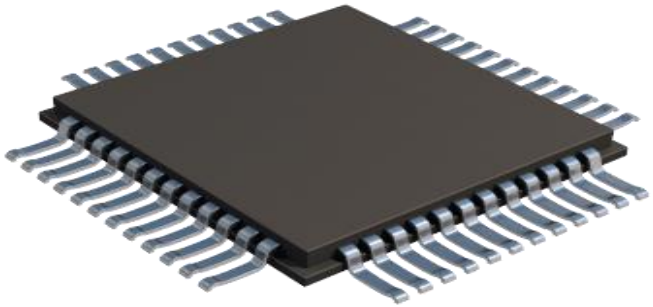
# Integration



Electronics and CPU

Light Sources

Power Management

Ceramic Tile

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This project has received funding from the European Union's Horizon 2020 for research and innovation programme under grant agreement No 641992.

# General structure of the Lumentile

## Stratified Structure

### Top Translucent Layer

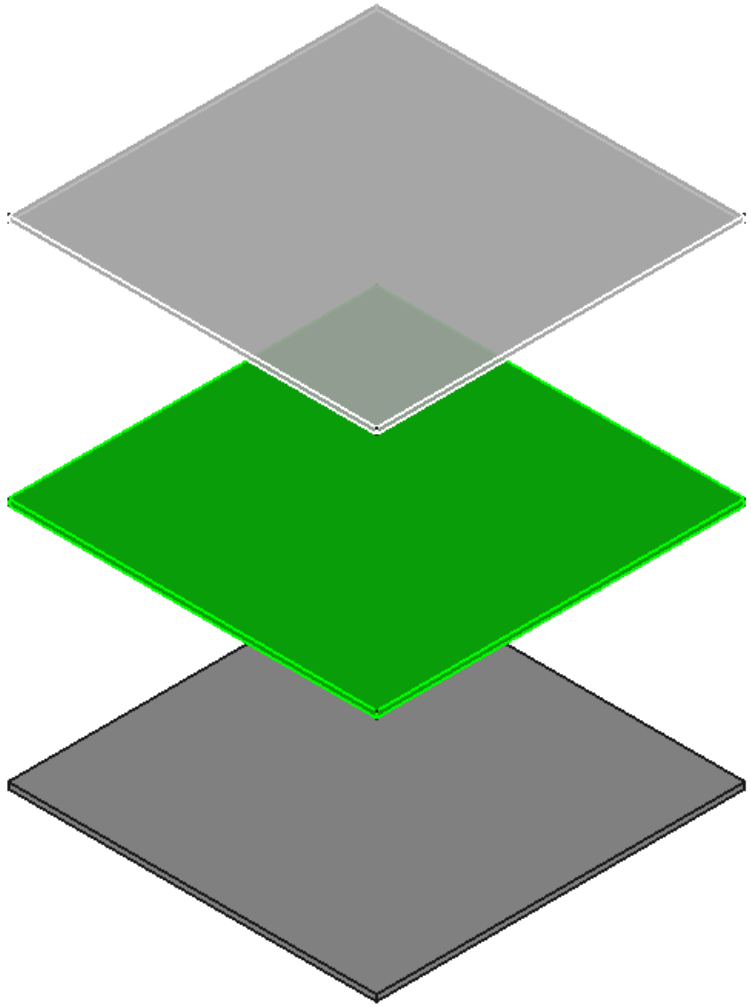
External layer of the tile, made of **ceramic** or **glass**. It must have high **mechanical resistance** and high **optical efficiency**.

### Electro-Photonic Layer

It contains the **electronics** components, the **light sources**, the **light management** structures.

### Bottom Layer

It gives structural, **mechanical strength**, and provides **heat dissipation**. It is made in **ceramic**, or special **thermally conductive plastic**.



**Size:**
**30cm x 30cm**

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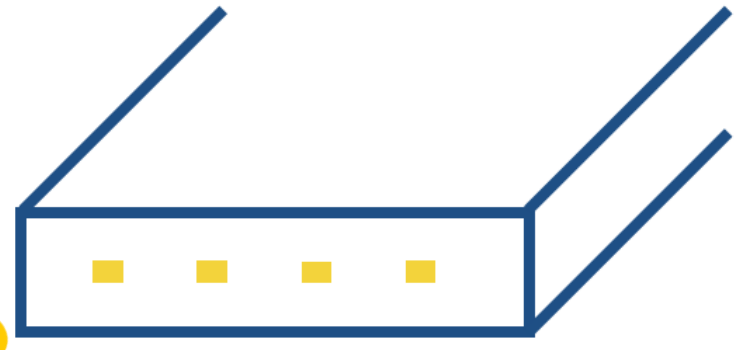
# Light Sources & Light Management

## Edge LEDs vs. Planar LEDs

### Edge

- Thinner structure ☺
- Avoids direct spotted light emission ☺
- More complicated assembly procedure ☹

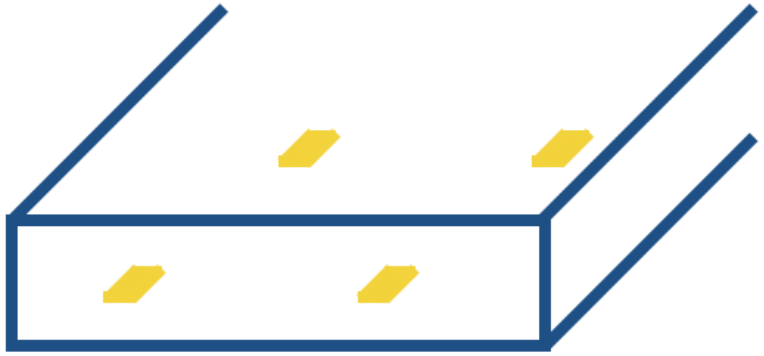
*Optimum choice for **interior/exterior design tile***
*(GOAL: **uniform illumination** of top layer)*



### Planar

- Thicker tile ☹
- Direct stray illumination ☹ ☺
- Easier assembly procedure ☺

*Optimum choice for **video tile***
*(GOAL: **high brilliance**)*



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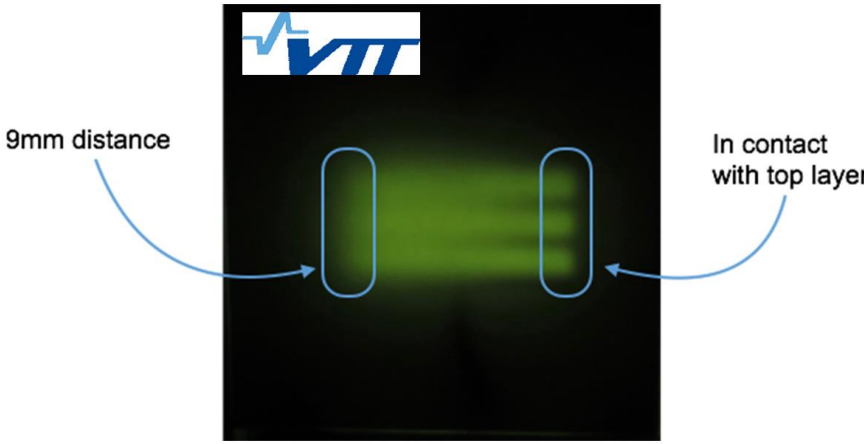
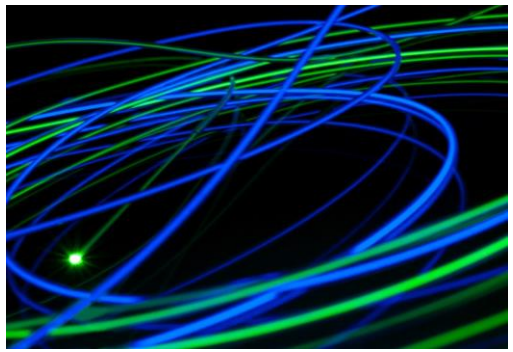
# Light Sources & Light Management

- **Light sources**:
  - High-brilliance, high-power **RGB LEDs** (24 triplets/tile)
    - Best choice so far
  - High-power **White LEDs**
    - For “lighting tile”




  - Alternative solutions:
    - **OLEDs** - Choice for 2022+ ???
    - **µLEDs** -
    - **Blue laser + (RGB) phosphors** - higher efficiency
    - **RGB lasers + out-scattering optical fiber** (Corning Fibrance®)



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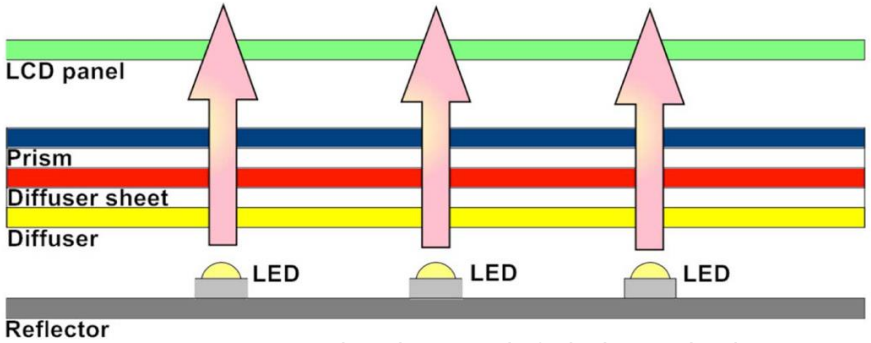
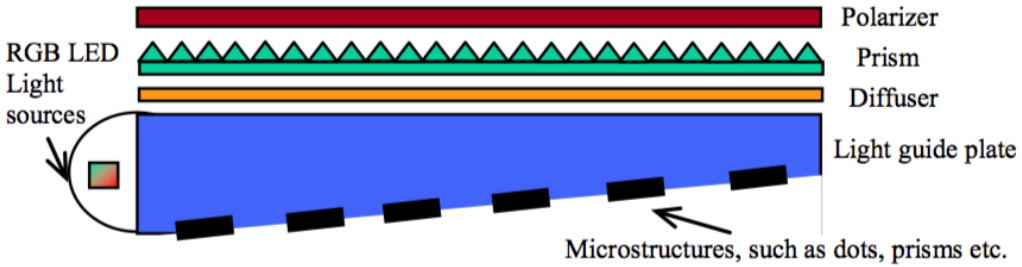
# State-of-the-art Backlighting




*Jang-Zern Tsai et al., Journal of Display Technology, 2012

## Direct Backlighting

- Constraint: height ≈ LEDs spacing




*Ying Hao et al., Communications and Photonics Conference, 2010

## Side Illumination

- Non-trivial, high-cost solutions
- Dark edge?

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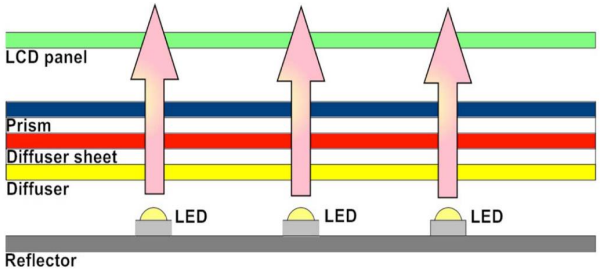
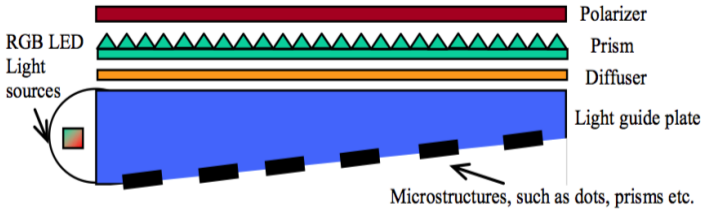
# Lumentile constraints




