THE TRANSITION

DESIGN AND ENGINEERING OF A SUSTAINABLE SOLAR CARPORT

NS Stations

J.A.DIJKEMA
4652487

TU Delft

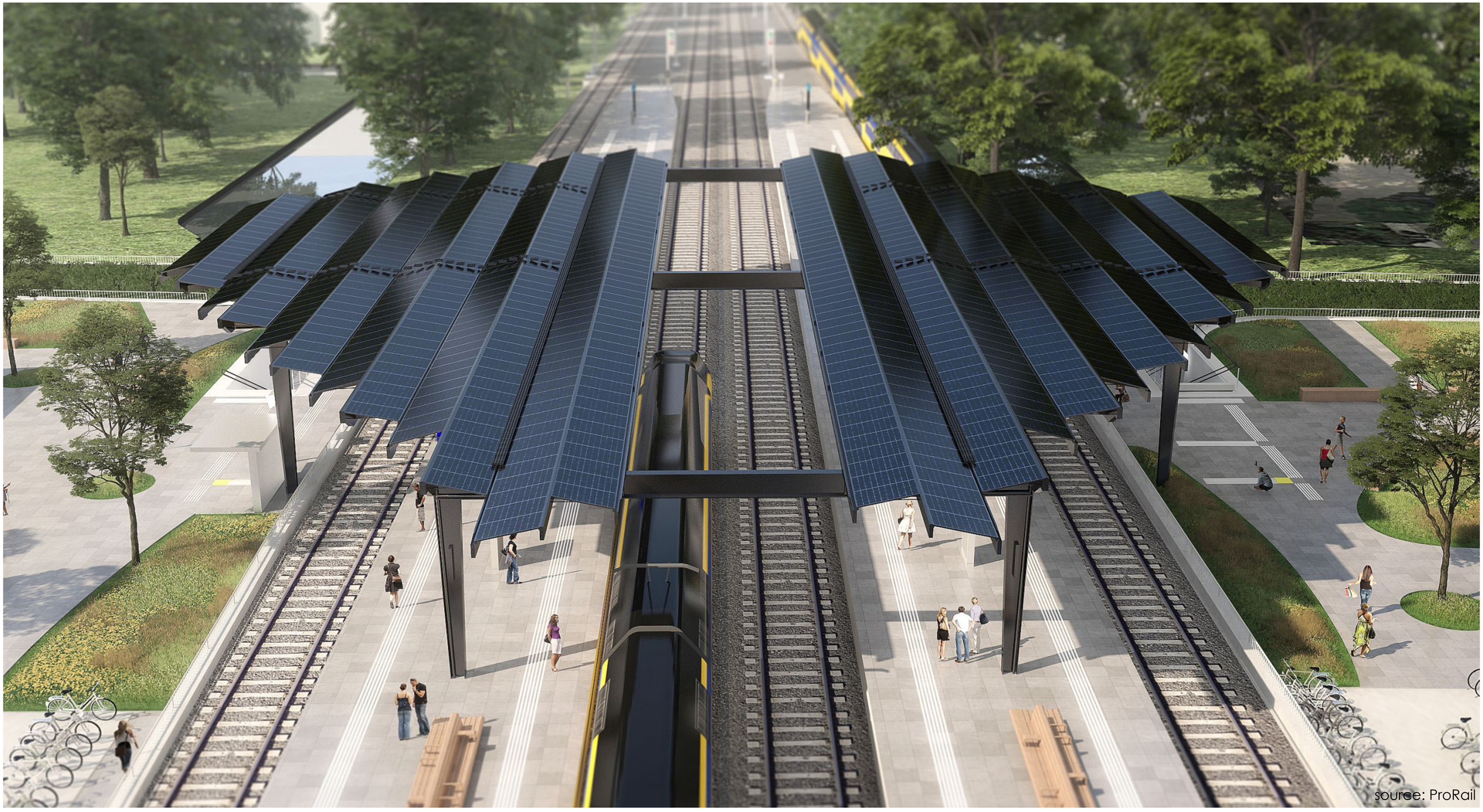
INTRODUCTION

RESEARCH

DESIGN

1. INTRODUCTION


source: NS


source: ProRail

P+R PARKING

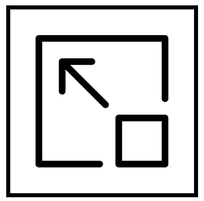
238 locations

Easy accessible

Un-compromising

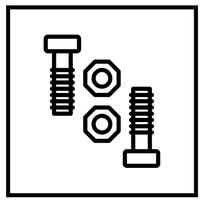
Large area

OBJECTIVE NS

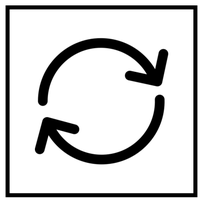


modular

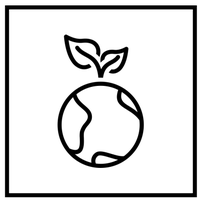
function



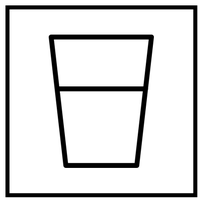
demountable



circulair materials

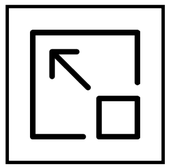


sustainable appearance



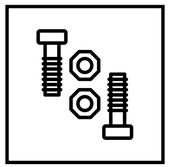
transparent

OBJECTIVE NS

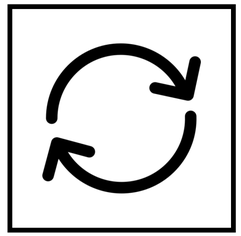


modular

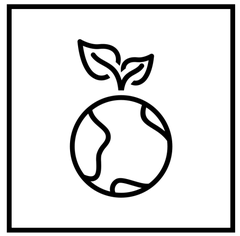
function



demountable



circulair materials



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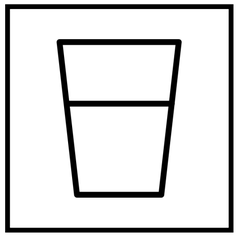


transparent


source: AirportWeeze


B3.5
B3.5
Ausfahrt/Exit
source: AirportWeeze


source: Blueoakenergy


source: Blueoakenergy

OBJECTIVE

Modular design

OBJECTIVE

Modular design

Optimized solar gain

OBJECTIVE

Modular design

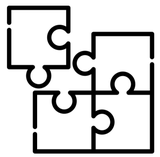
Optimized solar gain

Structural integration

OBJECTIVE

Modular design

Optimized solar gain



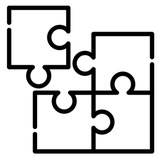
Structural integration

Image NS

OBJECTIVE

Modular design

Optimized solar gain



Structural integration

Image NS

Function parking lot

MAIN RESEARCH QUESTION

"What would the design of a modular shelter for cars be when taken into account the integration of solar panels into the structure with maximum solar gain in different orientations and the image of the NS whilst keeping the function as parking lot?"

RESEARCH PHASES

Knowledge

RESEARCH PHASES

Knowledge

Conceptual design

RESEARCH PHASES

Knowledge

Conceptual design

Design

RESEARCH PHASES

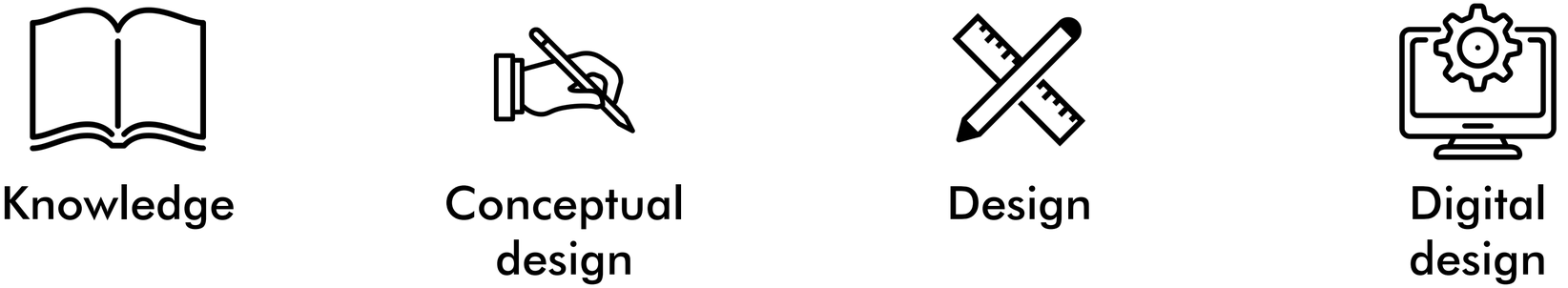
Knowledge

Conceptual design

Design

Digital design

RESEARCH PHASES

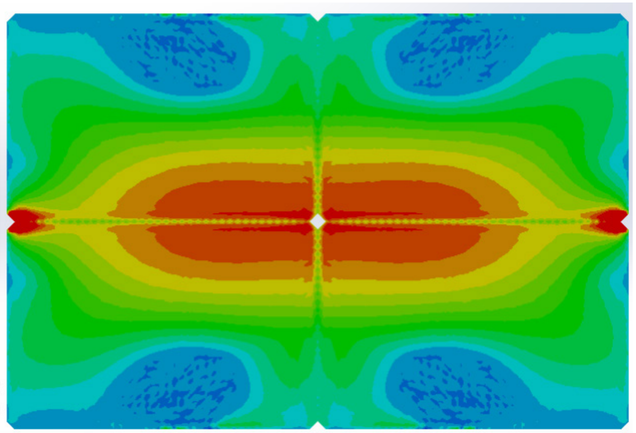


KNOWLEDGE PHASE

RESEARCH TOPICS

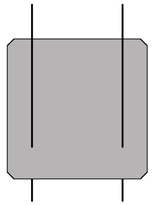
PV technologies

Structural PV

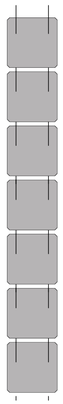


source:
solar cell techonlogies: EPFL
structural PV:

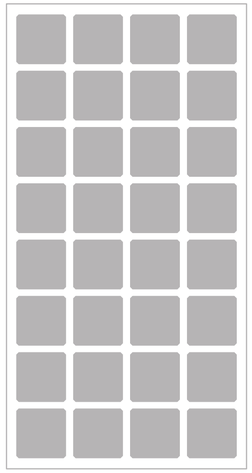
TERMINOLOGY



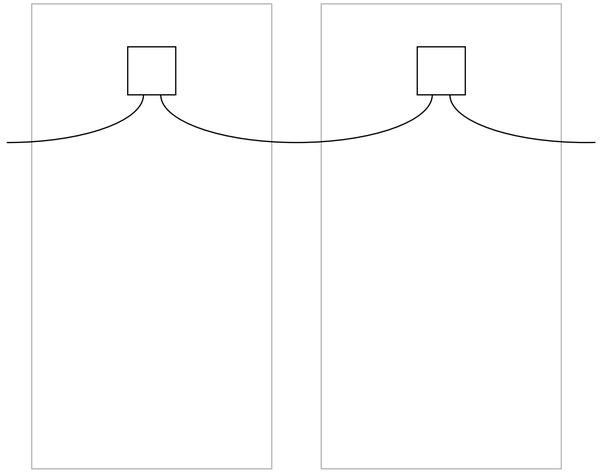
Cell



Cell string



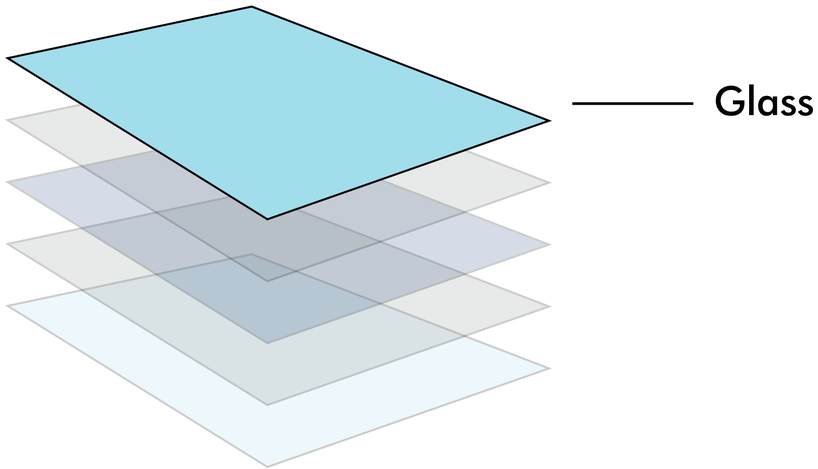
Module

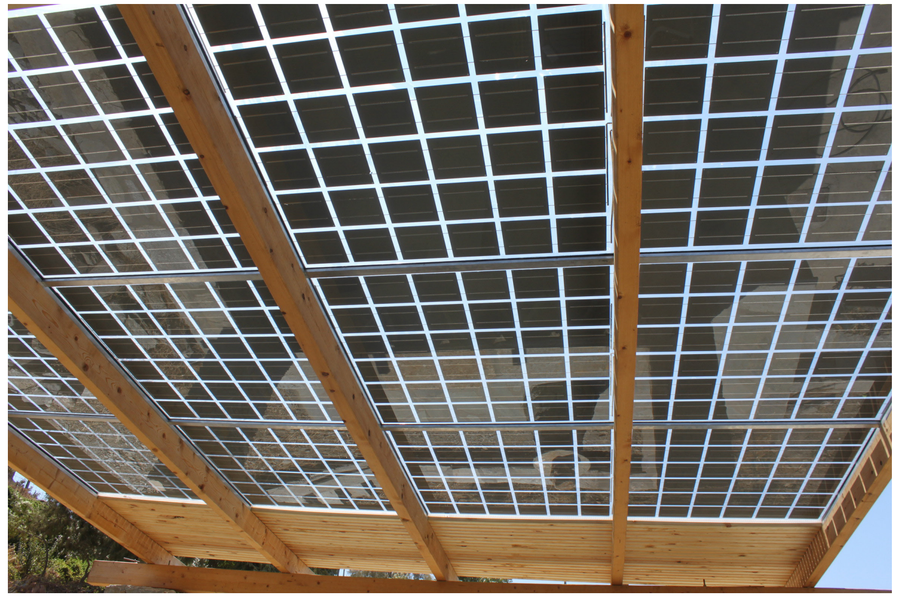


PV string

STRUCTURES PV

Glass-glass

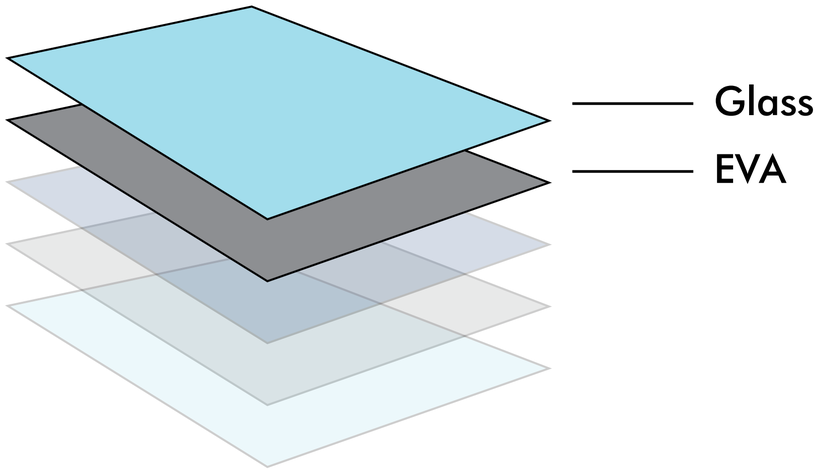


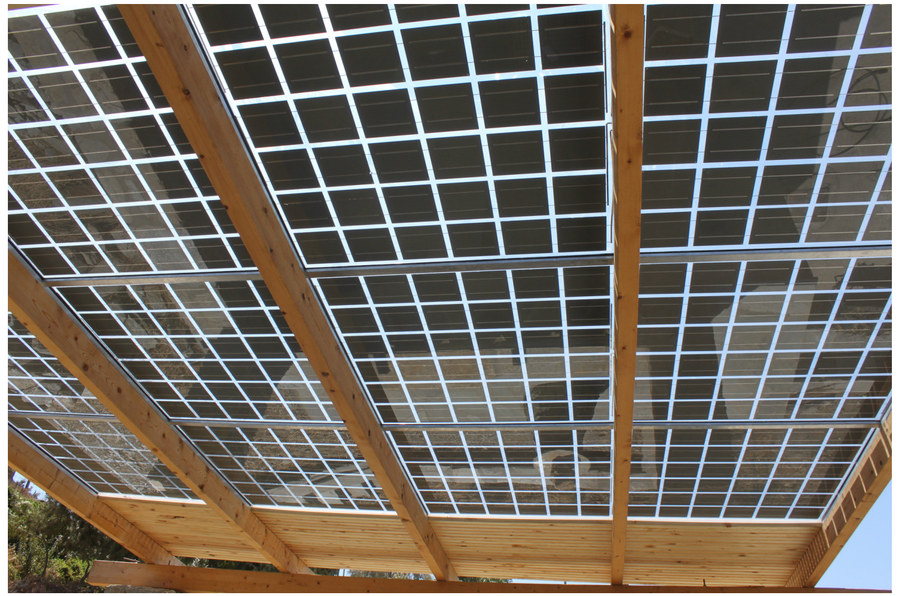


source: 2ES

STRUCTURES PV

Glass-glass





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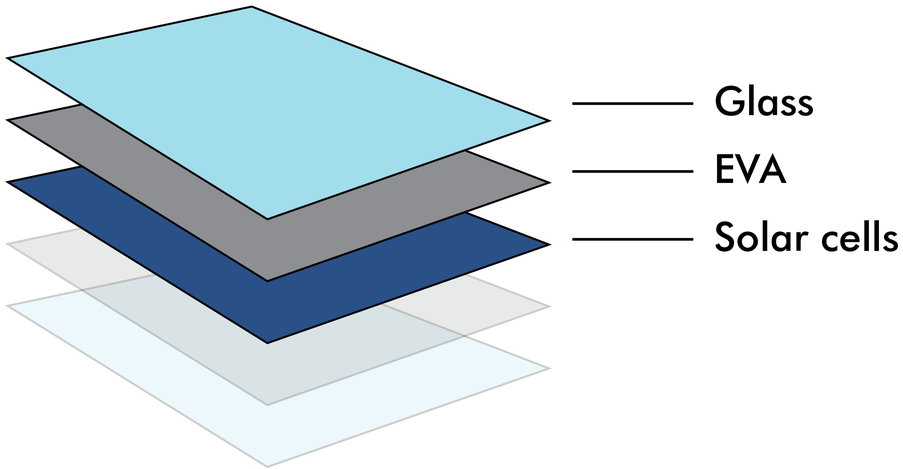
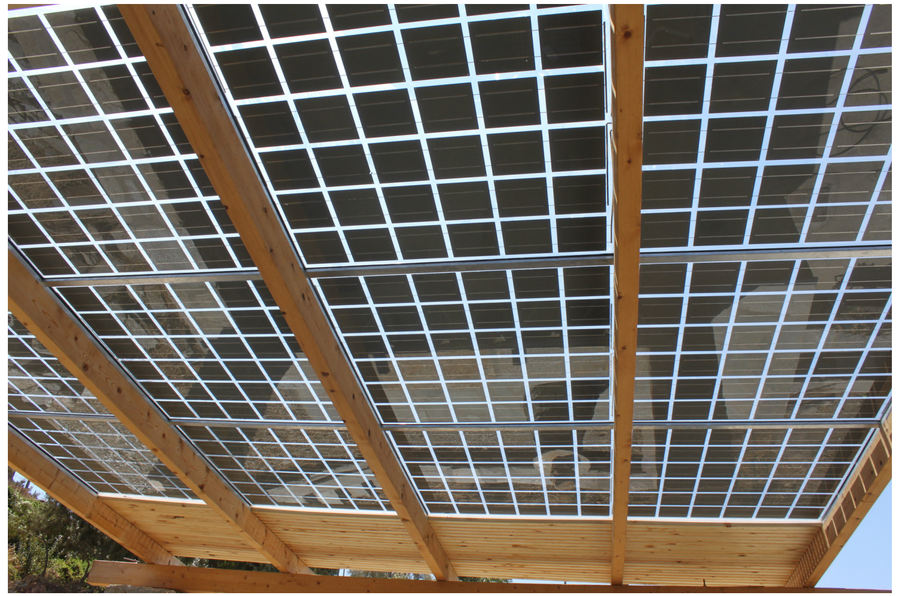
STRUCTURES PV

