U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Welcome to the Dept. of Energy’s “Building-Integrated Photovoltaics: Beyond the Shingle” Workshop!

Please help yourself to coffee and snacks. We will begin at 8:10am.

Agenda Overview

8:00a – 8:15a	**Breakfast/Introductions**
8:15a – 8:45a	**SETO/BTO BIPV RFI Report** G. Stefopoulos (SETO), M. Lafrance (BTO)
8:45a – 9:15a	**Barriers & Strategies for Integrating Architectural Solar – A U.S. Market Perspective** Chris Klinga, Stan Pipkin (ASA)
9:15a – 10:15a	**Industry Panel Discussion** GAF Energy, Mitrex, Next Energy Technologies, Toledo Solar
10:15a – 10:30a	**Break**
10:30a – 10:45a	**Boots on the Ground: Solar Roof Contracting Today** Amy Atchley (Starling RFS)
10:45a – 11:00a	**Let's Talk About BIPV Resilience** Dr. Mengjie Li (UCF)
11:00a – 11:50p	**R&D Panel Discussion** EPRI, Penn State, NREL, LBL, Sandia
11:50a – 12:00p	**Concluding Remarks**

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Challenges and Opportunities for Building-Integrated Photovoltaics

SETO/BTO Request for Information Report

Solar Energy Technologies Office / Building Technologies Office

RE+ BIPV Workshop – September 22, 2022

Outline

- Background
- RFI overview
- Responses and learnings
- Workshops
- Further discussion

Background

- **Building-sited distributed PV was about 30% of new solar capacity installed in 2020**
- **Roof-mounted systems are currently the dominant design**
- **Other approaches and technologies could provide a competitive value proposition**
  - Providing better potential given the building aspect ratio
  - Combining redundant parts
  - Reducing overall system costs
  - Improving efficiencies

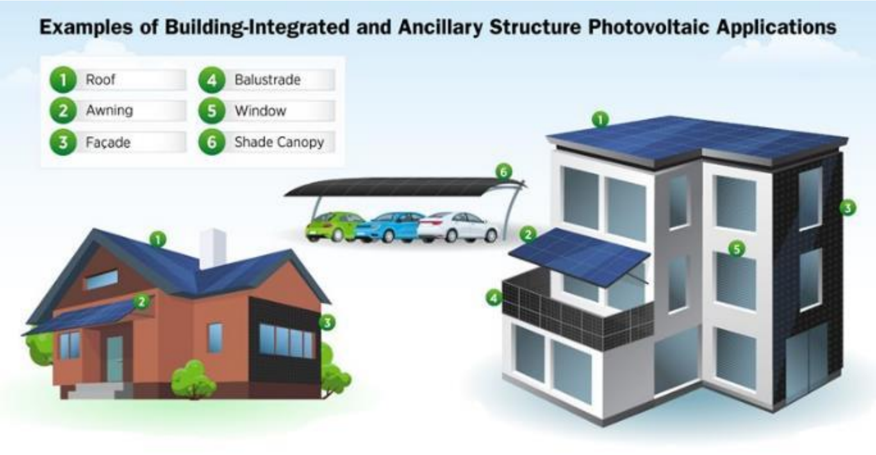
Background

Building-applied PV (BAPV)

- Conventional PV modules
- Fully-functional building
- Electricity generation

Building-integrated PV (BIPV)

- Specialized PV modules
- Integral part of building
- Electricity generation and building function



RFI Details

- Collaborative DOE RFI between SETO and BTO
- March 7 to April 1, 2022
- 37 responses from a variety of stakeholders
- Focus on current state of the industry, challenges and barriers, gaps, and R&D needs
- Summary report at https://www.energy.gov/eere/solar/summary-challenges-and-opportunities-building-integrated-photovoltaics-rfi

RFI Details – Focus areas


State of the industry and key domestic markets


Product requirements

Key barriers and perceptions

RDD&C needs and opportunities


Stakeholder engagement processes

Market Segments and Opportunities

Products

- **Roofing**
- Covering/Shading Elements
- Glass products
- Vertical products

Customer Segments

- **Commercial buildings**
- Residential buildings
- Government, education, healthcare
- Agriculture and greenhouses

Domestic Manufacturing

- Proximity to market
- Building products typically produced close to consumption
- Cost/emission reductions

Key Product Requirements

- Performance
- Cost
- Aesthetics
- Reliability, durability, and safety
- Process integration
- Supply chain integration

Key Barriers and Perceptions

Technical Barriers	Costs
	Performance
	Aesthetic considerations
	Technical complexity in installation, operation, and maintenance
	Certification and permitting challenges
Resource Shortages	Availability of products, product and supply chain reliability
	Expertise shortage and lack of educational resources
	Lack of sales, estimation, and other decision support tools
	Lack of financial incentives specific to BIPV
Awareness and collaborations	Technology awareness by designers and end-users
	Existing silos in operating and business models of various affected groups
	Disconnects between partnering groups and affected industries
Research and Development	Lack of fundamental research
	Lack of demonstration projects

RDD&C Needs

Product demonstration	Testing facilities and demonstration projects
	Availability of data
Models and tools	Production cost modeling
	Energy yield modeling
	Installed system cost modeling with consideration for O&M costs
	Comprehensive assessment of benefits
Performance improvements	Improved BIPV product designs – aesthetics, installation, O&M
	Efficiency and energy yield improvements
	Thermal management improvements
	Installation and maintenance processes
	Systems integration

Stakeholder Engagement and Outreach

Underrepresented groups	Architectural community
	Construction industry
	Manufacturers and product implementation teams
	Power-electronics companies
	Trade associations and organizations
	Local/state regulators
	Investors
Outreach mechanisms	Publishing case studies
	Supporting and promoting demonstration projects
	Establishing dedicated BIPV conferences, trade shows, workshops, and other educational opportunities
	Creating a steering committee to make recommendations for specific certification standards for BIPV
	Providing funding opportunities for research and commercialization of BIPV solutions
	Instituting BIPV rebate programs or financial incentives
	Creating a coordinated national effort, like establishing a U.S.-based consortium
	Promoting early-stage innovation

Purpose of Workshop

- Bring together various BIPV stakeholders from industry, academia, and research entities
- Create a forum for discussion and exchange of views and ideas
- Understand the current status and needs of the industry
- Receive input that would guide future DOE plans and activities

DOE BIPV Workshops

- **RE+**
  - https://www.re-plus.com/power/
  - Thursday, September 22, 2022, 8:00 – 12:00p
- **Greenbuild International Conference and Expo**
  - https://informaconnect.com/greenbuild/
  - Tuesday, November 1, 2022, 9:00 – 12:00p
- **Buildings XV**
  - https://www.ashrae.org/conferences/topical-conferences/2022-buildings-xv-conference
  - Thursday, December 8, 2022, 1:00 – 5:00p

Questions and Further Discussion

George Stefopoulos
georgios.stefopoulos@ee.doe.gov

US DOE BIPV Workshop - Building Technology Office

Marc LaFrance
US DOE
Advanced Technology and Energy Policy Manager
RE+ Conference, 22 September 2022

Core functions of building envelopes

- Keep the rain out
- Keep the heat out in summer
- Keep the heat in the winter
- Maintain a view to the outdoors
- Provide safe and comfortable space
- Avoid mold, bugs and rot
- Reduce chances of condensation
- Ventilate indoor pollutants
- Avoid infiltration of outdoor pollutants and latent loads

Building envelope infrastructure example – standards and ratings

Fenestration:

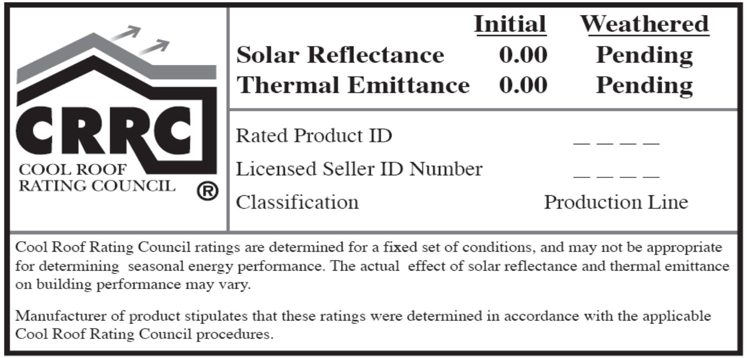
- Simulation of U-factor, Solar Heat Gain Factor and Visible transmittance - ISO 15099
- U-factor testing - ASTM C 1363, C1199, NFRC 102
- Solar Heat Gain Testing – NFRC 201
- Spectral Optical Property – ISO 9050, ASTM E903, NFRC 300, 301
- Air Leakage – ASTM E283, NFRC 400

Wall Insulation

- ASTM C 518, C 177

Wall System

- ASTM C1363, ASTM C1155



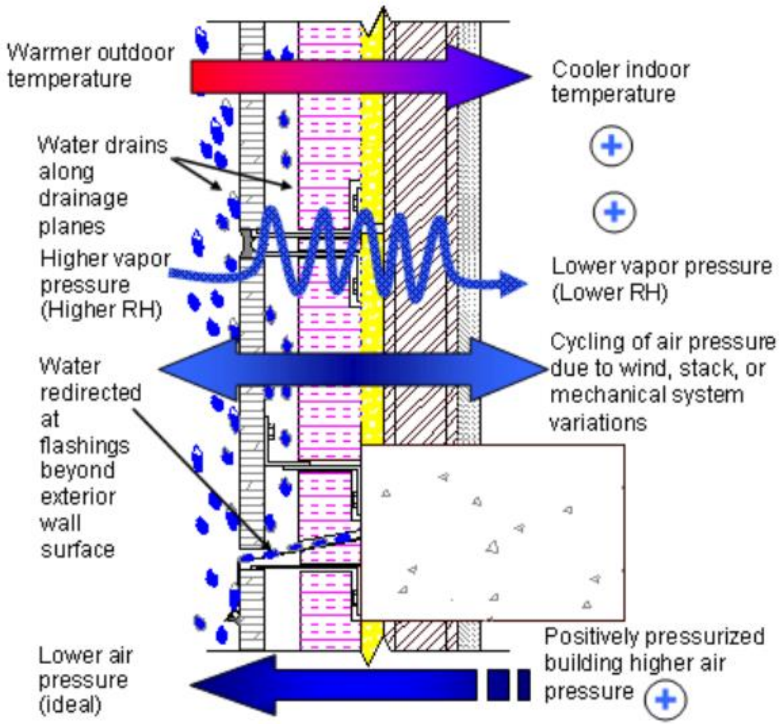
Air Leakage

Hot Box

Solar Calorimeter

Spectrophotometer

Wall systems – complex moisture and air management



Courtesy: Whole Building Design Guideline

BIPV needs to ensure core functions are maintained

Roofing conventional PV vs BIPIV

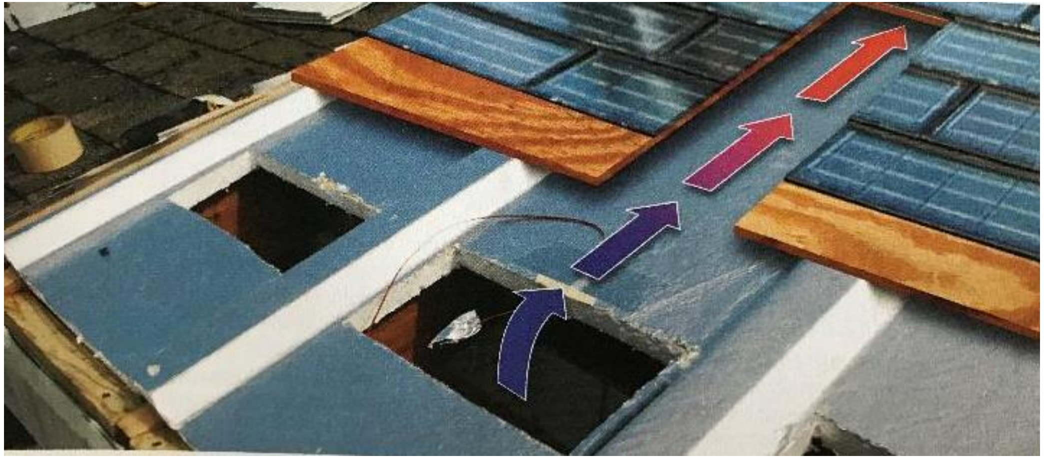
Conventional

- Shades roof from heat gain
- Allows panels to cool to produce higher output
- Not always aesthetically pleasing to some

BIPV

- Higher cell temperatures, lower output
- Increase in heat flux to attic/plenum compared to cool roofs
- Generally greater aesthetics

Above Deck Ventilation – lower peak cooling



Example of BIPV with high efficiency

Key Benefits

- Highest output PV
- Cells allowed to cool
- Optimized sun angle
- Shades windows from sun

Concerns

- Aesthetically less appealing
- Window cleaning is more difficult/costly

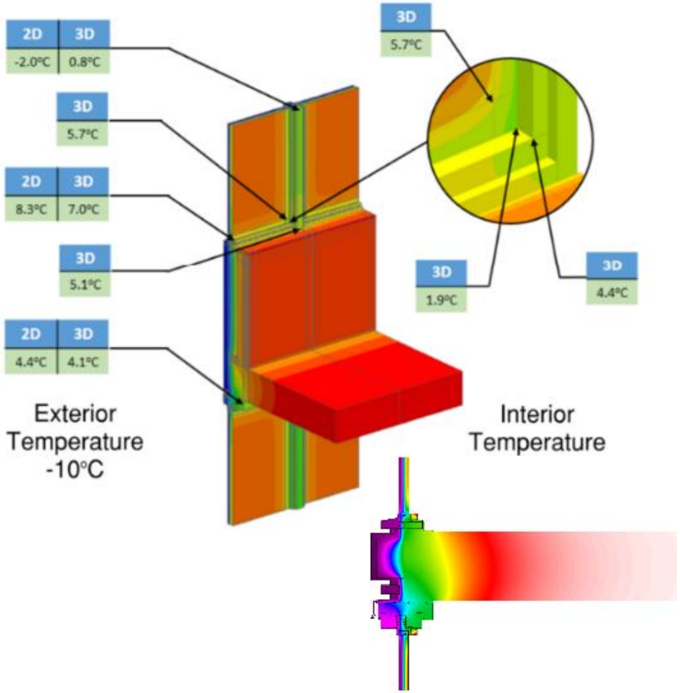
Source: "Transition to Sustainable Buildings, Strategies and Opportunities to 2050", IEA 2013

Thermal Performance of Spandrels in Glazing Systems

Issues:
- Thermal-bridging of aluminum framing
- Differing construction of opaque wall areas vs. transparent areas
- Lack of consensus in thermal modeling

Needs:
- Higher performing spandrel systems to meet more stringent codes
- Thermal modeling consensus based on validation and experimentation

Outcome:
- *Design Guidance* document with best practices and recommended modeling procedures



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aellis@pankowfoundation.org

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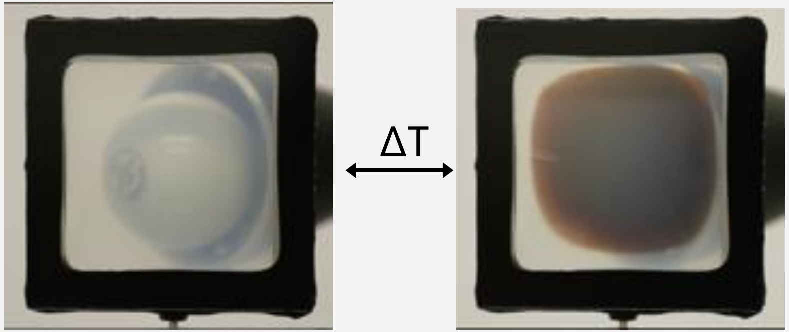
Simpson Gumpertz & Heger Inc.

Perovskite materials for photovoltaic windows project

Thermochromic PV

Dynamic solar heat gain control + PV generation



Transparent

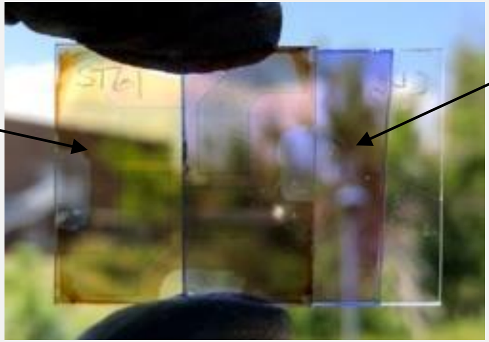
Colored + PV

- Generates electricity and modulates solar heat gain for significant building energy savings
- Proof of concept demonstrated.
- NREL holds >10 patents on the technology
- Durability improved
- Significant investment makes them market viable in ~5 years

Lance Wheeler, PhD
NREL

Neutral color semitransparent PV

High efficiency without sacrificing aesthetics



Perovskite PV

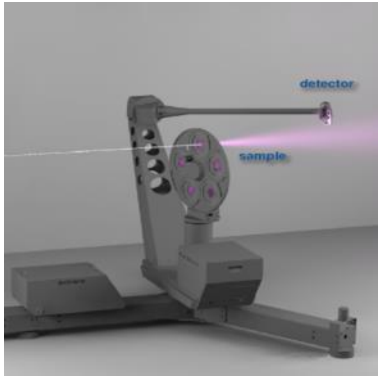
Color balance layer

- >6% geometric efficiency with >30 visible light transmittance and neutral gray color
- Compatible with current glazing and lamination processes
- Investment makes technology market viable in ~3 years.

National Laboratory expertise and advanced facilities

LBNL Flexlab

ORNL Guarded Hot Box



LBNL Goniophotometer

NREL Differential Thermal Cycling Unit

PNNL Lab Homes

Resources and contact info

US DOE – Pathway to Zero Energy Windows – Advancing Technology and Market Adoption - Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption (nrel.gov)

US DOE - Opaque Envelopes: Pathway to Building Energy Efficiency and Demand Flexibility Key to a Low-Carbon, Sustainable Future

Opaque Envelopes: Pathway to Building Energy Efficiency and Demand Flexibility

Grid-interactive Efficient Buildings Technical Report Series Windows and Opaque Envelope

Grid-interactive Efficient Buildings Technical Report Series: Windows and Opaque Envelope (energy.gov)

LBNL Core Window Lab – Primer videos and resources

Outreach | Windows and Daylighting (lbl.gov)

P Marc LaFrance, CEM
Advanced Technology and Energy Policy Manager
US Department of Energy
1000 Independence Ave, SW
Washington, DC 20585-0121
marc.lafrance@ee.doe.gov
Cell 240-474-2177

Barriers & Strategies for Integrating Architectural Solar – A U.S. Market Perspective

Christopher Klinga
Architectural Solar Association

- Technical Director of the Architectural Solar Association
- Principal at SolMotiv Design.
- Past experience with Lighthouse Solar and Lumos Solar
- B.S. in Mechanical Engineering from the University of Colorado in Boulder, CO.
- NABCEP PV Installer certification
- Licensed professional engineer in Colorado and Texas.

Stan Pipkin
Architectural Solar Association

- US Regional Manager of the Architectural Solar Association
- Owner of Lighthouse Solar and Pipkinc.
- Master of Architecture from the University of Texas.

1_Klinga_Pipkin_ASA - RE+ BIPV Workshop.pdf

BIPV Industry Panel Discussion

Moderator: **Jennifer DiStefano**
Contractor to the
U.S. Dept. of Energy

Danial Hadizadeh
Mitrex

Mark Hartel
Toledo Solar

Corey Hoven
Next Energy Tech

Scott Lowry
GAF

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BREAK 10:15 - 10:30am

Boots on the Ground: Solar Roof Contracting Today

Amy Atchley
Starling RFS

Amy Atchley is a solar roofing contractor in Sonoma County, CA. Amy is also the cofounder and COO of "Starling Roofing for Solar". Starling makes an award winning solar-roofing-system, giving solar roofers a product advantage to go with their business model advantages.

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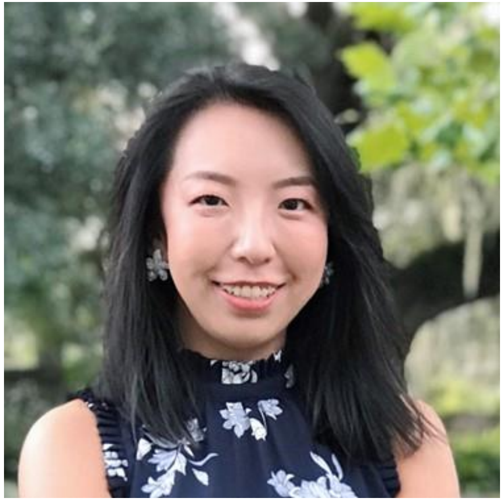
Let’s Talk About BIPV Resilience



Dr. Mengjie Li
University of Central Florida

Dr. Li is a research scientist at Florida Solar Energy Center and University of Central Florida. She has a background of high efficiency solar cell fabrication, and is currently focused on degradation pathway analysis of PV modules and improving energy and community resilience with renewable energy solutions. She will discuss the role of BIPV in improving energy resilience and the current state-of-art in BIPV durability and reliability characterization research.

3_Li_UCF - RE+ BIPV Workshop.pdf

BIPV R&D Panel Discussion

Moderator:
Jeff Cook, NREL

Laurie Burnham
Sandia Nat. Lab

Nadav Enbar
EPRI

Jacob Jonsson
Lawrence Berkley Nat. Lab

Simon Miller
Penn State Univ.

Lance Wheeler
NREL

Thank you! Join us at upcoming DOE BIPV events

1. Greenbuild Conference – November 1-3, 2022 – San Francisco, CA

– DOE BIPV Workshop on Tuesday, 11/1, 9am-12pm

Greenbuild | International Conference + Expo
FEATURING IWBC

2. Buildings XV Conference – December 5-8, 2022 – Clearwater Beach, FL

– DOE BIPV Workshop on Thursday, 12/8, 1-5pm

For questions about our BIPV workshop series, please reach out to George at georgios.stefopoulos@ee.doe.gov.

Learn About Upcoming Funding Opportunities

EERE Funding Opportunity Updates

Promotes the Office of Energy Efficiency and Renewable Energy's funding programs.

SIGN UP NOW:

energy.gov/eere/funding/eere-funding-opportunities

SETO Newsletter

Highlights the key activities, events, funding opportunities, and publications that the solar program has funded.

SIGN UP NOW:

energy.gov/solar-newsletter

Thank you!