✦Thickness < 5mm ➔ need for side illumination

✦Low-cost & large area ➔ in-house technologies

✦No dark edges ➔ trade-off with LEDs hot-spots on sides

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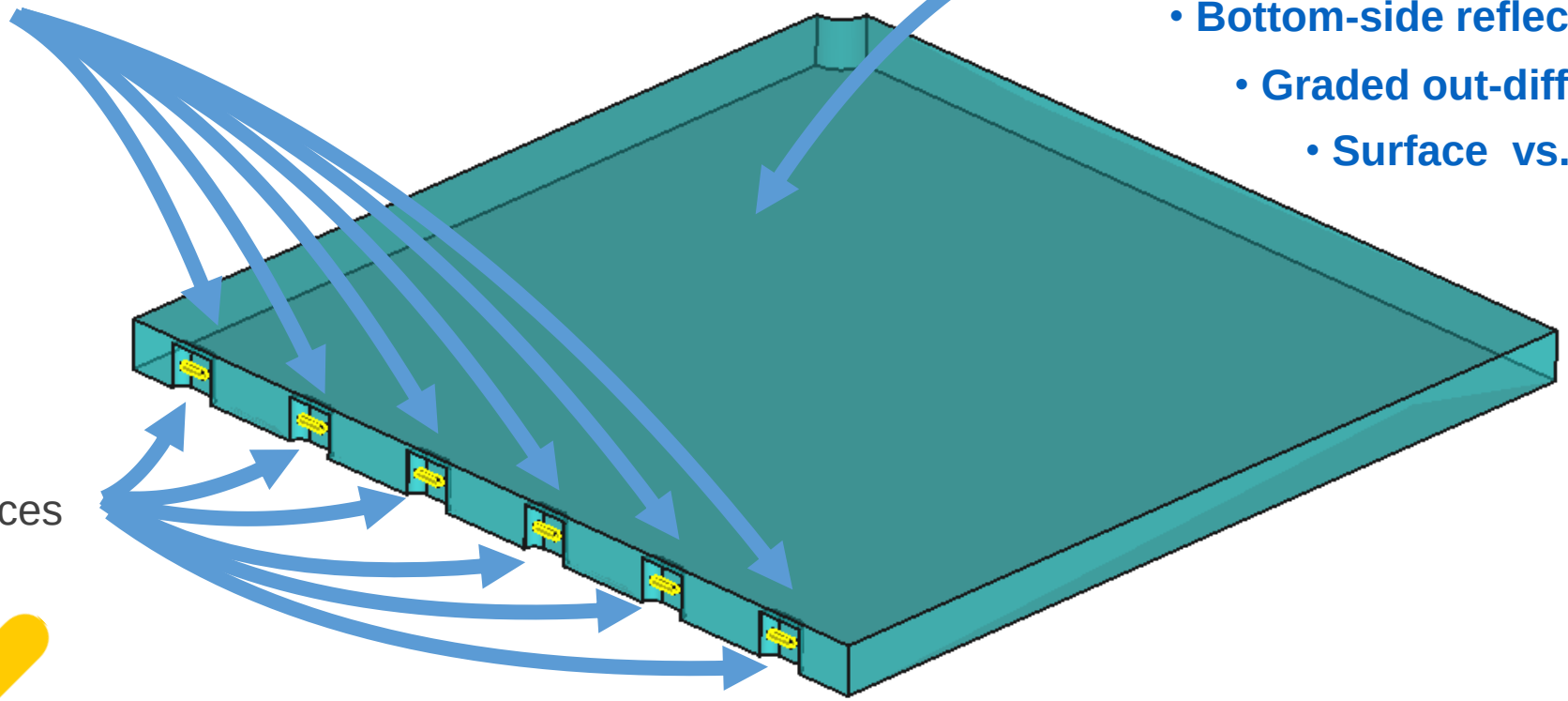
# Light-Guiding Layer

## Side Backlighting Structure

Management of LEDs hot-spots

Need for controlled out-diffusion of light
(for illumination uniformity)

- **Bottom-side reflector/diffuser**
- **Graded out-diffusing scattering centers**
- **Surface vs. Volume diffusers**



Light sources

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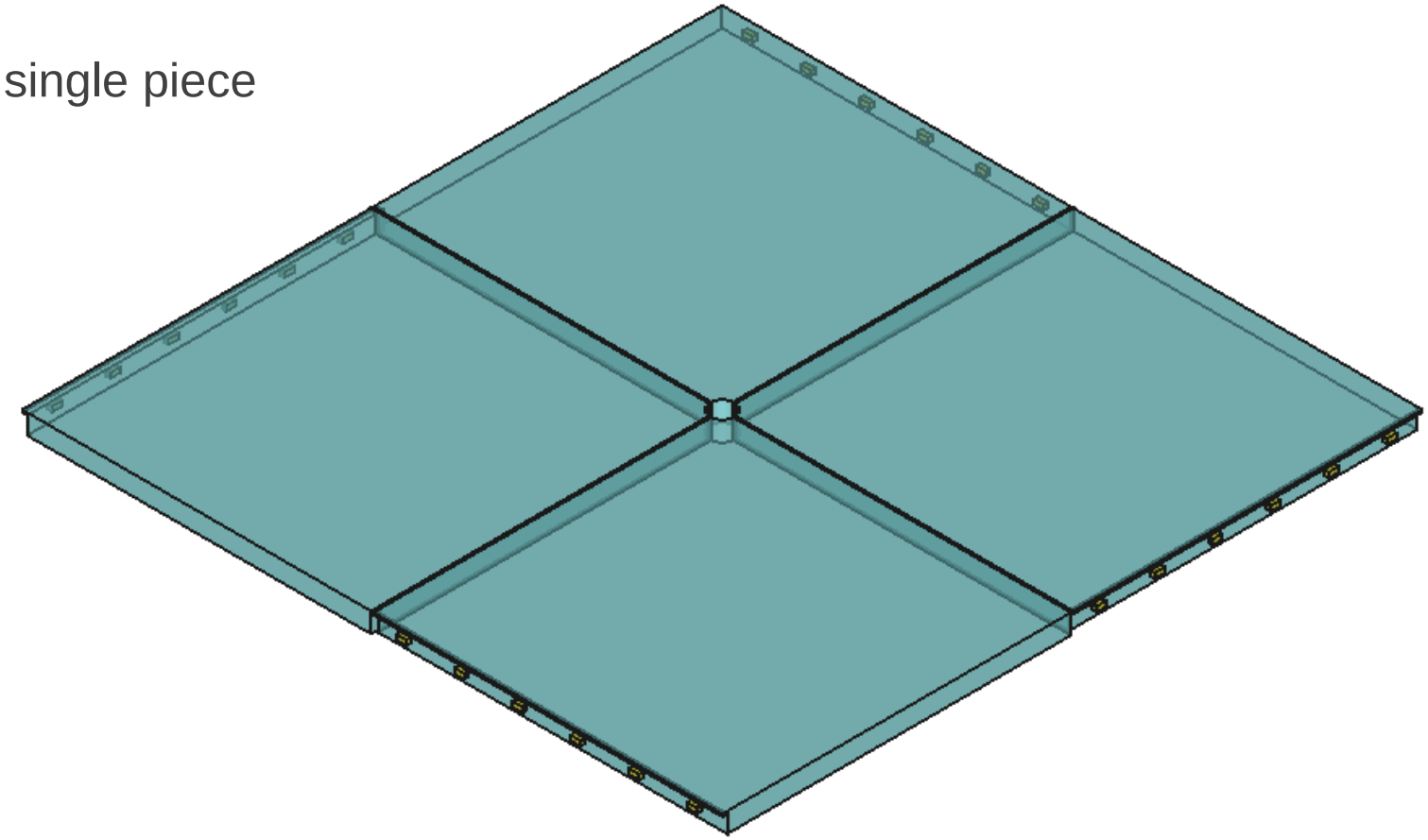
# Light-Guiding Layer

## Full tile backlighting system

To be realized in a single piece



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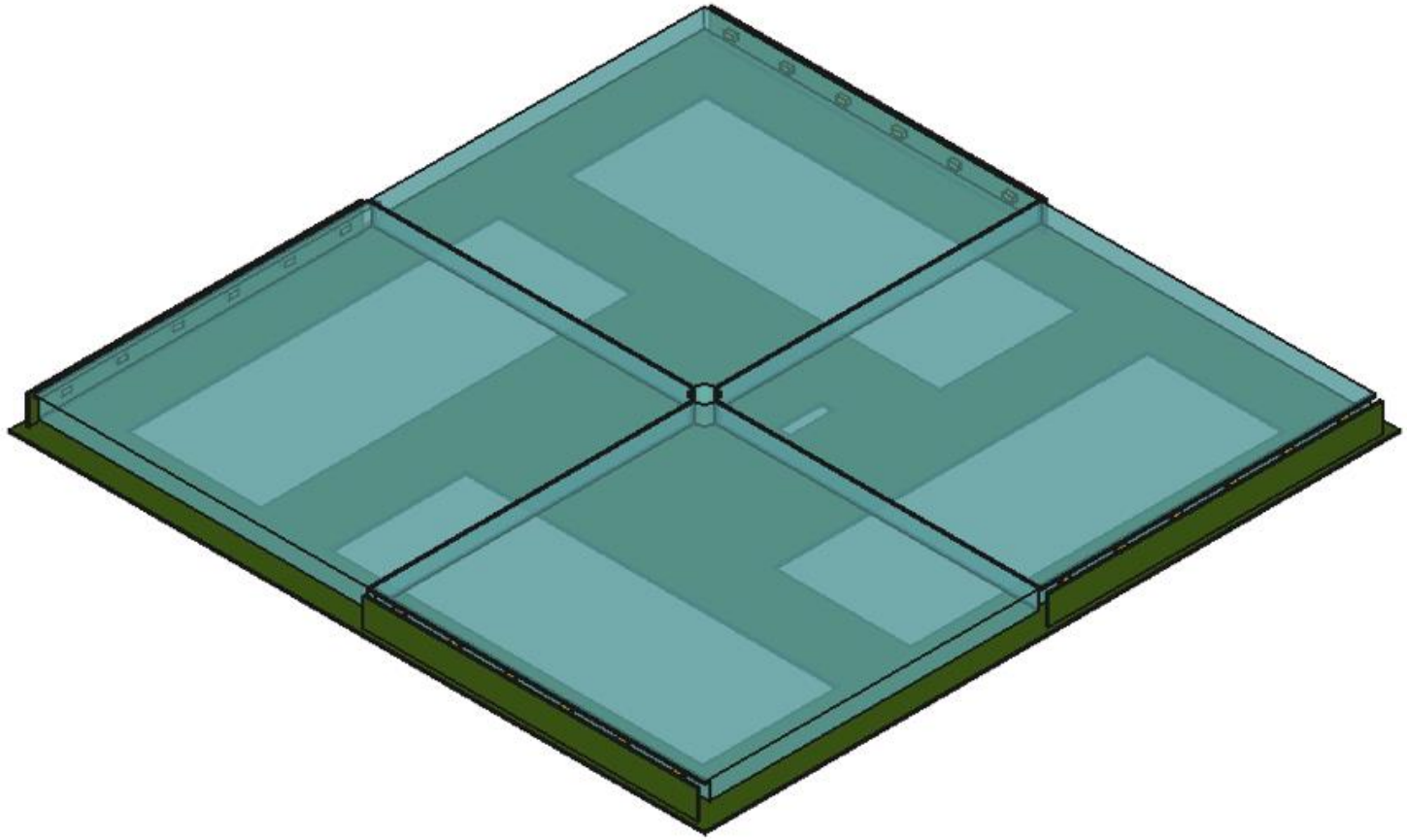
# Light-Guiding Layer

## Integration with electronics





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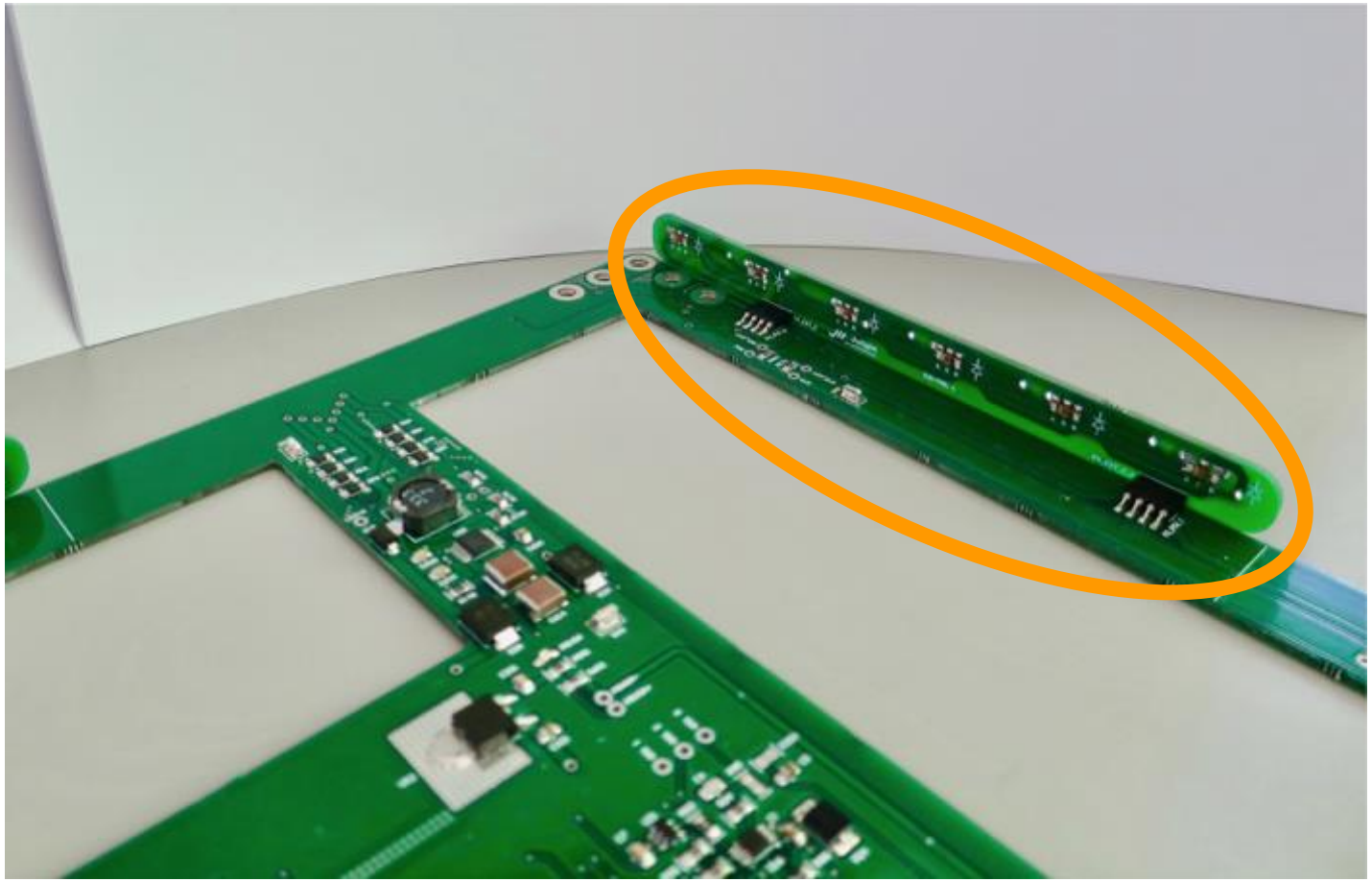
# Light-Guiding Layer