Glass-glass





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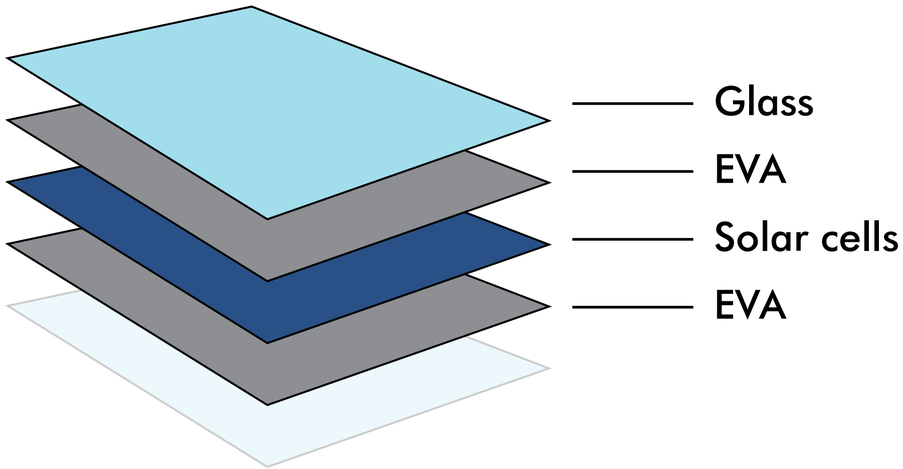
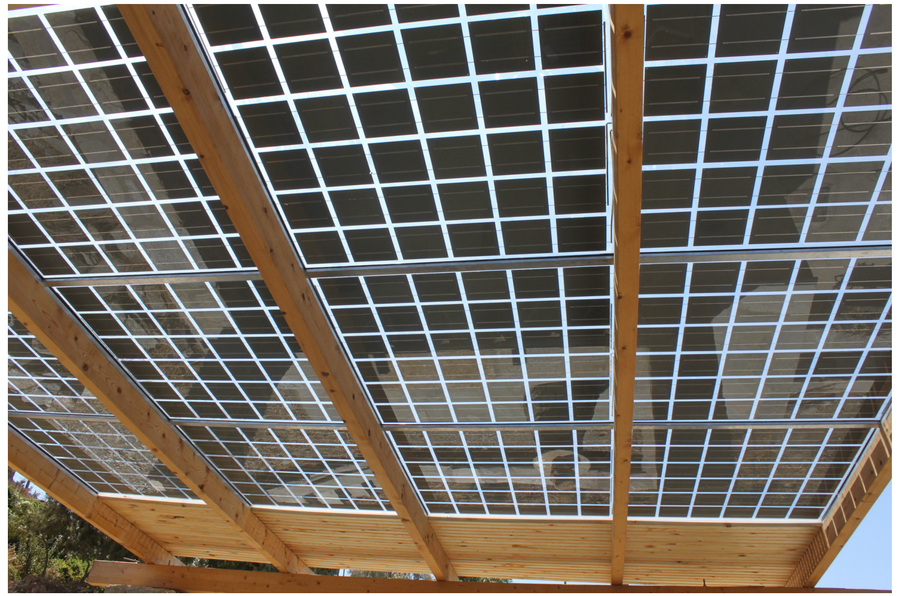
Glass-glass





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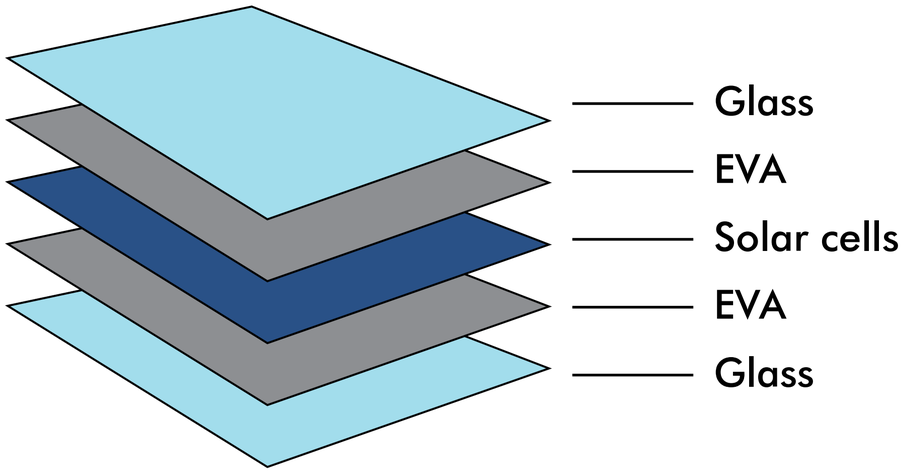
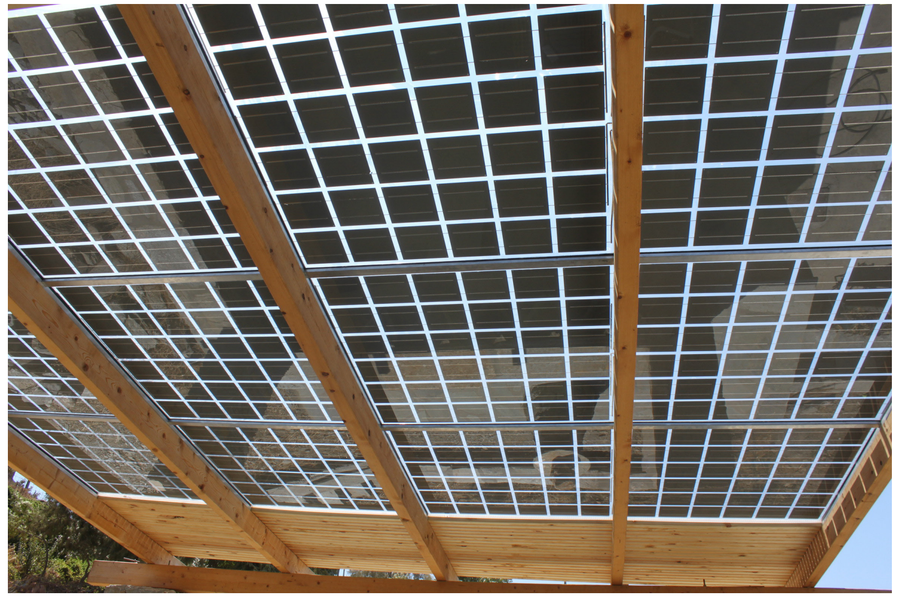
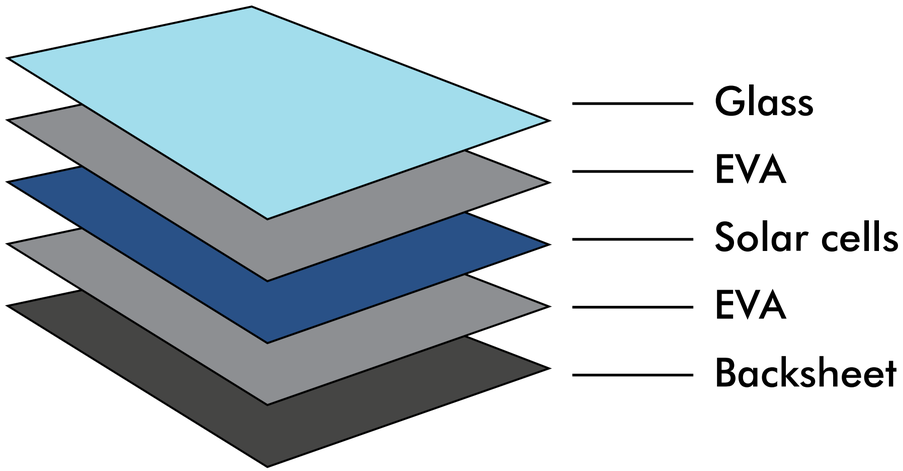




source: 2ES

STRUCTURES PV

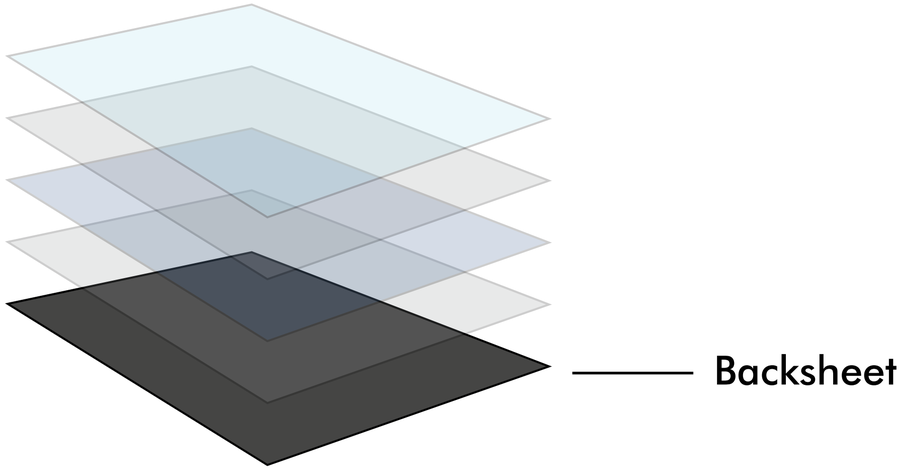
Glass-backsheet



source: Reviews

STRUCTURES PV

Glass-backsheet

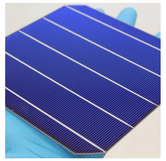


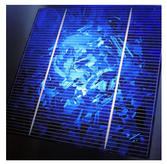
source: Reviews

PV TECHNOLOGIES

PV TECHNOLOGIES

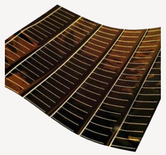
1ST Generation
Silicon wafer based

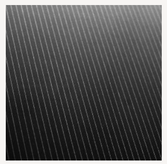

mono c-Si


poly c-Si

2ND Generation
Thin film technology

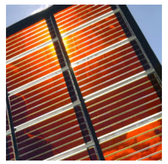

a-Si

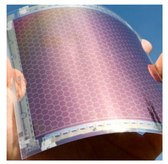

CdTe

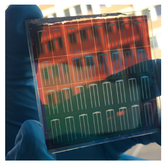

CI(G)S

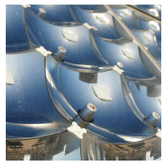
3RD Generation
Advanced technologies

(IRENA, 2012; Ranabhat, et al., 2016)


DSSc


OPV

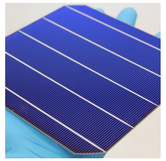

Perovskite

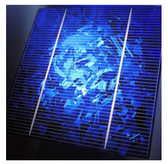

CPV

source:
mono c-Si: Ecoticias
poly c-Si: Solarcellskakedan
a-Si: unknown
CdTe: Empa
CIGS: Solar Power World
DSSc: Solvent Green
OPV: Solar Builder
Perovskite: Empa
CPV: SolFocus

PV TECHNOLOGIES

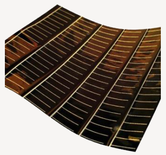
1ST Generation
Silicon wafer based

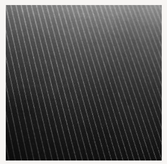

mono c-Si


poly c-Si

2ND Generation
Thin film technology


a-Si


CdTe


CI(G)S

3RD Generation
Advanced technologies

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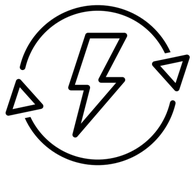
RESEARCH TOPICS