George Stefopoulos

georgios.Stefopoulos@ee.doe.gov

Jennifer DiStefano

jennifer.distefano@ee.doe.gov

Marc Lafrance

marc.lafrance@ee.doe.gov

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Barriers & Strategies for Integrating Architectural Solar

A US Market Perspective

Christopher Klinga, PE

Technical Director, ASA

Stan Pipkin

Regional Manager, ASA

September 22, 2022

Image courtesy of Issol

Who We Are

The Architectural Solar Association (ASA) represents a growing industry with a common goal of transforming building facades and other architectural surfaces into generating assets.

ASA

- Expands Awareness
- Acts as a Supply Chain Resource
- Develops Standards

Image courtesy of Spotlight Solar

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Christopher Klinga P.E.
T*echnical Director*, ASA
Principal, SolMotiv Design

- 2007-2016 - VP of Product Development Lumos
- Actively consulting in architectural solar product & project development
- B.S. Mechanical Engineering University of Colorado
- Colorado & Texas licensed professional engineer

Stan Pipkin
US Regional Manager, ASA
Owner, Lighthouse Solar & Pipkinc.

- 2007-Present, Lighthouse Solar Austin - hybrid solar EPC and architectural design firm.
- Principal of Pipkinc. design firm focusing on residential sustainable architecture.
- Masters of Architecture from the University of Texas
- Policy expertise at Solar Austin, TXSES
- IREC Design Award
- Product Design with Lumos Solar

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Architectural Solar Association

Overview

- Definition of Architectural Solar
- Architectural Integration Opportunities
- Market Barriers
- Path to Widespread Adoption

Image courtesy of Lumos Solar

Definitions of BIPV and BAPV

per EN 50583 / IEC 63092 / IEC 61730

3.3.1 Building Attached PV (BAPV)

Photovoltaic modules are considered to be building attached if the PV modules are mounted on a building envelope and do not fulfil the criteria for building integrated PV

3.3.2 Building Integrated PV (BIPV)

Photovoltaic modules are considered to be building integrated if the PV modules form a building component providing additional functions as defined in 4.5 b

Building Functions: (in addition to power generation)

Mechanical rigidity or structural integrity, Primary weather impact protection: rain, snow, wind, hail, Energy economy, such as shading, daylighting, thermal insulation, Fire protection, Noise protection, Separation between indoor and outdoor environments, Security, shelter or safety

Thus, the BIPV module is a prerequisite for the integrity of the building’s functionality. If the integrated PV module is dismounted , the PV module would have to be replaced by an appropriate building component.

Image courtesy of Lumos Solar

BIPV
Solar Technology with Architectural Significance

Image courtesy of Lumos Solar

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Image courtesy of Lumos Solar

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Architectural Solar

Solar energy generating technologies that are coordinated with the architectural design process.

Image courtesy of Lumos Solar

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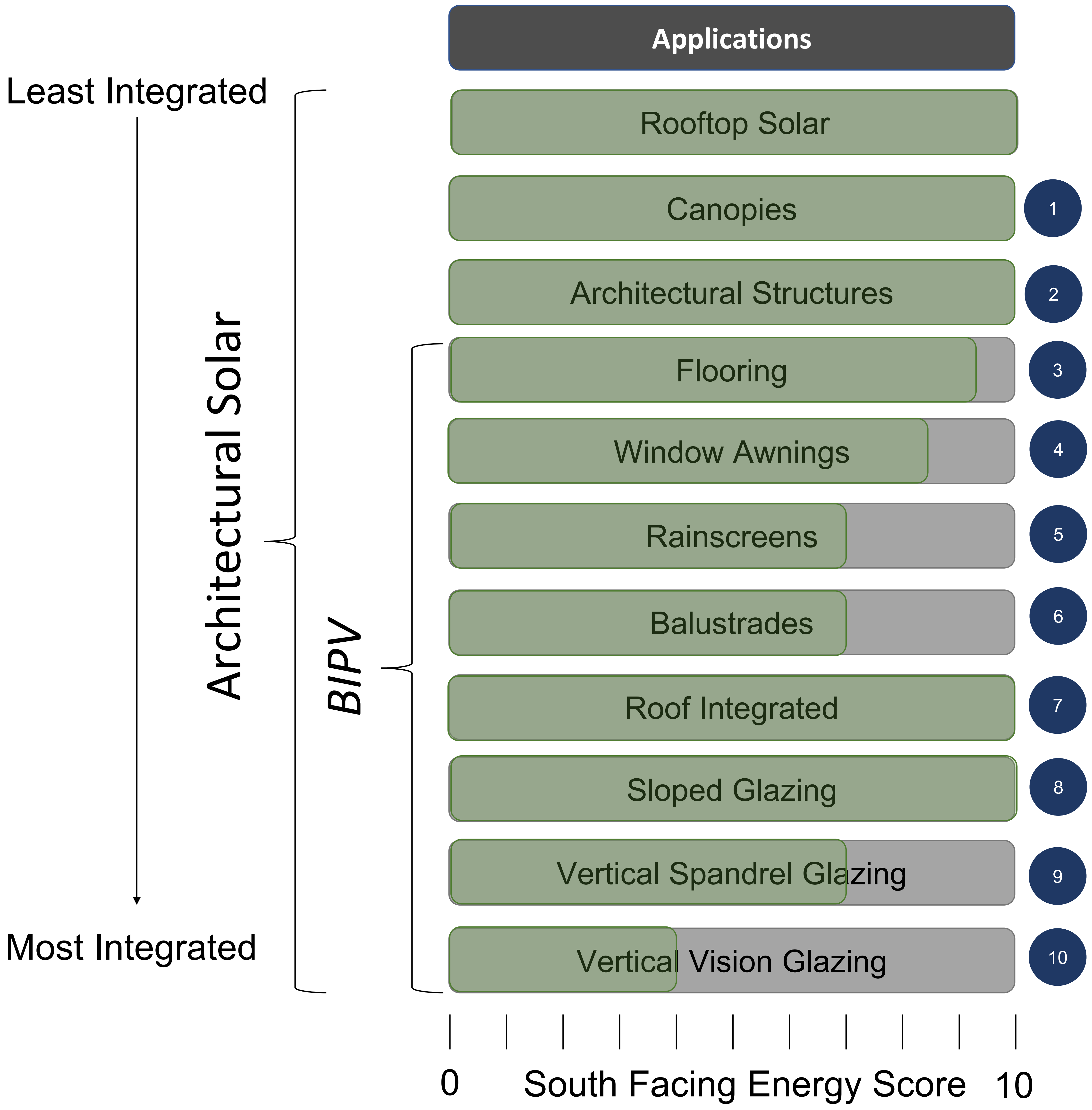

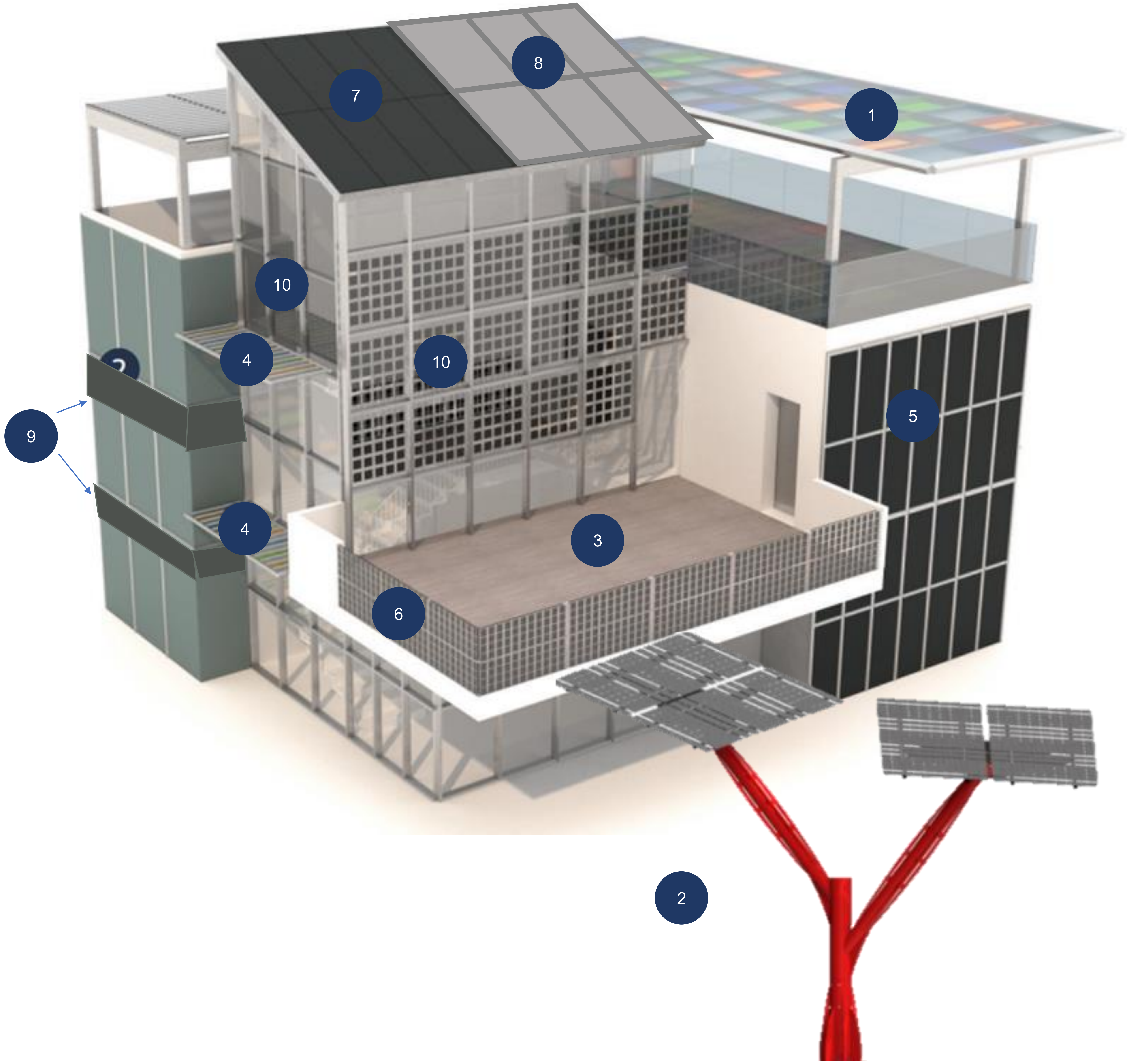

Graphic courtesy of SUPSI

Architectural Solar Continuum

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Rooftop Solar

Least Integrated — Most Integrated

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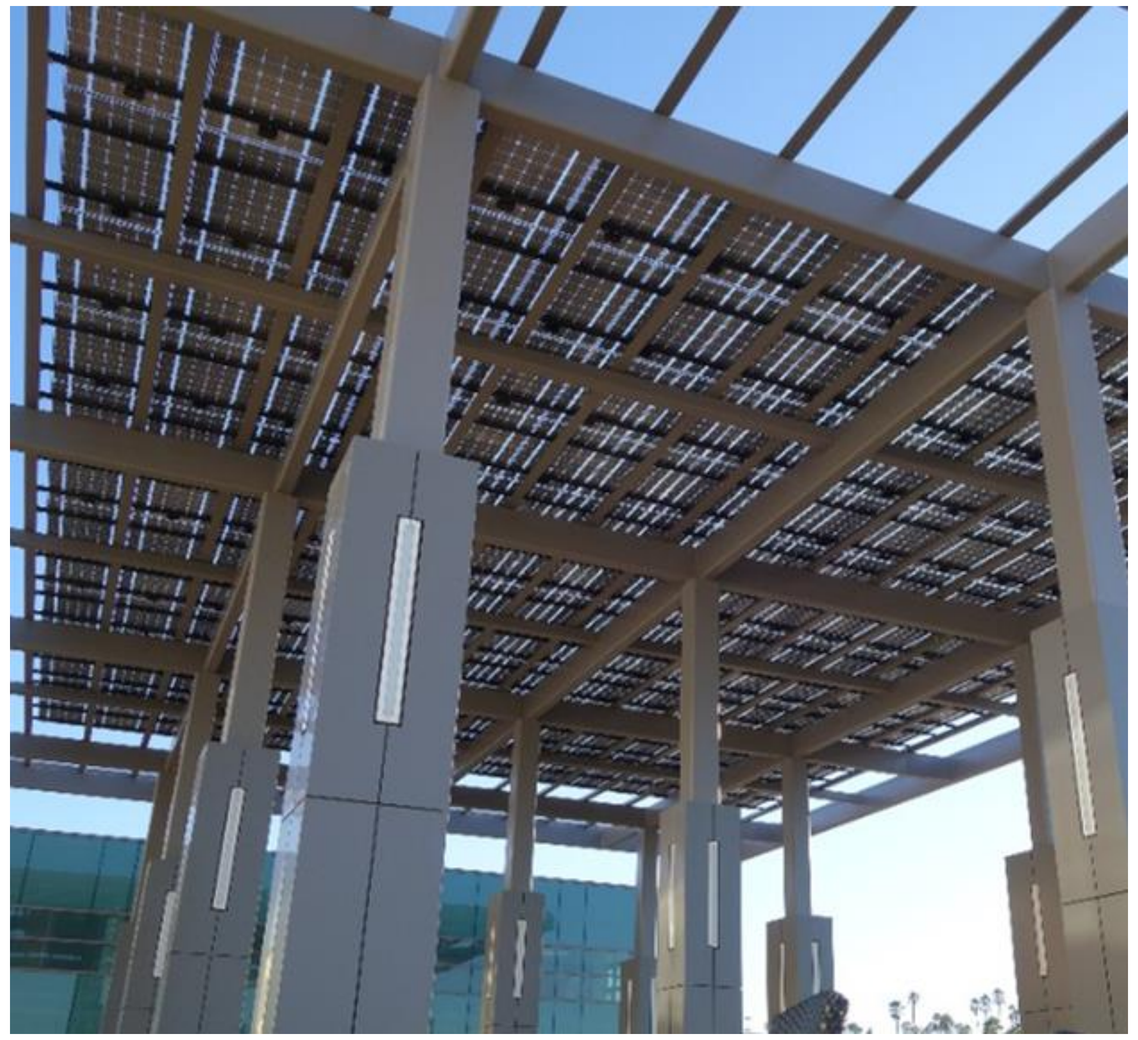

Canopies

Least Integrated

Most Integrated

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Architectural Structures

Least Integrated

Most Integrated

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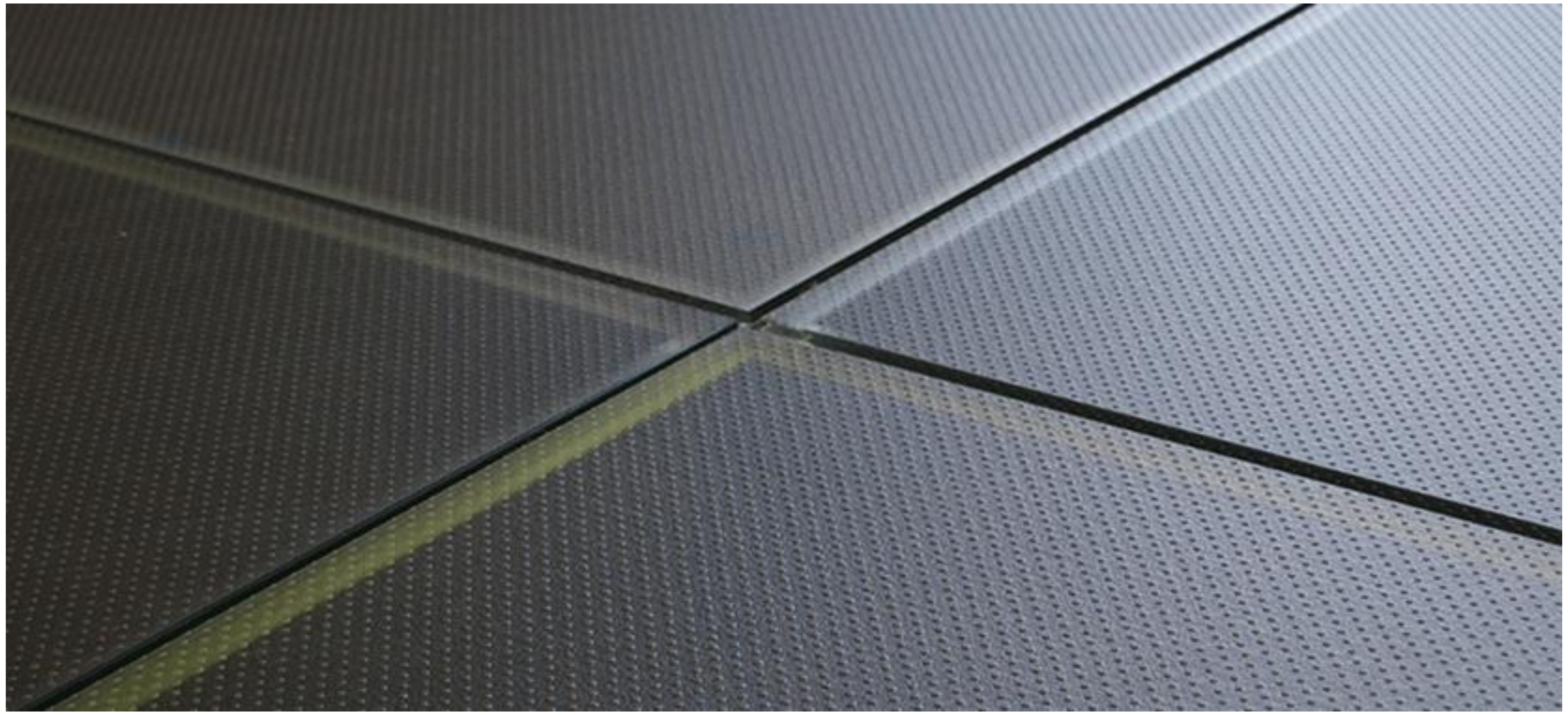

Flooring

Least Integrated — Most Integrated

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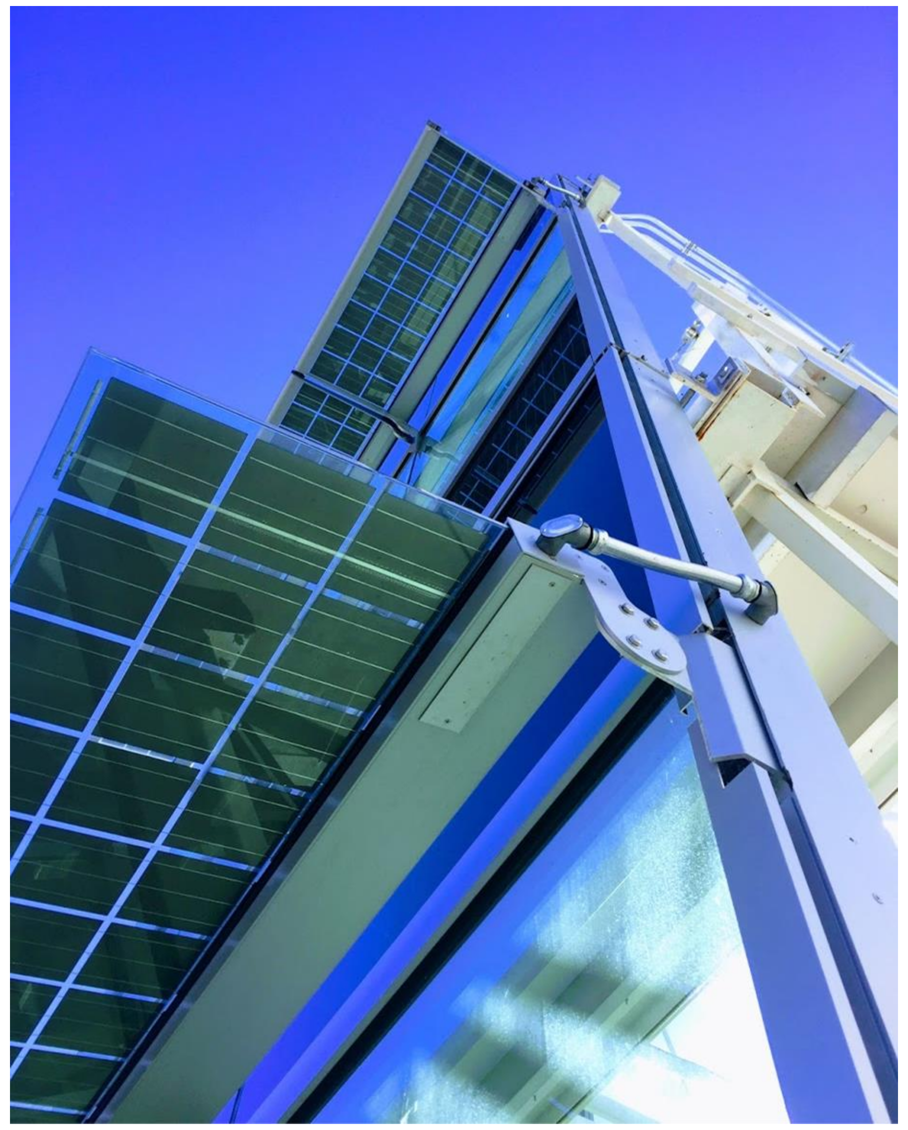


