BIPV in Singapore: Challenges & Opportunities

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NATIONAL RESEARCH FOUNDATION
PRIME MINISTER'S OFFICE
SINGAPORE

ENERGY MARKET AUTHORITY
Our Clean Energy Future

EDB SINGAPORE

SERIS is a research institute at the National University of Singapore (NUS). SERIS is supported by NUS, the National Research Foundation Singapore (NRF), the Energy Market Authority of Singapore (EMA) and the Singapore Economic Development Board (EDB).

SERIS

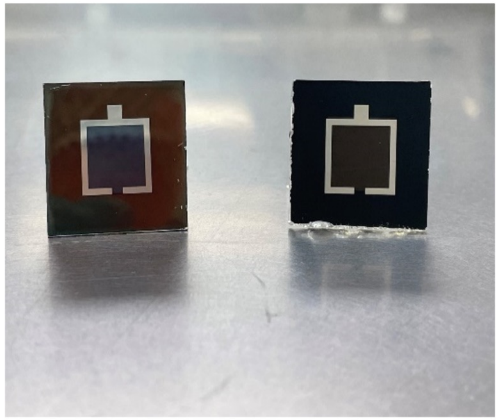
Solar Energy Research Institute of Singapore

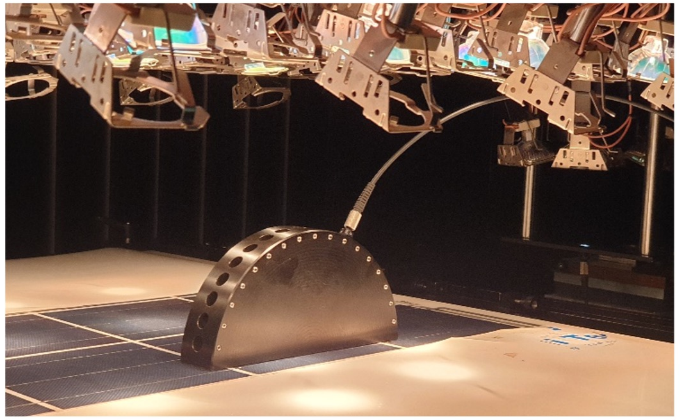
- ❑ National Lab founded at NUS in 2008; a global leader in solar research & development
- ❑ SERIS is supported by NUS, NRF, EMA & EDB
- ❑ Focuses on applied solar energy research (solar cells, PV modules, PV systems)
- ❑ > 110 staff, adjuncts & PhD students; state-of-the-art labs, ISO certified (9001, 17025)
- ❑ Close collaborations with companies & government agencies

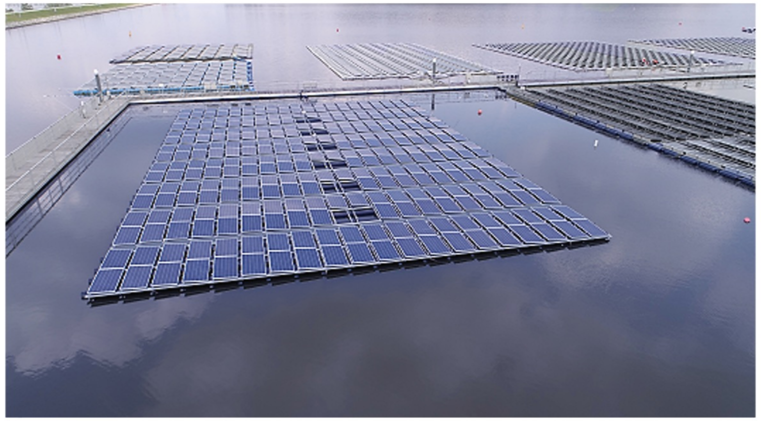

SERIS' main R&D facilities at NUS


SERIS' off-campus facility at CleanTech One

Main R&D areas of SERIS







Solar cells:

- ❑ Perovskite/silicon tandem solar cells
- ❑ Next-generation industrial solar cells
- ❑ Characterisation & simulation

PV modules:

- ❑ Module testing (indoor & outdoor)
- ❑ Module development
- ❑ **Building-integrated PV (BIPV)**
- ❑ Characterisation of optical properties
- ❑ Module reliability
- ❑ Recycling
- ❑ PV for vehicles

Solar PV systems:

- ❑ System technologies, incl. Floating solar
- ❑ Innovative deployment concepts
- ❑ Urban Solar, incl. agrivoltaics
- ❑ PV grid integration
- ❑ Solar potential & energy meteorology (solar forecasting)
- ❑ Smart Operation & Maintenance (O&M)
- ❑ Quality assurance of PV systems
- ❑ Solarisation of Singapore

Update of the PV Roadmap for Singapore

Technical Report + one Addendum, March 2020

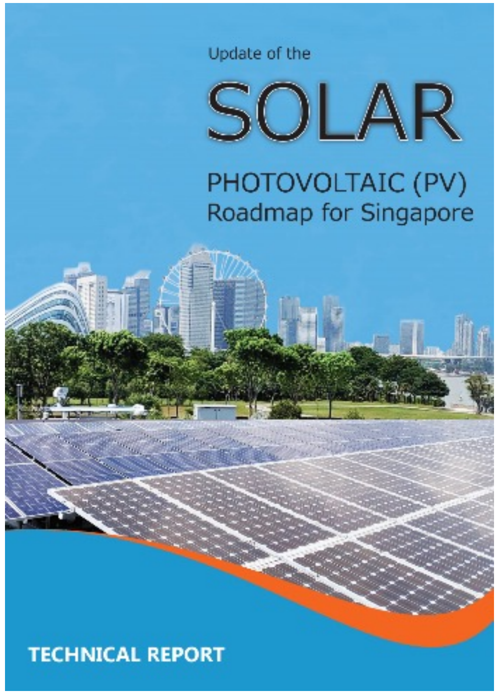
Freely available on the following websites:

SERIS
Solar Energy Research Institute of Singapore

http://www.seris.nus.edu.sg/publications/Technology_Roadmap.html

NCCS
NATIONAL CLIMATE CHANGE SECRETARIAT SINGAPORE
STRATEGY GROUP PRIME MINISTER'S OFFICE

https://www.nccs.gov.sg/media/publications/technology-roadmap



For any questions, don't hesitate to contact us:

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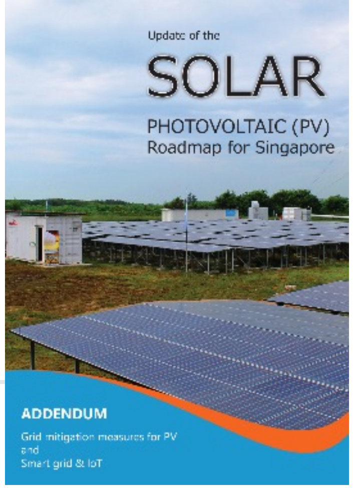


Possible areas for PV deployment in Singapore

Total available area is 36.8 km^2

Deployment type	Sub-category	Total net usable area ['000 m^2]	Remarks
Roof-top[1)]	HDB	2,225	
	Industrial	8,056	
	Commercial	1,656	
	Others	1,284	Including (amongst others): Non-HDB residential and educational institutions.
		13,221	
Facades	Retrofit[1)]	7,877	Using irradiation >750 kWh/m^2/yr; would be 56 km^2 for >500 kWh/m^2/yr
	New buildings	1,950	Until 2050, based on 100 new buildings per year
		9,827	
Mobile-/land-based PV		5,000	Conservatively using only 70% of the available land areas on Jurong Island (5 km^2), Pulau Semakau (0.85+0.85 km^2) and the main island (0.38 km^2)
		5,000	
Floating PV		4,616	Inland reservoirs and „dead sea" spaces
		4,616	
Infrastructure PV	Existing land	4,150	Potential areas for PV noise barriers and for over-building existing land, canals and roads.
		4,150	
TOTAL		**36.8k**	

1) Based on the existing building stock in 2014, and 3D model assessment.

Technical potential: ~8.6 GWp for a city state of 725 km^2 in size

Demystifying BIPV

There are commonly 3 myths, i.e., that "BIPV is…":