Performance

Design

Sustainbility

RESEARCH TOPICS

Performance

- efficiency
- performance drop off / celsius

Design

- flexibility
- customizability

Sustainbility

- recyclability
- energy payback time

RESEARCH TOPICS

Performance

- efficiency
- performance drop off / celsius

Design

- flexibility
- customizability

Sustainbility

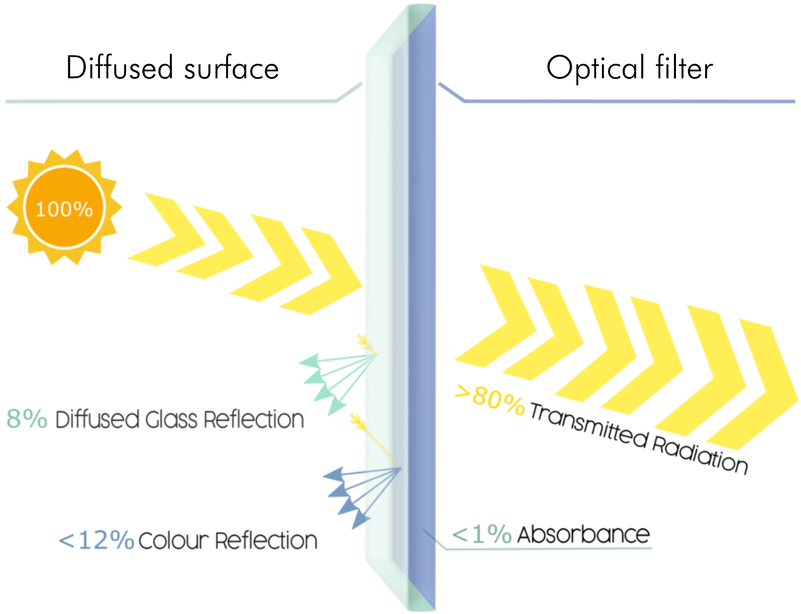
- recyclability
- energy payback time

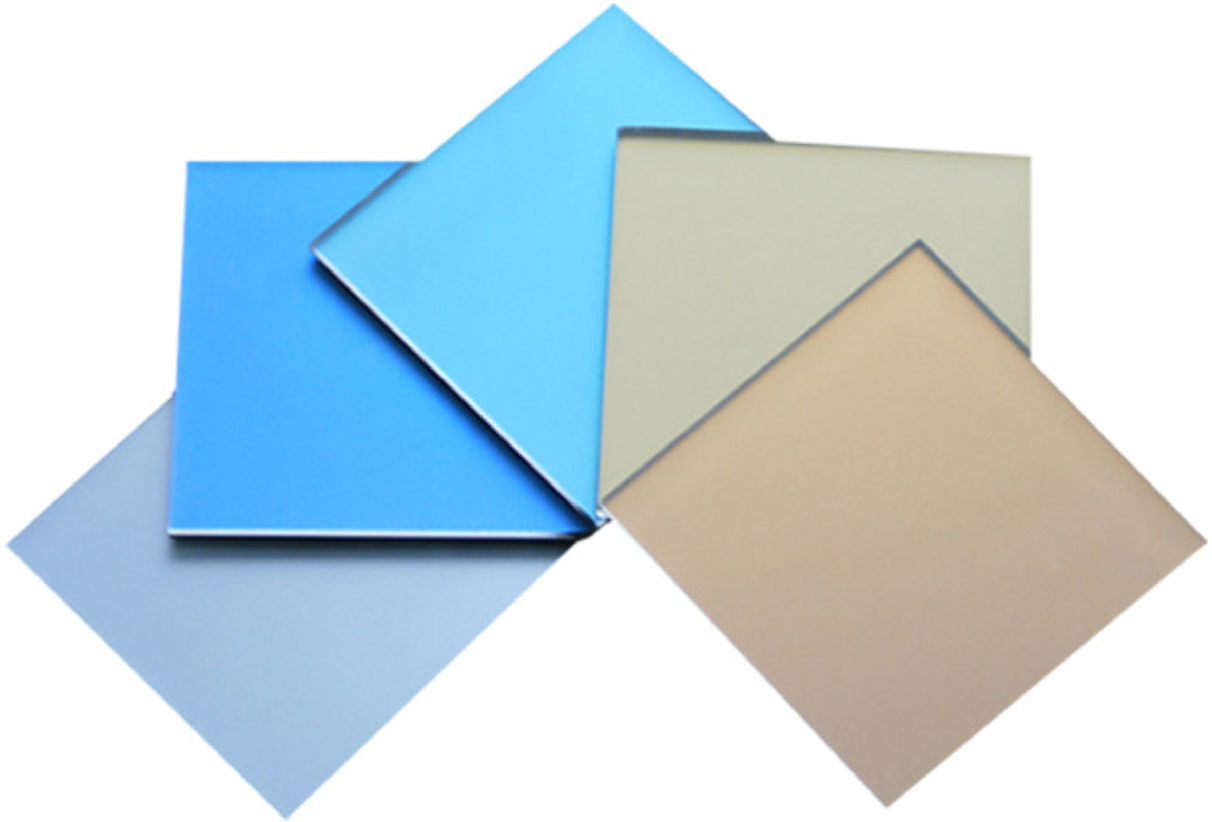
source: AleSpa


source: Emirates insolaire


source: Sorba

OPTICAL FILTER

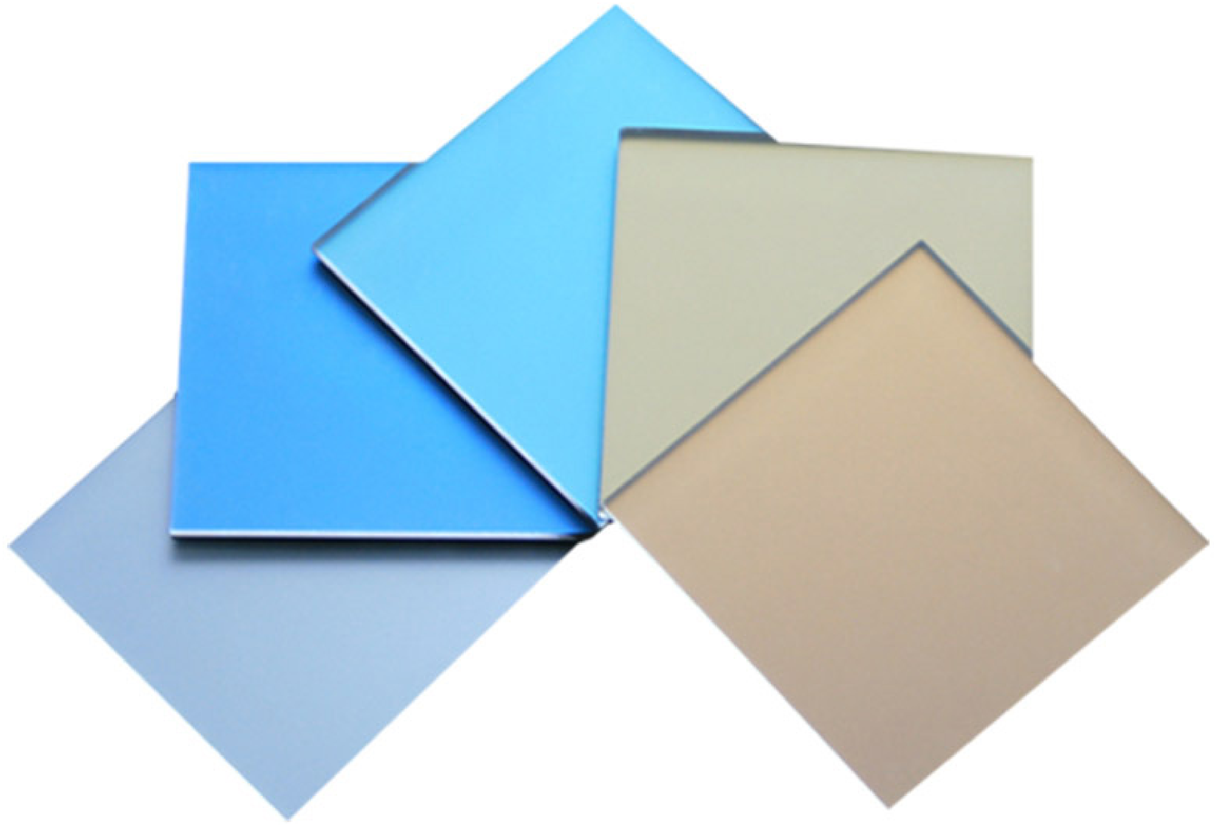




source: Swissinso

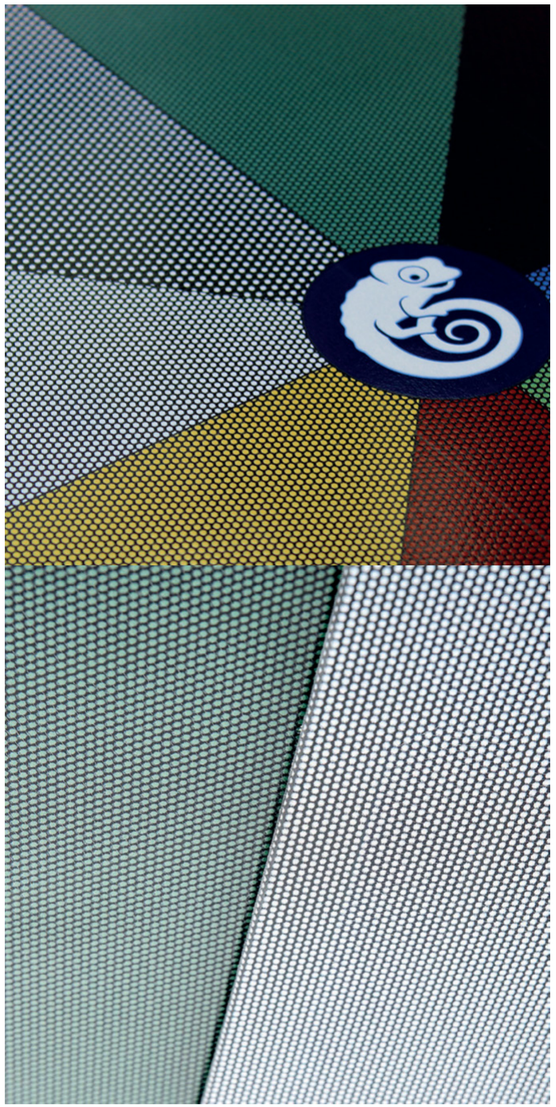
OPTICAL FILTER

Colour	Solar transmittance
Grey	90 +/- 1 %
Blue	88 +/- 1 %
Blue-green	88 +/- 1 %
Bronze	89 +/- 1 %
Brass	86 +/- 1 %



source: Swissinso

CERAMIC INK

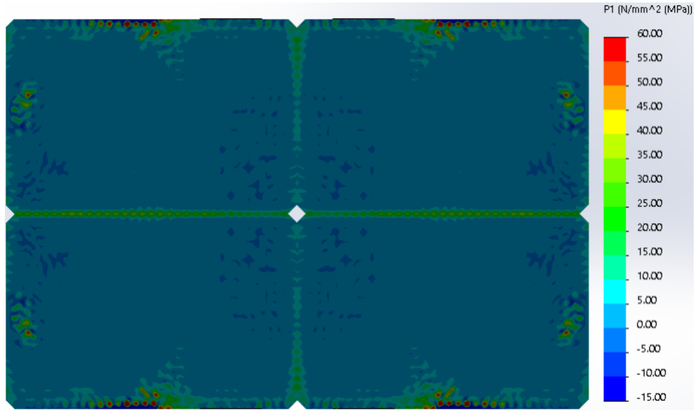


source: Kameleon solar

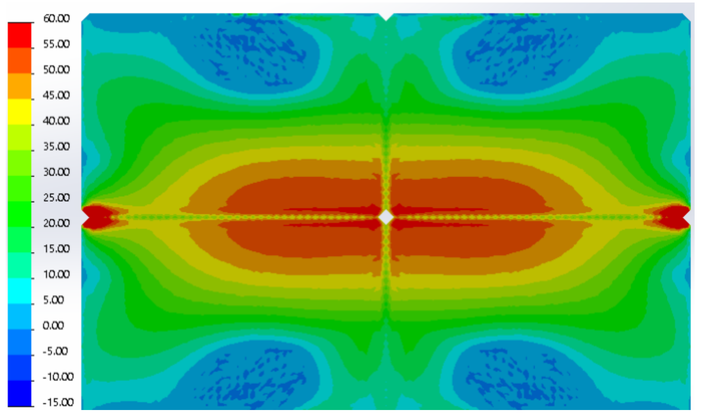
STRUCTURAL PV

COMPARISON PV STRUCTURES

Glass-glass

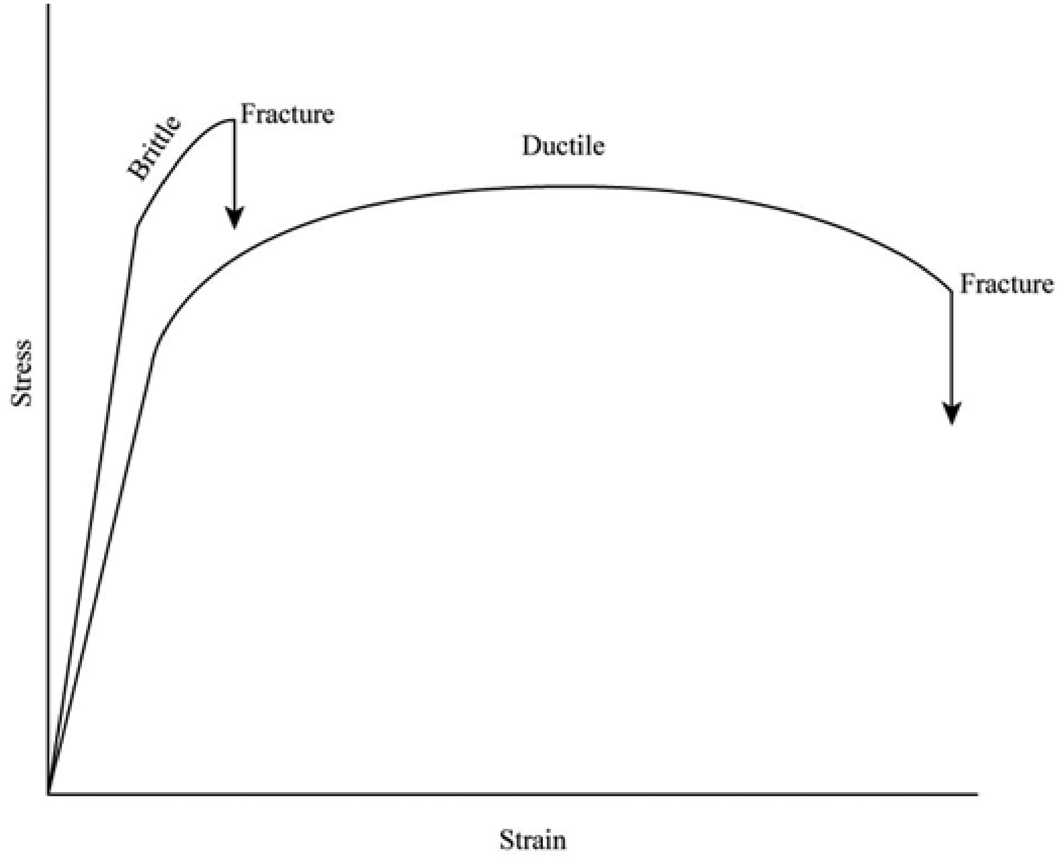


Glass-backsheet



Gabor, A., Janoch, R., Anselmo, A., Lincoln, J., Seigneur, H., & Honeker, C. (2018). Mechanical load testing of solar panels - Beyond certification testing

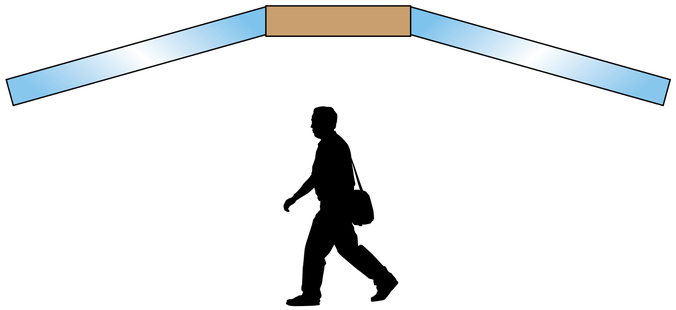
GLASS PROPERTY



GLASS REQUIREMENTS

RISK OF FALLING GLASS

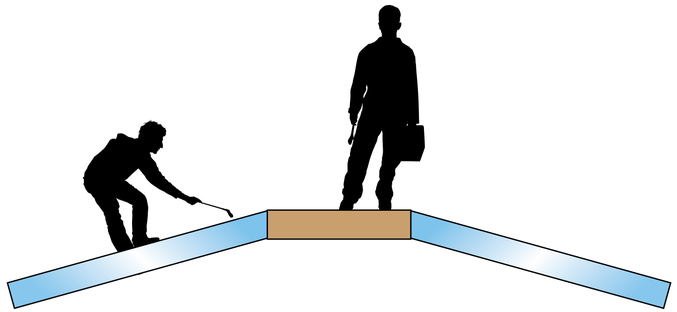
NON VERTICAL



Single glazing = laminated safety glass (LSG)
ACCORDING TO NEN-12600

RISK OF BREAKING THROUGH GLASS

NON VERTICAL, ACCESSIBLE FOR MAINTANCE



Single glazing = laminated safety glass (LSG)
ACCORDING TO NEN-12600

COMPARISON PV & LSG

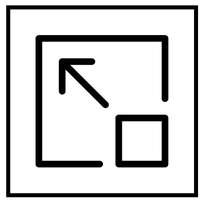
- Strengthened post breakage
- No influence on shear modulus
- Reduces adhesive bond

source: Hemmerle, C. (2017).Solar PV Building Skins – Structural Requirements and Environmental Benefits.