Awnings & Louvers

Least Integrated — Most Integrated

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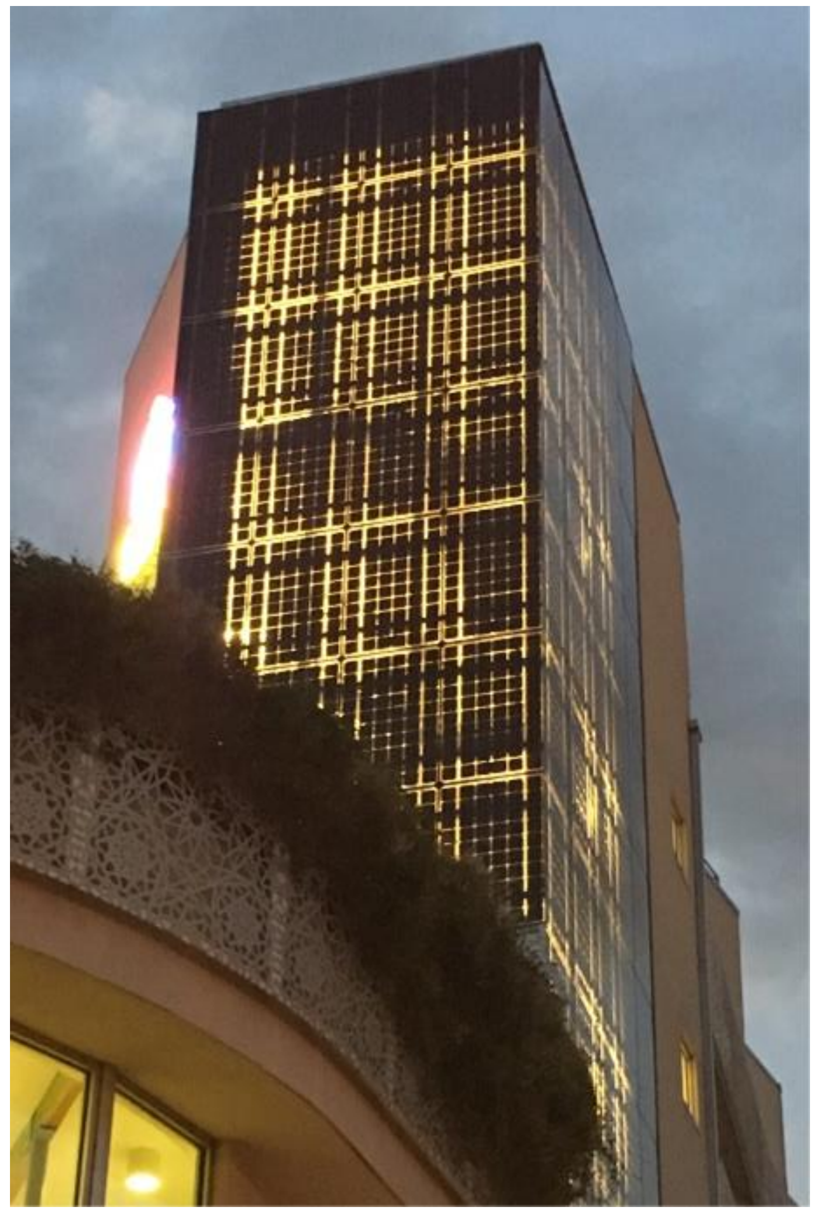

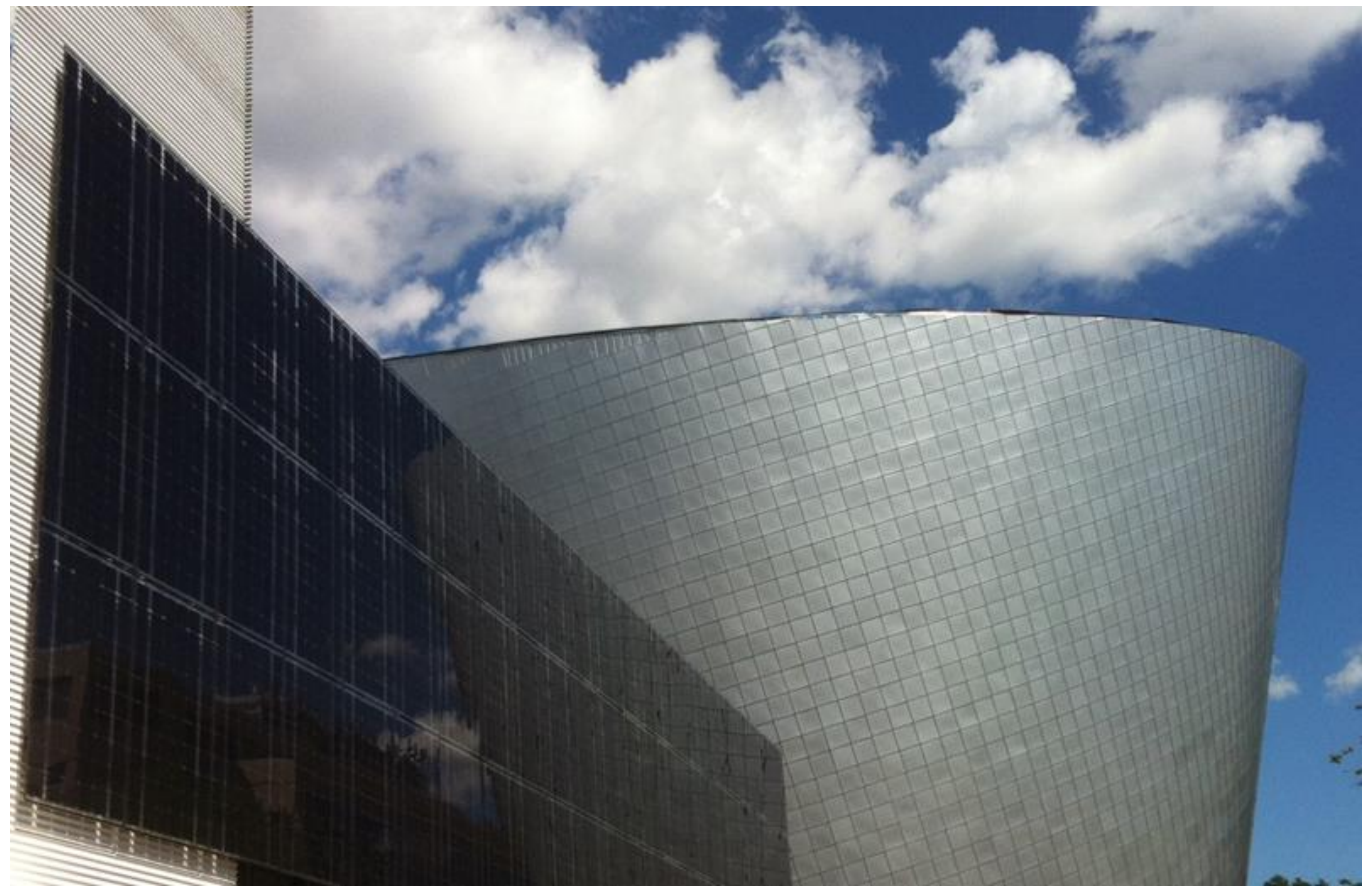

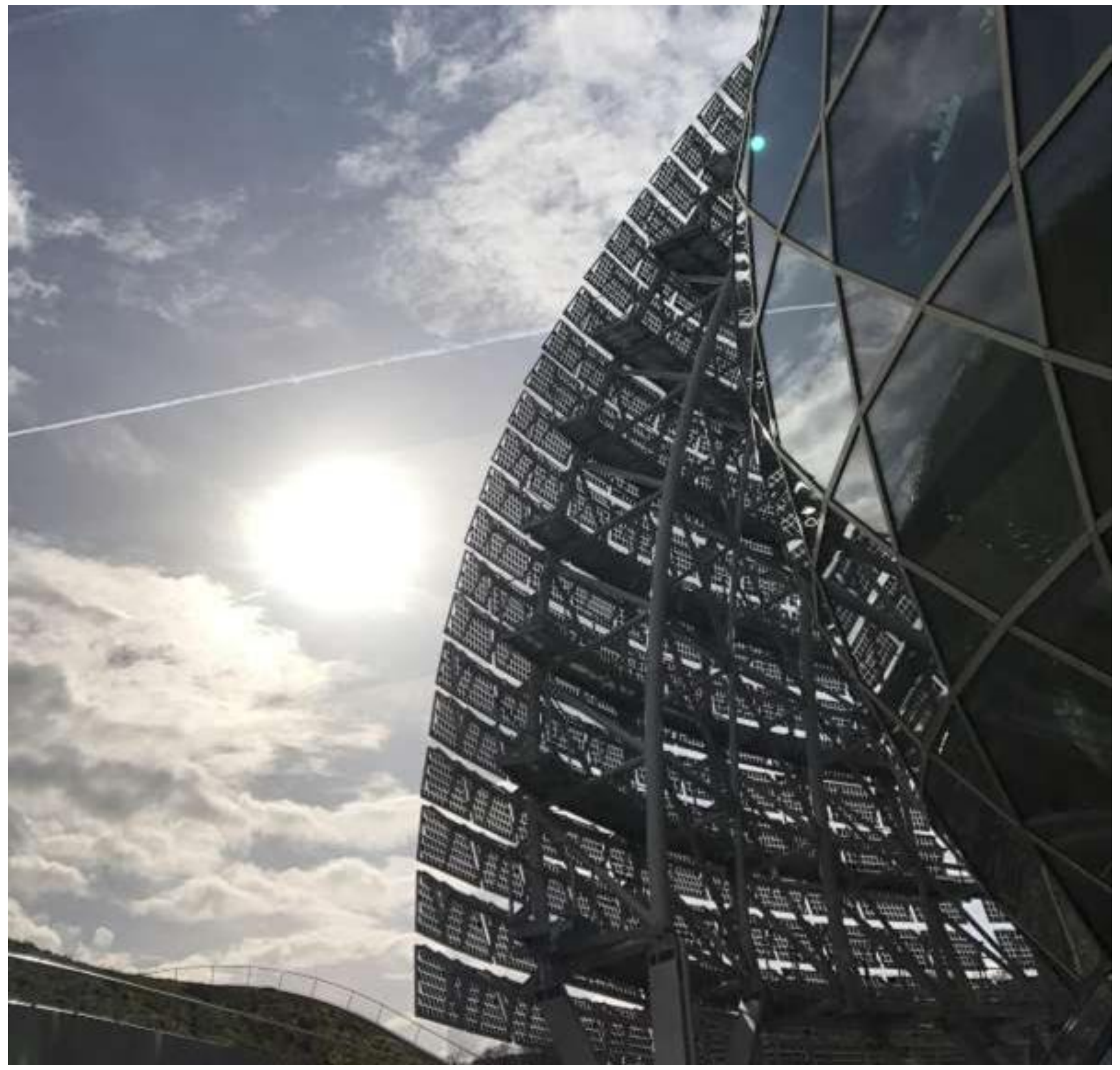

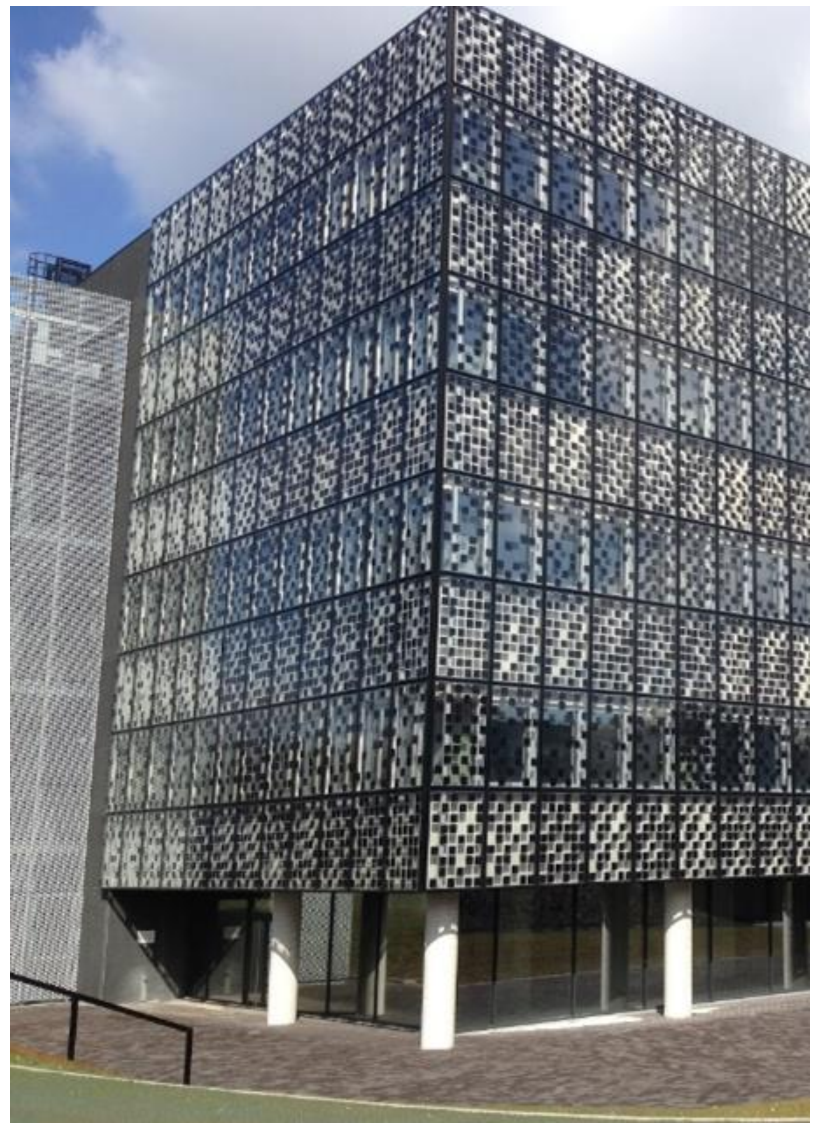

Ventilated Solar Facades/ Rainscreens

Least Integrated — Most Integrated

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Balustrades

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Roof Integrated

Least Integrated

Most Integrated

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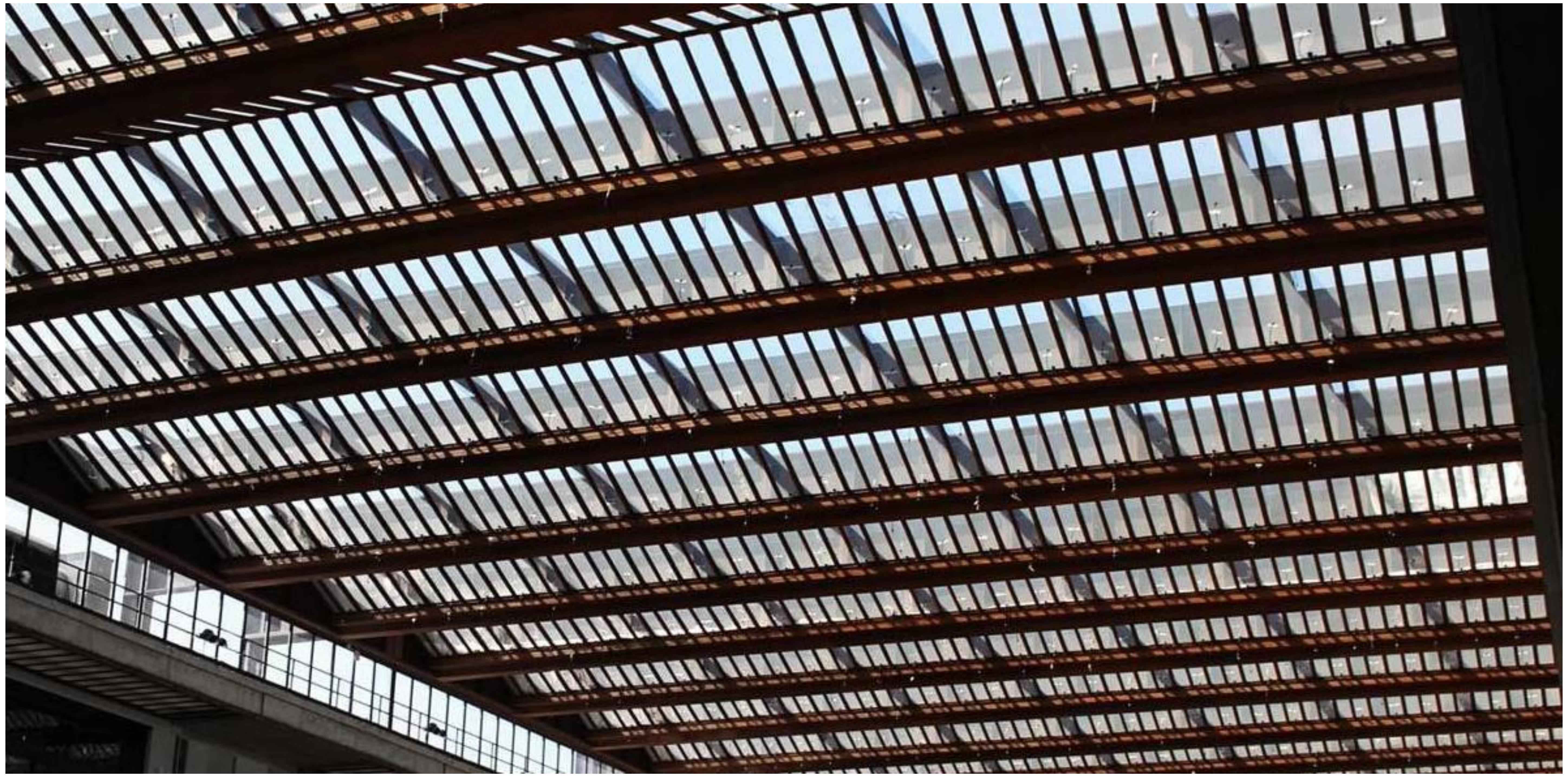

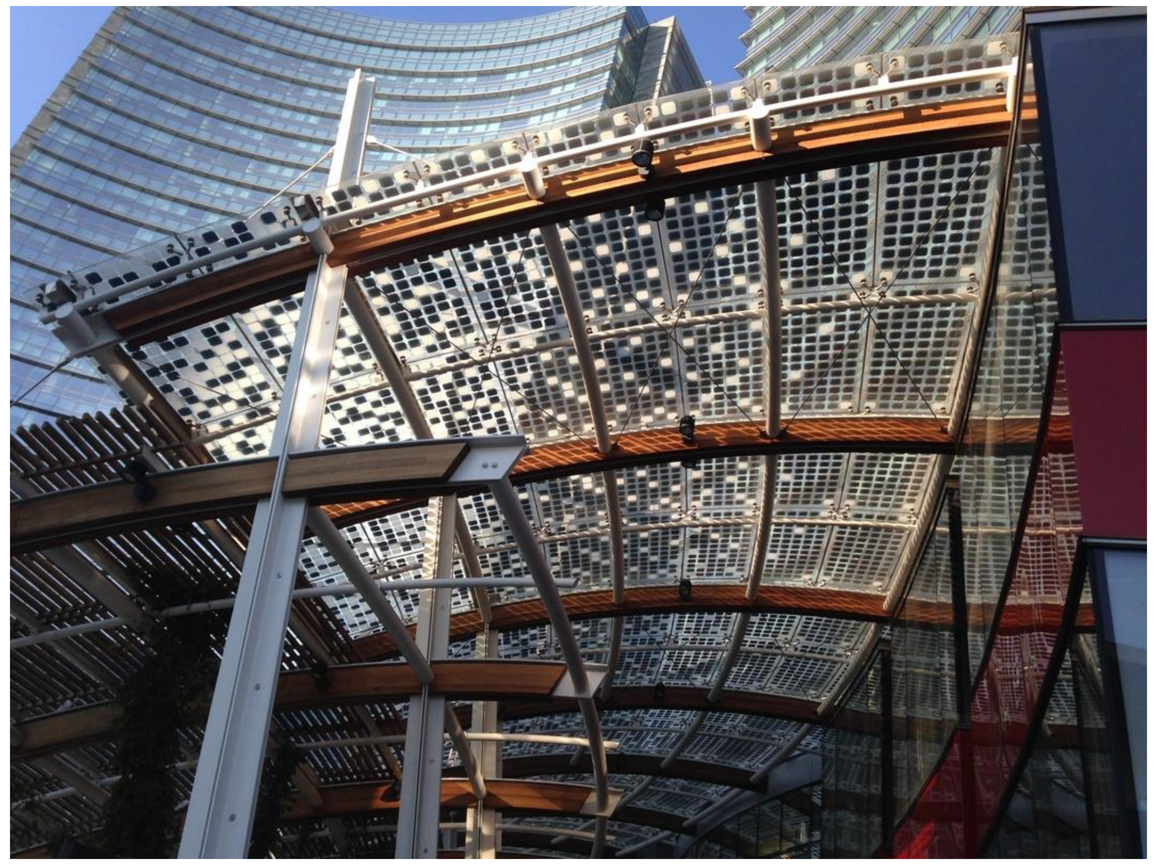

Sloped Glazing

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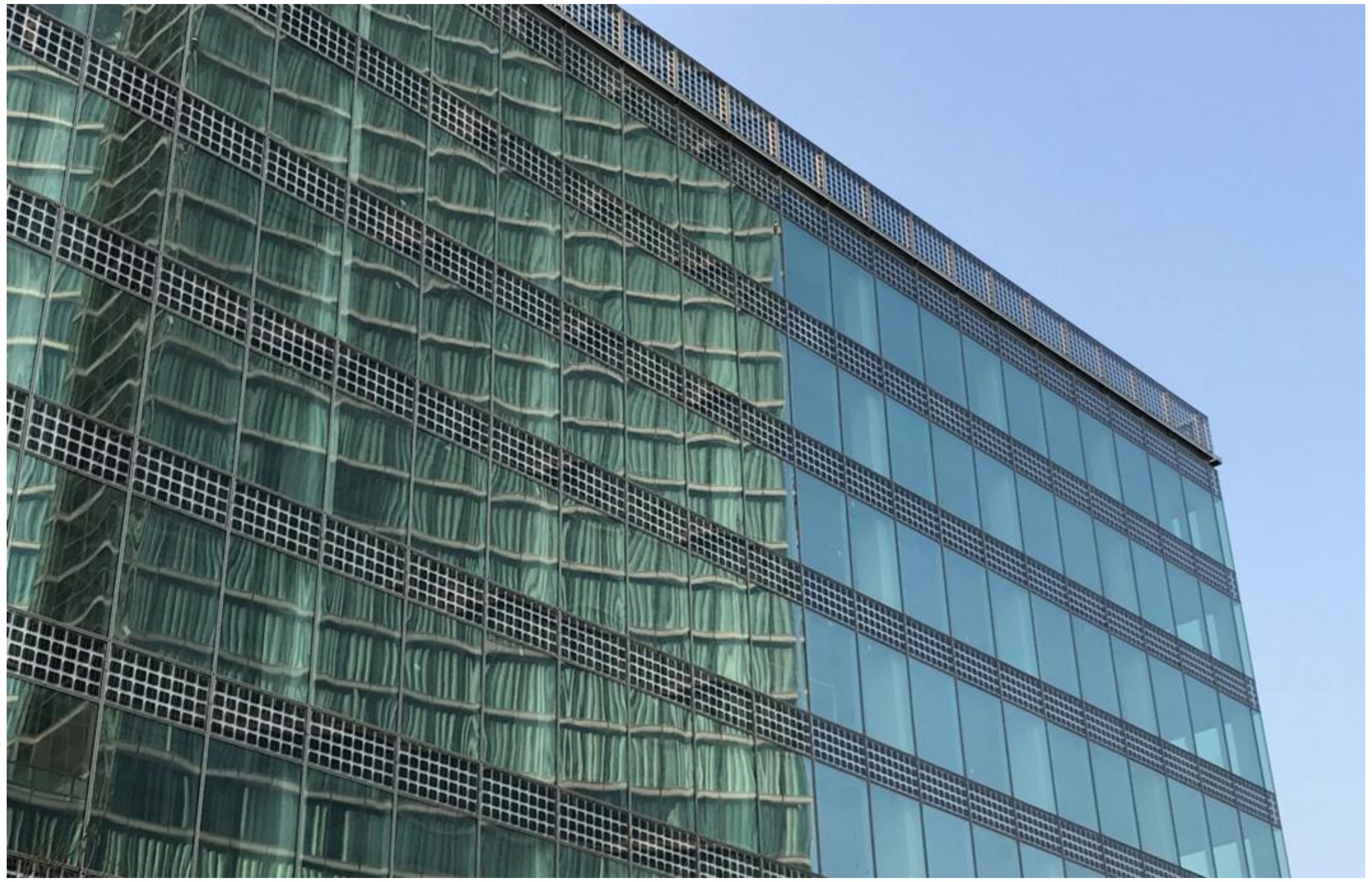