## Integration with electronics

LEDs are mounted onto a standard PCB connected to the main PCB



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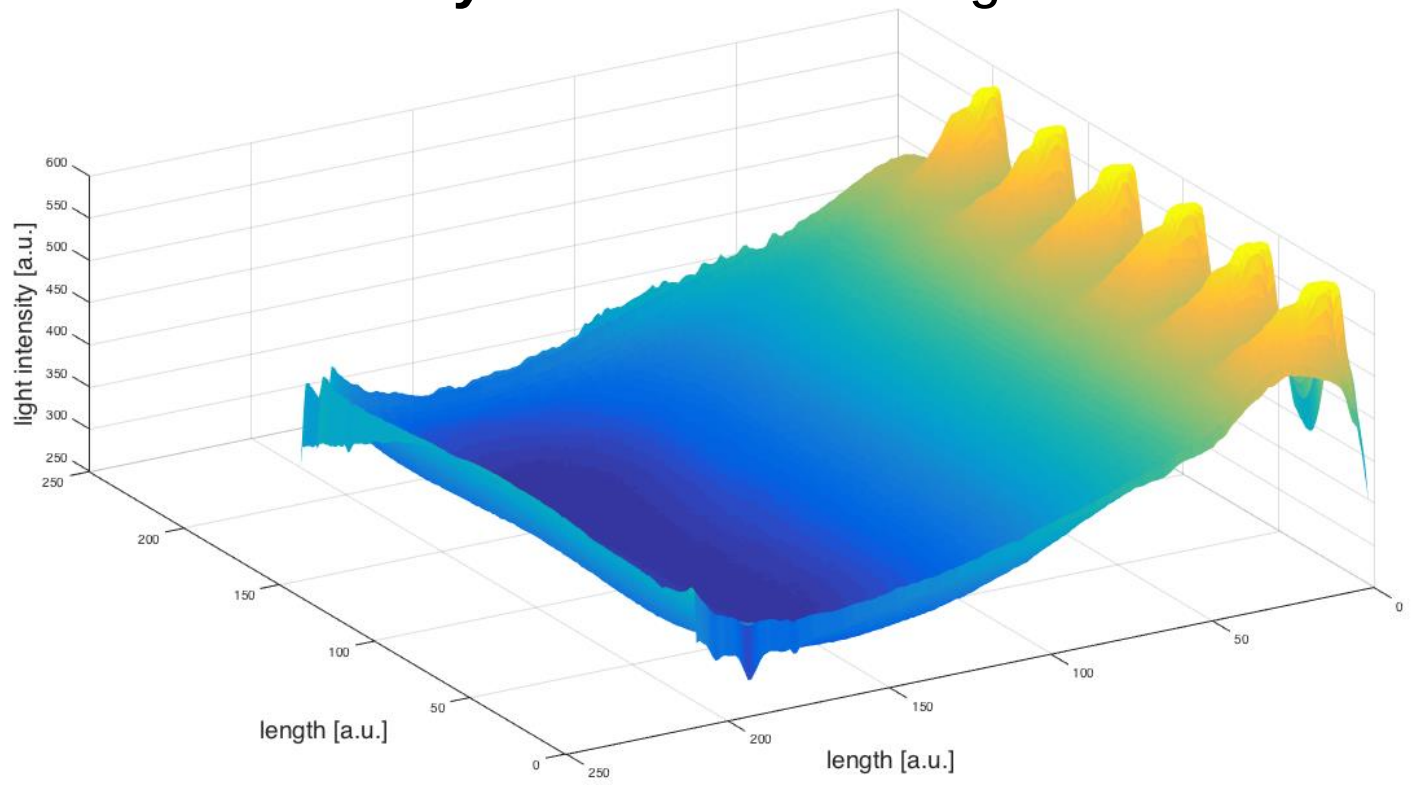
# Results

**Illumination uniformity** - uniform diffusing bottom side




**Poor**

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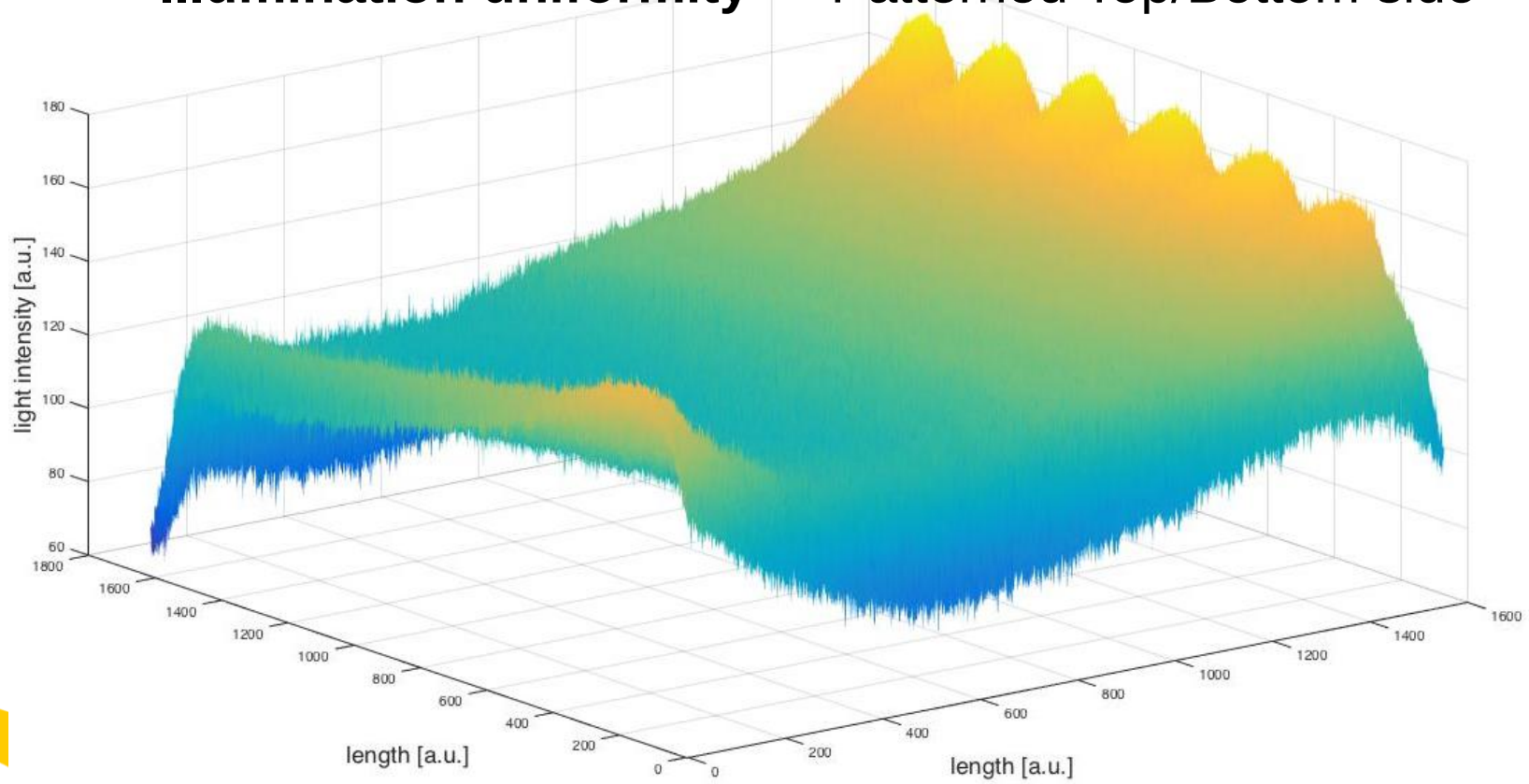
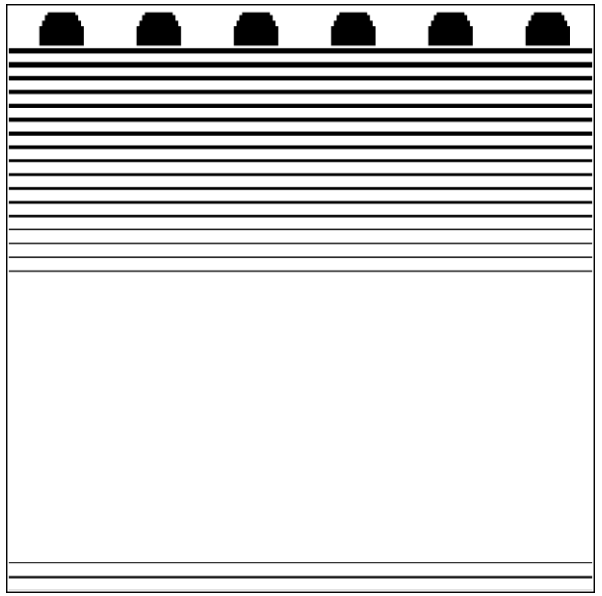
# Results

**Illumination uniformity** - Patterned Top/Bottom side



**Better**

To do:
- Volume scattering centers
- More efficient masking of hot-spots

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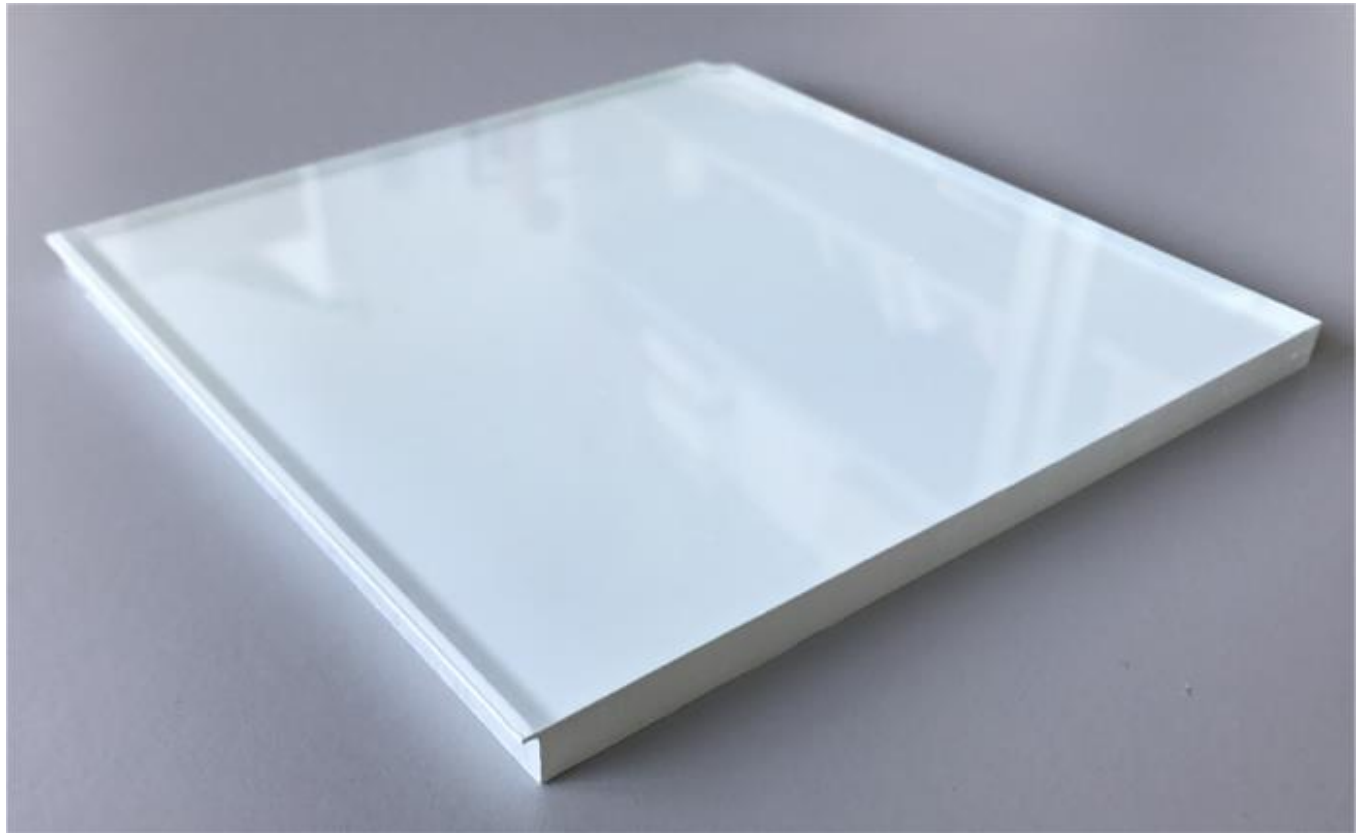
# Results