- *"…ineffective on the façade"*
- *"…too expensive"*
- *"…ugly"*

Myth #1…

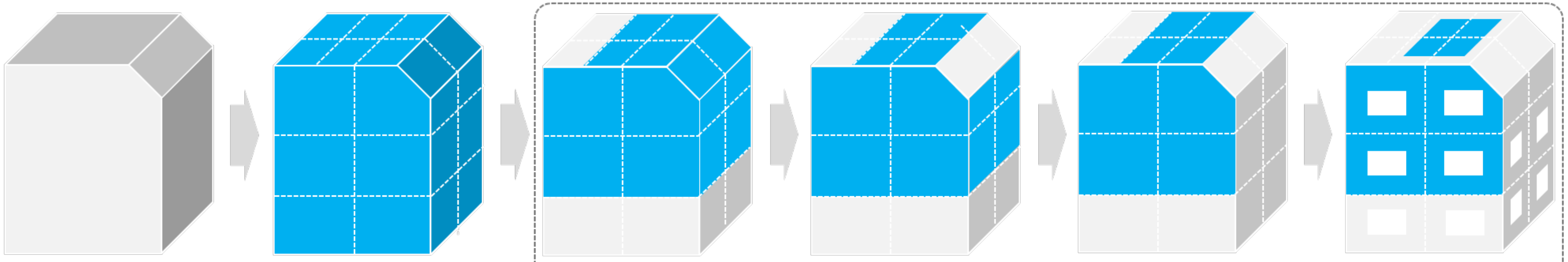
"BIPV in Singapore is…"

"… ineffective on the façade"

Answer:
Not necessarily !

“Qualified” & “usable” surfaces

Selection process for most suitable solar PV locations



3D model of the building envelope surfaces created from CityGML database

Simulating irradiance at the centre of each subdivided surface patch within context

Filter surface patches by **minimum irradiance thresholds** for roof and wall
→ **Qualified** building surfaces

Filter roof surfaces by **maximum surface tilting angle** ranges
→ **Qualified** building surfaces **suitable** for PV deployment

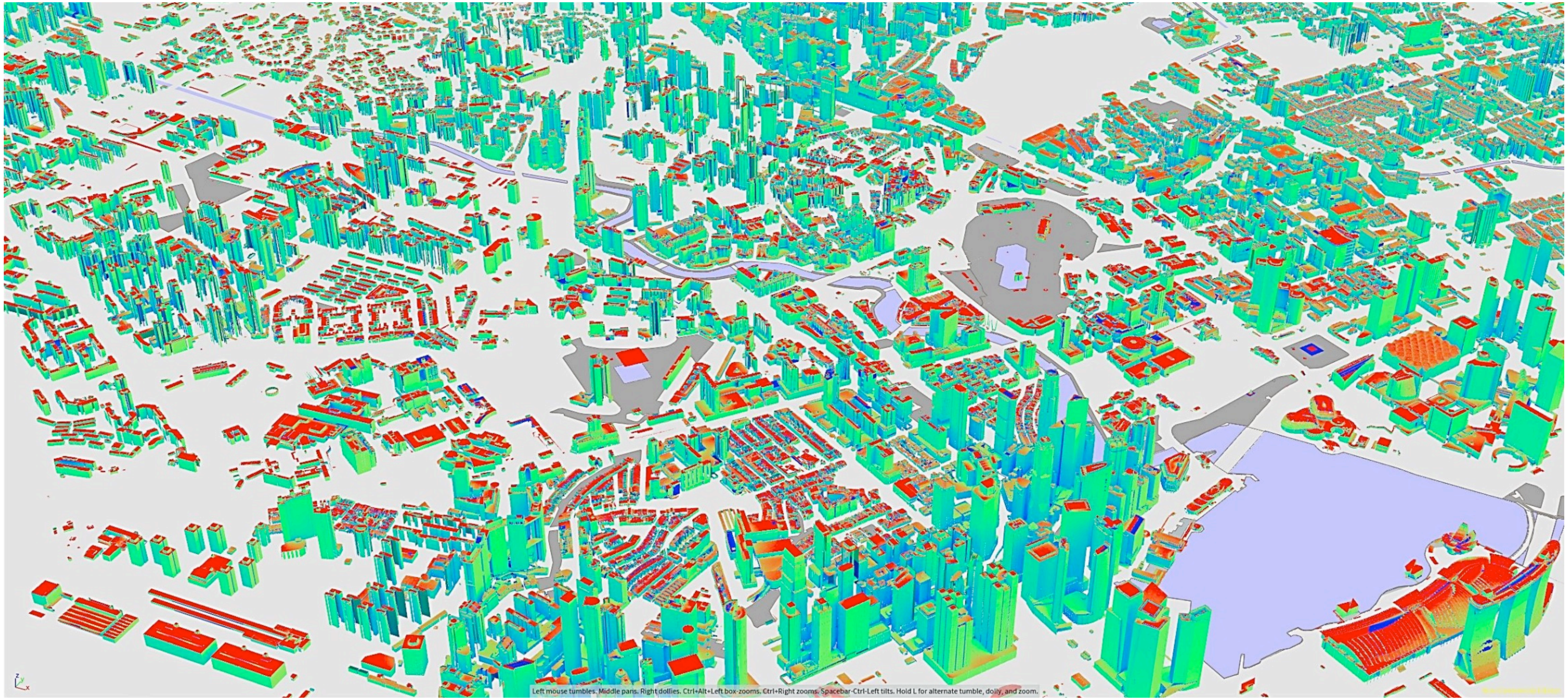
Filter surfaces by **minimum continuous surface area** ranges
→ **Qualified** building surfaces **viable** for PV deployment