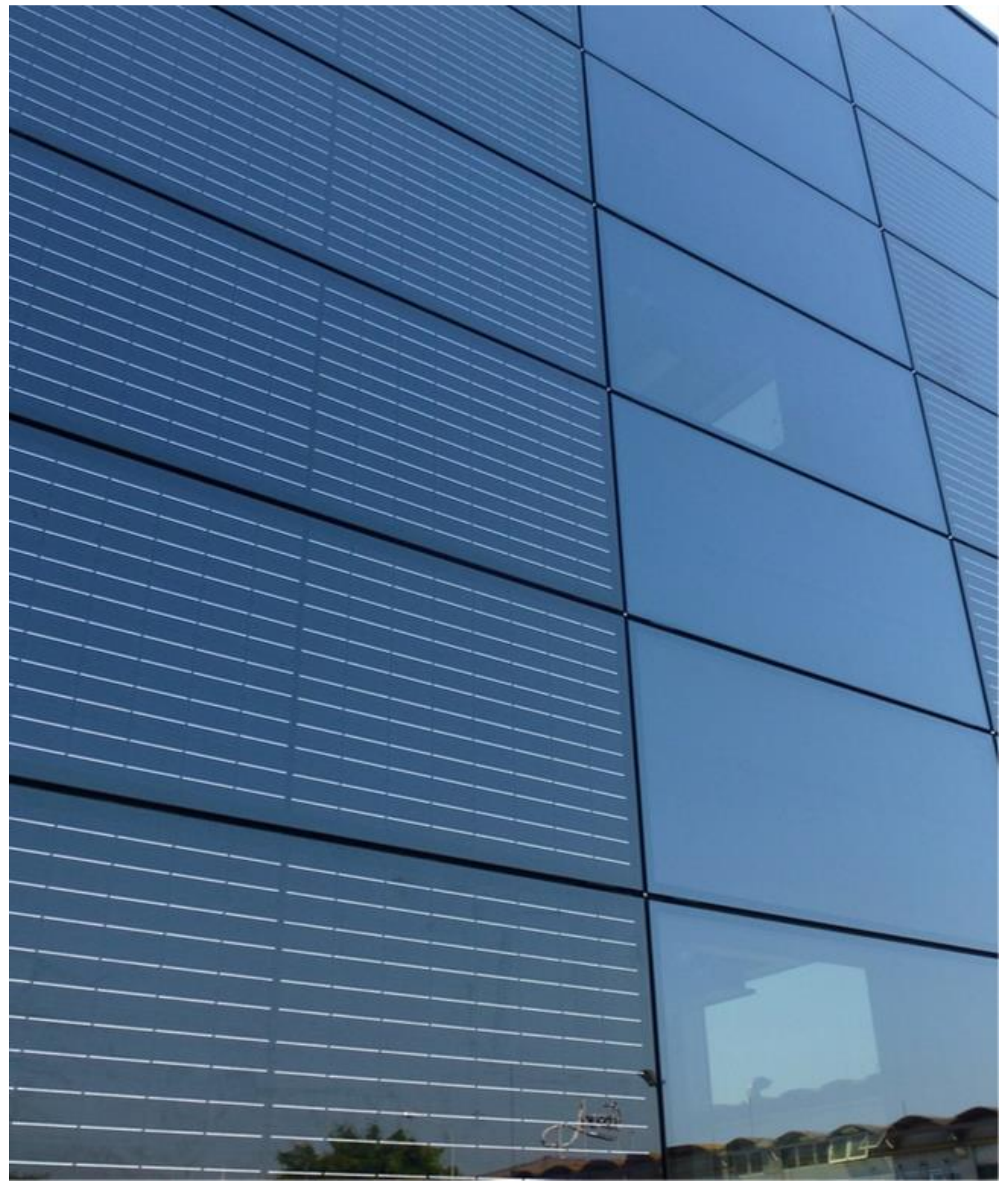

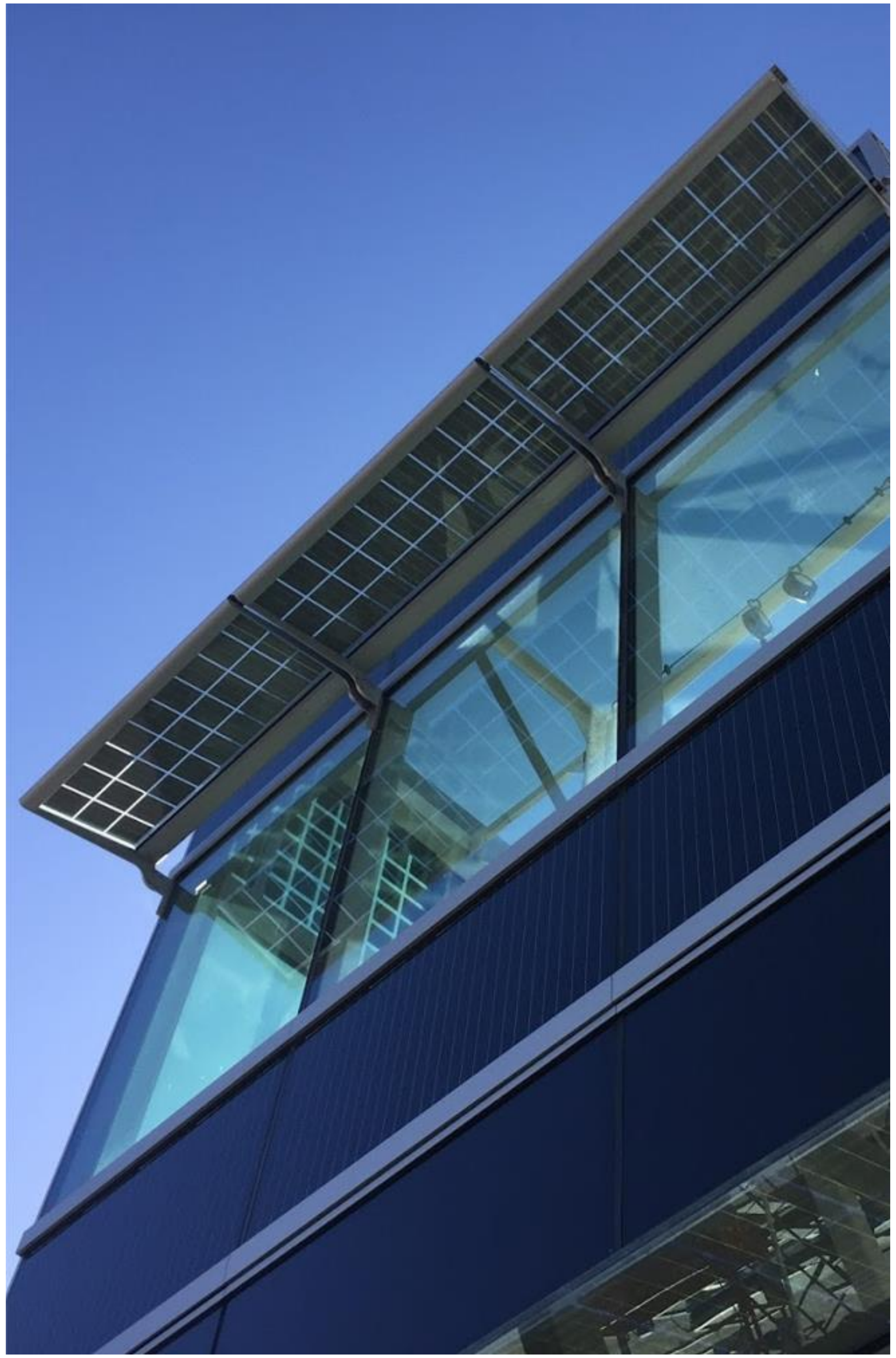

Spandrel Glazing

Least Integrated — Most Integrated

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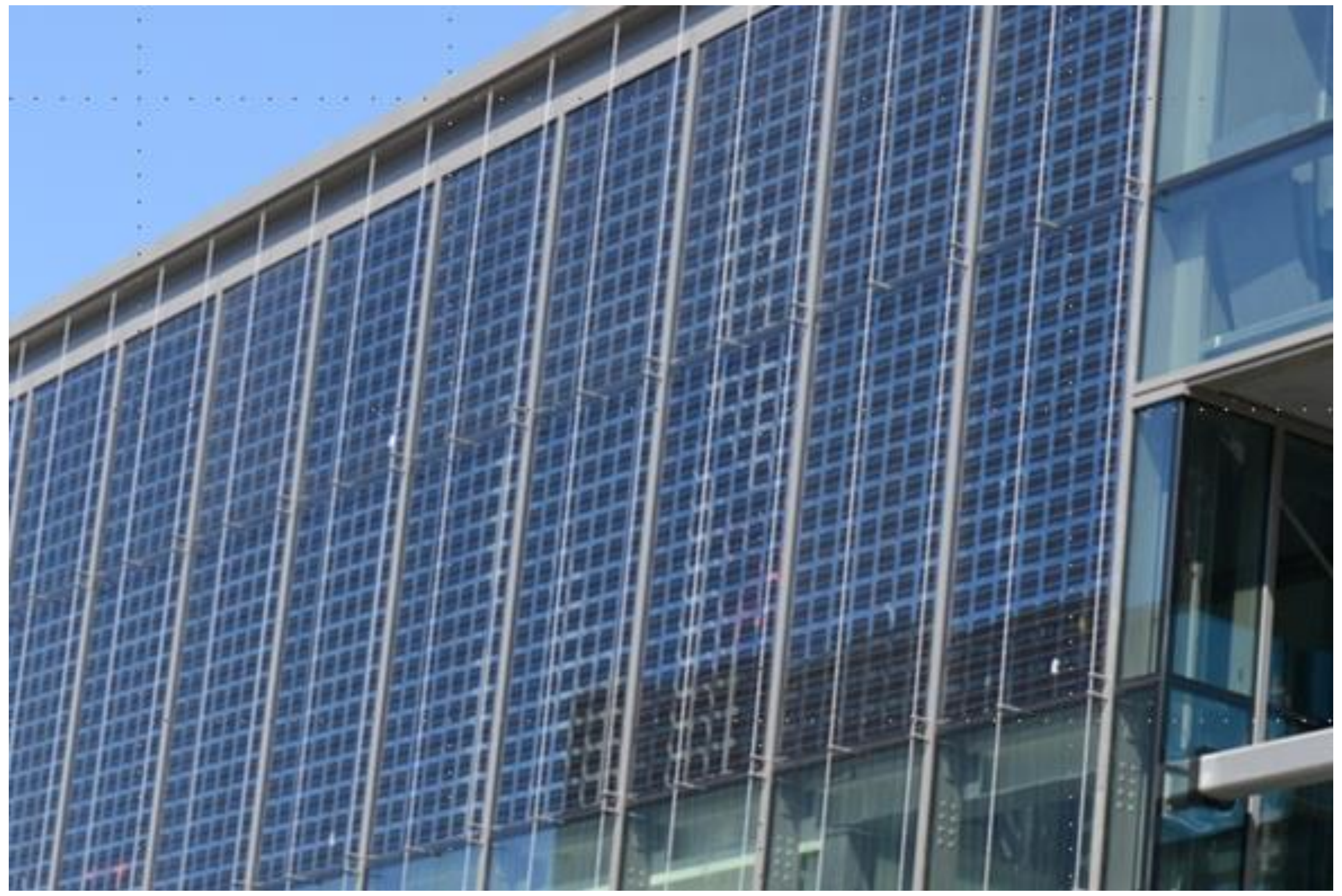

Vision Glazing

Least Integrated
Most Integrated

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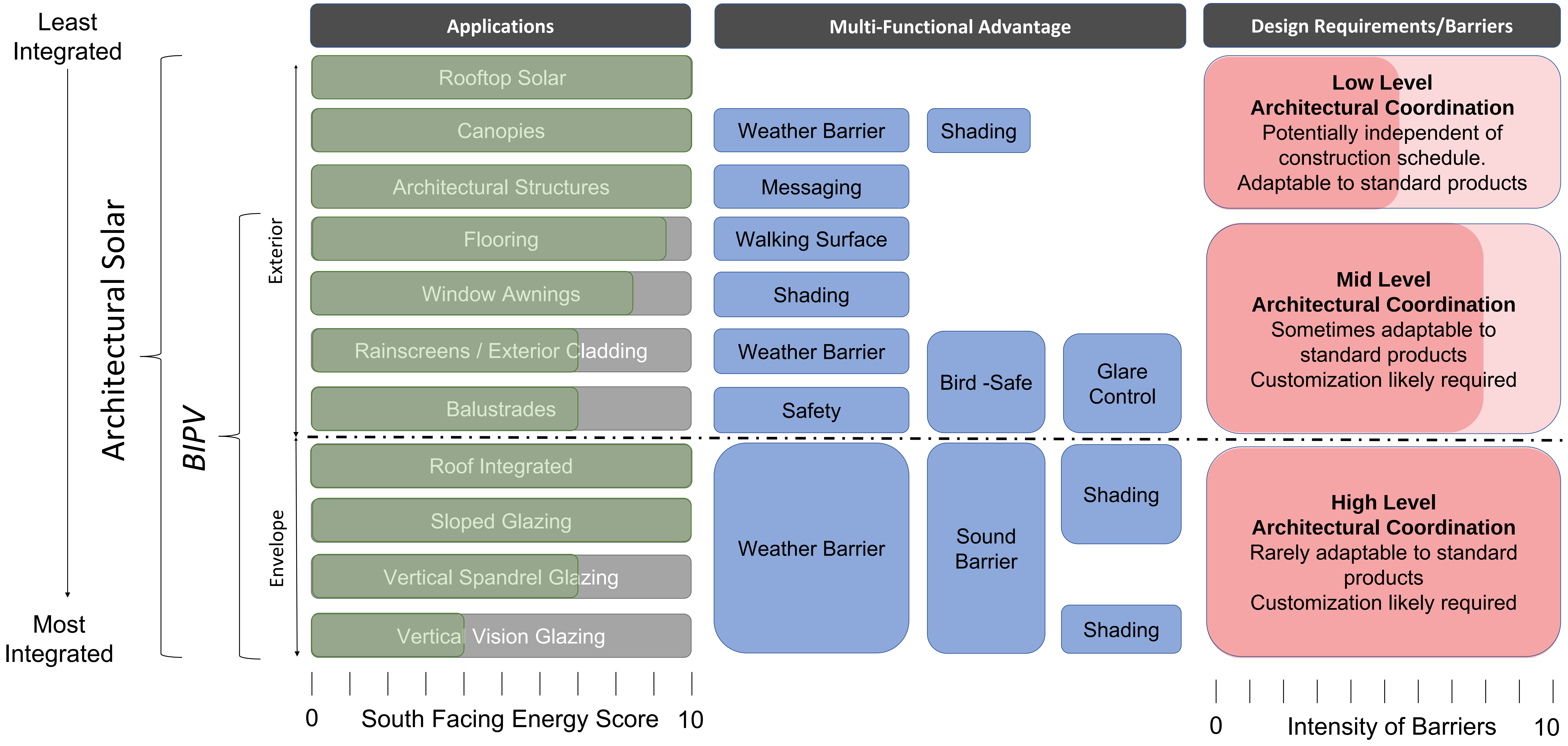

Architectural Solar - Advantages

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Market Barriers

Architectural Solar

Rooftop Solar

- Lack of Continuing Education
- High soft costs
- Incompatibilities with Arch. Workflows
- Lack of Awareness
- Building Industry Adoption
- Standards Development
- Limited Supply Chain

BIPV Specific Constraints

- 100+ glass sizes per project
- System design complexity
- Variable shading / orientations
- 3+ year construction schedule
- Concealed conductors
- BOS equipment locations
- UL Field listing due to lack of certified product suites.

Image courtesy of Onyx Solar

The Pull

New Construction Requirements
- Progressive Municipalities
- State Mandates

Net Zero Ambitions
- Maximizing energy potential

Cost Reductions
- Modules - $0.40/watt = $7.60/sqft*
- Installed Systems - $3.00/watt = $57/sqft*

*Assumes 19 watts/sqft technology

ESG
- Corporate Initiatives
- Climate Action Plans

Demand
- Market Growth
- IRA

Image courtesy of SolMotiv Design

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The Path to Widespread Adoption

- Embrace broad approach to integration
- An educated AEC community
- Business model innovation in design workflow
- Simplified design processes and integration methodologies
- Supply chain integration
- Non-export interconnection protocols

Image courtesy of Morgan C

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Architectural Solar Education
for
Design and Construction Professionals

Objective

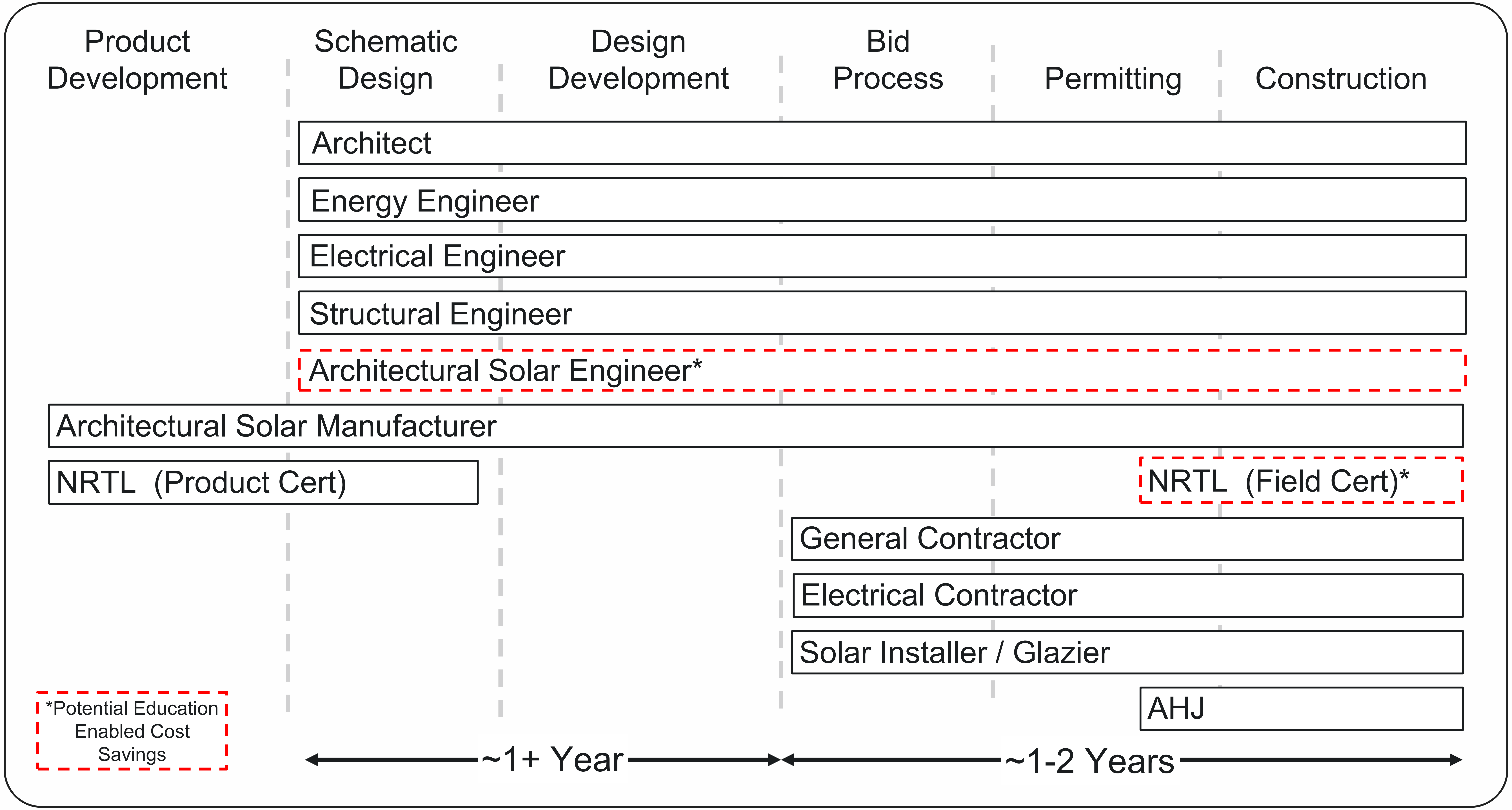
ASA & NREL will educate design and construction professionals on key principles of Architectural Solar; solar energy generating technology that has architectural significance or is coordinated with the architectural design process.

Project Impact

The project will equip solar and building industry professionals with the skills to work at the intersection of solar energy and the building industry. It will break down key barriers inhibiting the widespread adoption of architectural solar, increasing the penetration of on-site renewable energy and enabling grid-efficient buildings (GEB). The program will promote architectural solar innovation and deployment.