## Manufacturing Techniques

### Mask painting





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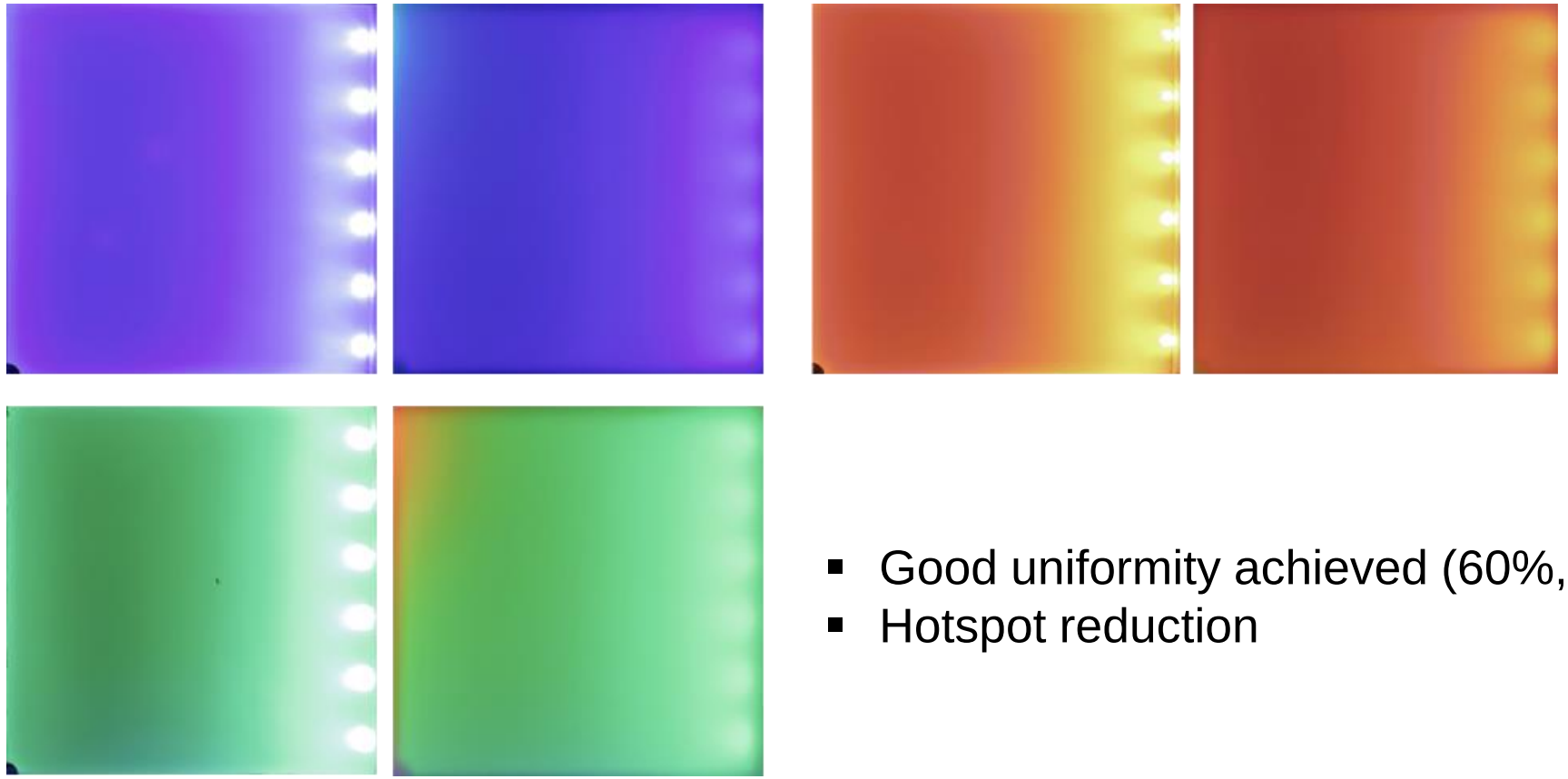
# Results



- Good uniformity achieved (60%, to be improved)
- Hotspot reduction

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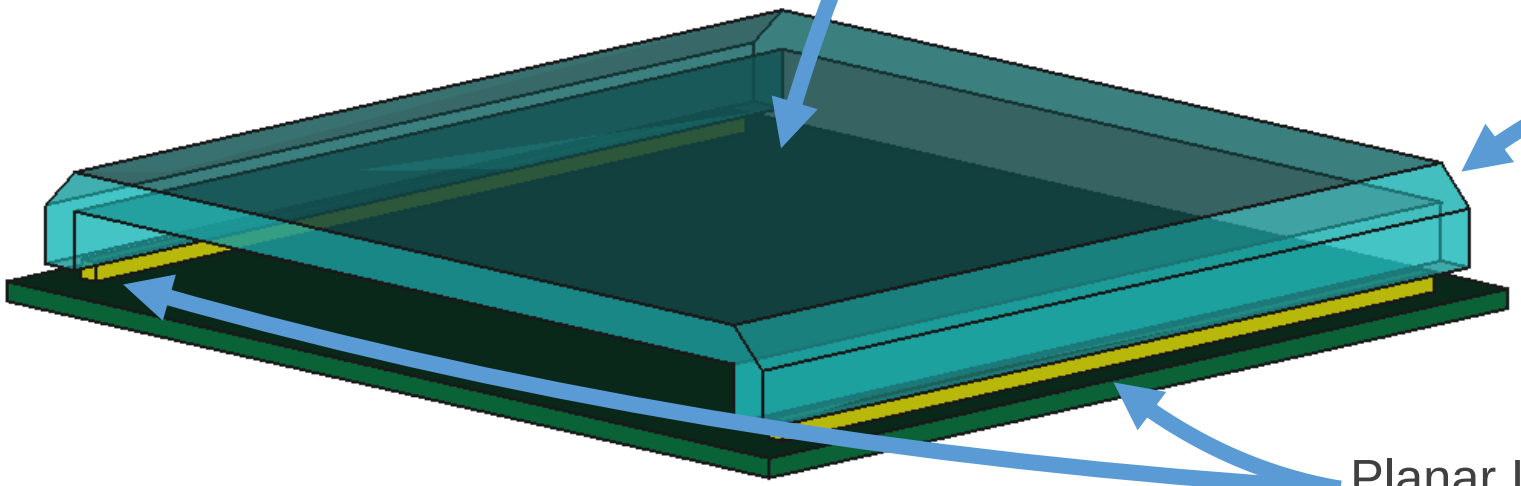
# Final Light-Guiding Layer (3D)

Dual-side LED illumination
➔ Reduced need for volume/surface scattering centers
➔ Cost reduction



Total Internal Reflection
(plus scattering centers)

Planar LEDs mounted
on the main PCB
(ease of manufacturing, reduced cost)

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# Final Light-Guiding Layer (3D)

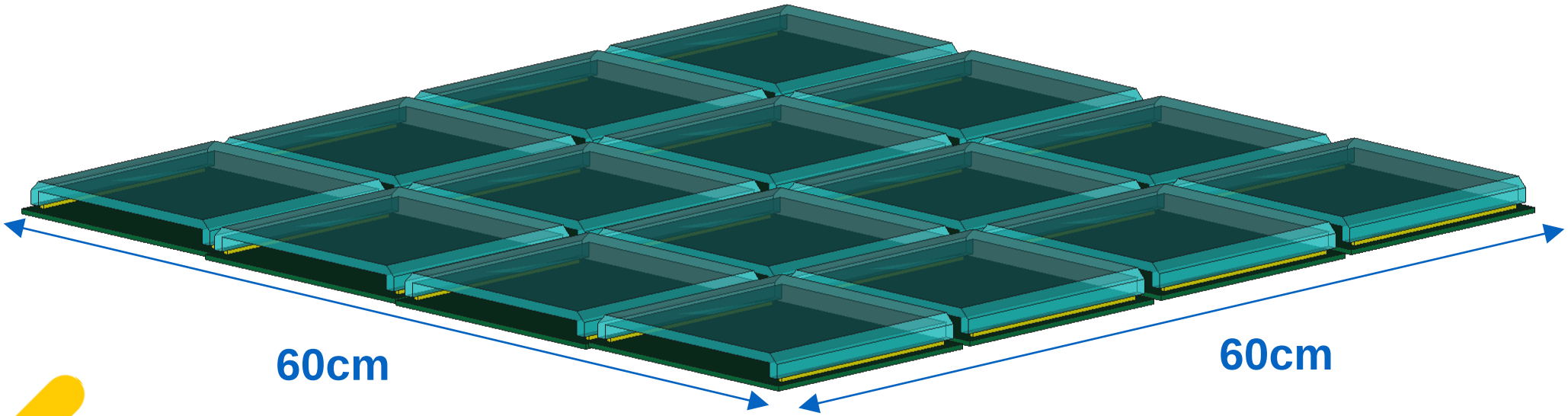
Allowance for larger tile size (60cm x 60cm ; 30cm x 60cm ; …)

➔ Nicer look

➔ Modular structure

➔ Reduced cost/area

➔ Increased versatility for installation (30cm x 15cm ; 15cm x 15cm ; …)

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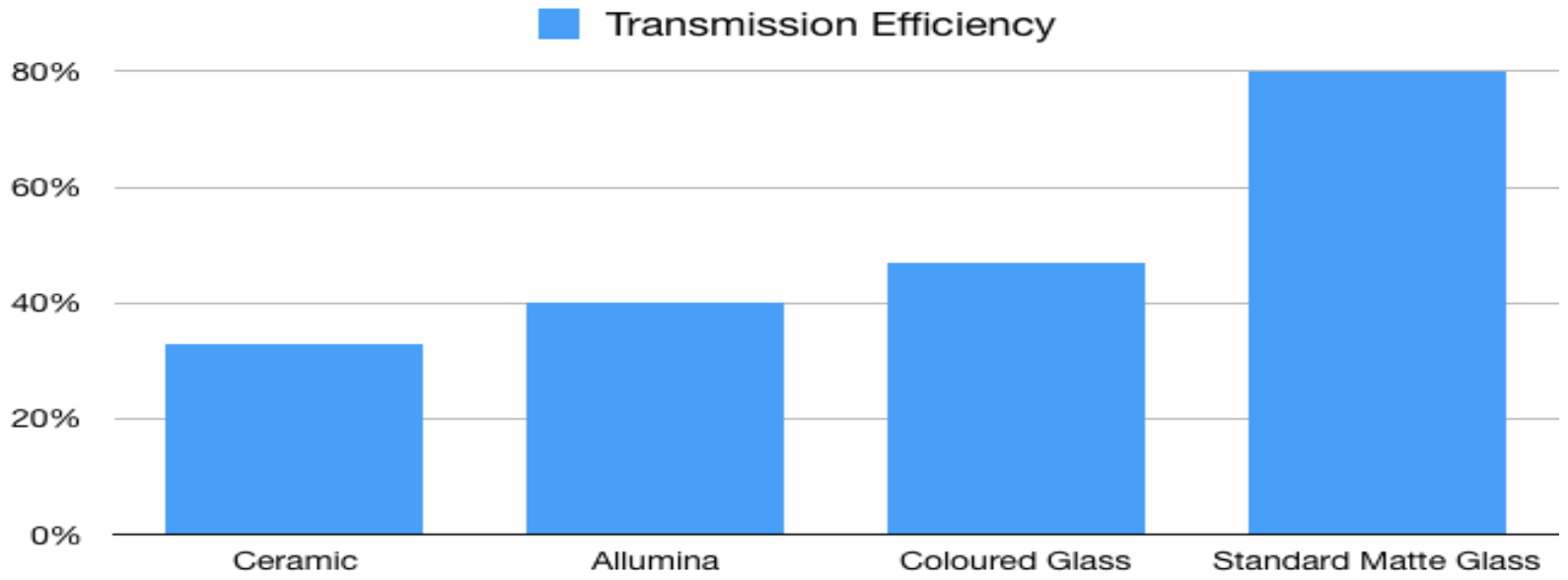
# Top Layer