source: Jeroen Mens

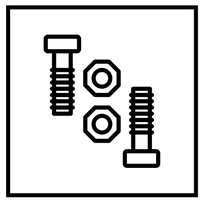
CONCEPTUAL DESIGN PHASE

REQUIREMENTS NS

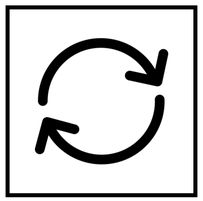


modular

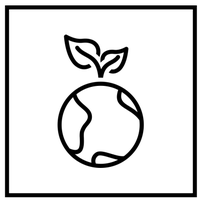
function



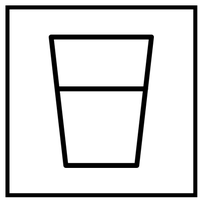
demountable



circulair materials

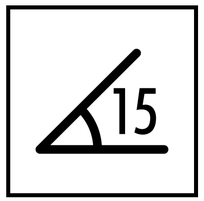


sustainable appearance



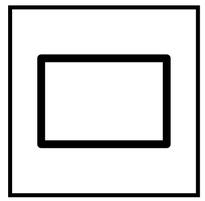
transparent

DESIGN REQUIREMENTS

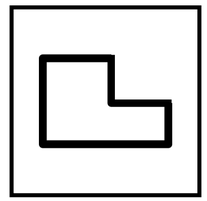


minimum angle

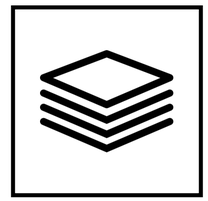
avoid blunt edges



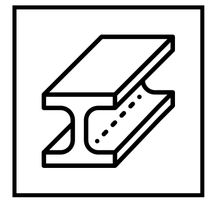
rectangular shape



avoid cut-outs



glass-glass modules



edge beam

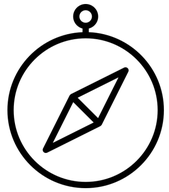
CONCEPTUAL TOPICS

cost-effective

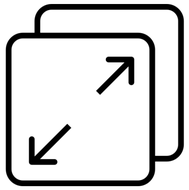
architectural

sustainable

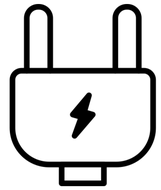
COST-EFFECTIVE DESIGN



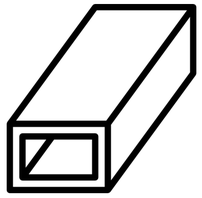
orientation independt



standardized solar panels



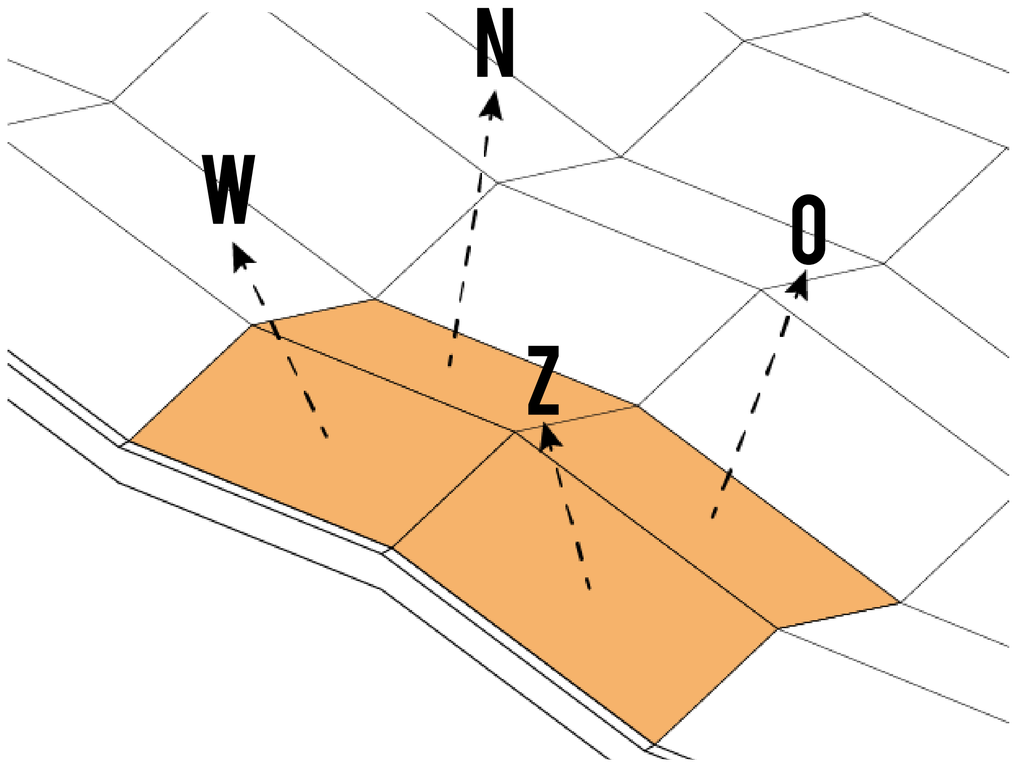
output > design



durable structure

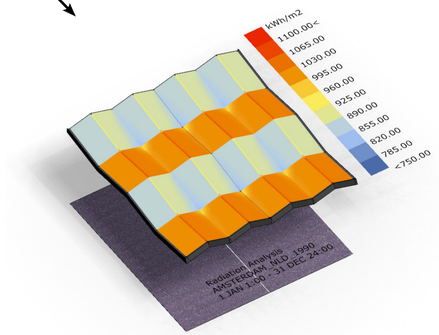
COST-EFFECTIVE DESIGN

COST-EFFECTIVE DESIGN

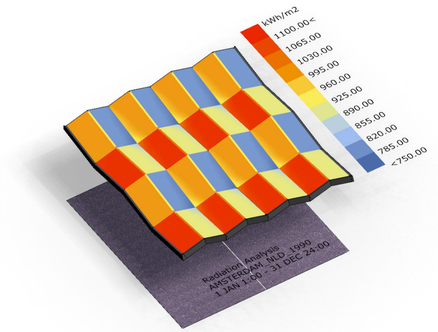


COST-EFFECTIVE DESIGN

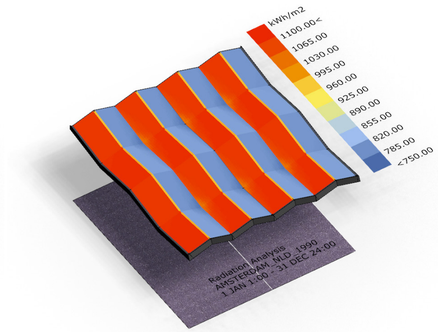
N 935 kWh/yr/M²



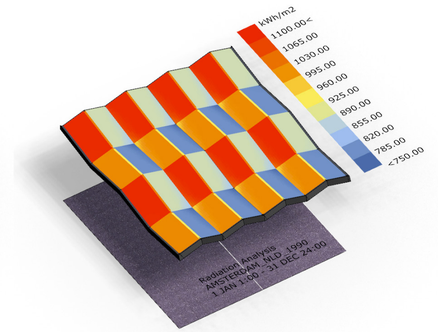
N 935 kWh/yr/M²



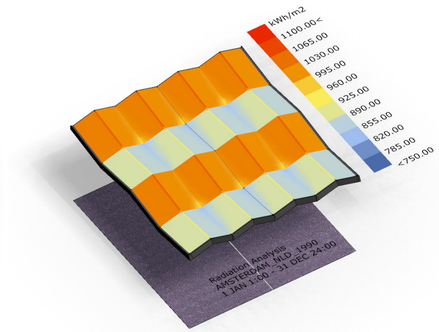
N 935 kWh/yr/M²



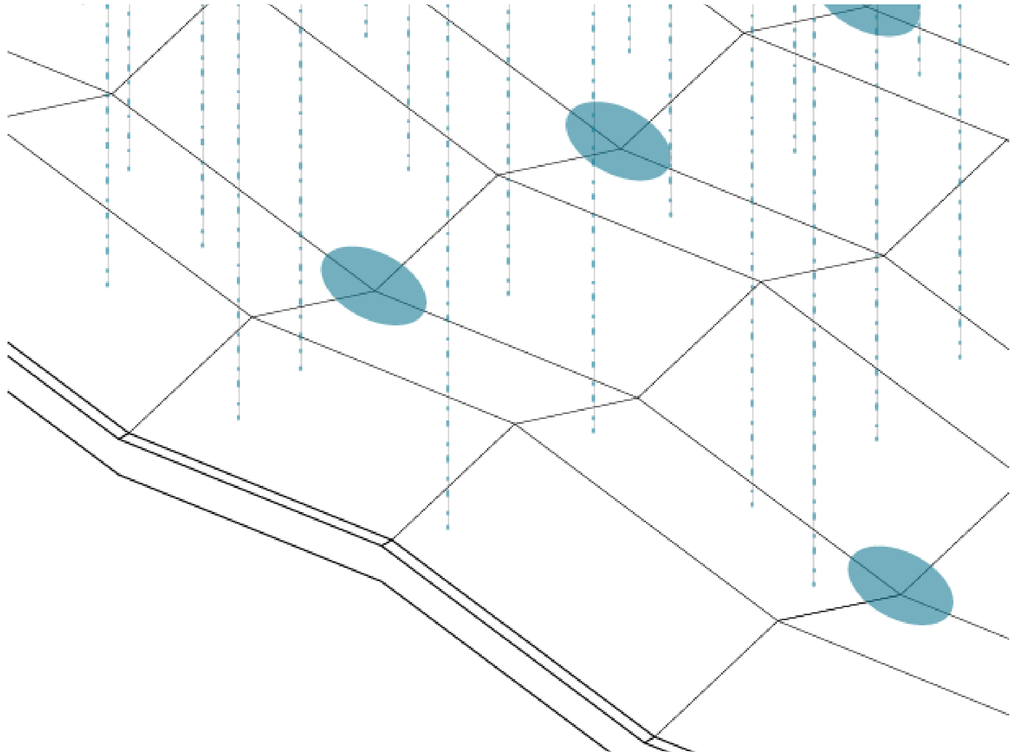
N 935 kWh/yr/M²



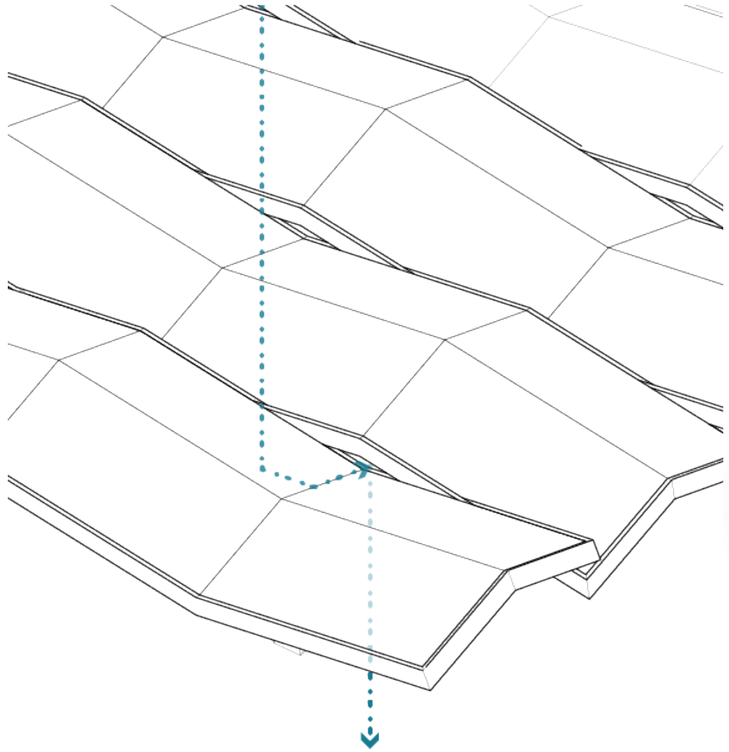
N 935 kWh/yr/M²



COST-EFFECTIVE DESIGN

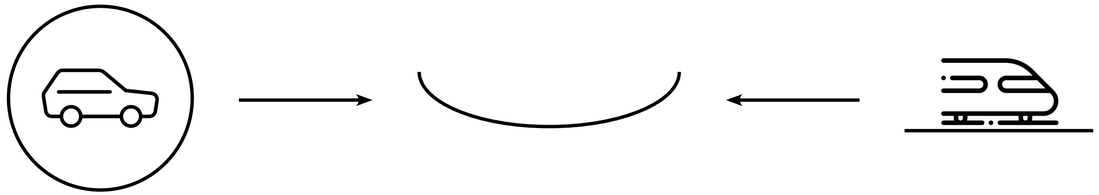


COST-EFFECTIVE DESIGN



ARCHITECTURAL DESIGN

SOCIAL CONNECTION DESIGN & USER

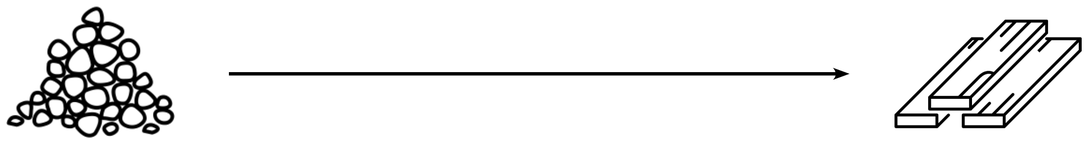


private
(closed)

design

public
(open)

CONNECTION DESIGN & STAKEHOLDER

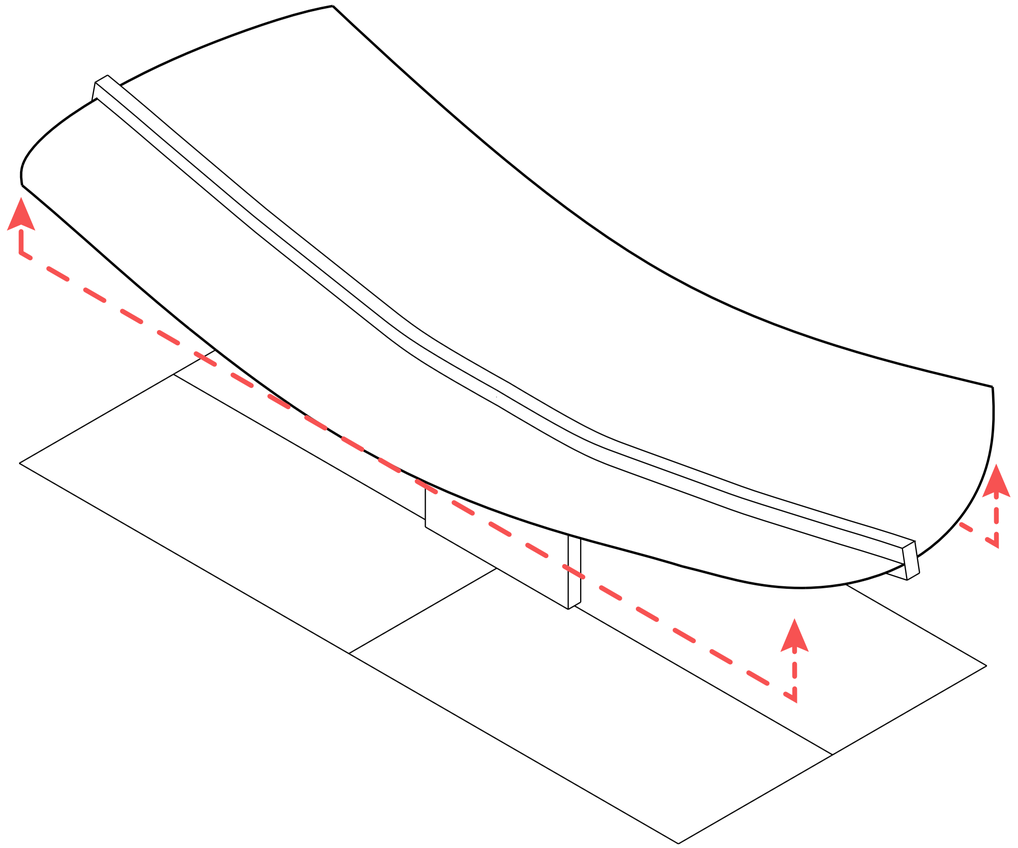


concrete
(unsustainable)

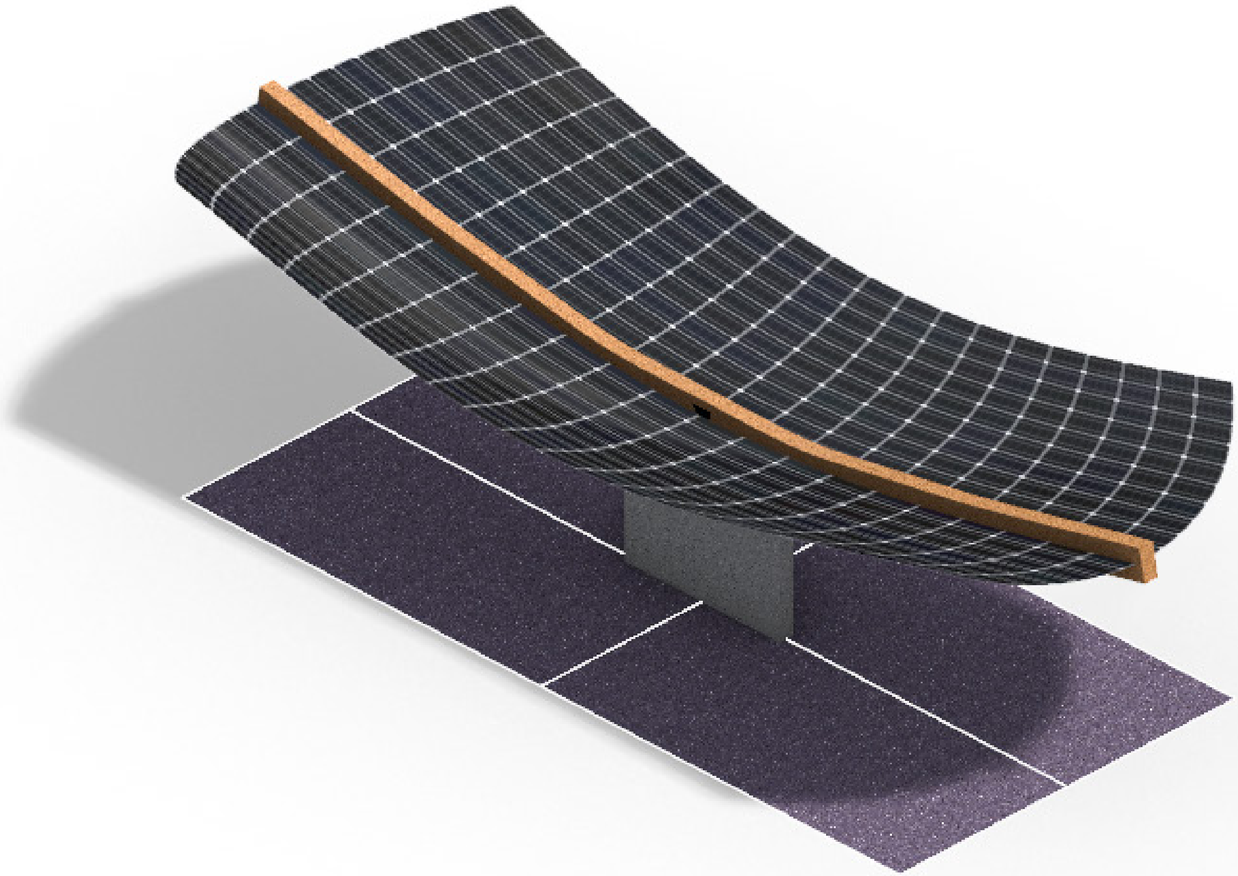
wood
(sustainable)