Duration: 2-3 Years **Budget:** $750,000

All thanks to the help from the following supporting organizations;



Architectural Solar Process

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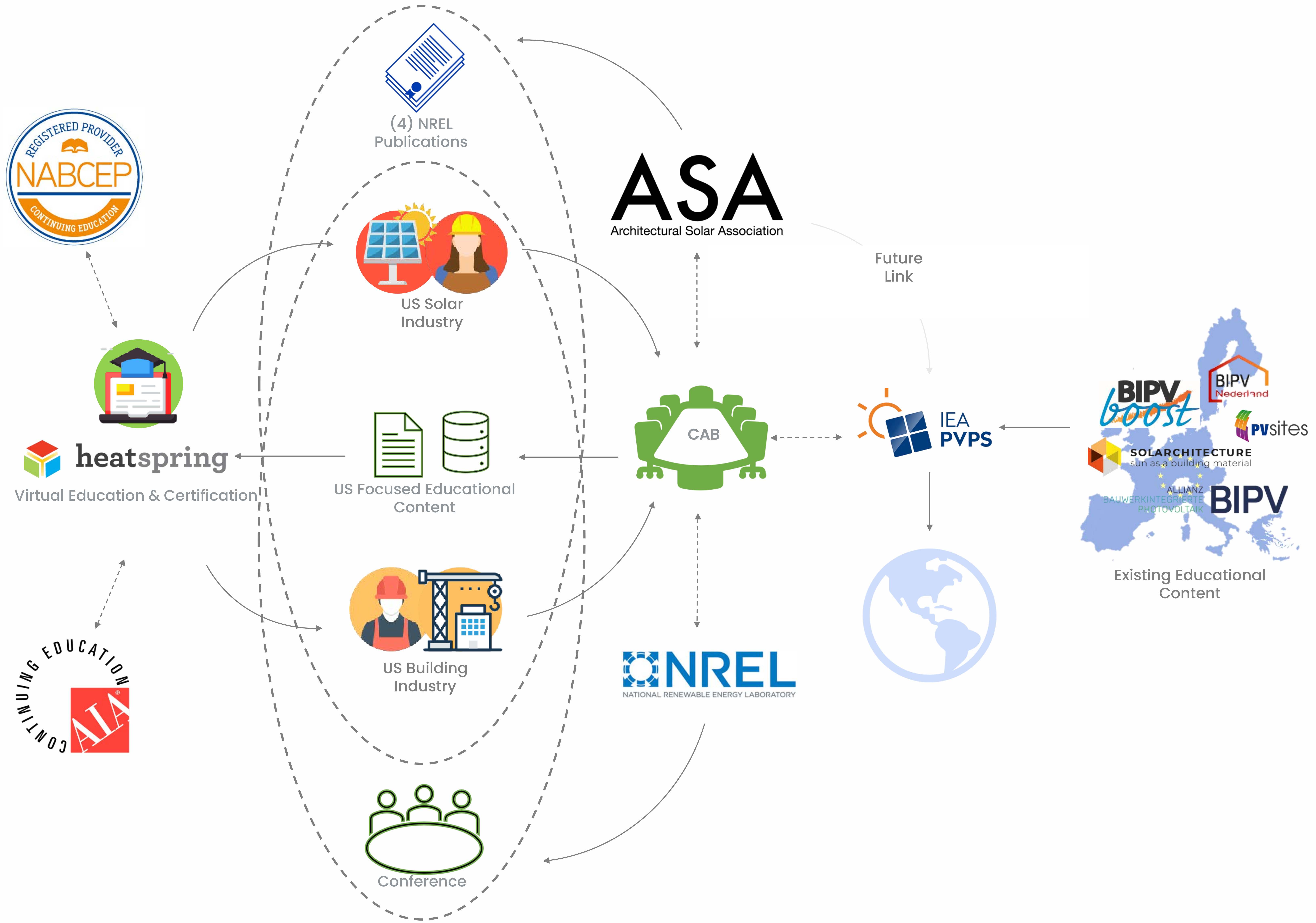


ASA Educational Framework

Thank you!

Christopher Klinga P.E.
Technical Director, ASA
chris@archsolar.org

Stan Pipkin
US Regional Manager
stan@archsolar.org

Architectural Solar Association
1035 Pearl St.
Suite 325
Boulder, CO 80302

Images courtesy of BIPV Boost, Energy Glass, IEA, Issol, Lumos Solar, Lighthouse Solar, Morgan Creek Ventures, NRG, Onyx Solar, SolMotiv Design, Solaria, Spotlight Solar, SUPSI, Tres Birds, Walters & Wolf

ASA
Architectural Solar Association

Boots on the Ground:
Solar Roof Contracting Today

September 22, 2022

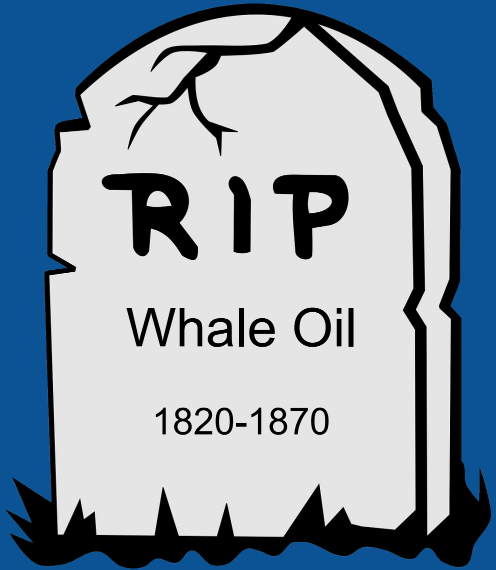
Amy Atchley
amy@amyrs.com

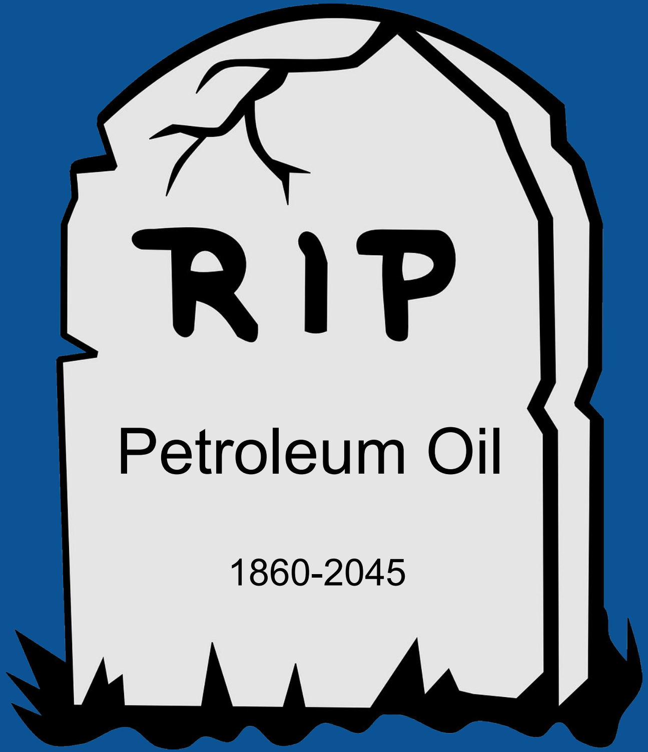
starling
ROOFING FOR SOLAR

Amy's
roofing & solar

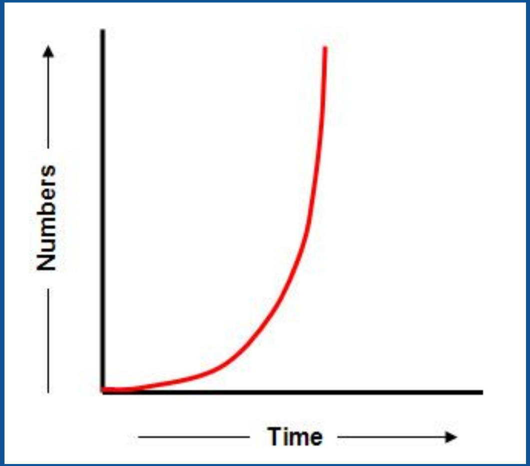
CA License# 1070189

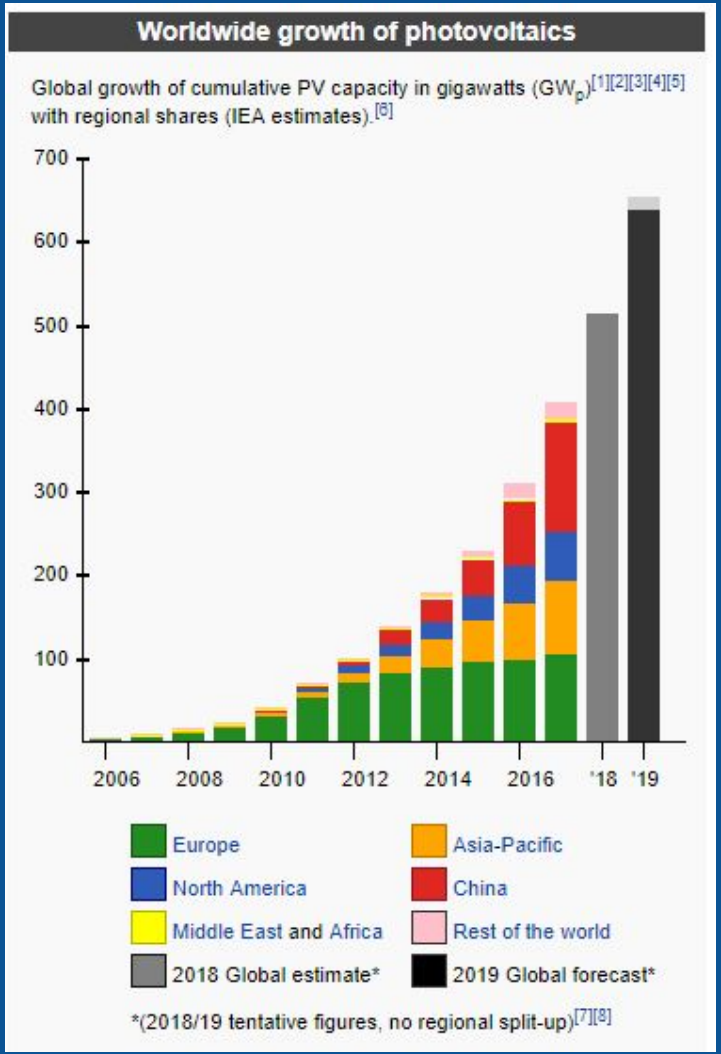
- Macro
- Market Needs
- Micro
- Questions


RIP
Whale Oil
1820-1870


RIP
Petroleum Oil
1860-2045

Solar growth

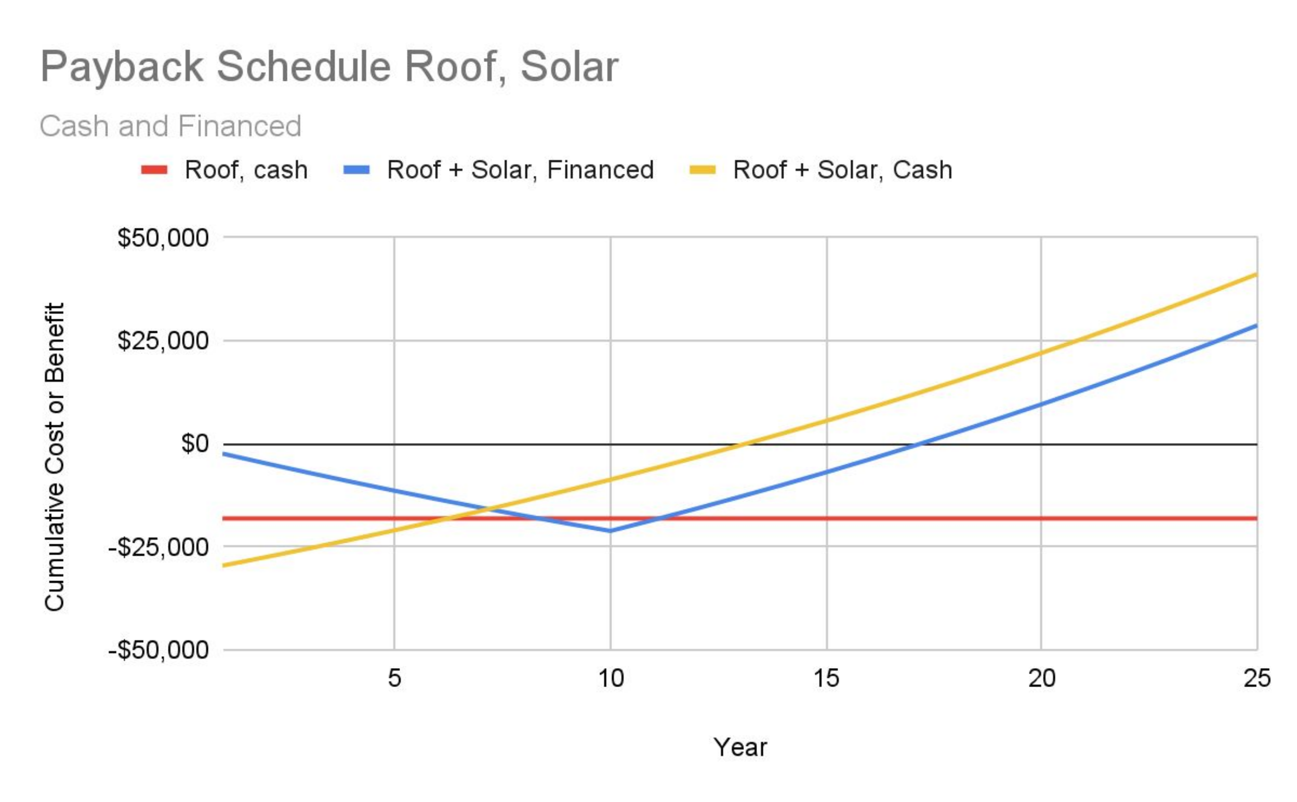




Source: https://en.wikipedia.org/wiki/Growth_of_photovoltaics

So What’s the Problem?

Asphalt Roof and Retrofit



The problem is…

Homeowners are not offered solar at the time of re-roof.

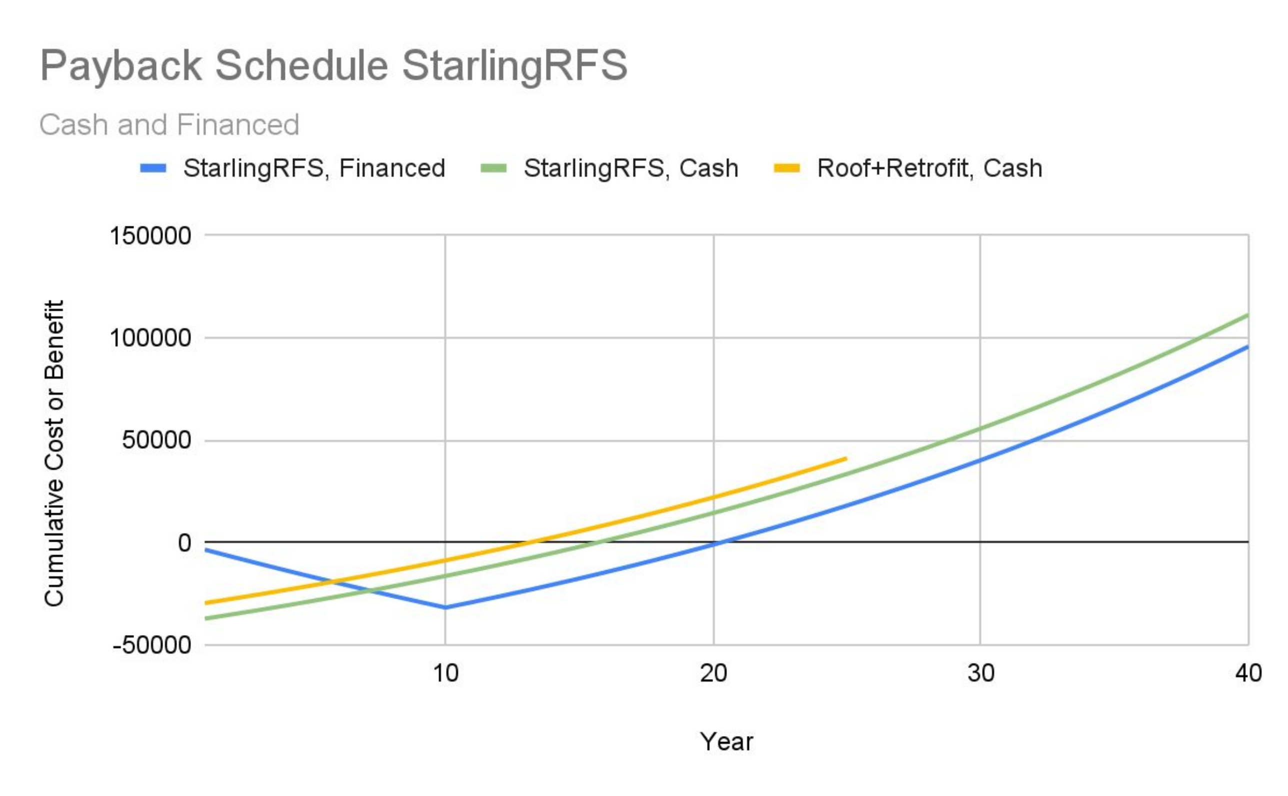
Why?

Road Blocks to Successful Solar-Roof Integration:

Infrastructure:

- Status Quo Bias
- Sales
- Access to tools & products

Solutions



Payback Schedule StarlingRFS
Cash and Financed
StarlingRFS, Financed
StarlingRFS, Cash
Roof+Retrofit, Cash
150000
100000
50000
0
-50000
10
20
30
40
Cumulative Cost or Benefit
Year

Starling Solar Roofing System

Nuggets to take with you:

Tools/ Infrastructure:

- General Contracting/ Solar Roofers
- Incentivize Integration
- Create Infrastructure


QUESTIONS?

A Roof That Pays

Amy's roofing & solar

starling
ROOFING FOR SOLAR

AMERICAN MADE SOLAR PRIZE
U.S. DEPARTMENT OF ENERGY

Let’s Talk About BIPV Resilience

Mengjie Li
Florida Solar Energy Center, UCF
Resilient, Intelligent and Sustainable Energy Systems (RISES) Cluster, UCF
Department of Materials Science and Engineering, UCF

Overview

- 00:00 - 00:30 Introduction
- 00:30 - 03:00 What is BIPV Resilience and Why it's Important
- 03:00 - 06:00 State of Art
- 06:00 - 09:00 Imaging Techniques
- 09:00 - 10:00 Challenges and Opportunities

What is BIPV resilience

Energy Resilience ⇄ BIPV Resilience

Extreme weather scenario

- BIPV can improve community energy resilience, by providing power, particularly during the response and recovery period

- Challenge of severe weather
  - Wind
  - Hail
  - Hurricane
  - Fire
  - Heavy snow
  - Cold & Heat shock

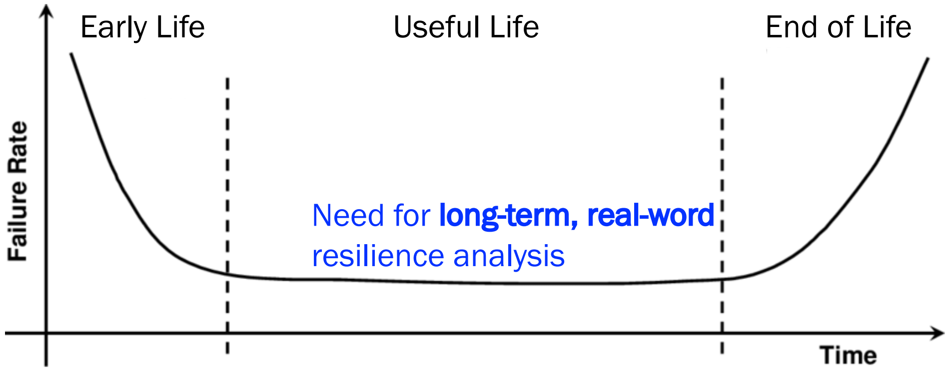
Normal weather scenario

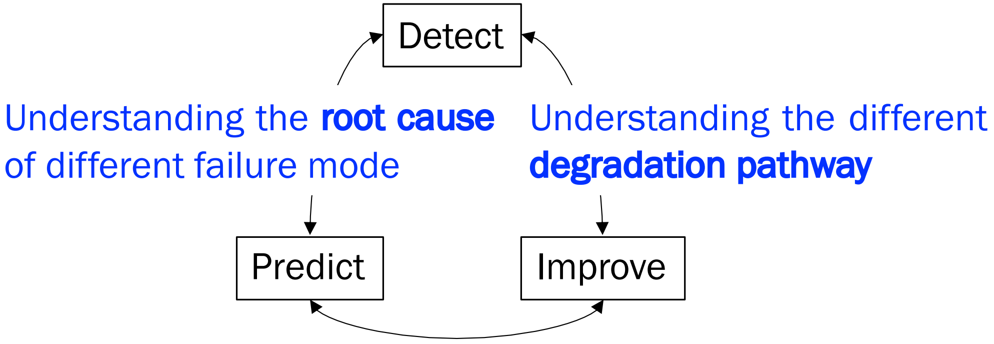
- BIPV modules – only effective when deployed in direct sunlight

- Inherently harsh service environment
  - Damaging solar radiation (especially UV)
  - Heat
  - Humidity
  - Biological factors (mildew, algae, bird's dropping…)
  - Mechanical factors (sand abrasion, hail …)

What is BIPV resilience analysis

Combining **long-term field inspection** and **lab degradation characterizations** to perform a multi-scale **qualitative** and **quantitative** analysis to understand the BIPV behavior (degradation pathway) as both a **building material** and **PV system**