Transmission efficiency
~ 30% Ceramic
~ 40% Alumina based ceramic
~ 50% Enamel coloured glass
> 80% Standard matte glass

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# Functional integration

**Smart LEDs driving** system to optimize the performance up to 500lux → 2x current generators, supplying up to 3A peak current

**Embedded sensors** to implement interactivity with the user →
- Embedded **gesture and proximity sensors** based on IR optical technology
- **Pressure sensors** (strain gauges) to detect people walking/standing on the tiles

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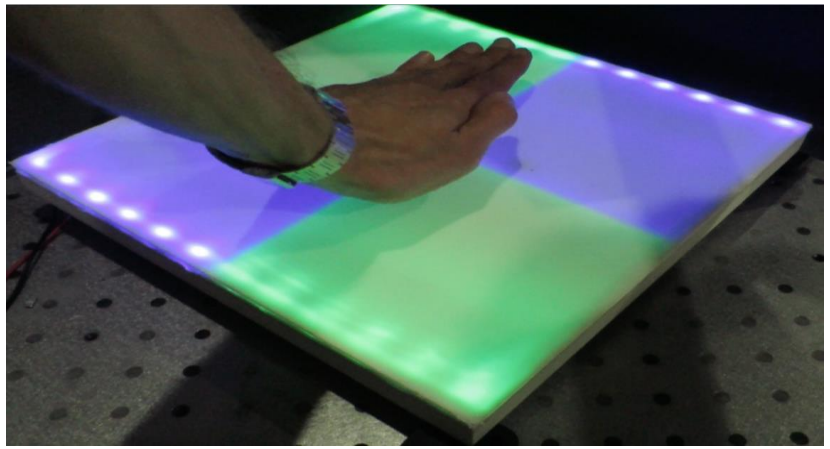
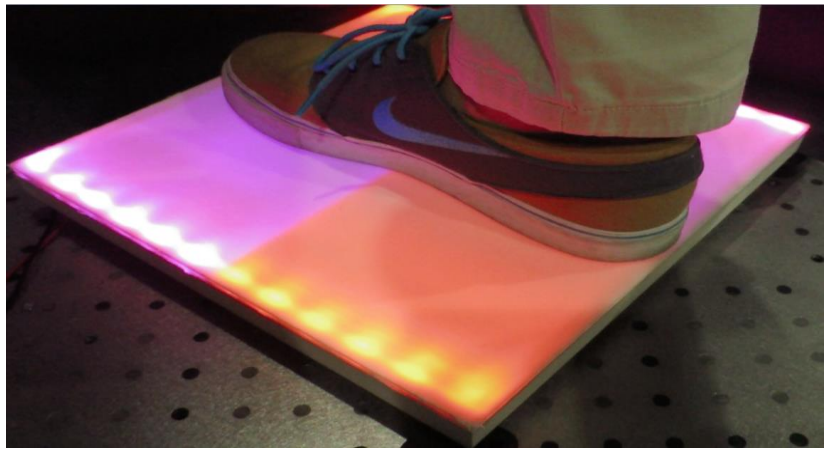
# Functional integration

## Sensing Systems

**Proximity and gesture detection**
• optical IR sensor



**Pressure detection**
• contact strain sensors



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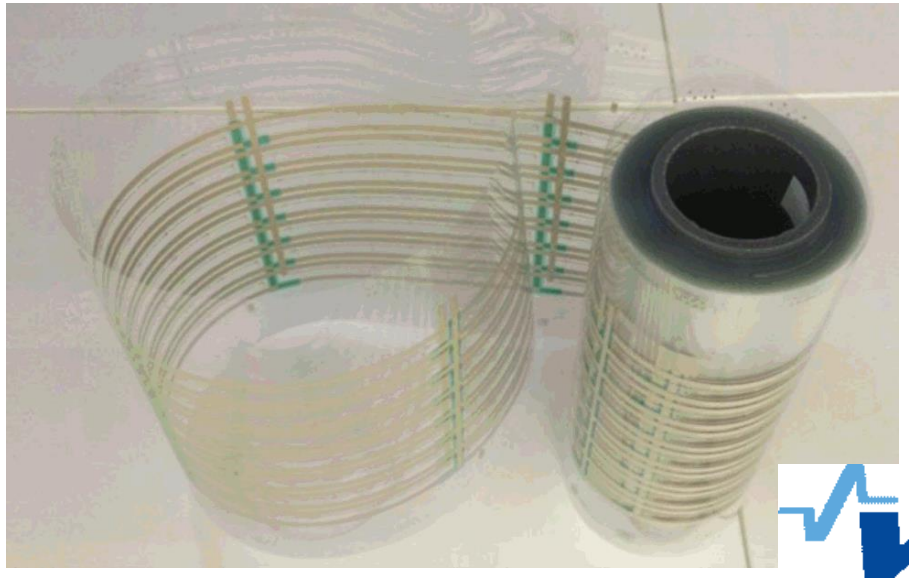
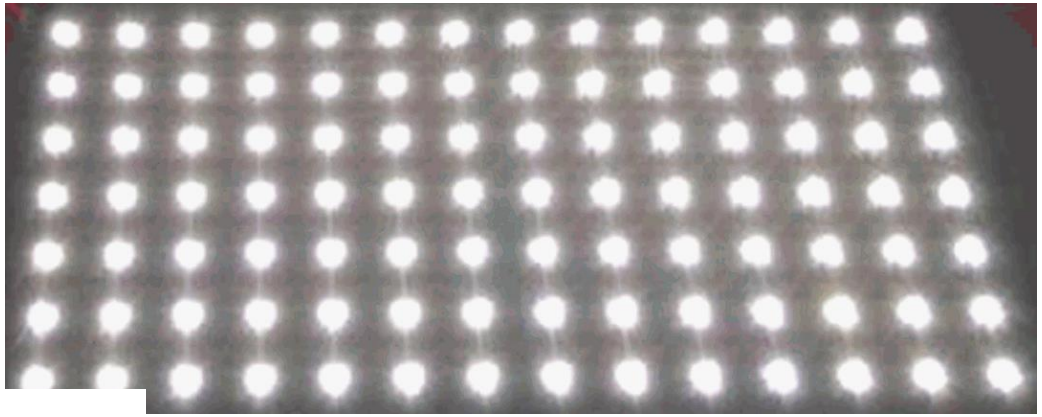
This project has received funding from the European Union's Horizon 2020 for research and innovation programme under grant agreement No 644302.

# Printed, Large-Area Electronic

- Goal: realize all the **(large-area) electronic circuits** using **printed technology on PET**
  - Flexible substrate
  - Roll-to-roll, low-cost production process





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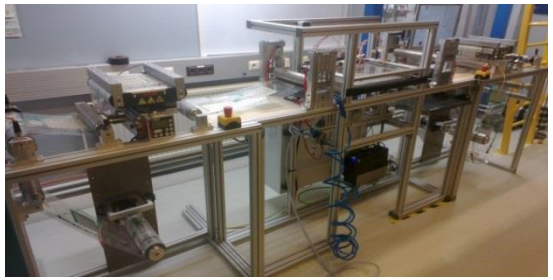
# VTT R2R pilot manufacturing environment

MAXI – In-air roll-to-roll pilot line

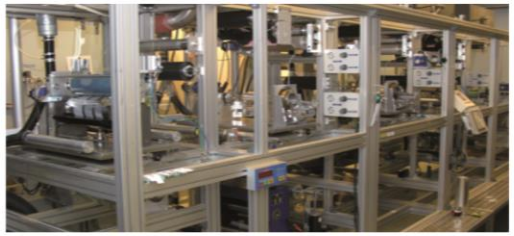
NICO – inert roll-to-roll pilot line



TESLA – functional testing


ENGEL - Injection moulding

PICO – in-air roll-to-roll pilot line



ROKO – in-air roll-to-roll pilot line

EVO - R2R assembly and bonding

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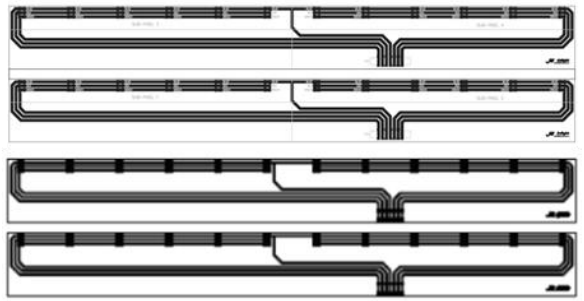
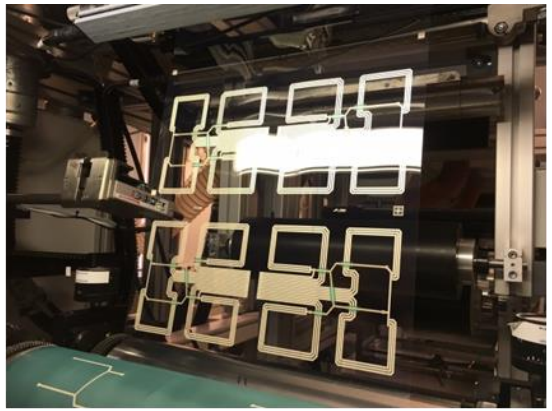
# R2R processing of flexible LED foils