Apply different surface **utilization factors** for roof and wall by building type
→ **Qualified** and **utilizable** building surfaces for PV deployment

To identify **qualified** and **usable** building surfaces which are **suitable** and **viable** for PV deployment

Solar Potential Assessment

for both rooftop and façade areas of the existing building stock in SG



Source: SERIS, SDE, SLA

Myth #2…

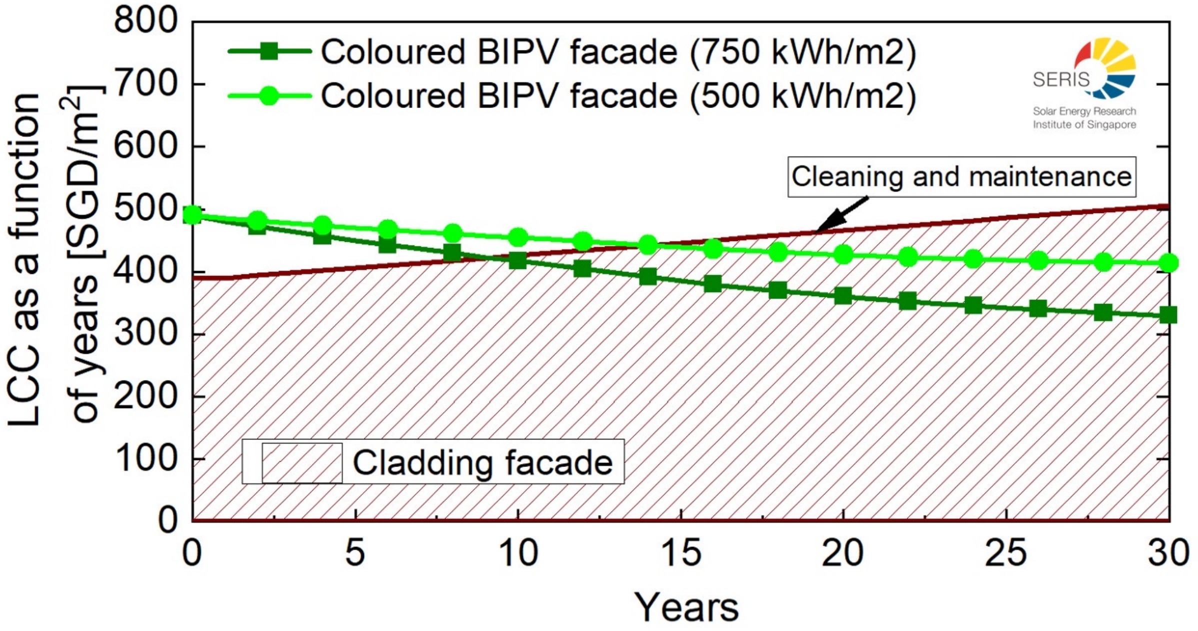
“BIPV in Singapore is…”

“… too expensive”

Answer:
Not more than other façade materials !

Lifecycle cost (LCC) of BIPV in SG

Compared to a conventional cladding facade



LCC (main calculation parameters)	Coloured BIPV facade	Traditional cladding facade
BIPV system (capex)	490 SGD/m^2	--
Cladding system (capex)	--	390 SGD/m^2
O&M for BIPV system (annually)	4 SGD/m^2	n/a
Cleaning (annually)	4 SGD/m^2	4 SGD/m^2
Base of electricity value	Contestable rate	n/a
Inflation rate	1.7% p.a.	1.7% p.a.
Performance ratio	80%	n/a
Degradation rate	0.8% p.a.	n/a

BIPV LCC Calculator

BIPV LCC Calculator

NUS National University of Singapore | SERIS Solar Energy Research Institute of Singapore