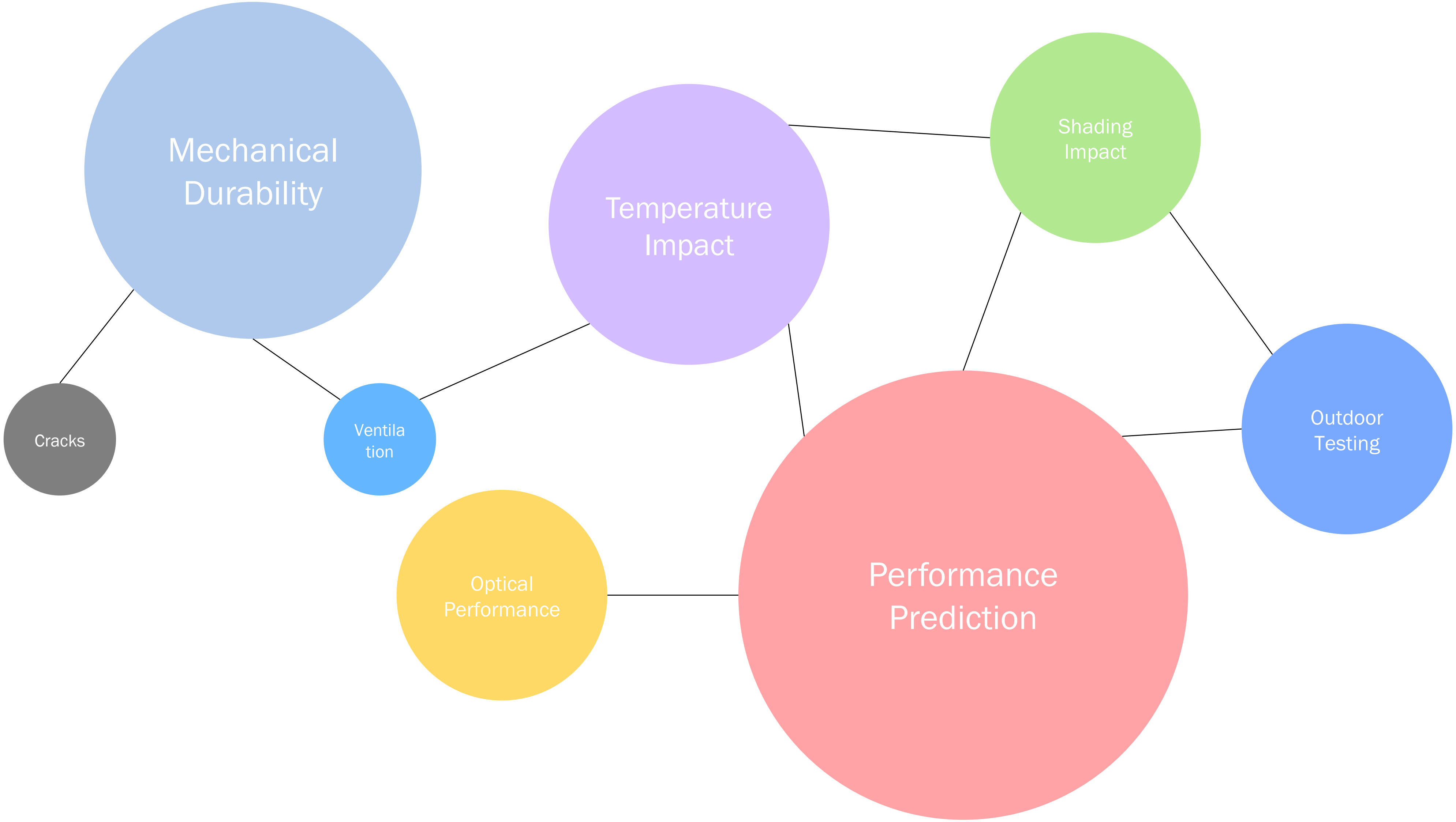


BIPV vs. BAPV vs. BIPVT ⇄ PV

Least integrated (Open rack-mounted PV) | **More integrated** (Close roof rack-mounted PV) | **Fully integrated** (Direct-mounted BIPV, multifunctional)

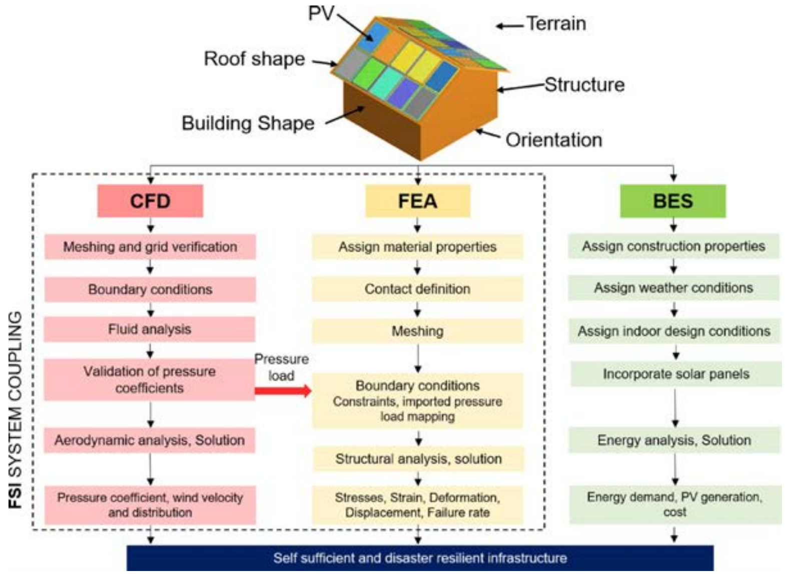
Improving **accuracy** of energy yield prediction, degradation rate calculation and provide input for techno-economic analysis, ultimately **de-risk** the investment and support **market growth**

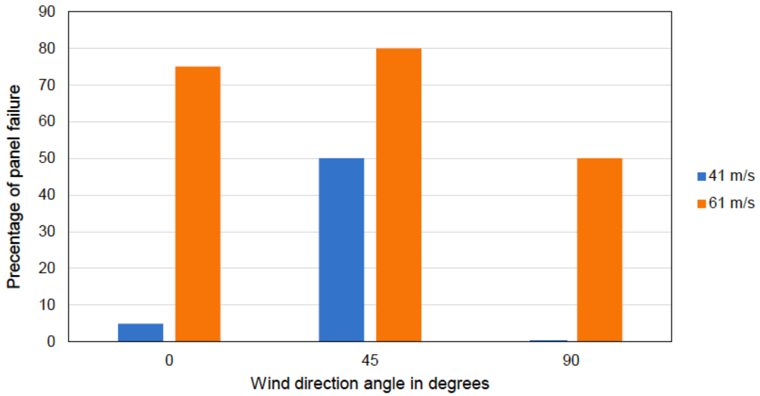
State of Art - Overview

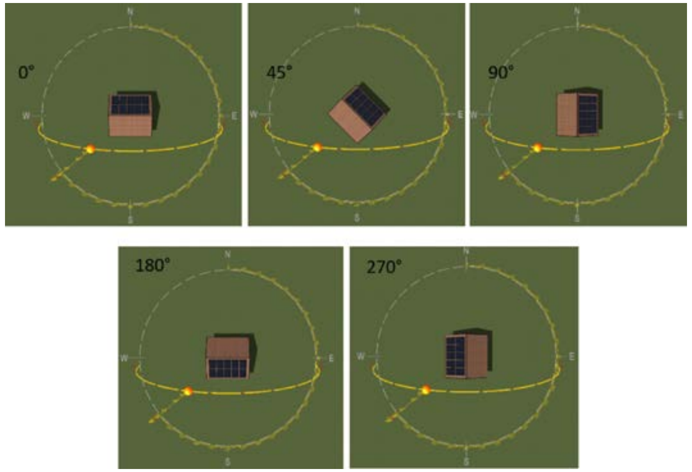


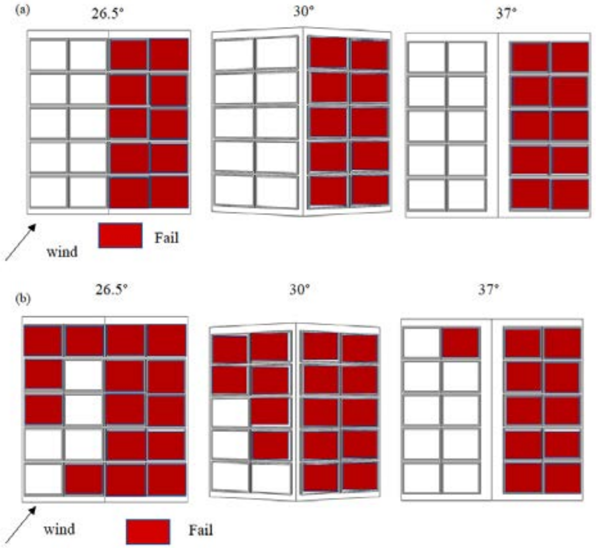
State of art – Mechanical durability

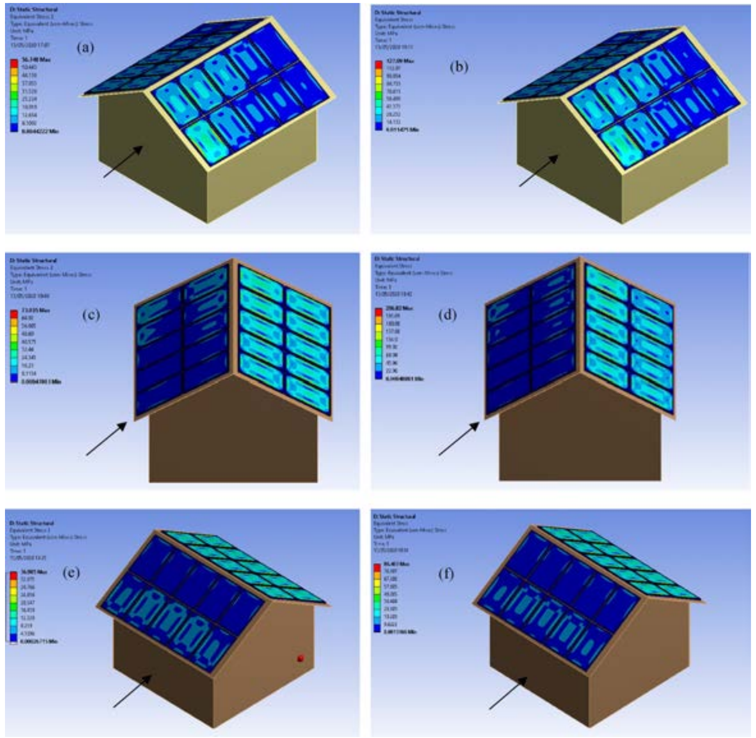
2021 C. A. J. Pantua *et al.*

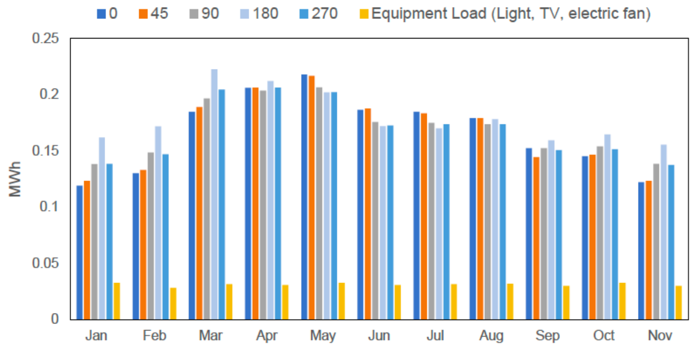












C. A. J. Pantua *et al*. Sustainability and structural resilience of building integrated photovoltaics subjected to typhoon strength winds, *Applied Energy*, 2021. https://doi.org/10.1016/j.apenergy.2021.117437

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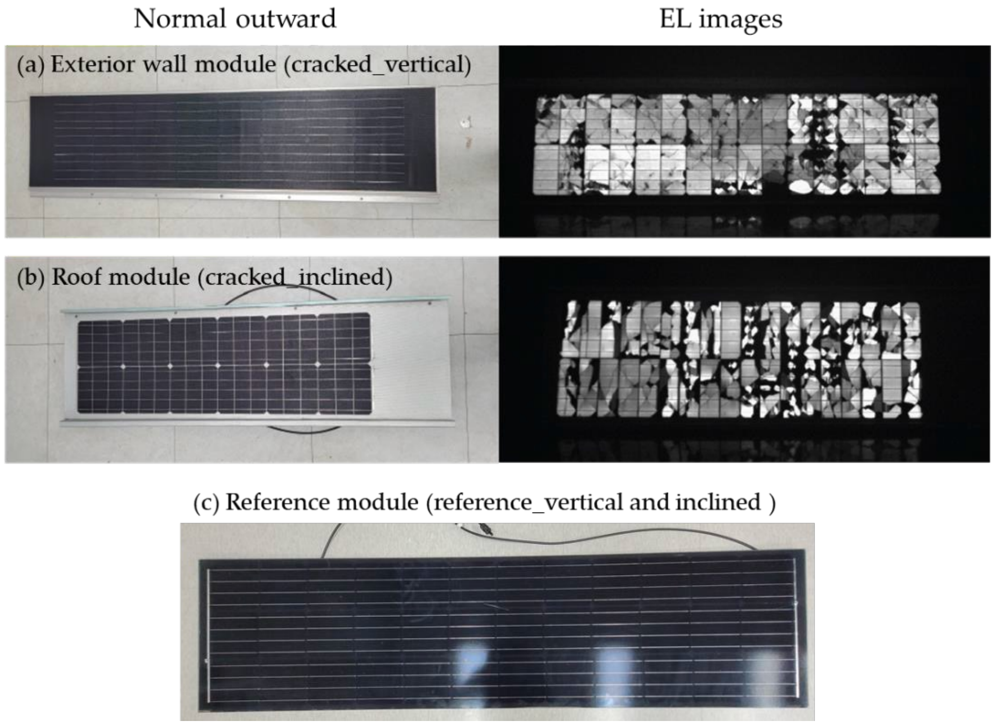
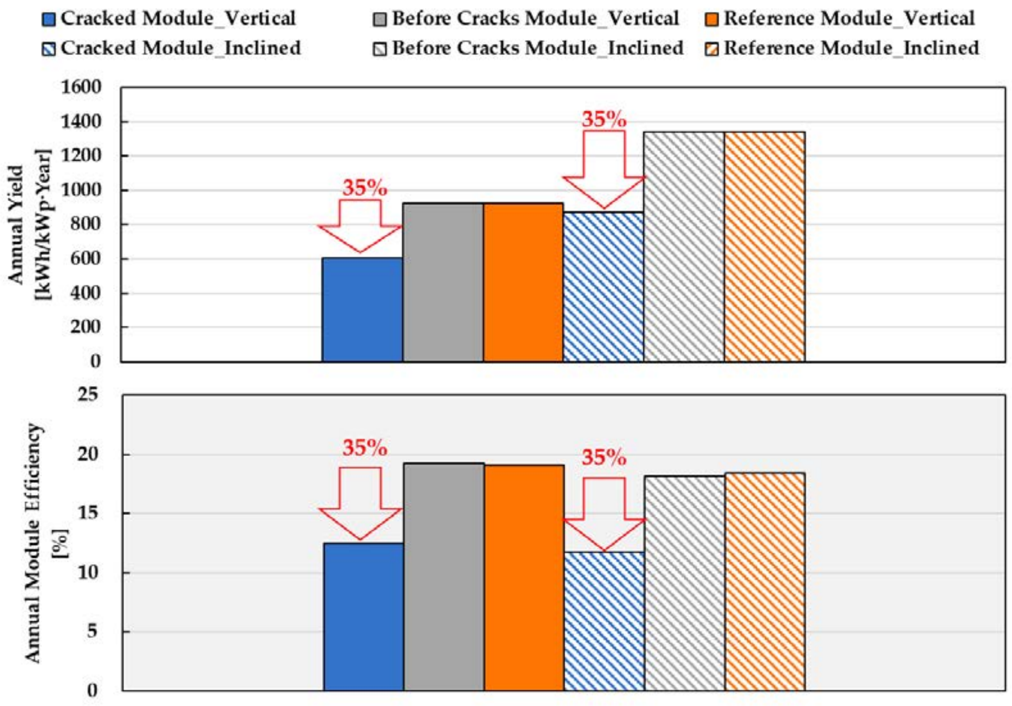
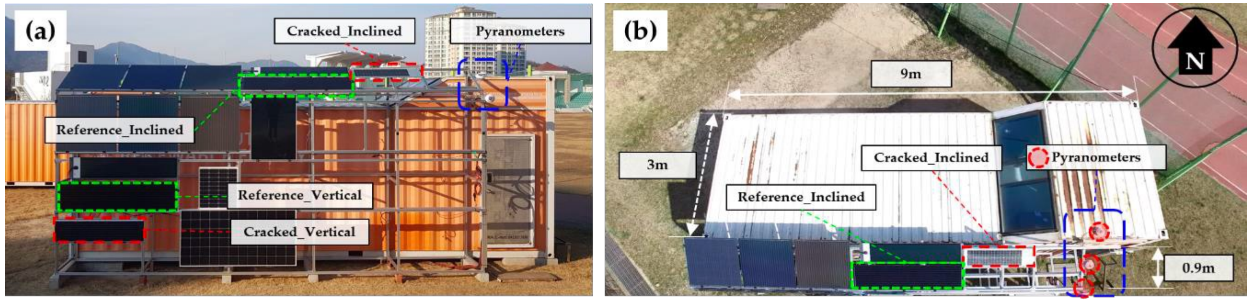
State of art - Mechanical durability

2021 K. Lee *et al*.







K. Lee et al., The Impact of Cracks in BIPV Modules on Power Outputs A Case Study Based on Measured and Simulated Data, energies, 2021. *https://doi.org/10.3390/en14040836*

State of art – Colored BIPV

2019 R. R. Molinero *et al*.

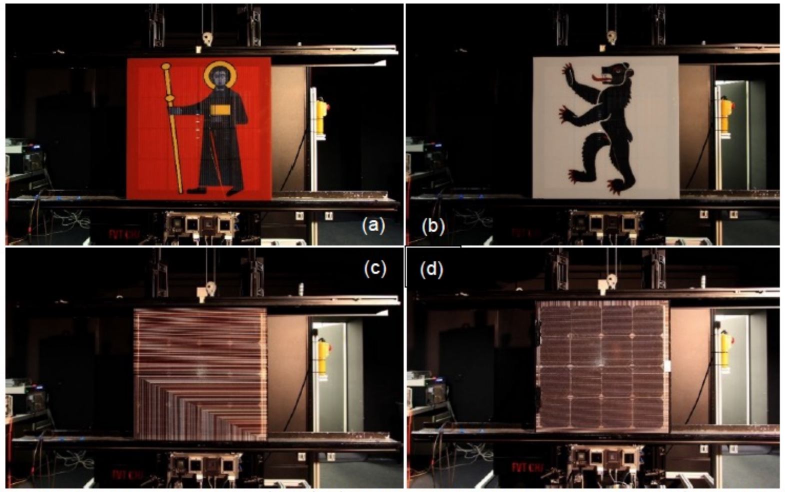


Figure 1: PV modules coloured by ceramic digital printing technology: (a) C13-A1, (b) C13-B1 and (c) & (d) front and rear side of module C13-C1.

Figure 3: Two different PV modules with terracotta appearance: (left) C13-F1 module with prismatic glass and (right) C13-I1 module.

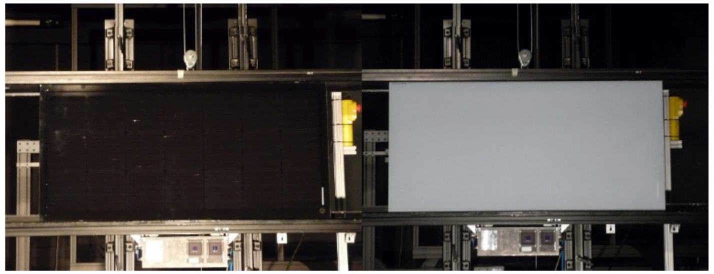
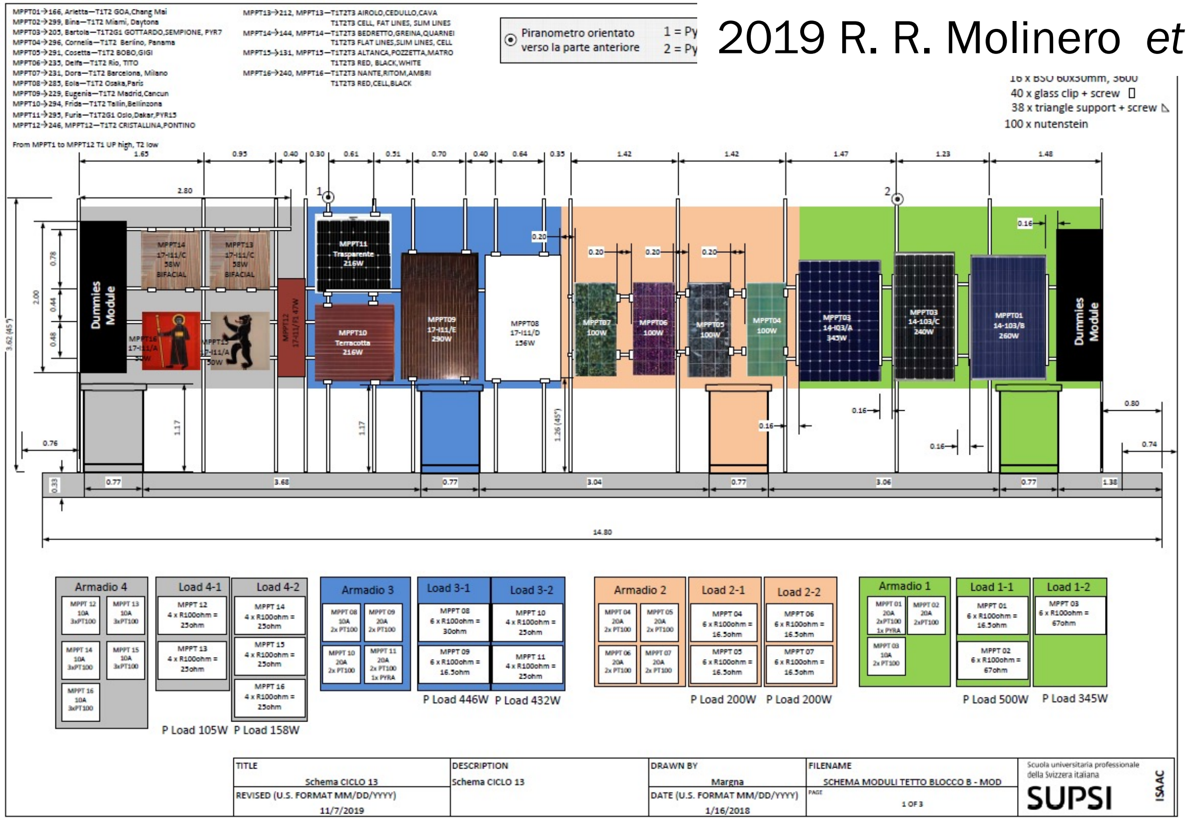
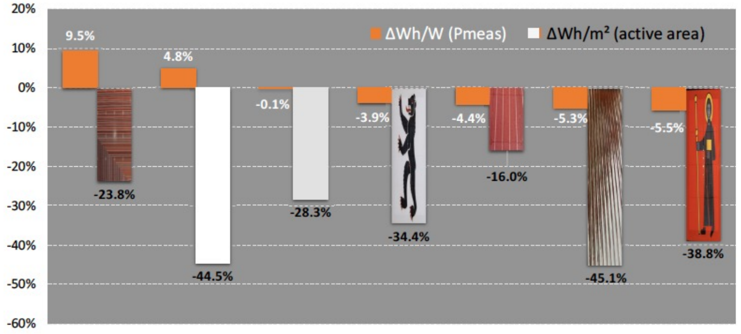


Figure 4: PV modules with full-surface printing with UV-resistant and translucent special inks: (left) C13-SA2 reference module and (right) C13-SC2 light grey module.