ARCHITECTURAL DESIGN

social connection design & user



ARCHITECTURAL DESIGN



SUSTAINABLE DESIGN

low embodied energy

additional function

SUSTAINABLE DESIGN

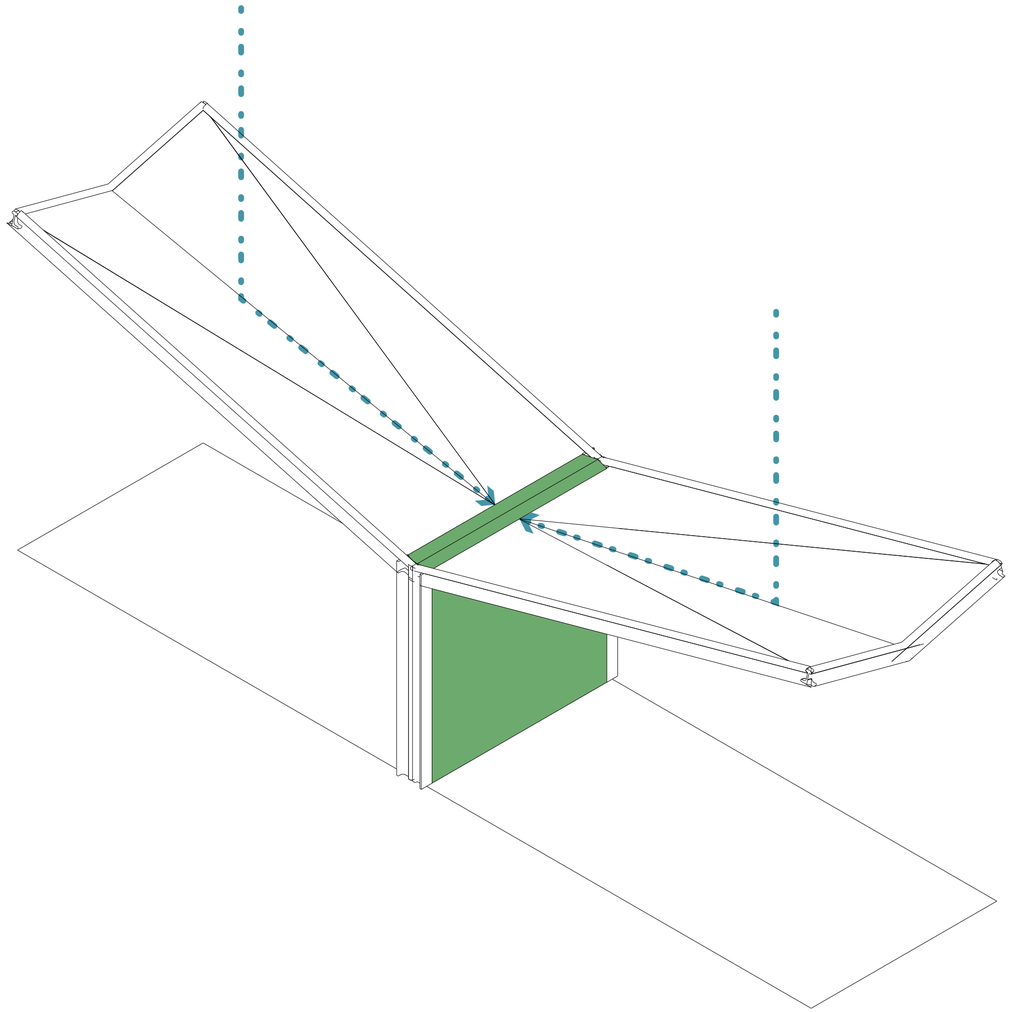
CO2

low embodied energy

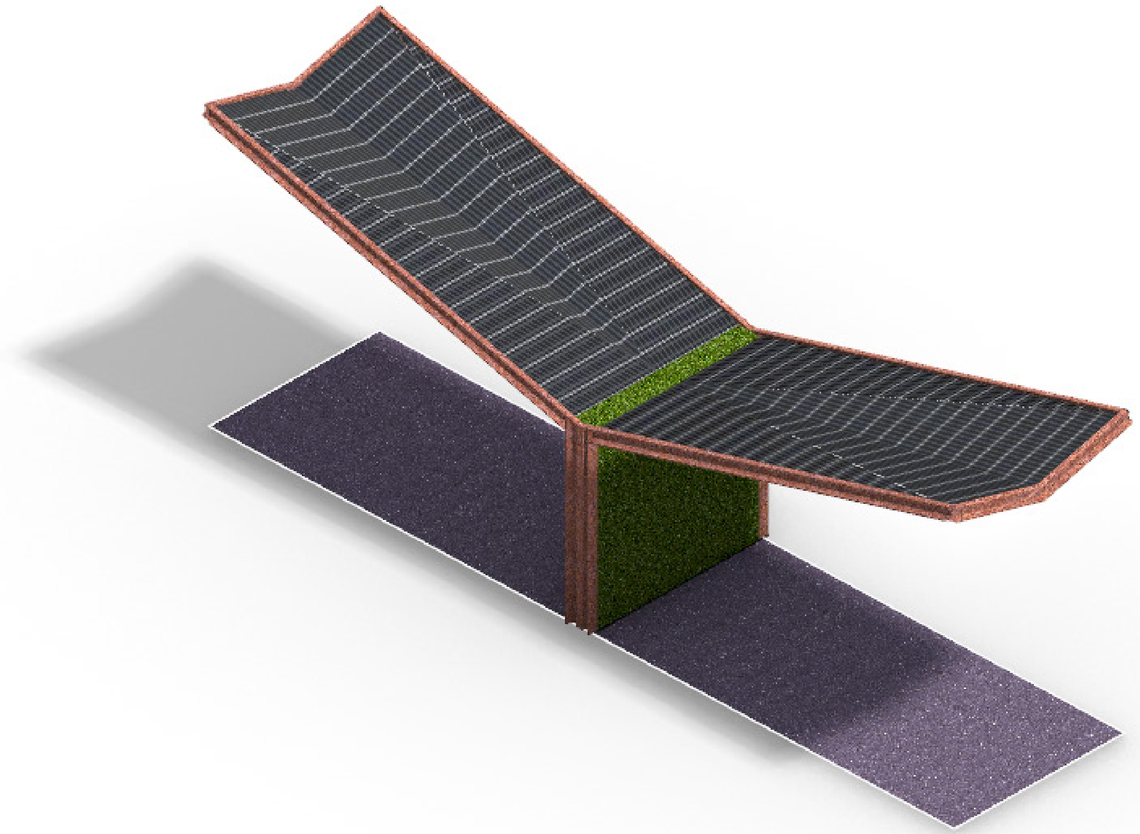
source: Jeroen Mens

SUSTAINABLE DESIGN

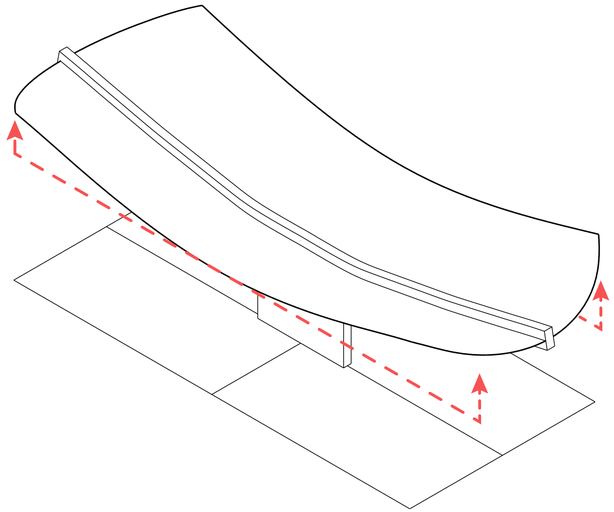
additional
function



SUSTAINABLE DESIGN



DESIGN DECISION



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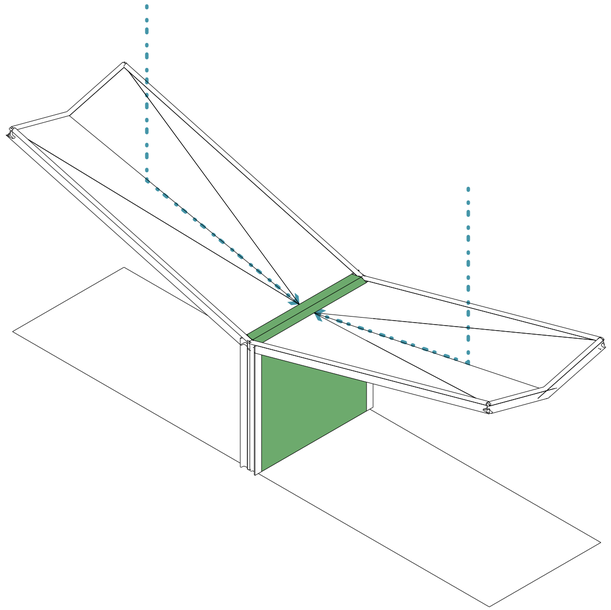
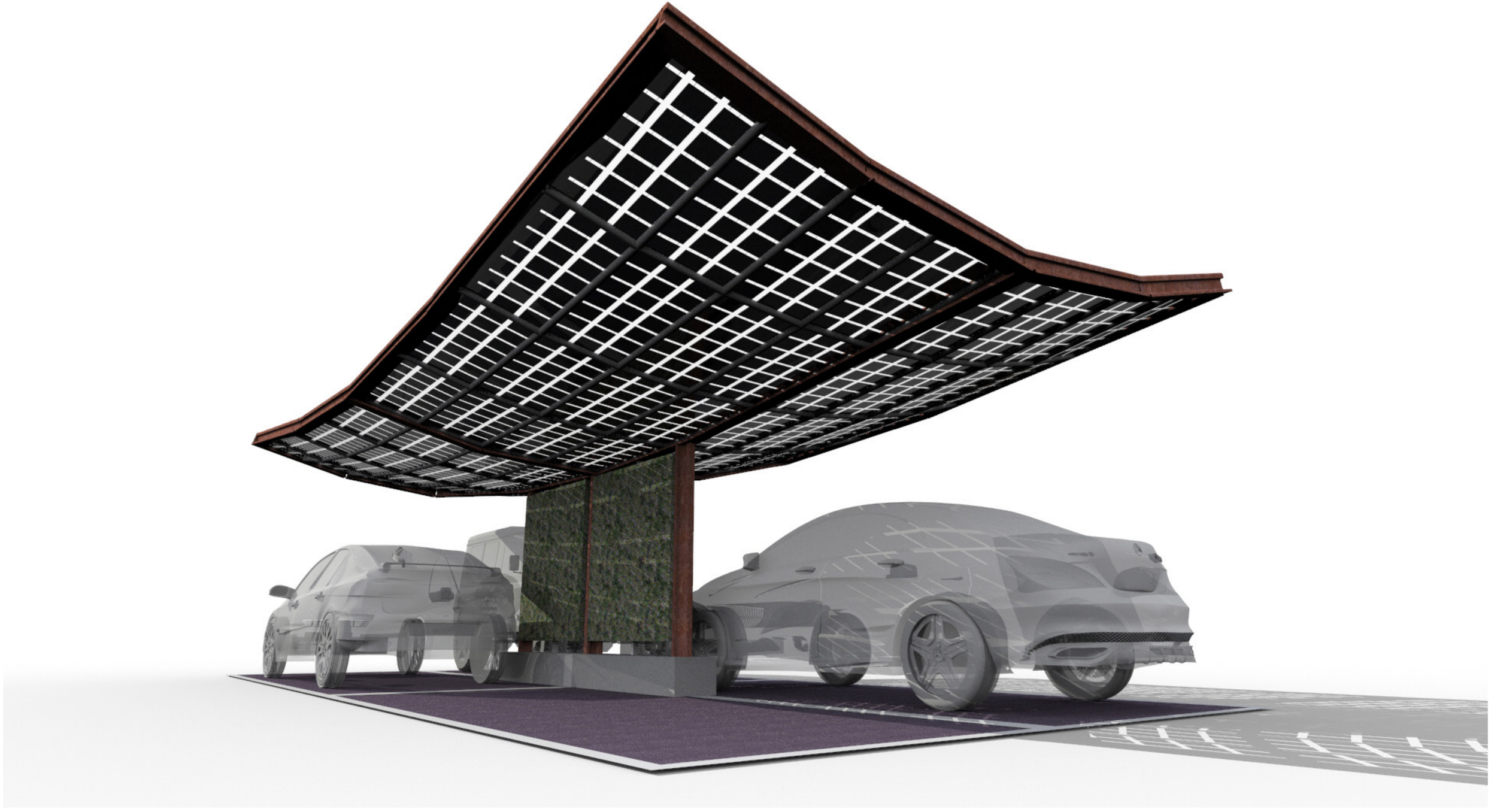
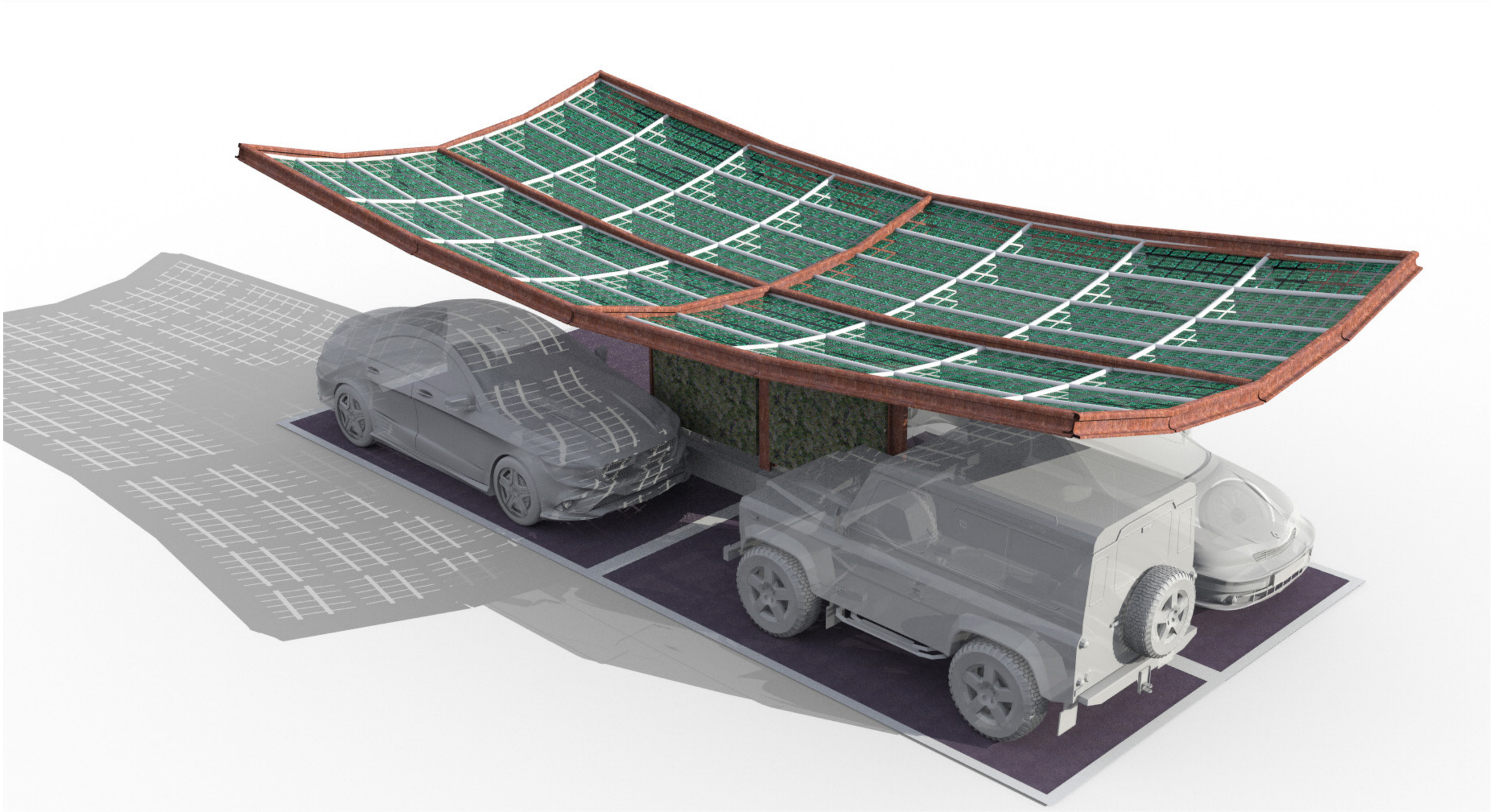