Layout design

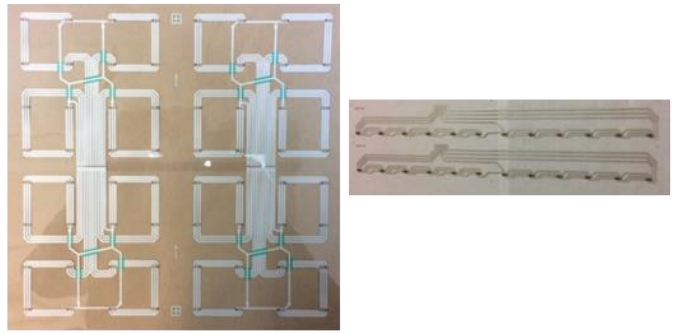


R2R printing of planar LED system on PET

R2R assembly pilot machine

R2R printing with pilot machine

R2R printed planar LED system roll



Assembled planar and edge type RGB LED substrates

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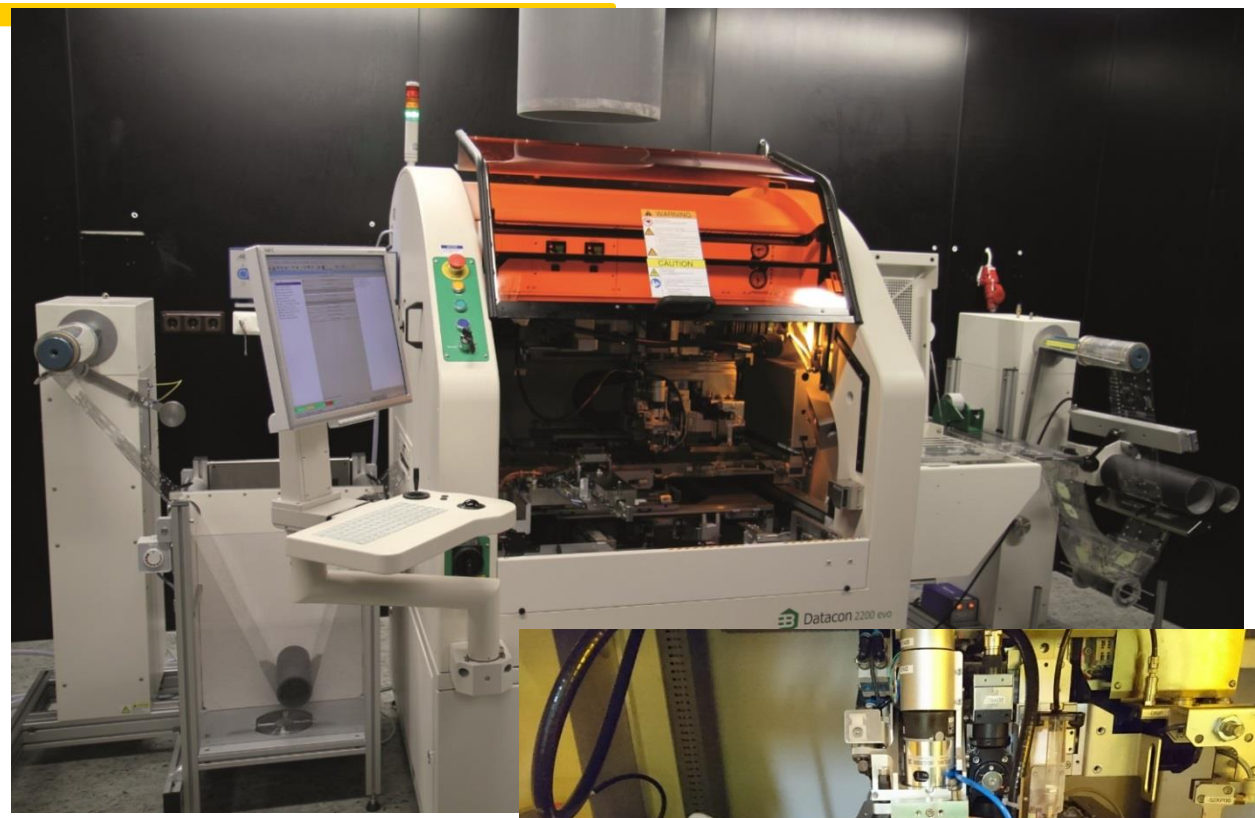
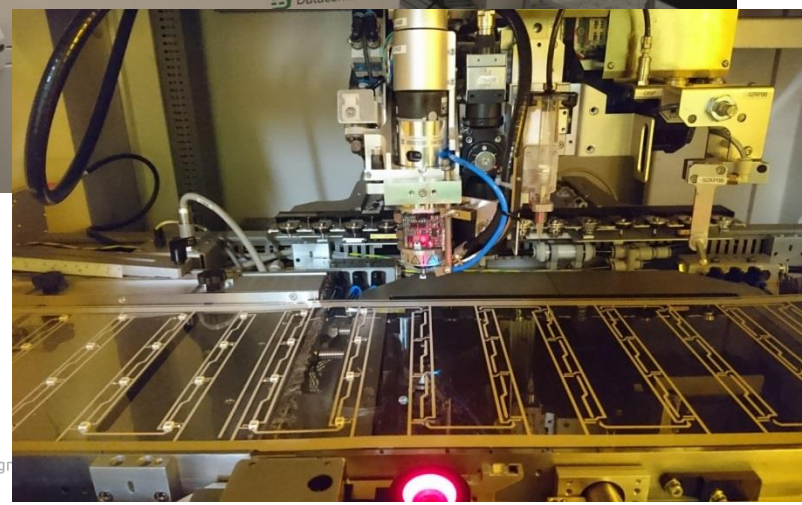
# R2R bonding

- Automated component assembly and bonding of various types of components on flexible substrates in continuous 200 mm width WEB Stop & Go process:
- Die attach, flip chip, multichip: chip-size down-to 100 mm
- Flex (solar cells, thin batteries, straps, etc.) + standard SMDs
- Adhesives dispensing & stamping (ICA, ACA, NCA)
- Adhesive curing by thermo-compression and UV
- Highest accuracy ± 7 µm @ 3 Sigma
- Die pick from wafer, waffle pack, gel pack
- Continuous WEB, sheet substrate, lead frame, wafer
- Individual process parameters for each interconnect



***New line in 2018! Above 300 mm line width!***

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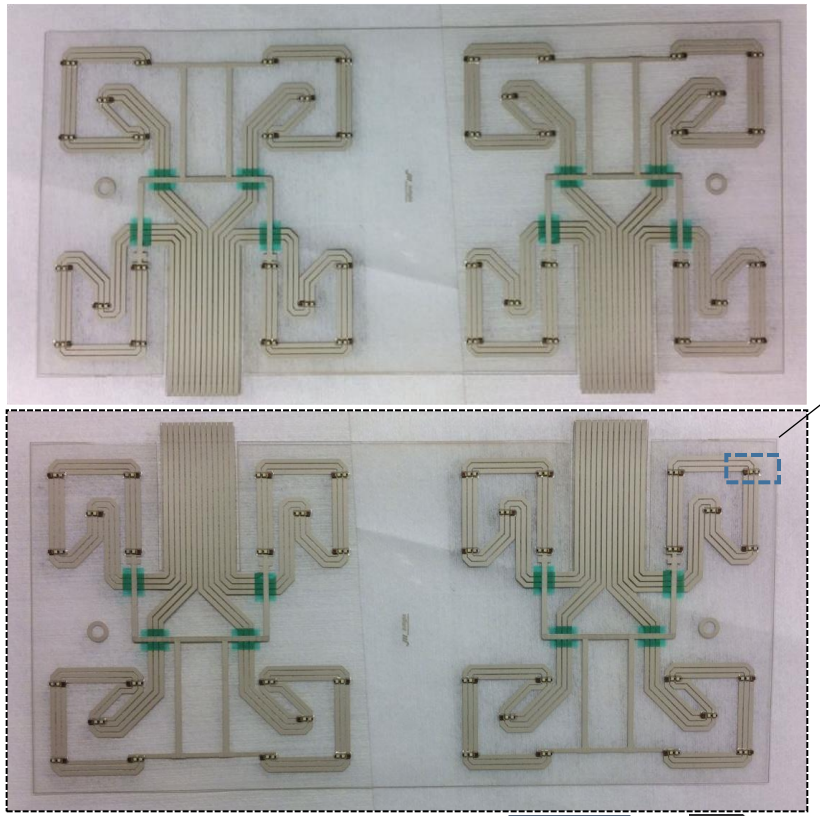
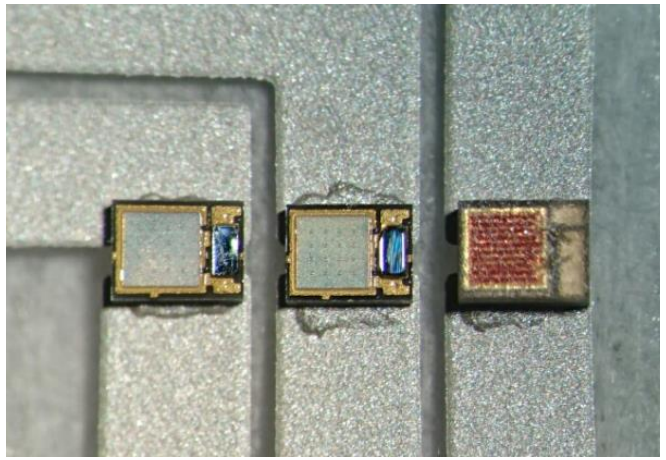
# HDR (Planar) LED foils

- Printed LED foils for Wall HDR video have 2 x 2 x 20 x 3 RGB LEDs, 240 in total





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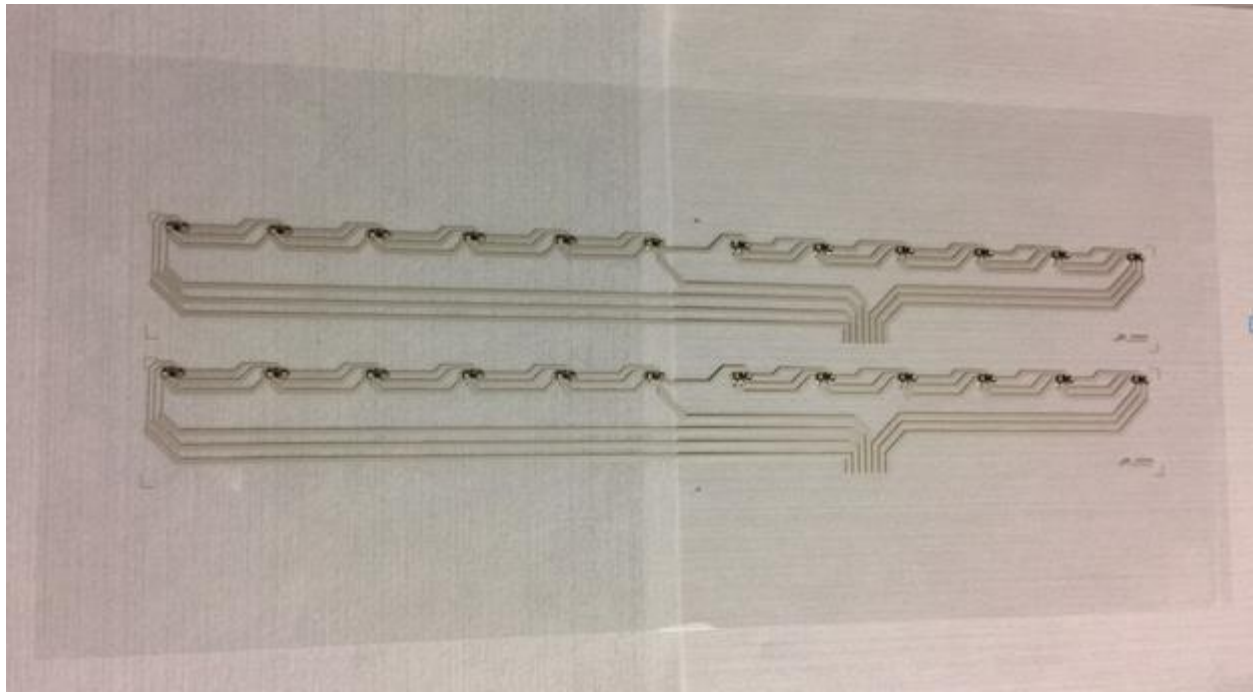
# LDR (Edge-coupled) LED foils

- Printed LDR LED foils for Wall and Floor luminous tiles have 2 x 12 x 3 RGB LEDs, 72 in total



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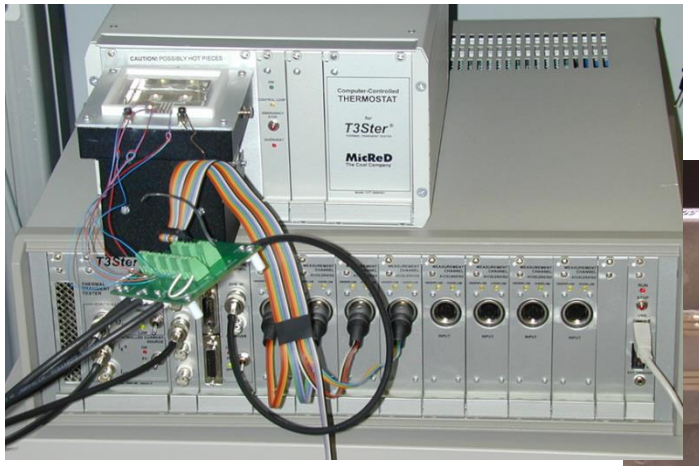
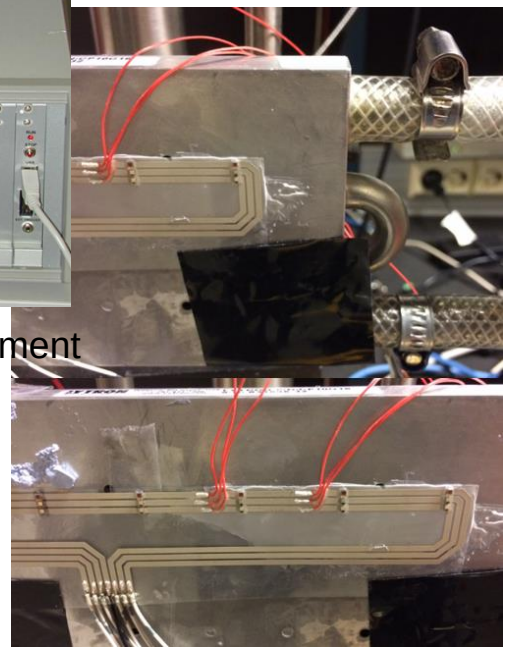
# LED temperature on foil

- PET material thermal conductivity is very low ~0.2 W/m*K => substrate acts as a thermal barrier for excess heat generated by the LED => over heating of LEDs on foil can occur with high driving current => over heating.
- Excess heat is dissipated through convection and radiation.
- Special heat management structures developed in LASSIE-FP7 EU project can be processed on foil, if needed.
- However, added value is not worth loading on foil if adequate luminous flux can be achieved with driving current, which still keeps LED junction temperature under temperature limit specified by the manufacturer => thermal characterization of system => electro-optical optimization of operation.