R. R. Molinero *et al*. Enhance next generation photovoltaic performance, 2019.

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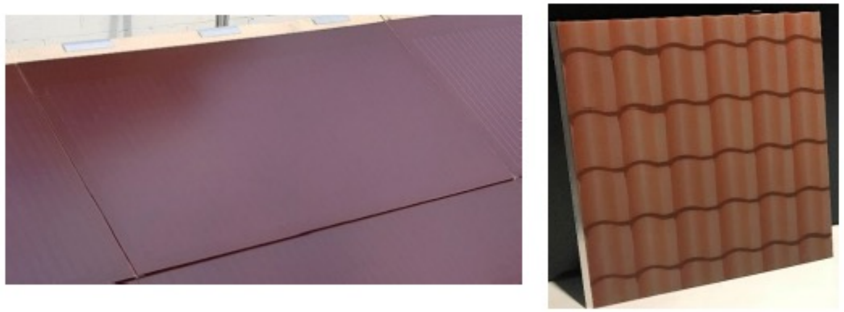
State of art - Colored BIPV

2020 M. Pelle *et al*.



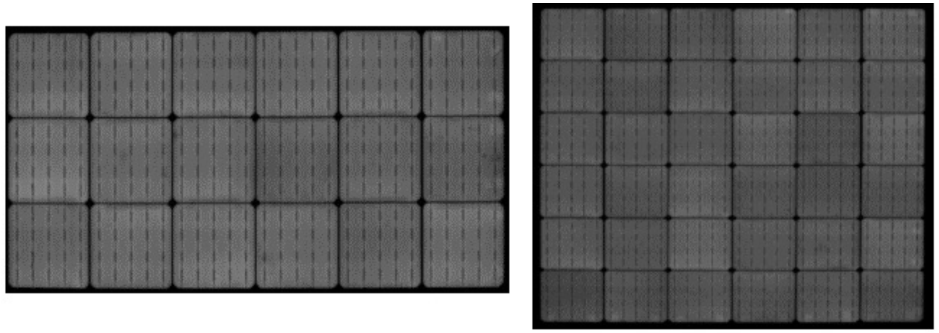
(a) (b)

Figure 4. Tested modules samples: Suncol® Tile-Terracotta Simil RAL 8015 (**a**); and Suncol® Tile-Texturing Simil roof tile (**b**).

Table 2. Detail of the two tested modules typologies.

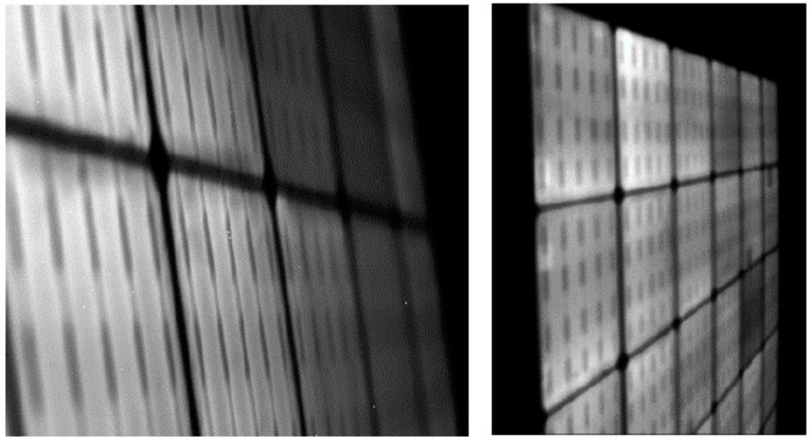
	Suncol® Tile-Terracotta	**Suncol® Tile-Texturing**
Solar tempered front glass	Simil RAL 8015	Simil roof tile
Active layer	18 monocrystalline cells	36 monocrystalline cells
Solar tempered back glass	Black printed	Black printed
Dimensions [m × m]	1 × 0.575	1 × 1.05

(a) (b)



(a) (b)

Figure 8. Electroluminescence images obtained at normal incidence shooting for: (**a**) Terracotta; and (**b**) Texturing Roof Tile.



(a) (b)

Figure 9. Electroluminescence images obtained at small incidence shooting for: (**a**) Terracotta; and (**b**) Texturing roof Tile.

M. Pelle *et al*. Coloured BIPV Technologies- Methodological and Experimental Assessment for Architecturally Sensitive Areas, *Energies*, 2020. doi:10.3390/en13174506

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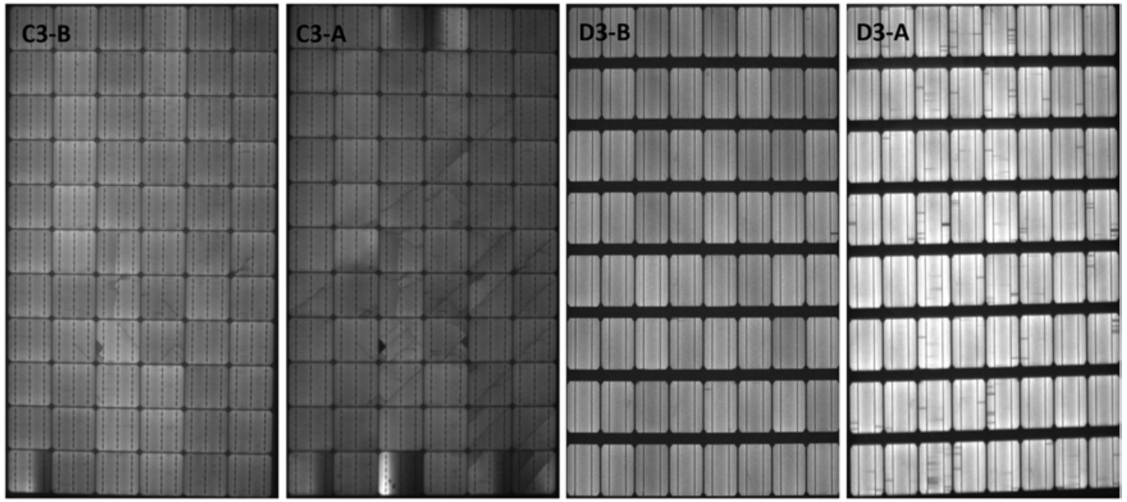
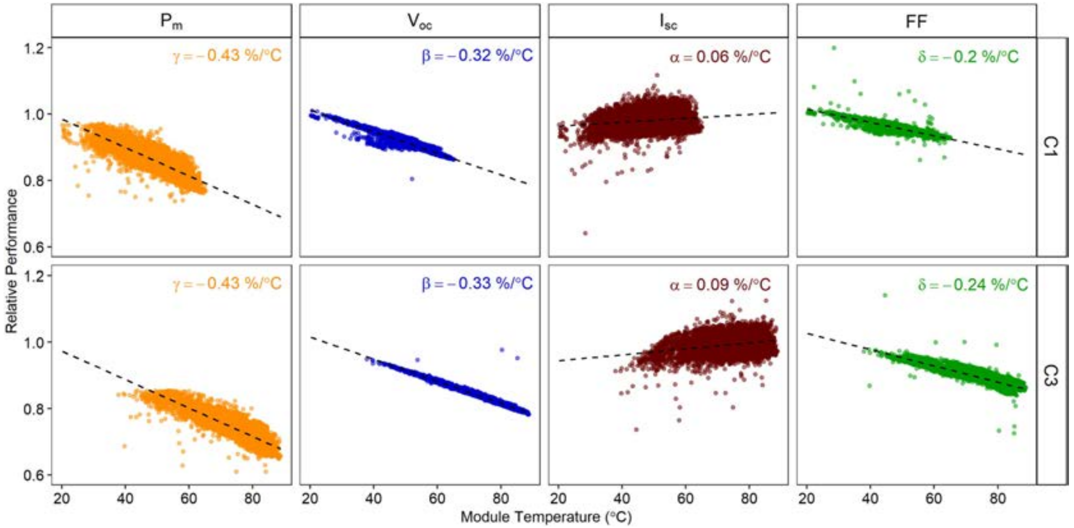
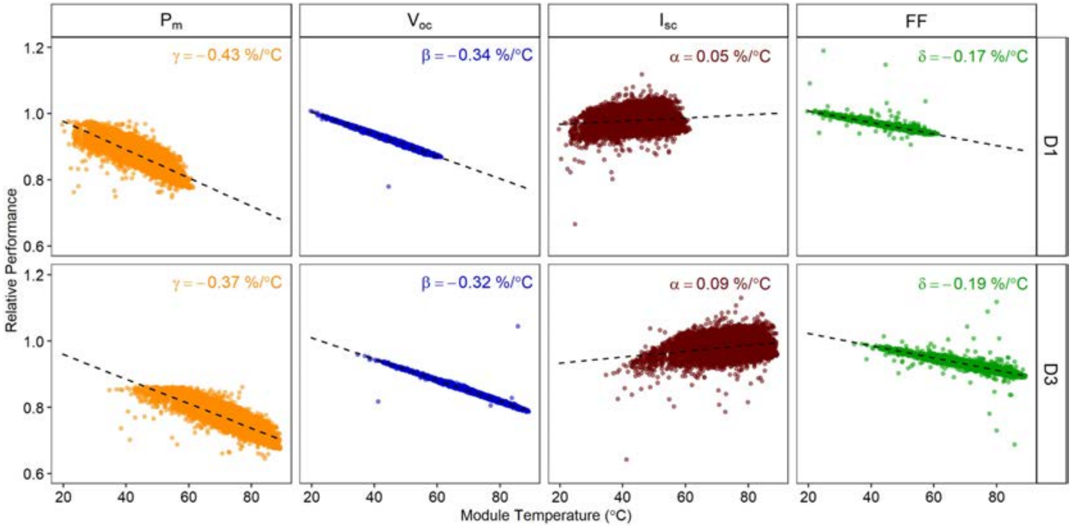
State of art – T impact

2020 A. Gok *et al*.



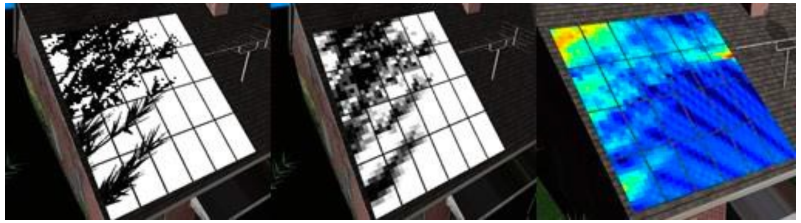




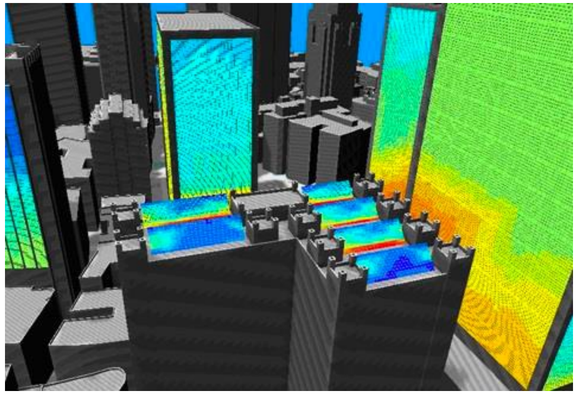
A. Gok *et al*. The influence of operating temperature on the performance of BIPV modules, *IEEE JPV*, 2020. 10.1109/JPHOTOV.2020.3001181

State of art – T impact, shading

Shading analysis



2019 IEA Task 15



Temperature effect

Type of tested property	Tested property	Property testing level (Module/ System)	BIPV feature to be considered	Recommended tests/procedures (including references to existing ones)
5. Durability and reliability	Thermal cycling	Module	Frequent shading	Increase number of cycles compared to standard IEC tests
5. Durability and reliability	Thermal stress	Module	Frequent partial shading (by close and distant objects)	Adapted IEC hot-spot test to new boundary conditions
5. Durability and reliability	Thermal stress	Module	Frequent partial shading (by close and distant objects)	Make IEC 62979 (bypass diode thermal runaway) mandatory if frequent shading may occur

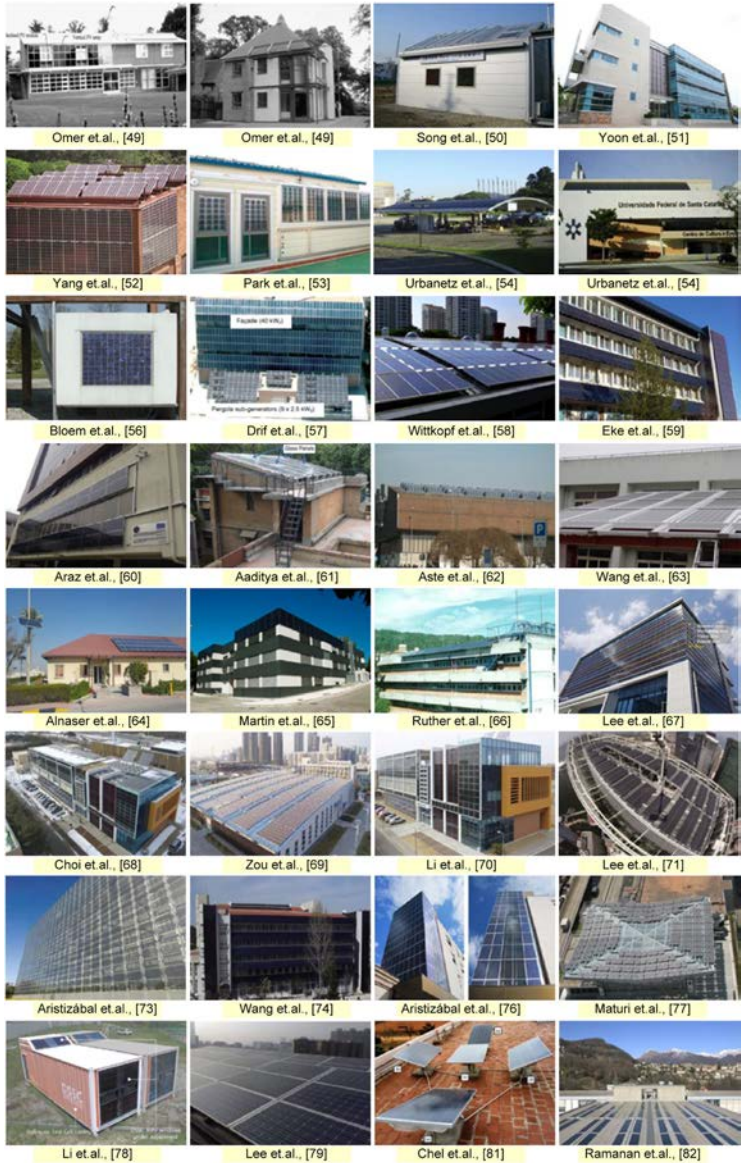
Type of tested property	Tested property	Property testing level (Module/ System)	BIPV feature to be considered	Recommended tests/procedures (including references to existing ones)
1. Electrical	Module defect identification	Module	Inhomogeneous surface coverage	Electroluminescence testing - Mask back surface with opaque material
1. Electrical	Module defect identification	Module	Inhomogeneous surface coverage	IR imaging (problems with IR-transmissive materials like thin polymers)
1. Electrical	PID	Module	Module decoration	PID test, See Section 3.1.2.1
1. Electrical	Rated module power output	Module	Bifacial modules	Refer to IEC standardisation work on bifacial modules: Define BIPV-relevant illumination conditions for I-V measurement.
1. Electrical	Rated module power output	Module	Curved modules	Test under natural sunlight to achieve a realistic variation of incidence angles
1. Electrical	Rated module power output	Module	Large module dimensions	Test "representative-size" modules and apply extrapolation procedures; Outdoor testing; measure IV curves of individual strings within module separately
1. Electrical	Rated module power output	Module	Modules of many different dimensions	Testing "representative-size" modules and interpolation procedures
1. Electrical	Rated module power output	Module	Frequent partial shading (by close and distant objects)	Adapt IEC hot-spot test to BIPV-relevant boundary conditions
1. Electrical	Rated module power output	Module	Module decoration causing mismatch within module	Area-weighting; Optical modelling; I-V measurement
1. Electrical	Annual electricity yield	System	Treatment of front glass surface, e.g. structured, anti-reflective, anti-glare	Simulation, taking correct angular dependence of electrical data into account

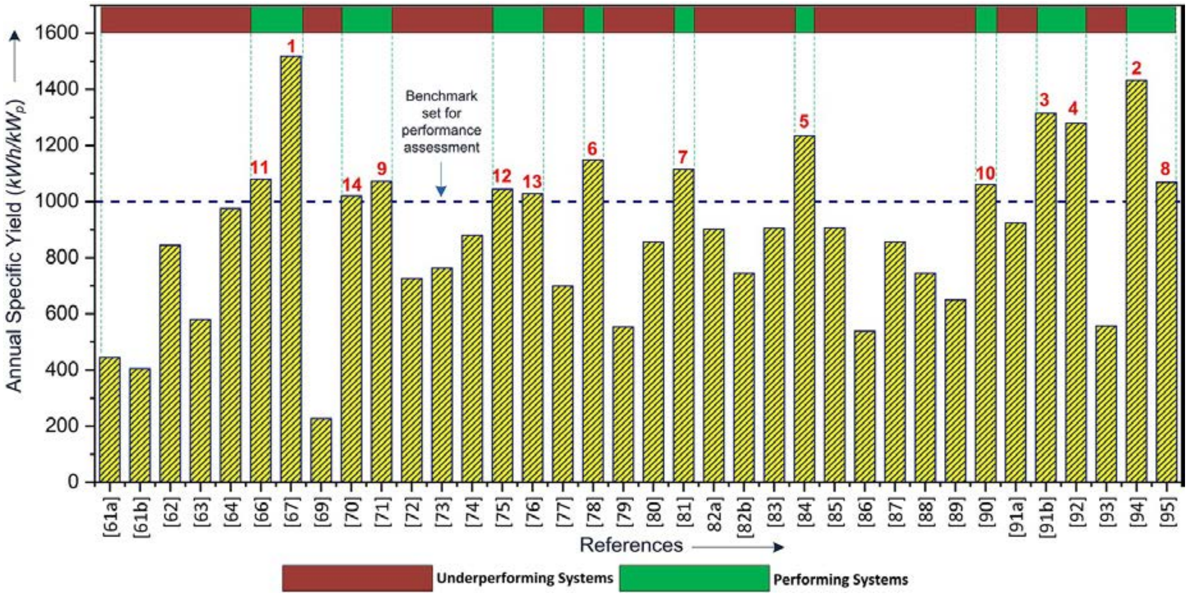
2020 IEA Task 15

IEA Task 15: Multifunctional characterisation of BIPV - proposed topics for future international standardisation activities, 2020.

State of art - Performance

2022 D. S. Pillai *et al*.





D. Pillai et al., A comprehensive review on building integrated photovoltaic systems Emphasis to technological advancements, outdoor testing, and predictive maintenance, *Renewable and Sustainable Energy Reviews*, 2022. https://doi.org/10.1016/j.rser.2021.111946