DESIGN PHASE

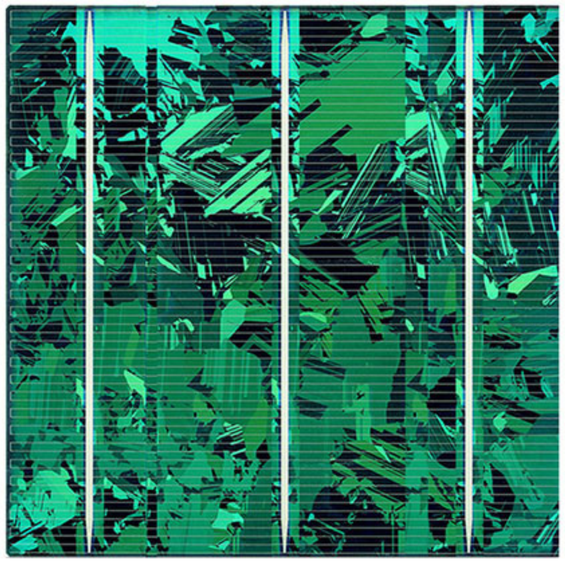




SOLAR CELL TECHNOLOGY

- MCA method: AHP
- Poly crystalline silicon

Emerald Green



source: Kameleon solar

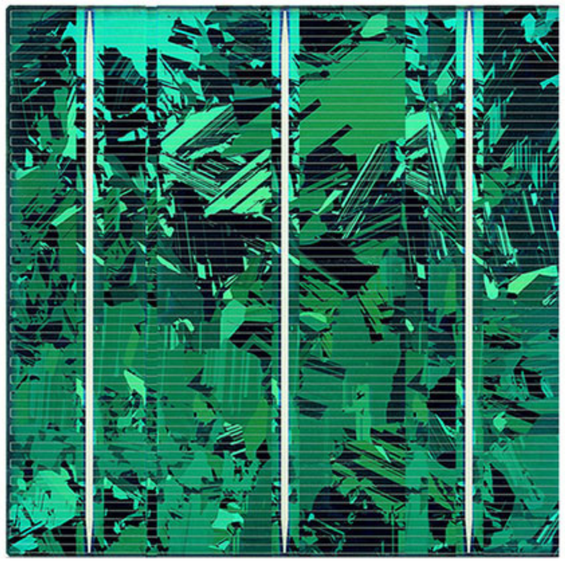
SOLAR CELL TECHNOLOGY

efficiency

recyclability

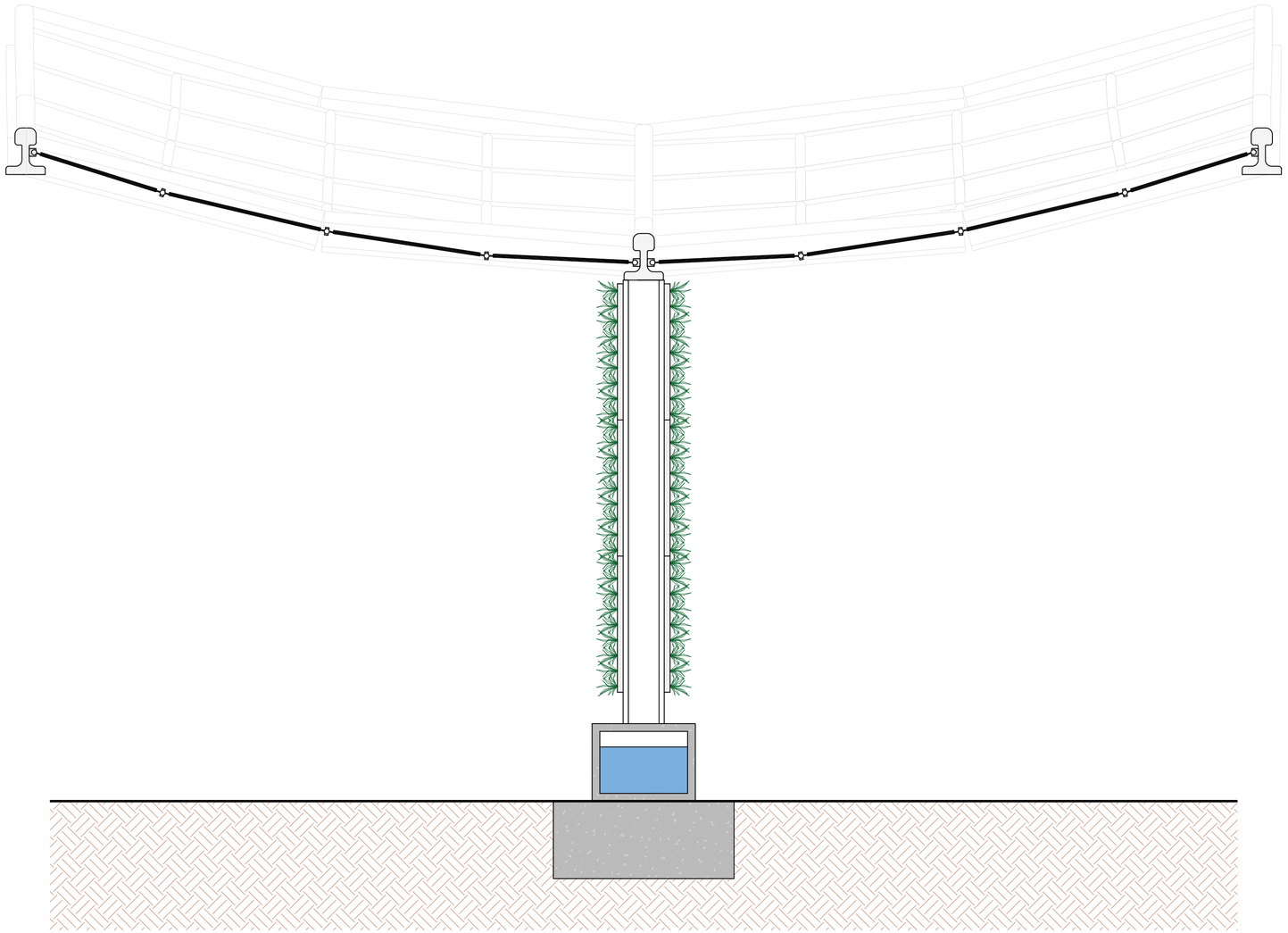
energy payback time

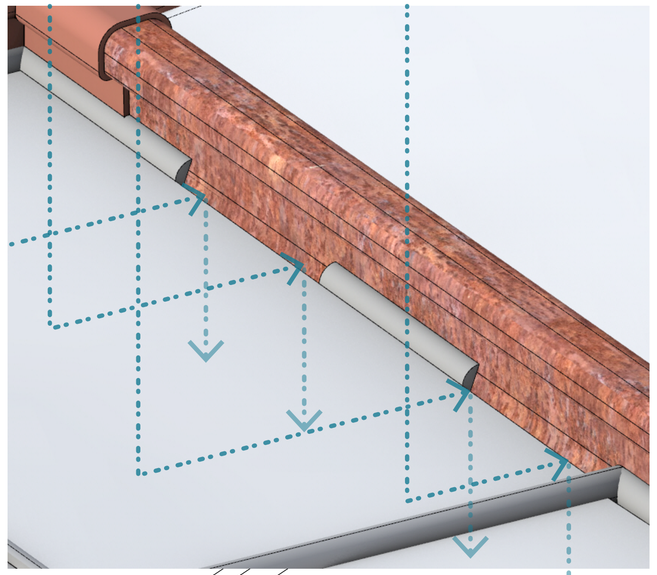
Emerald Green

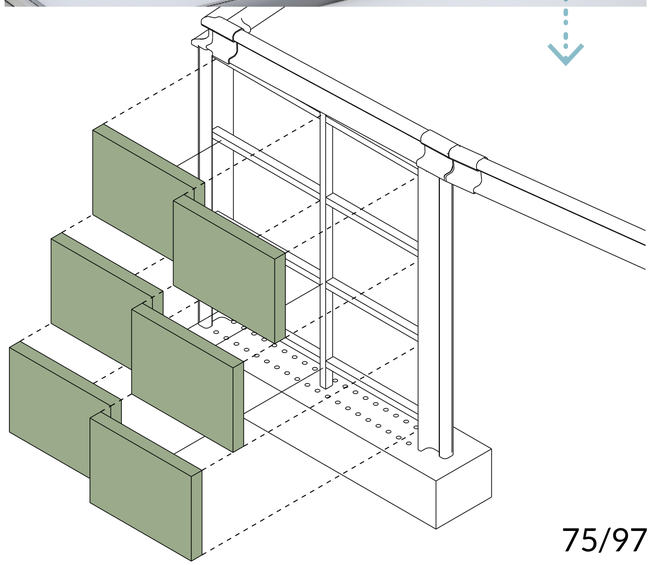


source: Kameleon solar

GREEN WALL







PLANTS

Bacopa perennial
requires: direct sunlight

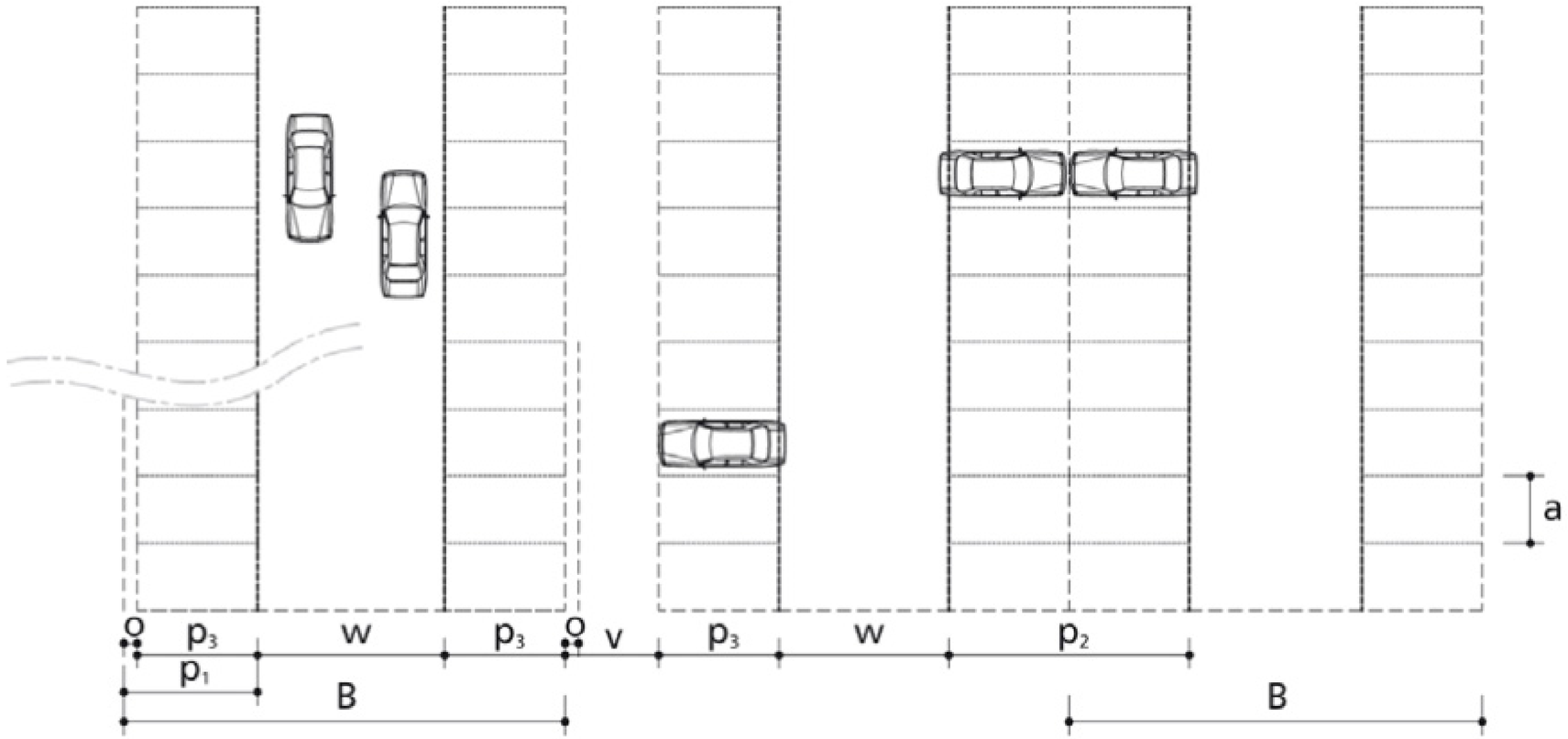
Heuchera perennial
requires: shade

source:
bacopa: Nature & Garden
heuchera :Bluestone perennials

GREEN WALL DESIGN

source: WorkDesign

MODULARITY

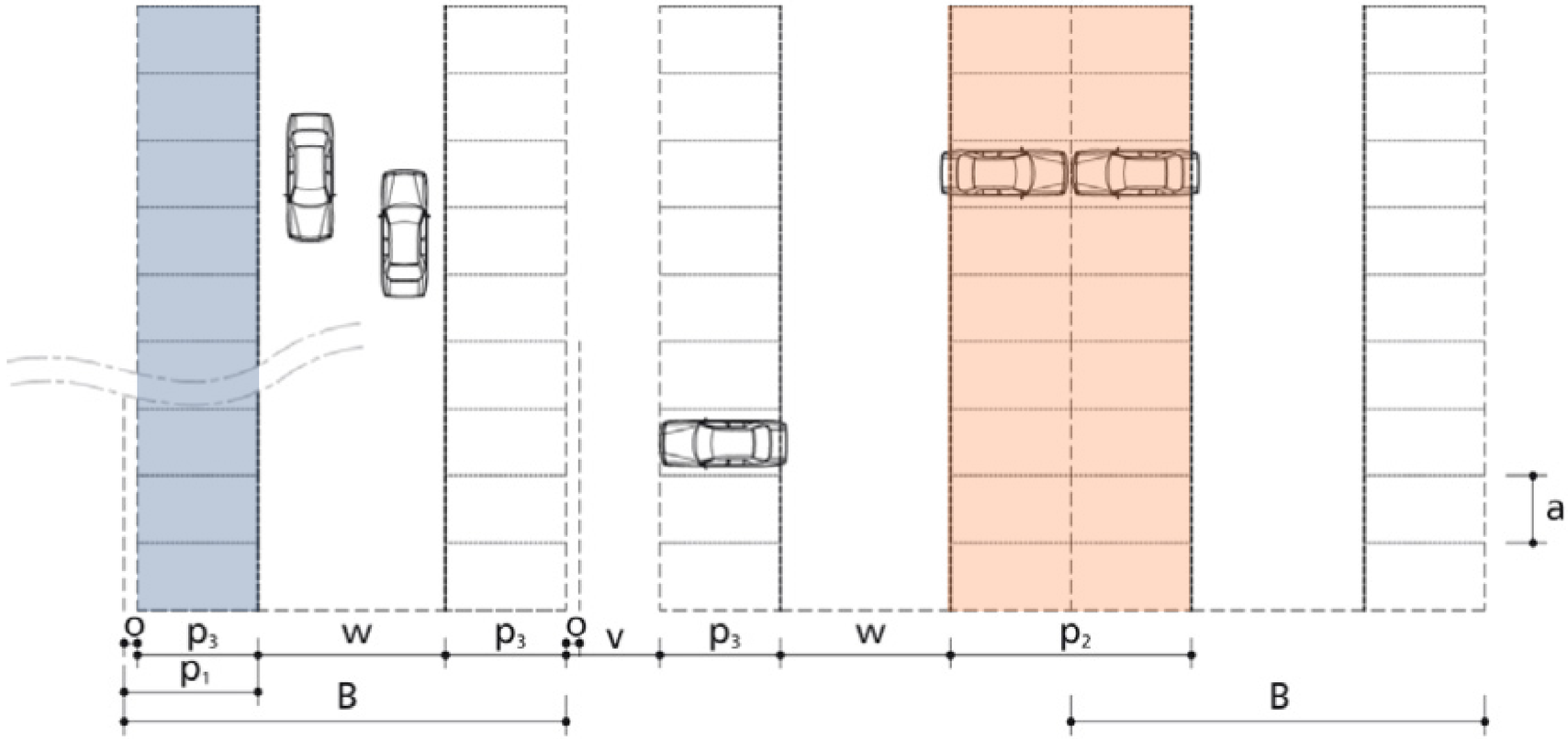


source: NS

MODULARITY

single row configuration

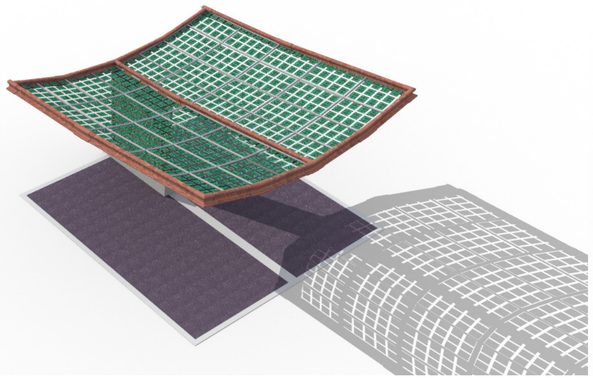
double row configuration



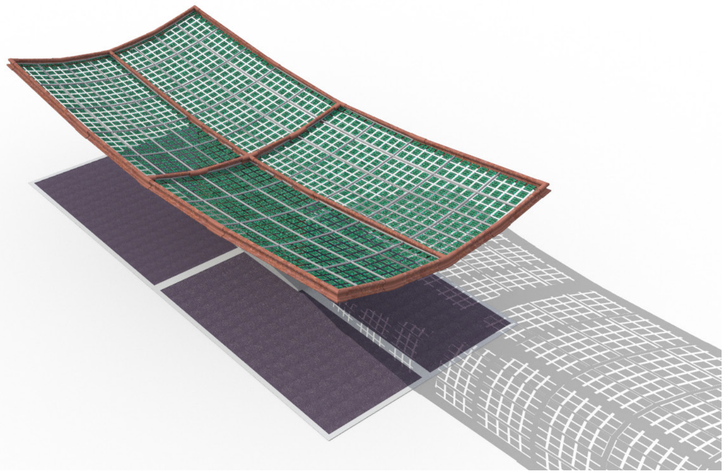
source: NS

MODULARITY

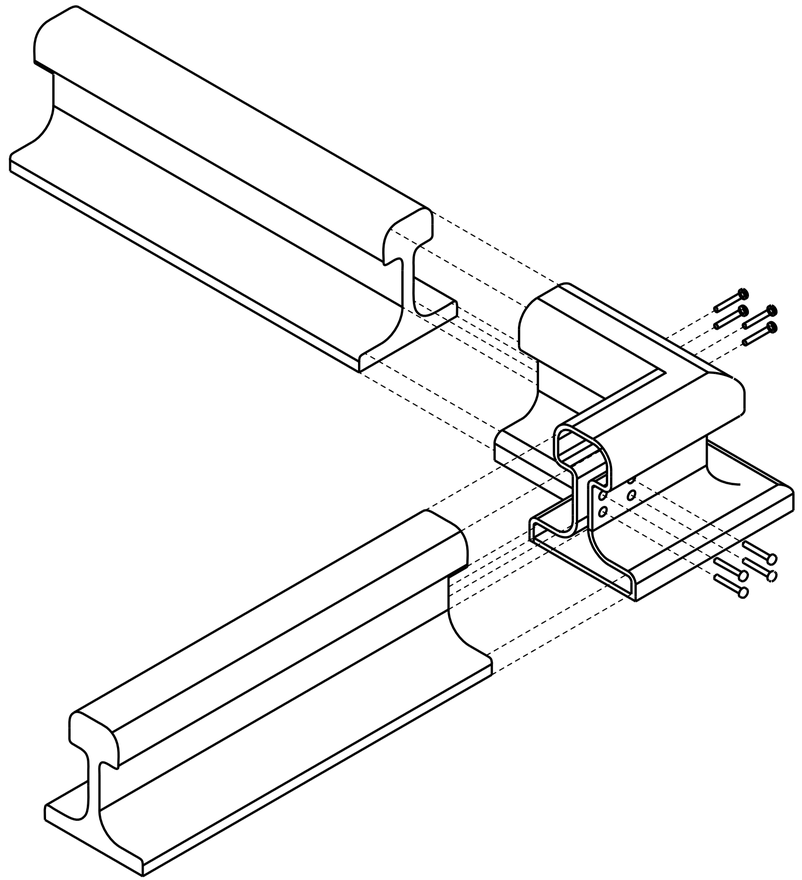
single row configuration



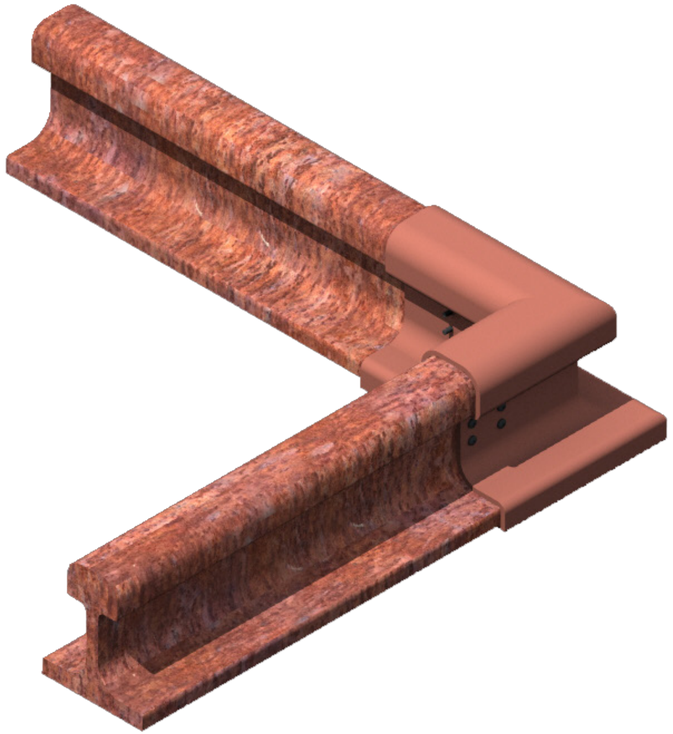
double row configuration

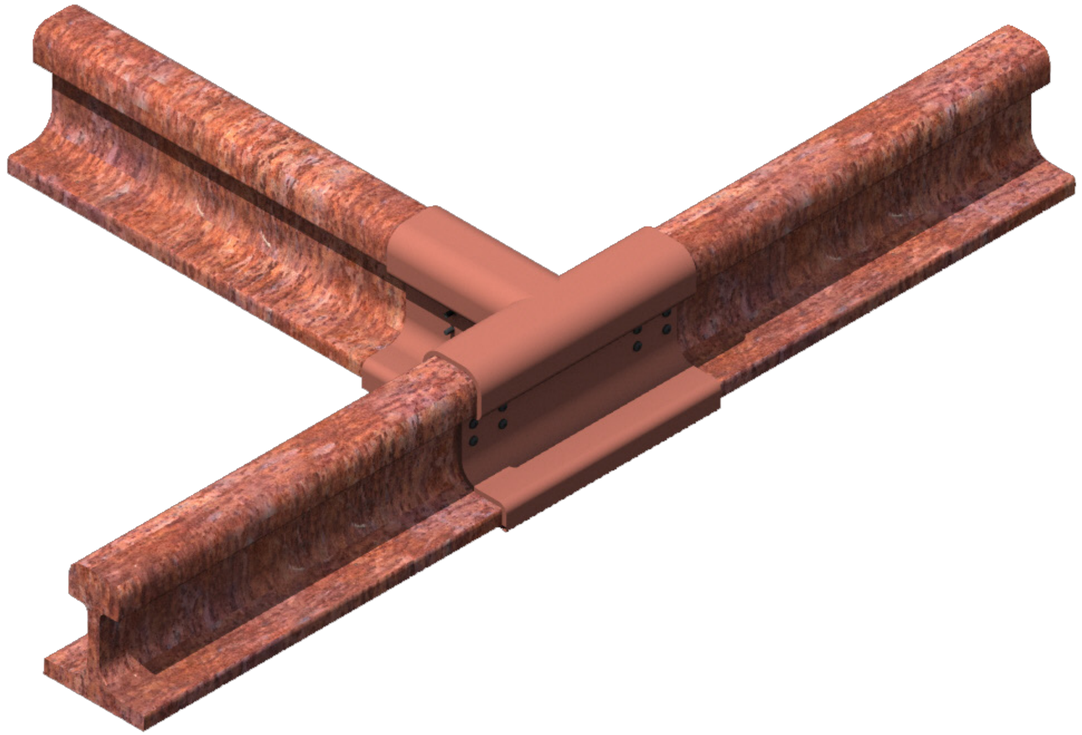


CONNECTION RAILTRACKS



CONNECTION RAILTRACKS



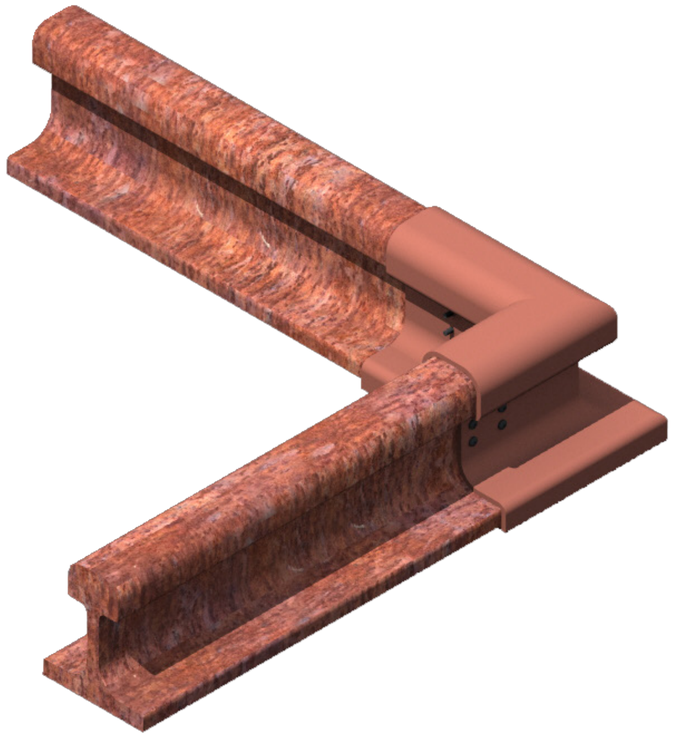