T3Ster thermal characterization instrument


Sensitivity calibration of LED system

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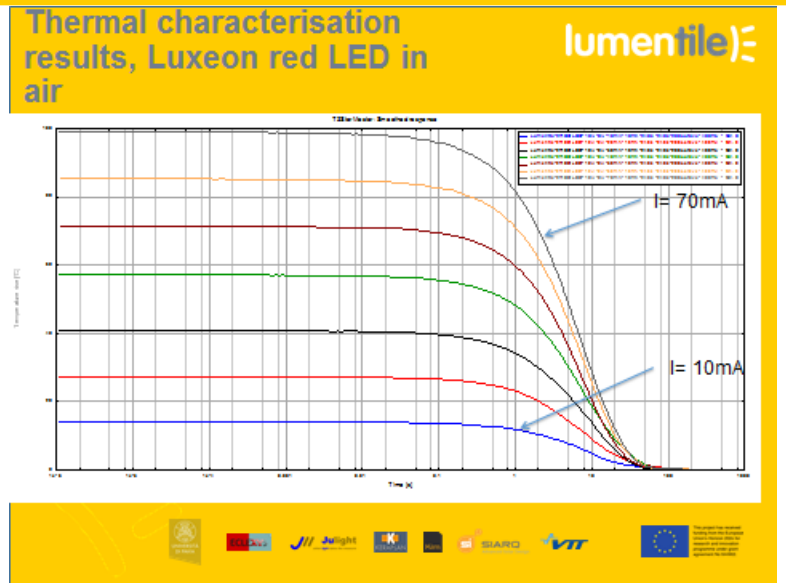
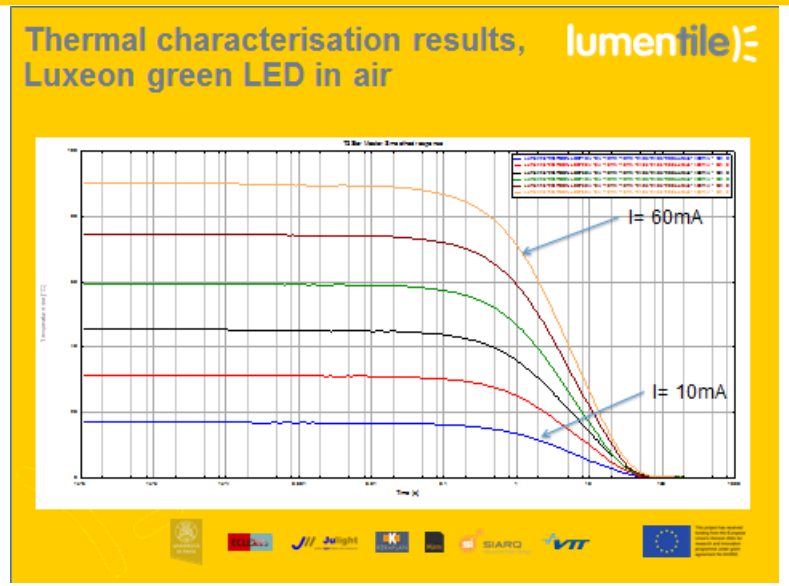
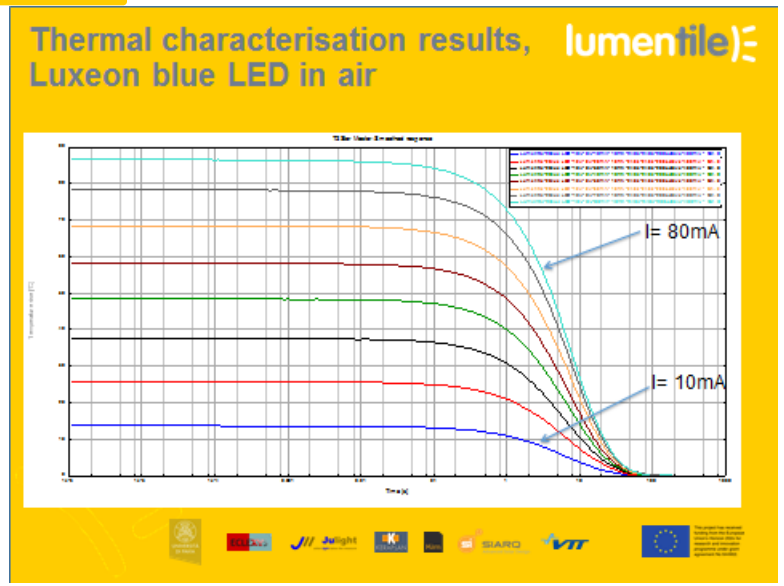
# Thermal characterization results, conclusions




According to the measurements maximum allowed driving currents for separate R, G and B LEDs on foil (foil installed (surrounded) in air is about:

- 115mA for blue LEDs
- 75mA for red LEDs
- 70mA for green LEDs

These max driving currents are well sufficient to produce required luminous flux by the system => LED foils does not need processing of special heat management structures.

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# Outline

- The **LUMENTILE Project**: facts sheet
- **Objectives** & **Products**
- **Photonics & Electronics Technology**
  - Light sources
  - Light management
  - Printed, large-area electronics
- **Other Technologies**
  - Tile-to-tile connection
  - Tile-to-tile communication
  - Materials integration
  - Towards large-scale production
- **Conclusions**

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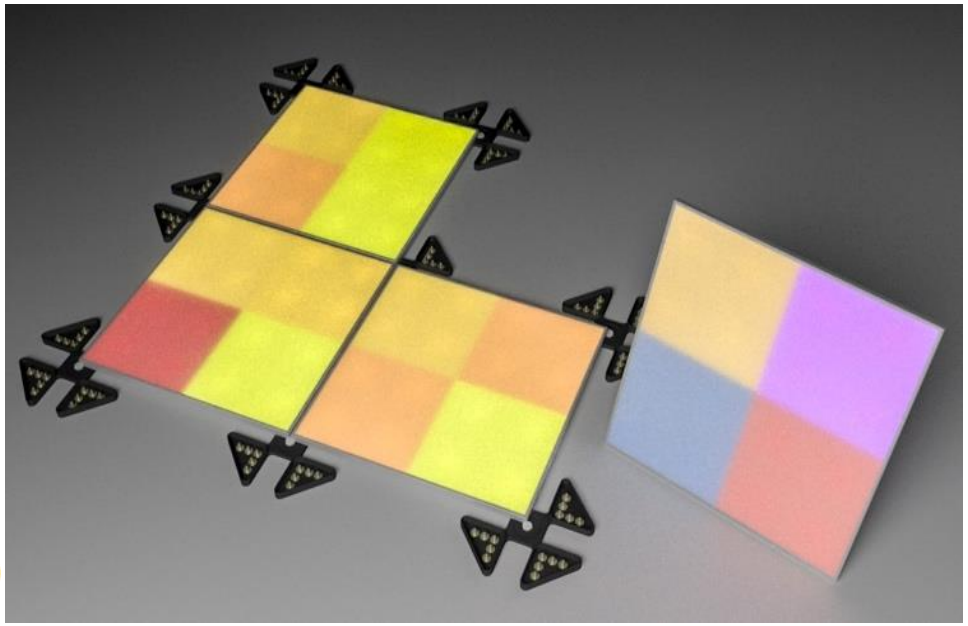
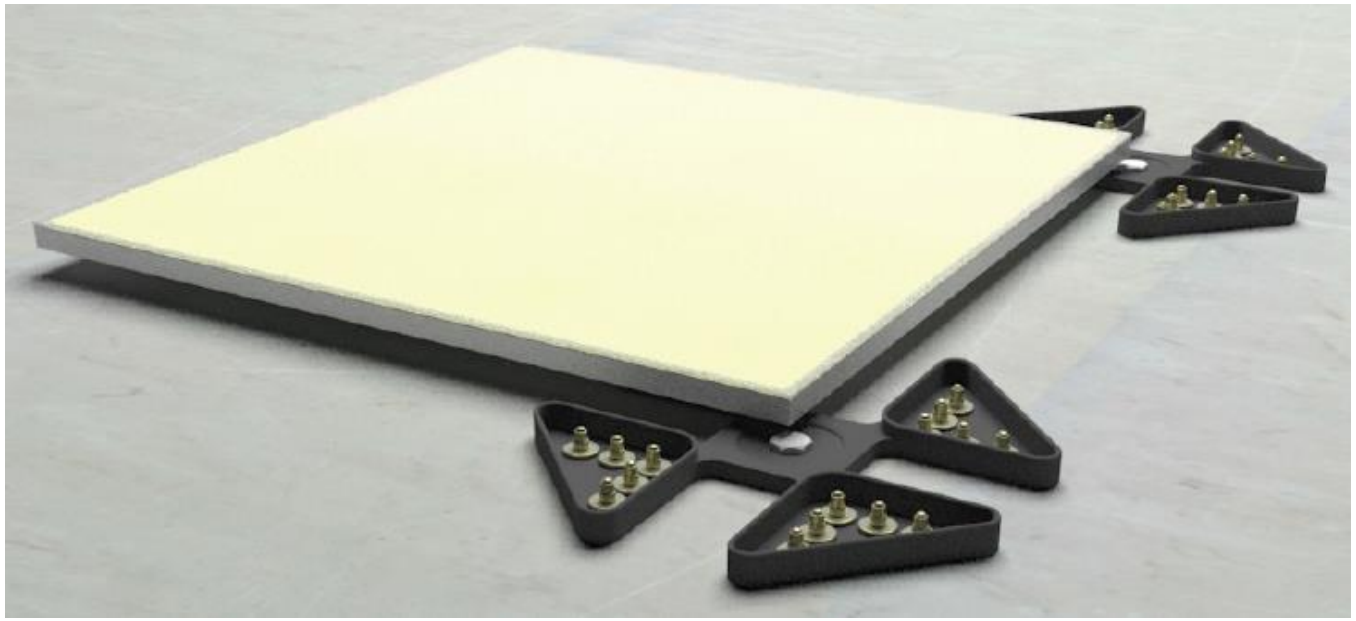
# Tile-to-tile connecion: the ConnecTile™

- All tiles are electrically connected to one another, via the **ConnecTile™** device





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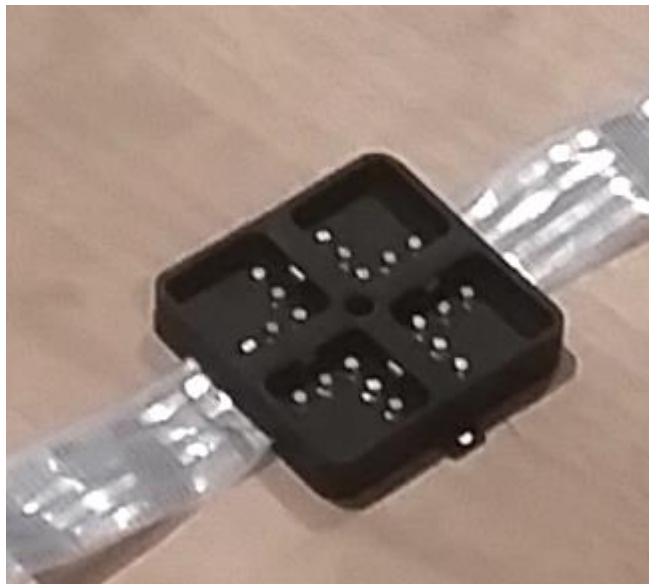
# Tile-to-tile connecion: the ConnecTile™