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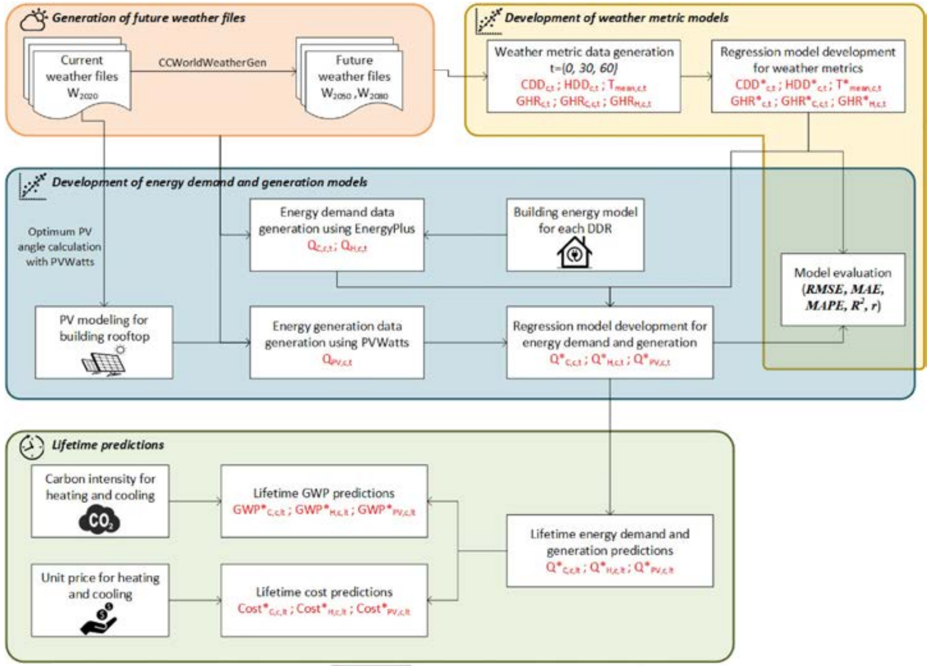
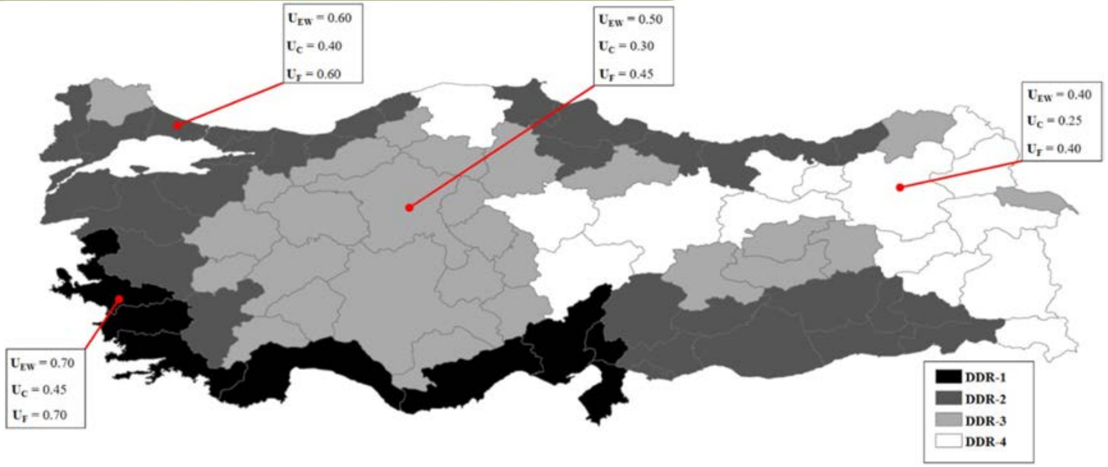
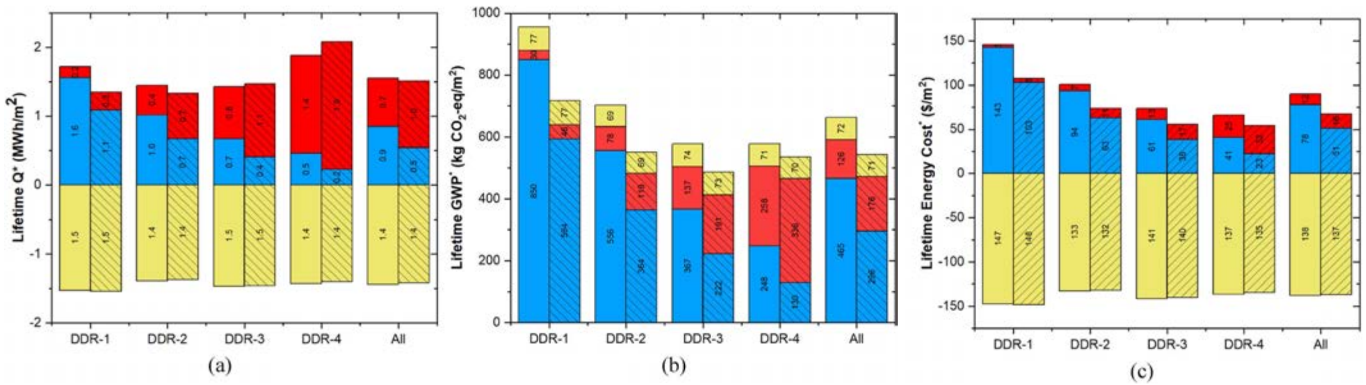
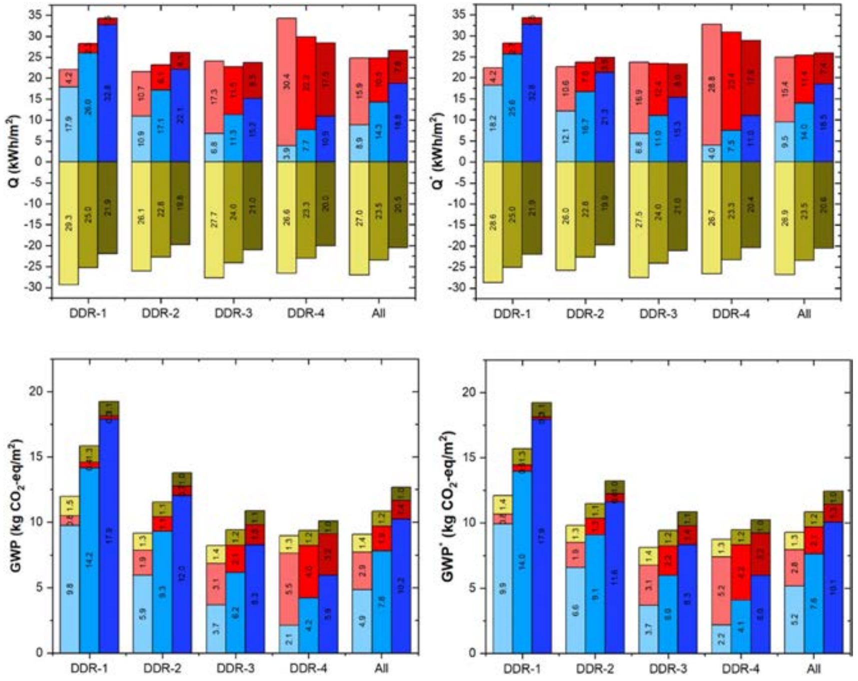
State of art - Performance

2022 T. Tamer *et al*.









T. Tamer et al., Data-driven, long-term prediction of building performance under climate change- Building energy demand and BIPV energy generation analysis across Turkey, *Renewable and Sustainable Energy Reviews*, *2022*. https://doi.org/10.1016/j.rser.2022.112396

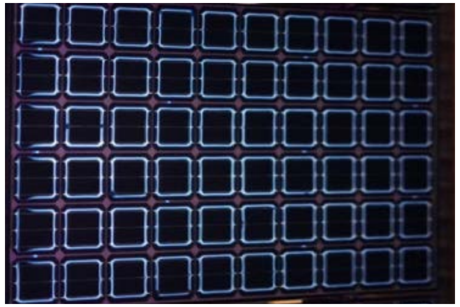
Imaging Techniques

What information we can get from images?

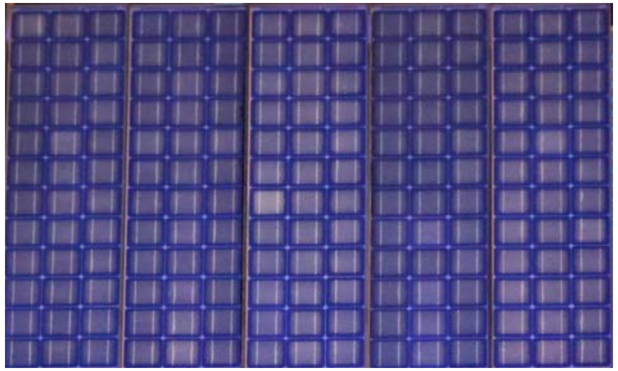
Degradation Analysis – UVF imaging

Mono AlBSF, System age = 4 years

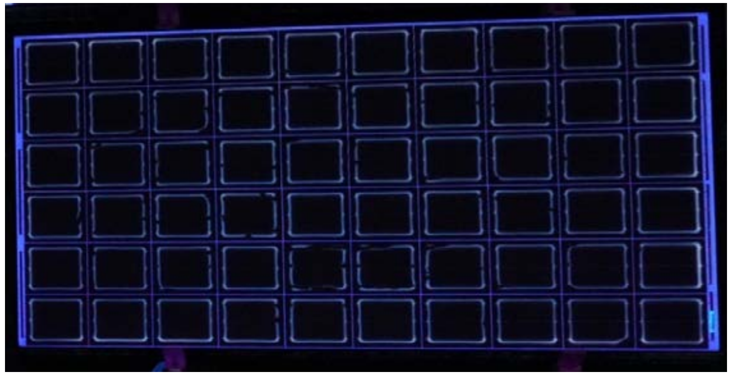
Mono AlBSF, System age = 10 years



Mono AlBSF, System age = 20 years

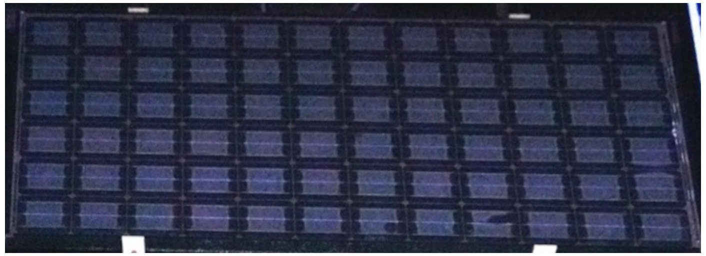


Multi AlBSF, System age = 4 years

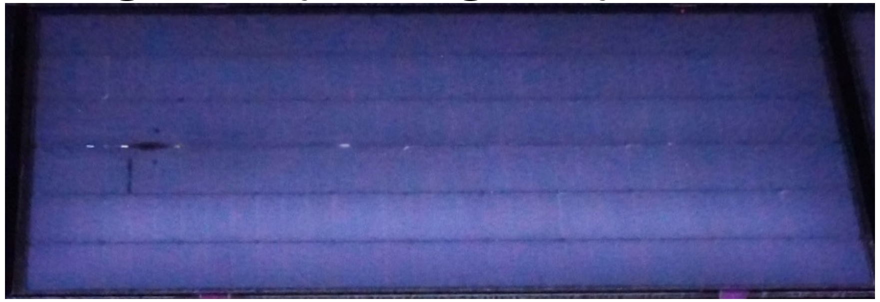


Mono PERC, System age = 4 years

HIT, System age = 4 years

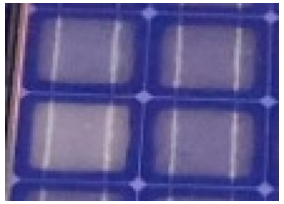


Shingle HIT, System age = 6 years

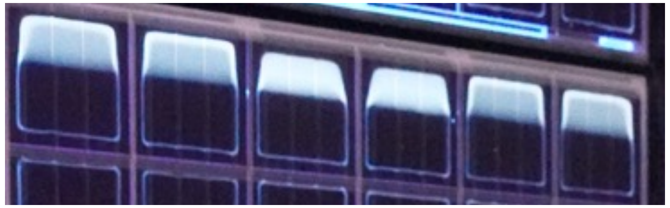


- Cracks

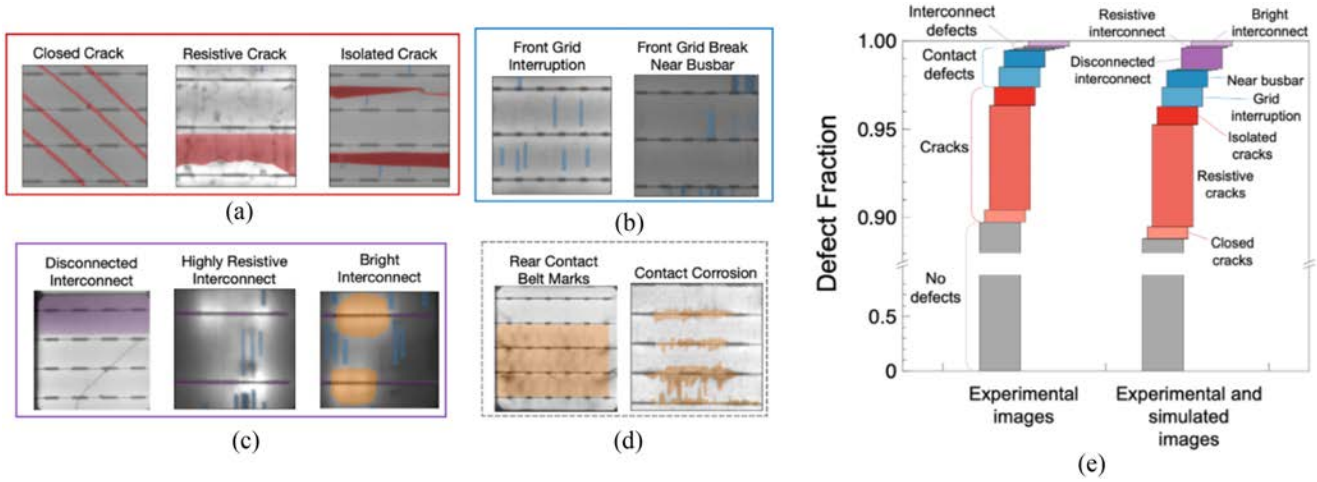
- Hot cells



- Different BOM

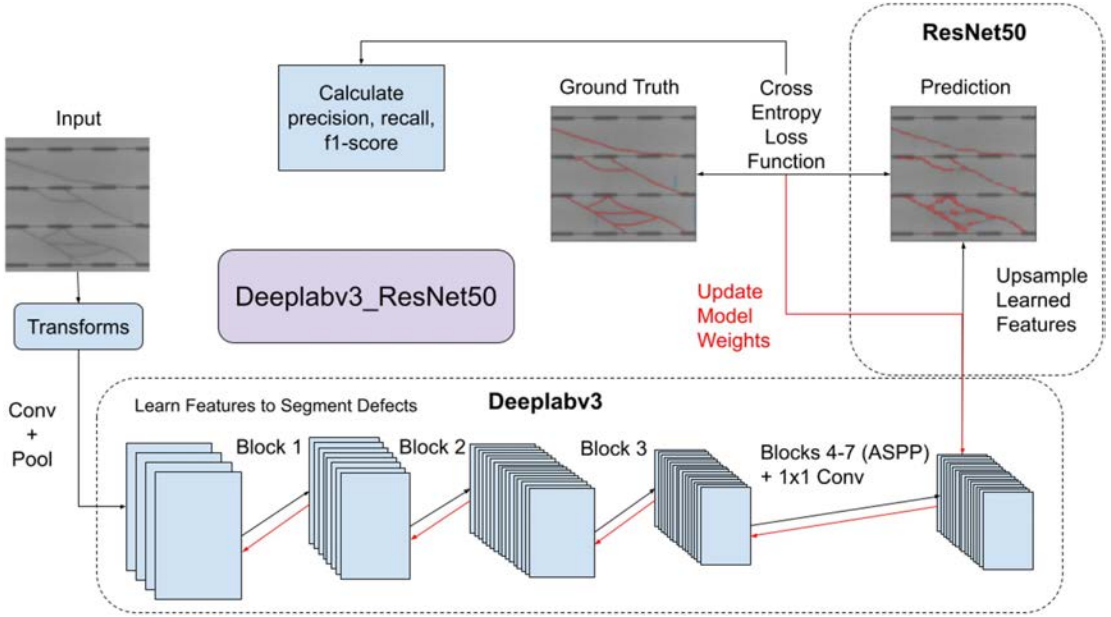


Degradation Analysis – EL imaging



Automatic defect detection using semantic segmentation

- Input of module EL images
- Indexing each individual cells within the module
- Output percentage of cells with certain type of defect



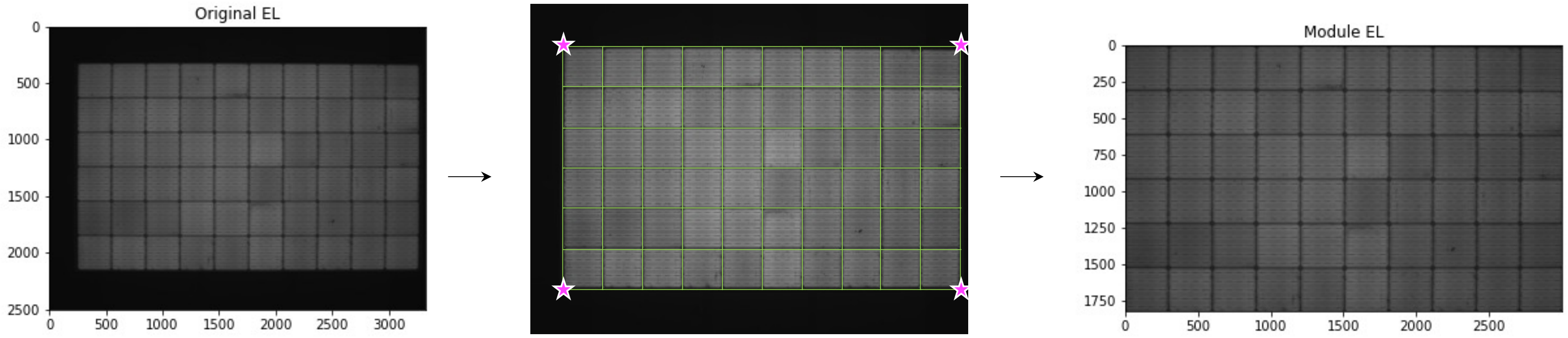
Defect	Modules with Defect	Percent of Total
Backsheet bubbling	2	1.3
Front delamination	156	100
Backsheet burn marks	10	6.4
Backsheet bumps	27	17.3
ARC corrosion	80	51.3
Snail trails	30	19.2

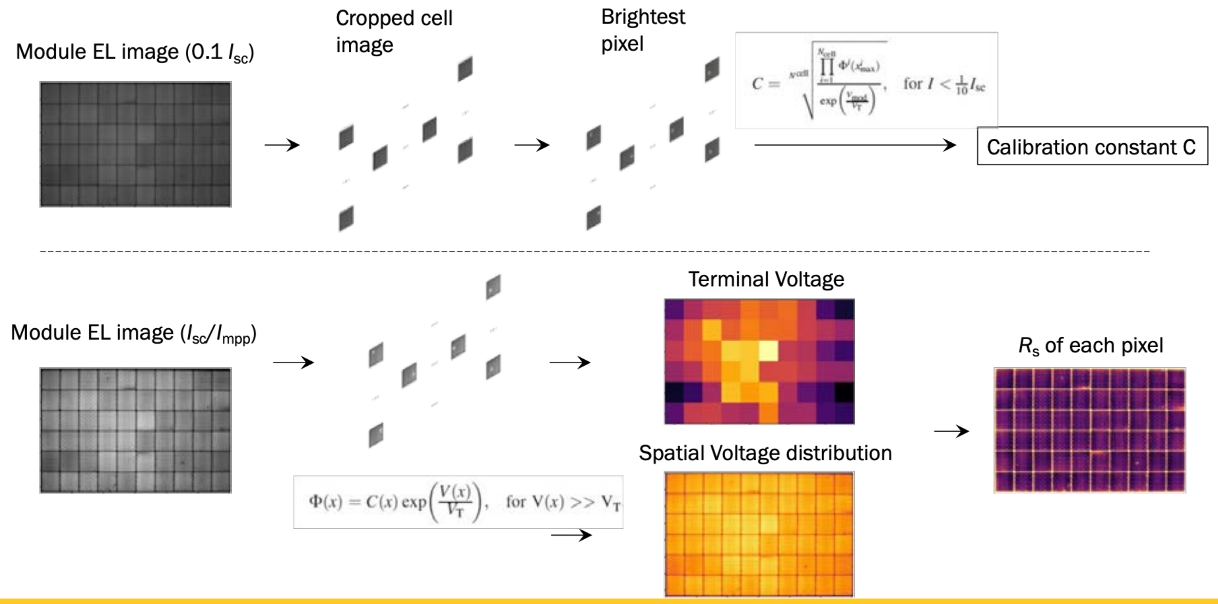
J. Fioresi, D. Colvin, R. Frota, R. Gupta, **M. Li**, H. Seigneur, S. Vyas, M. Shah, K. O. Davis, "Automated Defect Detection and Localization in Photovoltaic Cells using Semantic Segmentation of Electroluminescence Images", *IEEE Journal of Photovoltaics*, vol. 12, issue 1, pp. 53-61, 2021.

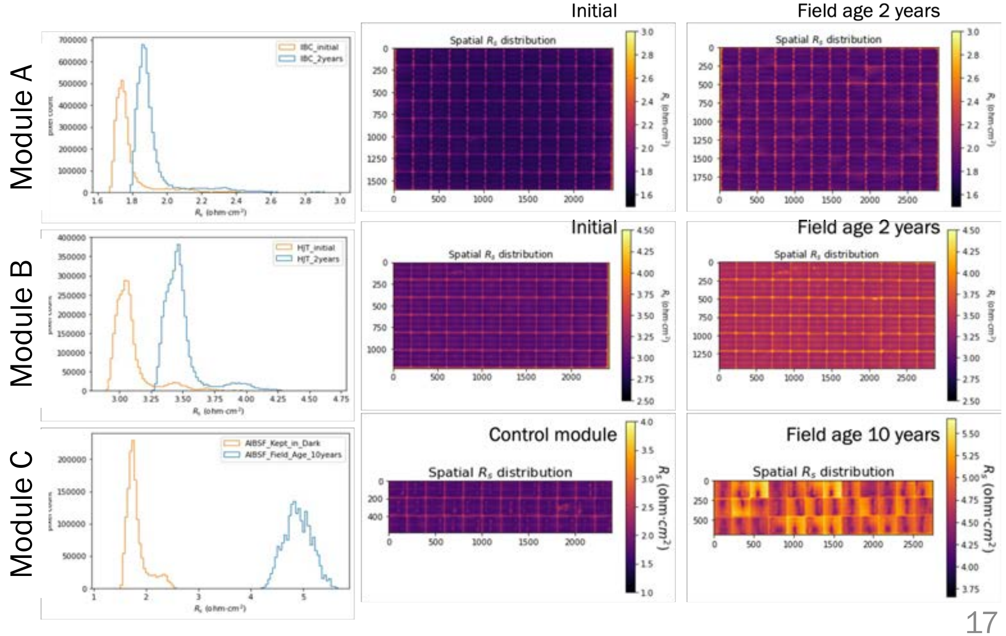
Degradation Analysis – EL imaging

Streamline series resistance imaging

- Input of minimum of 2 EL images
- Automatically calculate terminal voltage and spatial voltage distribution at pixel level
- Output module R_s images

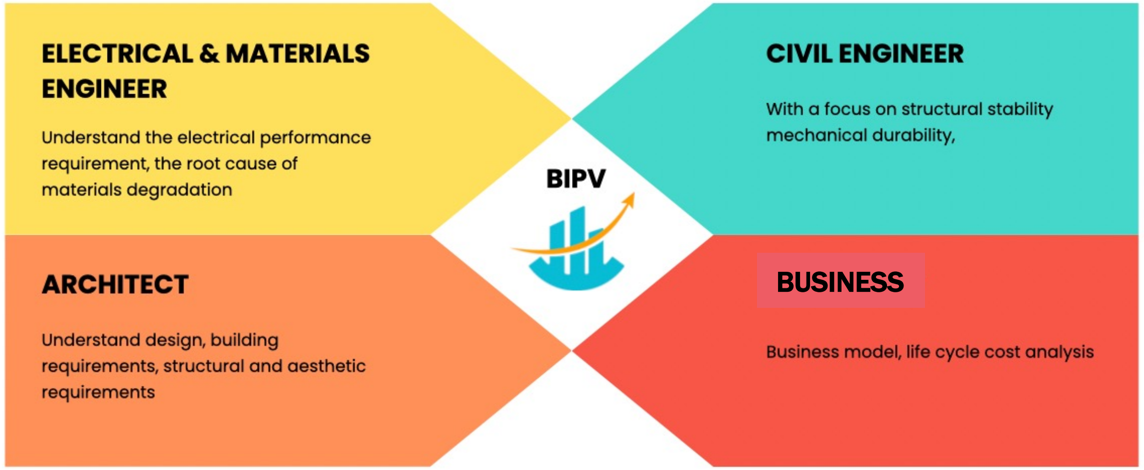






Challenges and Opportunities

- Different BIPV products
  - Foil
  - Tile
  - Module
  - Shingles
  - Glazing



- Difference between BIPV and PV
  - No specific standards for BIPV
- Understanding root cause vs. global degradation rate estimation
- Challenge with long-term field testing

Thanks! Questions?

mengjie.li@ucf.edu

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