COMPLICATION CONNECTION

E Youngs modulus

Makeability

Obstructing PV connection

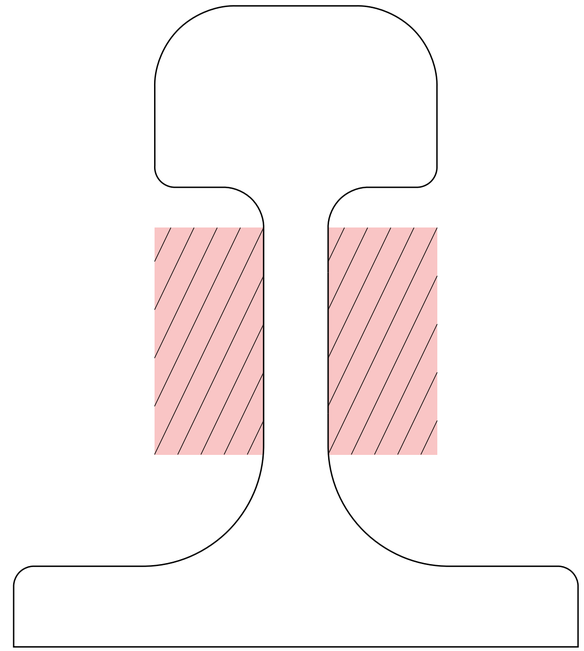


CONNECTION RAILTRACKS

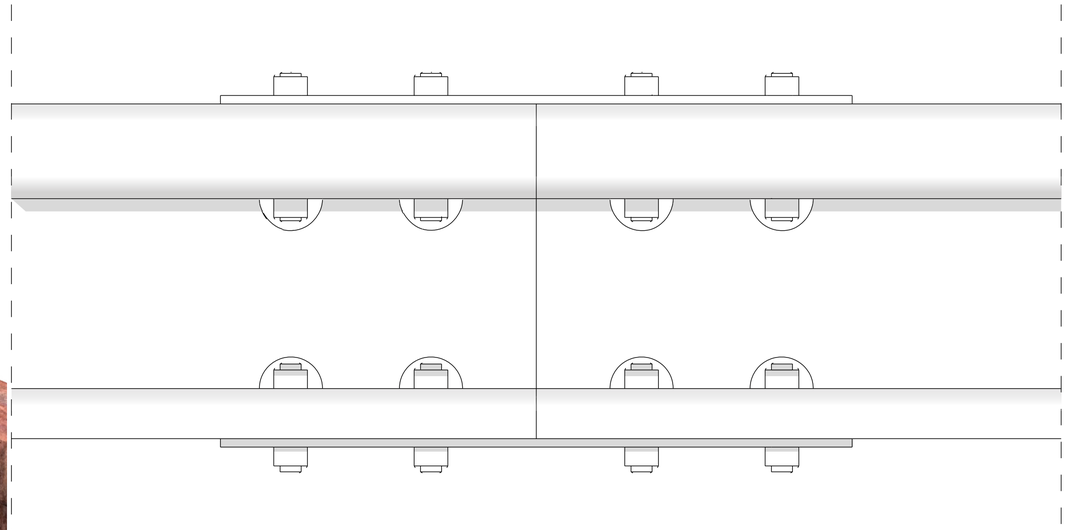
E Youngs modulus

Makeability

Obstructing PV connection

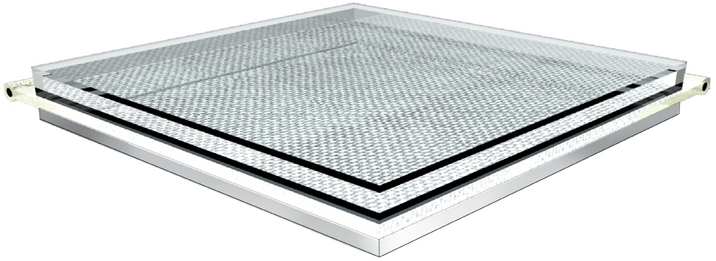


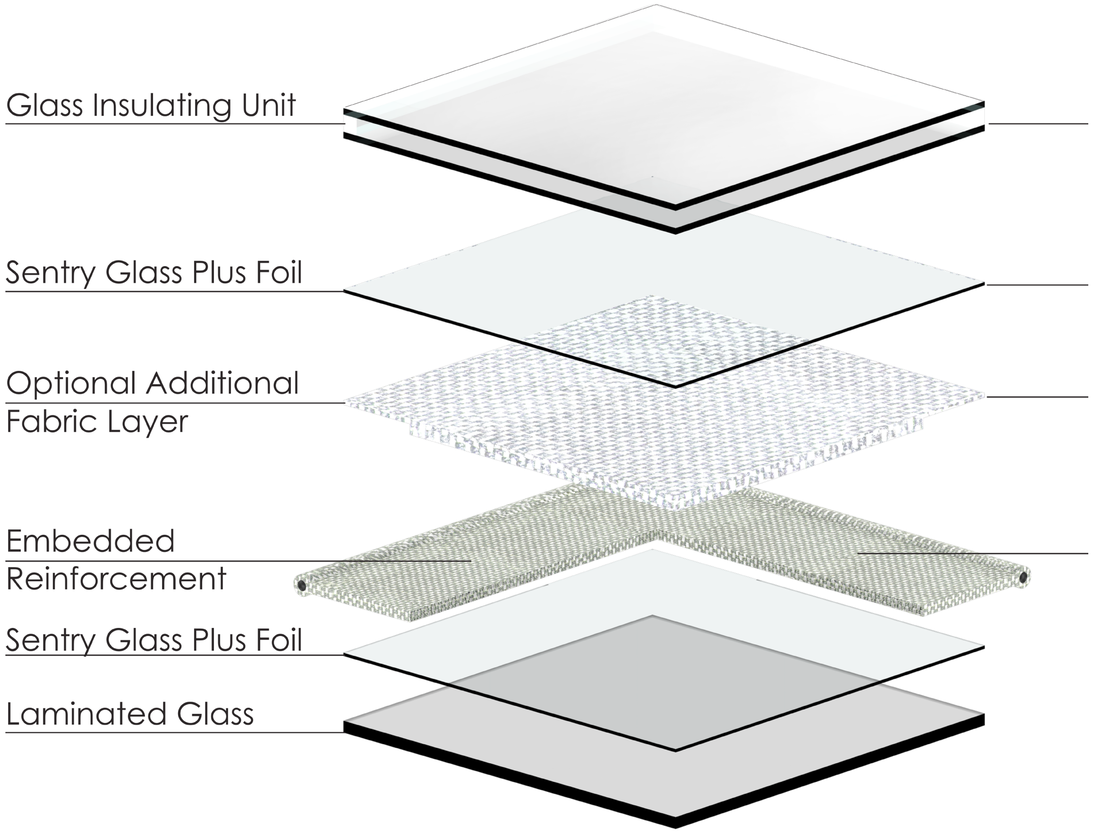
CONNECTION RAILTRACKS



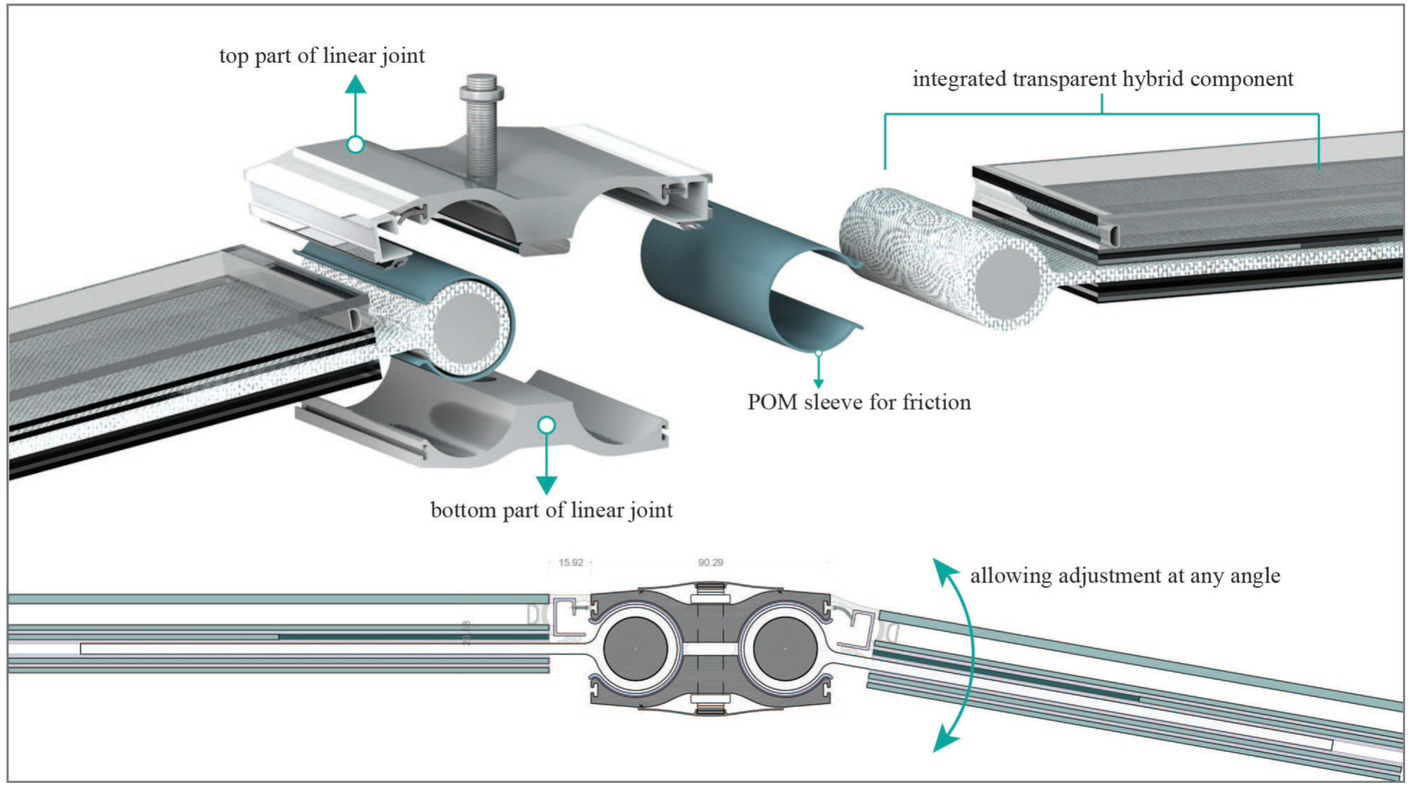
CONNECTION SOLAR PANELS

SECTION OF THE HYBRID
TRANSPARENT COMPOSITE



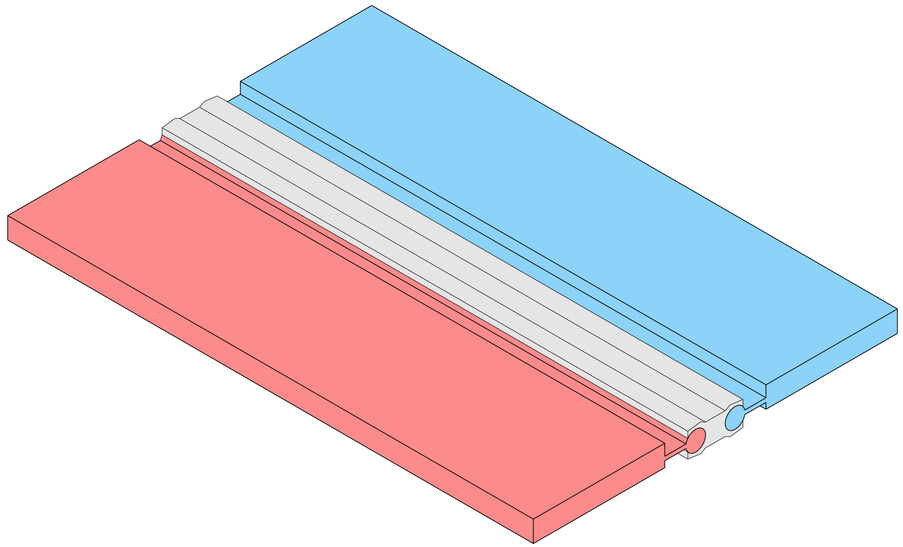


CONNECTION SOLAR PANELS

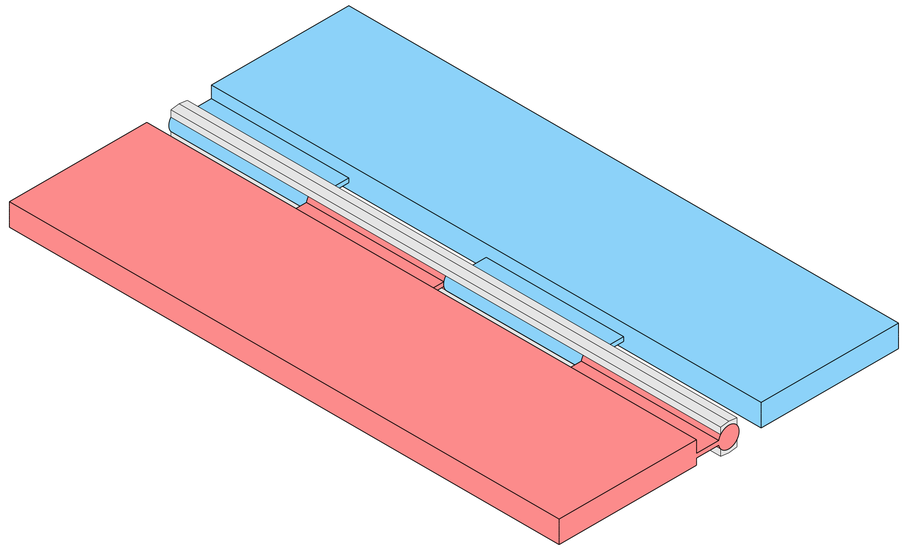


EVOLUTION CONNECTION

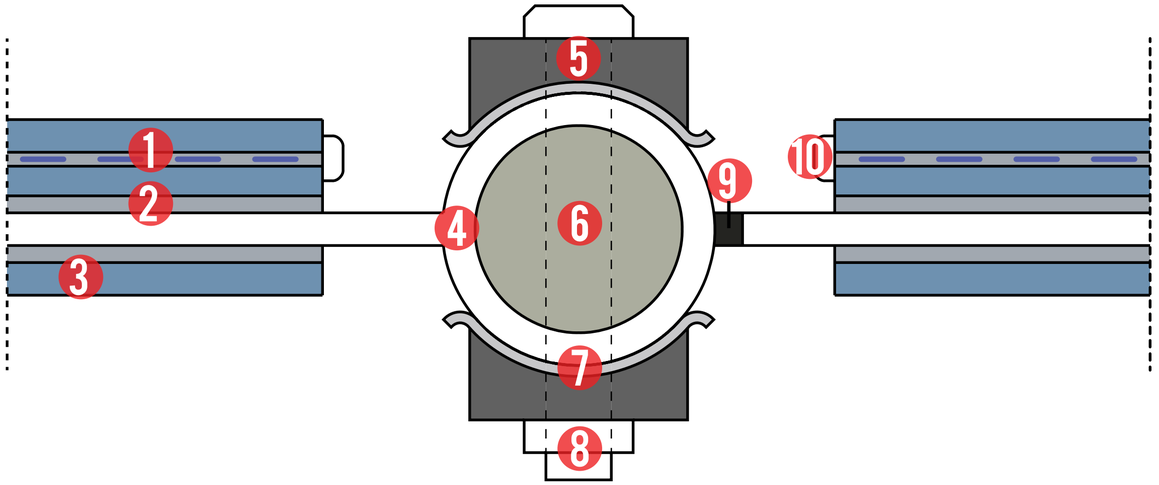
OLD



NEW



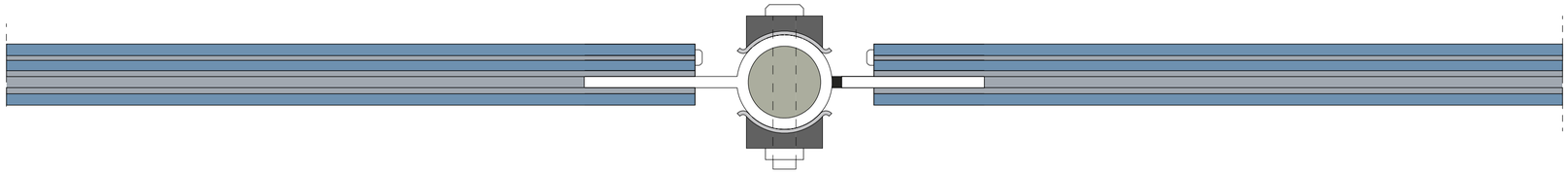
EVOLUTION CONNECTION

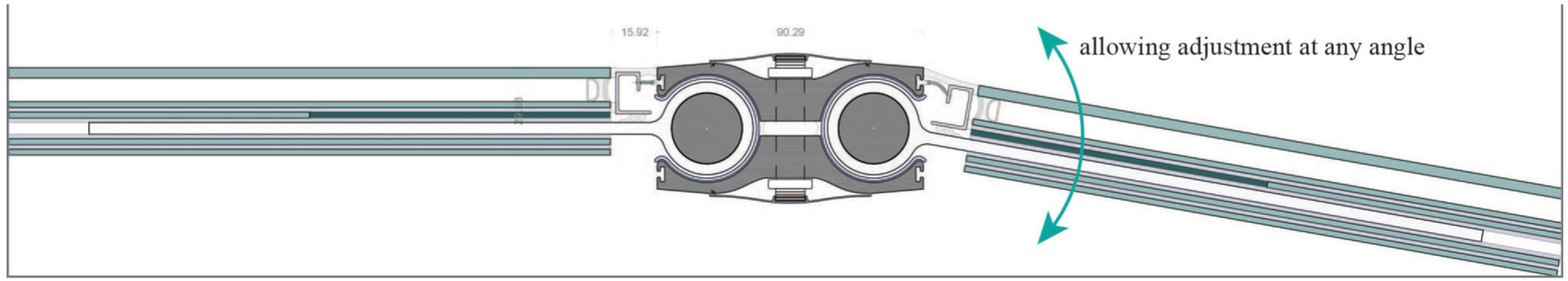


Connection detail

1. solar module, 2 x 3mm tempered glass
2. Sentry glass for lamination, 1,52mm
3. 3mm tempered glass
4. phenolic/E-fiber woven fabric composite biaxial lamina, 3mm thickness
5. 7mm steel linear contact block
6. pultruded glass fiber composite tube with 20mm diameter
7. protective sleeve made of POM coated with rubber for extra friction
8. prestressing bolt
9, sealing rubber gasket
10. junction box