- The real **ConnecTile™** device



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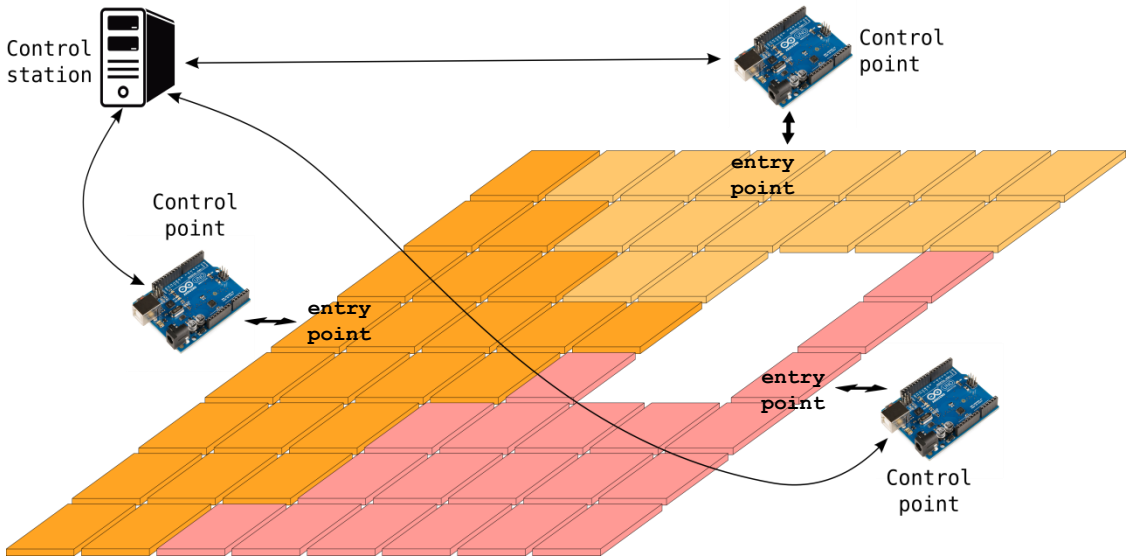
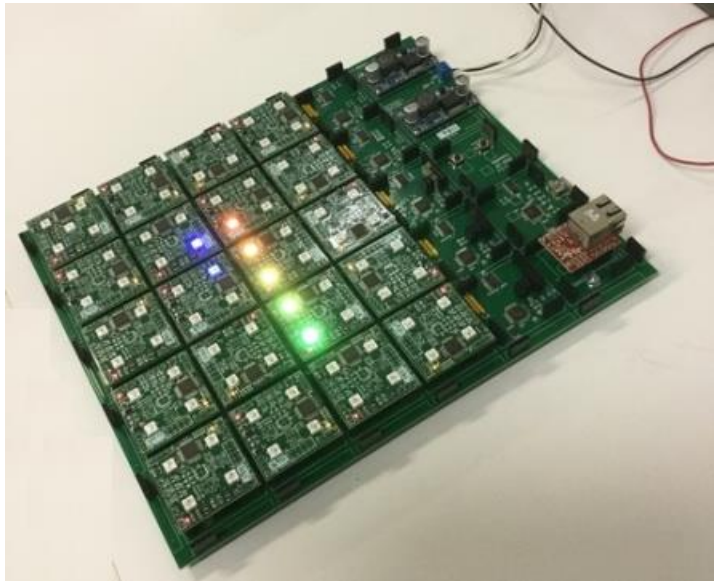
# Tile-to-tile communication

- Algorithm and protocol to identify tile topology
- Tile-to-tile communication
  - Color / intensity updates + sensor network interrogation




Mock-up demonstrator



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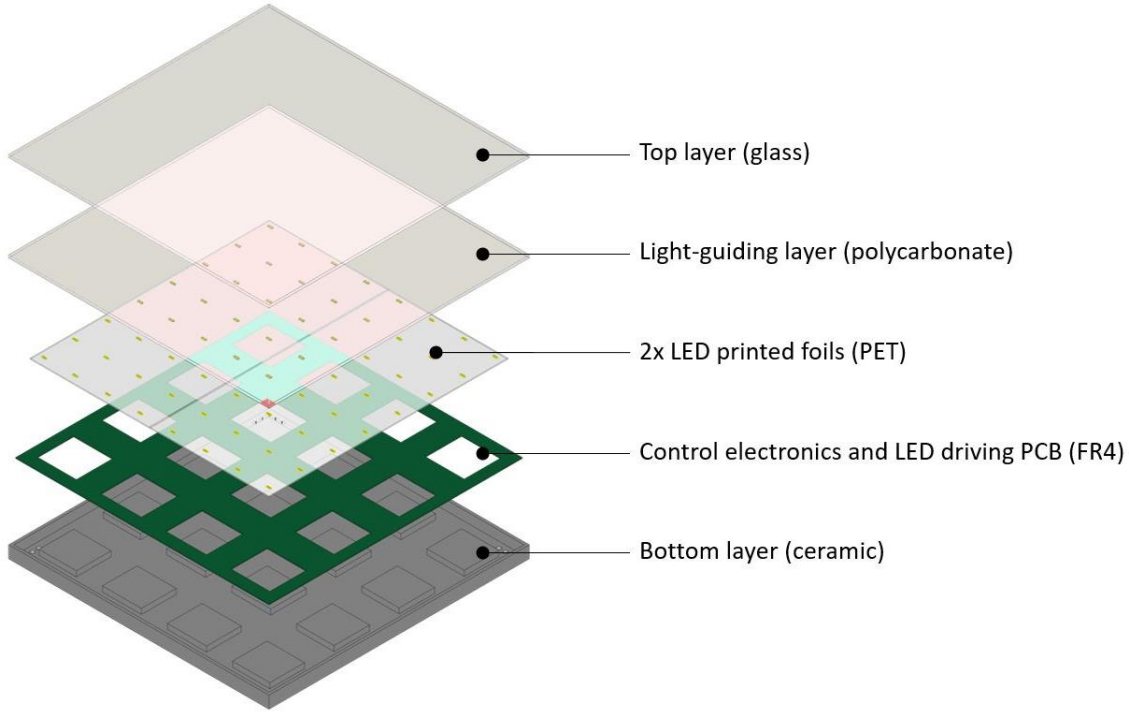
# Materials integration
# Towards large-scale production

- **Materials integration**
  - Ceramic bottom layer
  - Photonic / Electronic layer (flexible PET)
  - (Light Guiding Layer)
  - Top layer (translucent ceramic, glass, polycarbonate)

- **Towards large-scale production**
  - Assembly process (IP64/IP67)
  - **Cost optimization** (target: 300$/sqm)
  - **Pilot production line** to be started in **2019**

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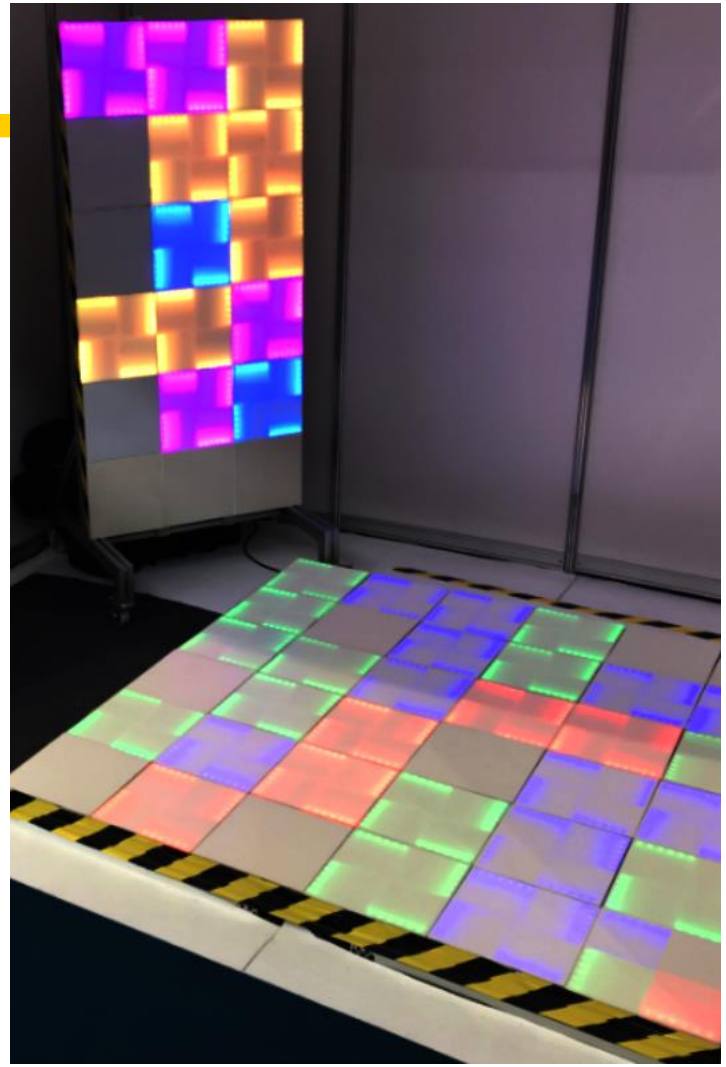
# Conclusions

- LUMENTILE Project Status (Oct 2017):
  - 3° generation of prototypes assembled
    - sub-parts design review to be completed
  - 2x moveable demonstrators completed
    - FLOOR - 1.8m x 1.8m
    - WALL - 0.9m x 1.8m
  - 3x fixed Demonstrators (≈ 50sqm total) to be installed in Winter 2017-18
- Partner search for pilot production and worldwide commercialization



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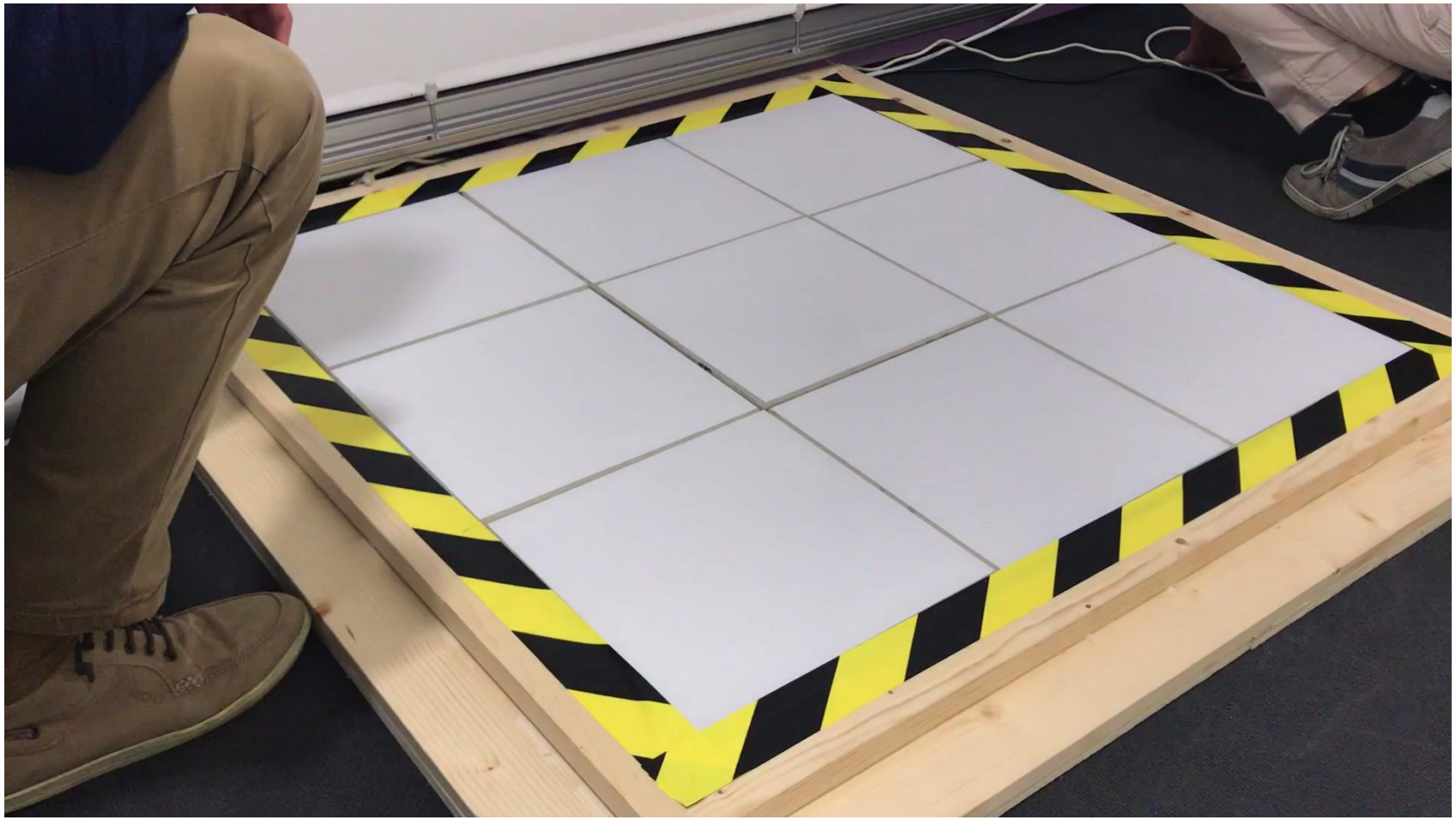
# Conclusions

- Come and see the LUMENTILE live demonstrator during the Apéro !!!!!!!



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# Conclusions

- 3x **FIXED DEMONTRATORS**:
  - FLOOR - 18.0 mq ; pressure sensing (walking)
  - WALL - 3.6 mq ; gesture sensing
  - VIDEO - 23.0 mq (4.8m x 4.8m) ; HD streaming video

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# Conclusions - Lesson Learned

- Integration of large-area electronics and photonics in an architectural/construction element
- Find solutions for large-scale manufacturing (millions sqm / yr)
- Tackle environmental issues (temperature, maintenance, …)

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