EVOLUTION CONNECTION





DIGITAL DESIGN PHASE

ANALYSIS TOOLS

grasshopper

solar analysis

honeybee

ladybug

structural analysis

overall structure

Karamba 3D

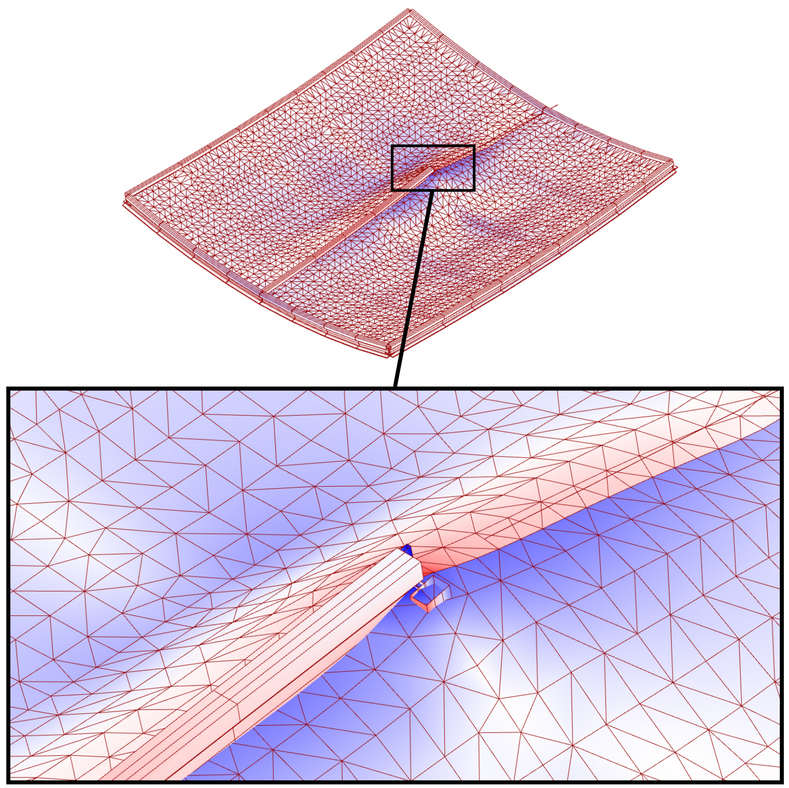
connection

Diana

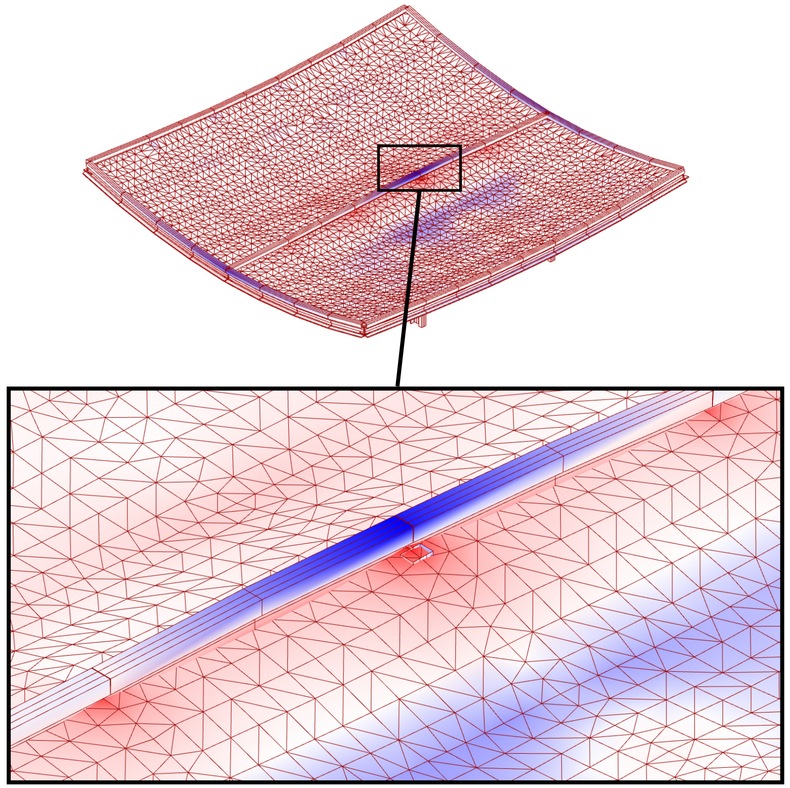
OVERALL STRUCTURE

SINGLE ROW CONFIGURATION

Max deflection: 4,67 cm
Max tensile stress: 41,8 kN/cm^2



Max deflection: 2,24 cm
Max tensile stress: 13,6 kN/cm^2

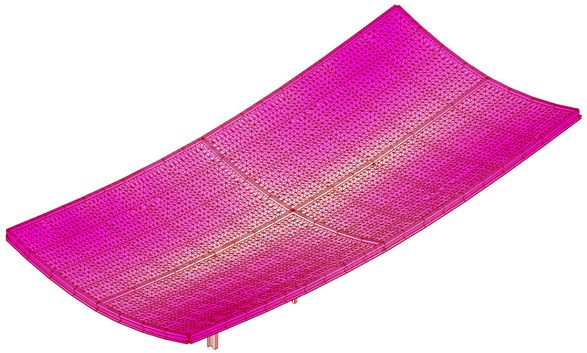


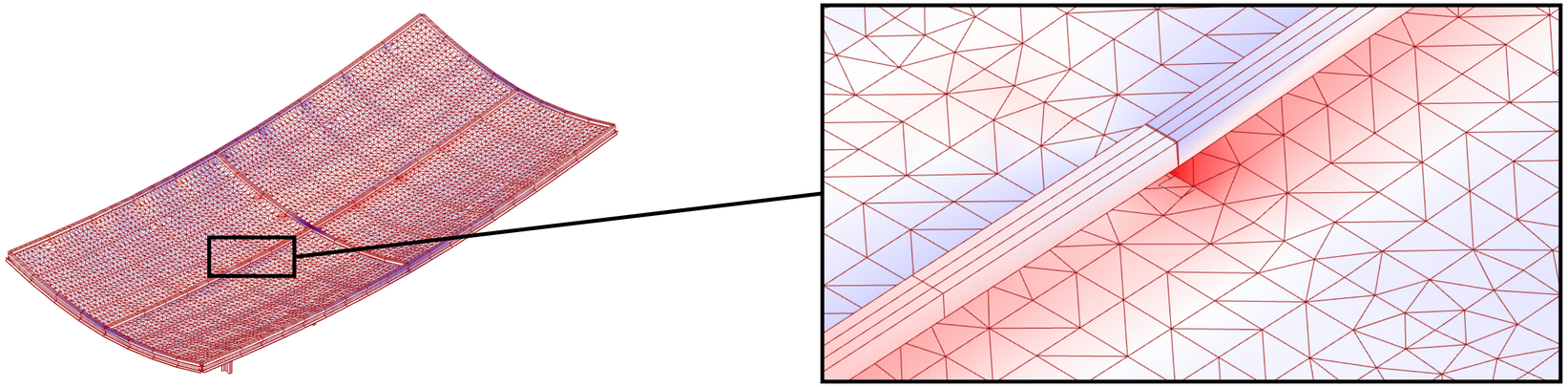
OVERALL STRUCTURE

DOUBLE ROW CONFIGURATION

Max deflection: 0,53 cm

Max tensile stress: 3,94 kN/cm²

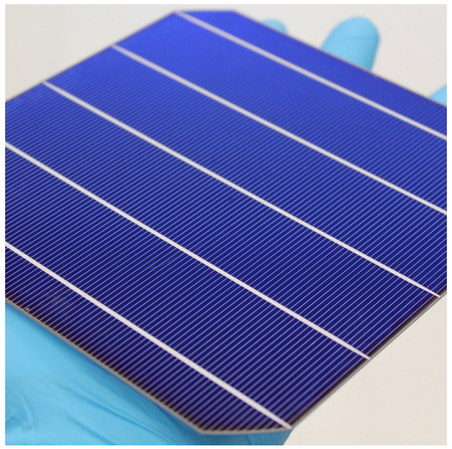




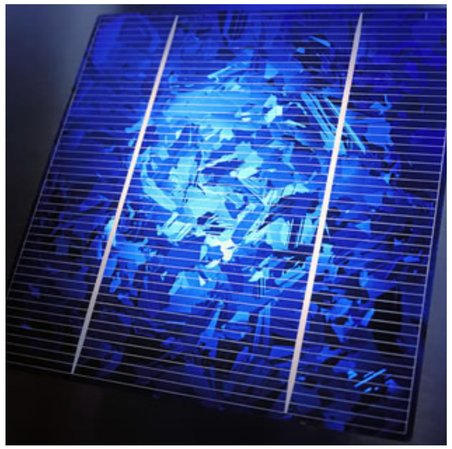
RECOMMENDATIONS NS

SOLAR CELL TECHNOLOGY

1ST Generation
Silicon wafer based



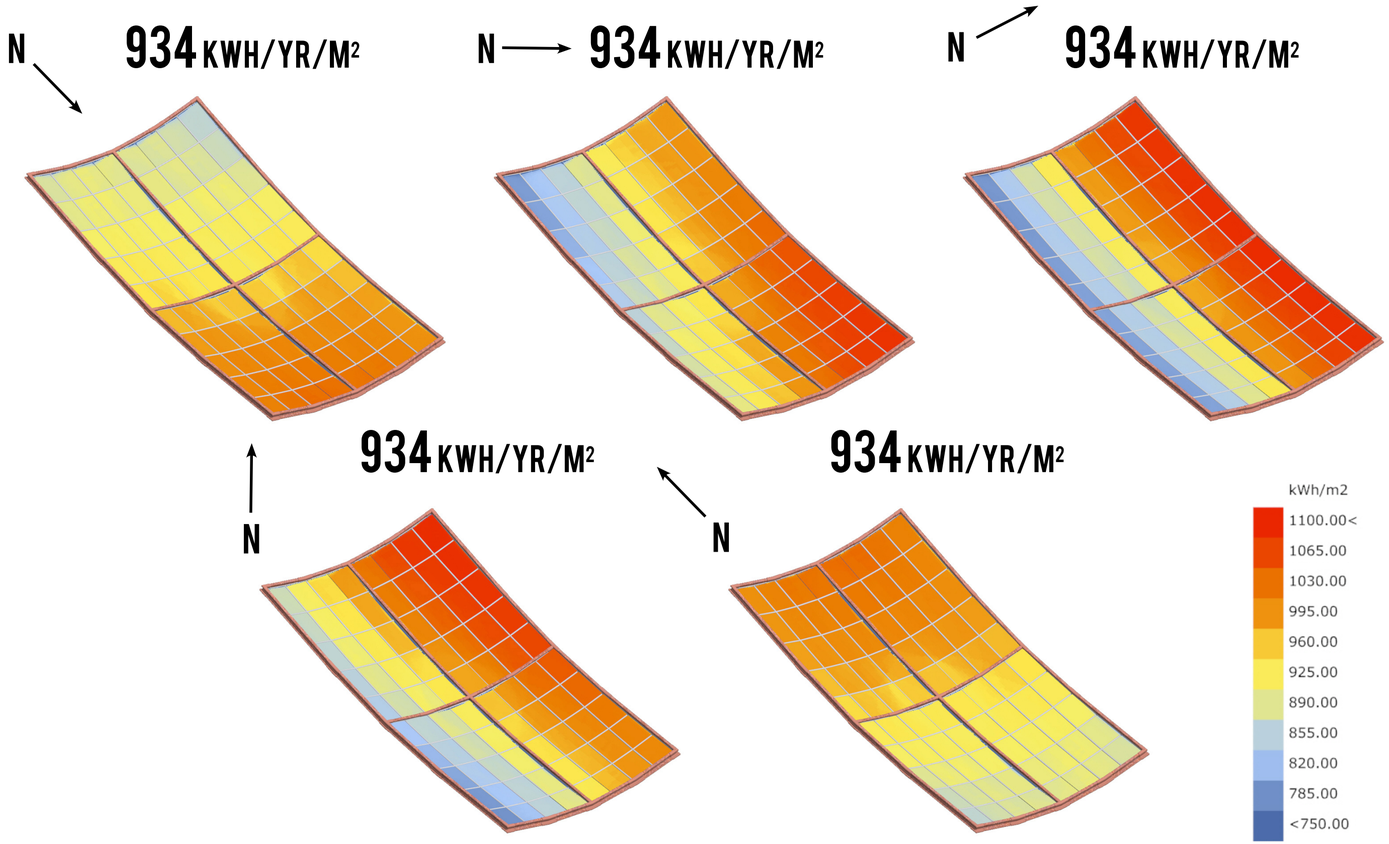
mono c-Si



poly c-Si

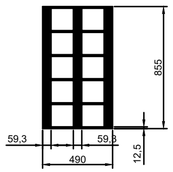
RECOMMENDATIONS NS

DESIGN

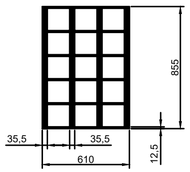


SOLAR PANEL DIMENSIONS

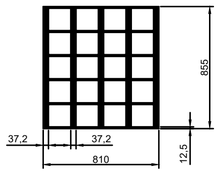
5x6 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
300 solar cells in 1 park conf.
41,9% glass



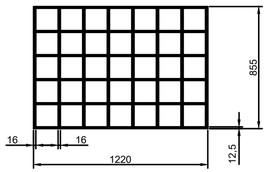
4x6 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
360 solar cells in 1 park conf.
30,0% glass



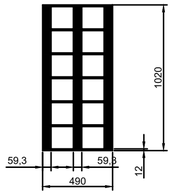
3x6 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
360 solar cells in 1 park conf.
29,7% glass



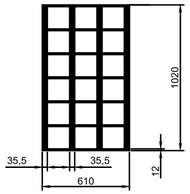
2x6 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
420 solar cells in 1 park conf.
18,3% glass



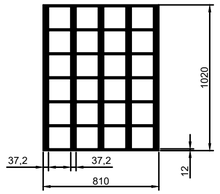
5x5 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
300 solar cells in 1 park conf.
41,6% glass



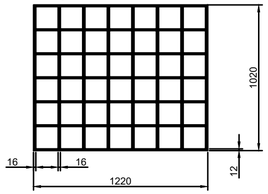
4x5 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
360 solar cells in 1 park conf.
29,5% glass



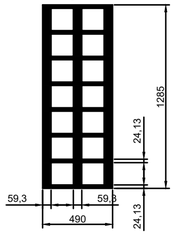
3x5 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
360 solar cells in 1 park conf.
29,3% glass



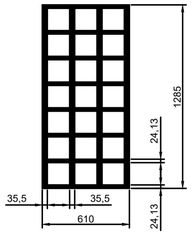
2x5 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
420 solar cells in 1 park conf.
17,8% glass



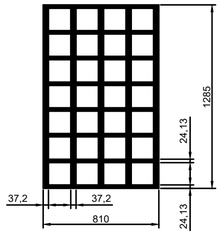
5x4 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
280 solar cells in 1 park conf.
45,9% glass



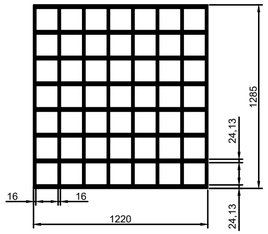
4x4 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
336 solar cells in 1 park conf.
34,8% glass



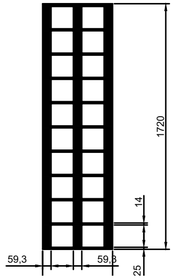
3x4 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
336 solar cells in 1 park conf.
34,5% glass



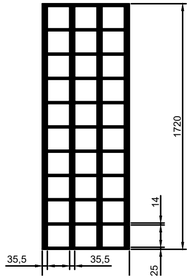
2x4 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
392 solar cells in 1 park conf.
23,9% glass



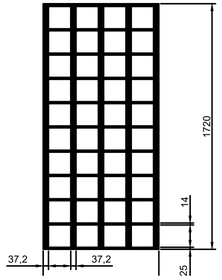
5x3 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
300 solar cells in 1 park conf.
42,4% glass



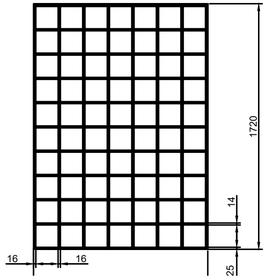
4x3 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
360 solar cells in 1 park conf.
30,4% glass



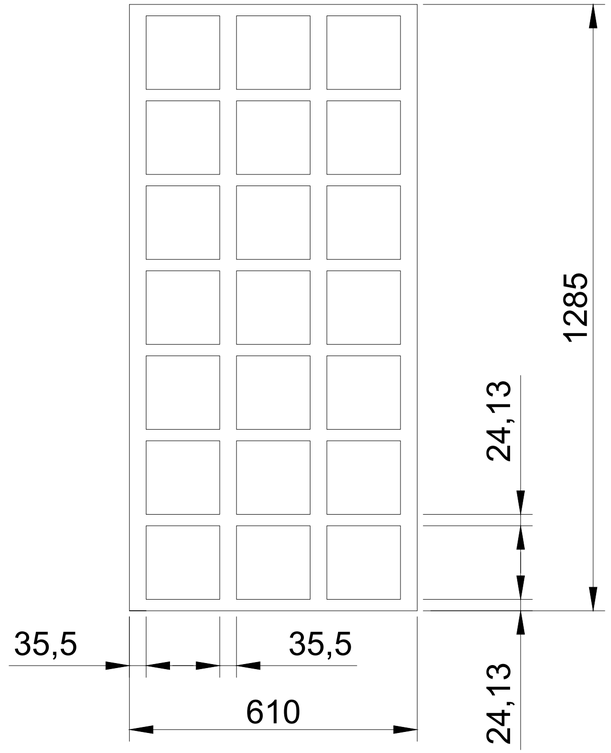
3x3 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
360 solar cells in 1 park conf.
30,1% glass



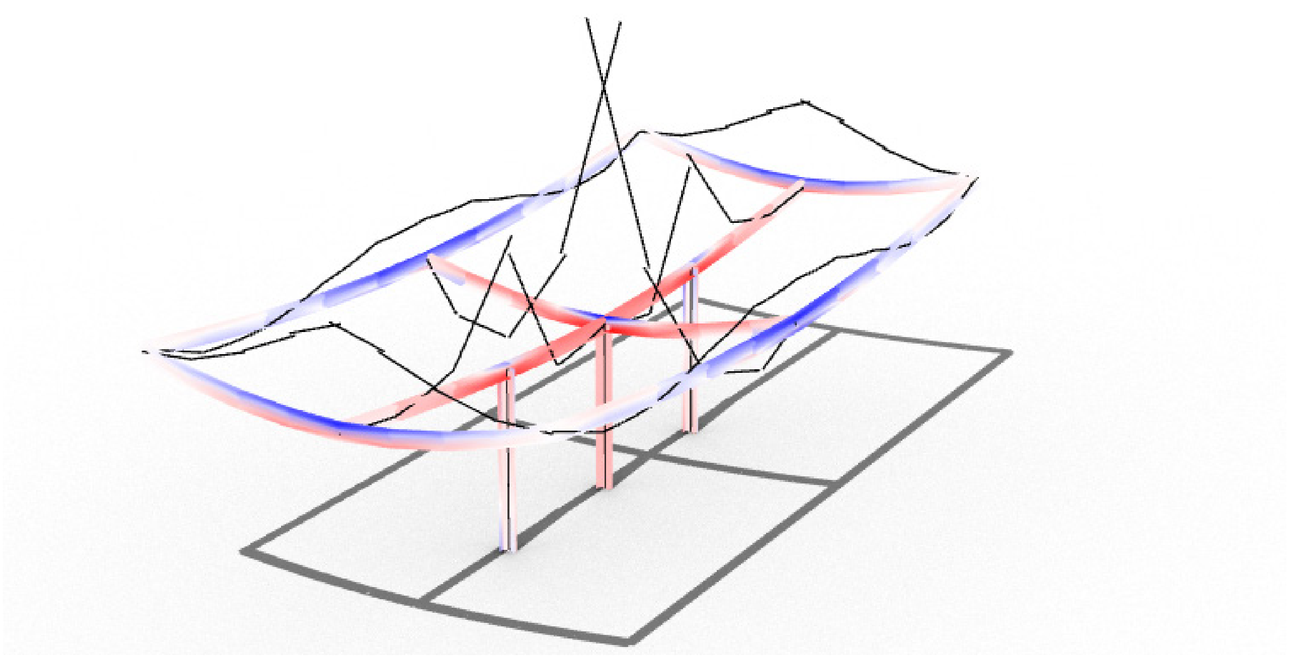
2x3 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
420 solar cells in 1 park conf.
18,8% glass

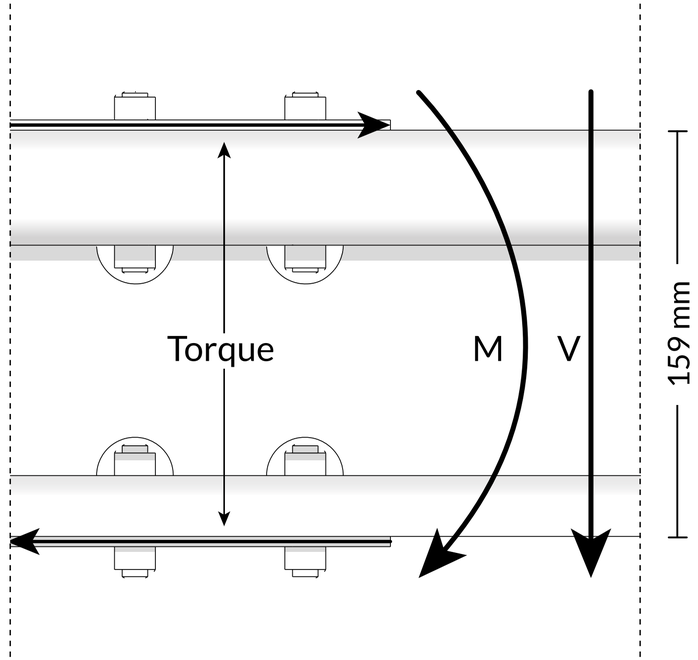


4x4 (W x L) of solar modules
In 1 parking spot conf.
Max. amount of solar cells
336 solar cells in 1 park conf.
34,8% glass



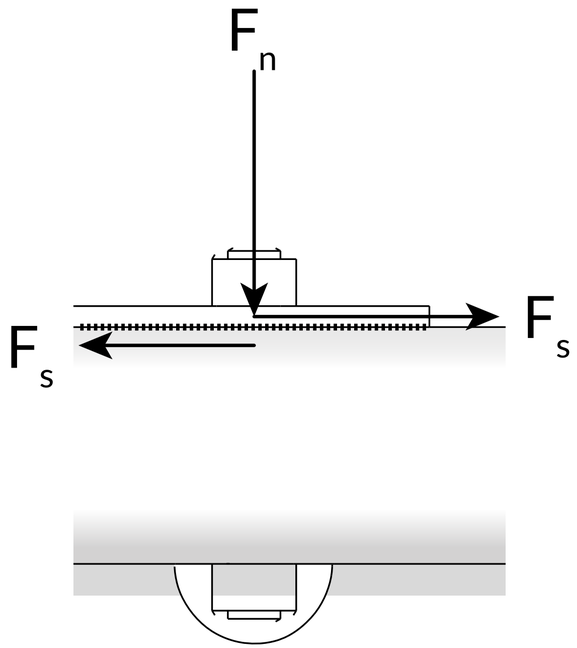
CALCULATIONS CONNECTION



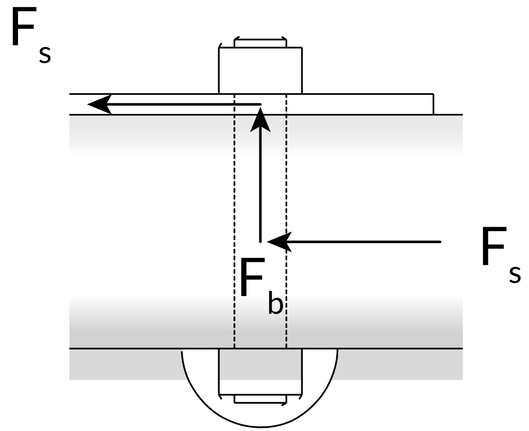


CALCULATIONS CONNECTION

Friction



Shear force



CALCULATIONS CONNECTION

Number of bolts (n)=	4
Vz=	10,6 kN
Vzs=	5,3 kN
Torque (T)=	46,5 kN
Force per bolt (F)=	(Vzs + T) / n
	12,96 kN
Strength bolts (S)=	300 GPa
Area per bolts=	F/S
	43,20 mm
Diameter per bolt=	7,42 mm (M8)

Shear force