Step 1: Select available area

7 Engineering Drive 1, Block E3A, #06-01 | nsr-solar@nus.edu.sg | My Account | Register as a PV System Owner

nsr

HOME | ABOUT | PV SYSTEM @ SG | WEATHER @ SG | SOLAR INFO | CONTACT

BUILDING INTEGRATED PHOTOVOLTAICS (BIPV) LIFE-CYCLE COST (LCC) CALCULATOR

This BIPV LCC calculator is a simplified assessment tool that should enable architects and building-related professionals to make a decision about implementation of BIPV into the façades during early design stage. The calculator includes certain benefit calculations of integration of BIPV systems (i.e. electricity bill savings, and environmental implications), which are based on generalised energy efficiency assumptions, using SERIS' most-likely future price scenarios. Future electricity prices in Singapore are influenced by many factors such as: unpredictable oil prices, supply-demand characteristics, and competitor's behaviour, to name a few. Note that for contestable clients, contractual arrangements vary from case-to-case. This calculation uses a simplified average price assumption and does not account for tax implications (e.g. depreciation period is aligned to operational life). The calculator provides an indication of the LCC of a BIPV application and should not be the only basis for making an investment decision.

Disclaimer and limitation of liabilities

This calculation tool represents the professional opinions of the members of the evaluation team. The evaluation team members, the Solar Energy Research Institute of Singapore (SERIS) and the National University of Singapore (NUS), exclude any legal liability for any calculation made with this tool. In no event shall the evaluation team members, SERIS, and NUS of any tier be liable in contract, tort, strict liability, warranty or otherwise, for any special, incidental or consequential damages, such as, but not limited to, delay, disruption, loss of product, loss of anticipated profits or revenue, loss of use of the equipment or system, non-operation or increased expense of operation of other equipment or systems, cost of capital, or cost of purchase or replacement equipment systems or power.

BIPV LCC Calculator

Step 2: User inputs

Discount Rate

This should be the overall "general" financing cost for the real estate project. The BIPV façade should be treated as an integral part of the real estate investment.

5%

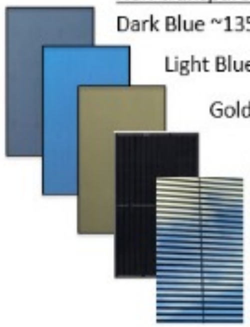
Area Factor

The area factor is dependent on the selected BIPV module power output (in Wp) and its area. The area factor can be computed by dividing the total Wp by the total area of the module.

135 W_p/m^2

Examples of BIPV area factors:

Non-transparent coloured BIPV



Dark Blue ~135 W_p/m^2

Light Blue ~135 W_p/m^2

Golden ~135W_p/m^2

All Black ~165 W_p/m^2

Semi-transparent BIPV

~49 W_p/m^2

System Price

This would include the BIPV module price, cost of cabling, installation, inverter, and if needed, framing, especially when BIPV is included in curtain walls.

450 SGD/m^2

BIPV LCC Calculator

Step 2: User inputs

Operating & Maintenance

Operating expenses vary with system size and exceeds the maintenance cost for conventional rooftop PV systems due to the higher complexity. Including a cost premium of ~50-100% over rooftop PV systems a ~4-5 SGD/m^2 cost assumption for BIPV seems conservative. General façade cleaning cost can be added in the range of ~3-4 SGD/m^2.

4 SGD/m^2

Annual Reserve for Inverter Replacement

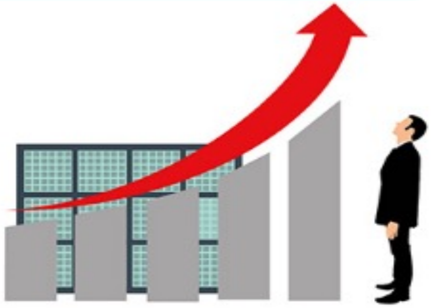
This is based on a warranty extension cost every fifth year with escalating premiums (i.e. 25%, 40%, 60% etc.). It is assumed that inverter cost per W_p will reduce to around 0.07 SGD/W_p within the next 13 years and remain stable thereafter (from a 0.1 SGD/W_p base value). The annualised reserve charge needs to be adjusted if the system lifetime assumption changes: ~4.8 SGD/kW_p for 20 years, ~5.5 SGD/kW_p for 25 years, and ~6.0 SGD/kW_p for 30 years.

5.5 SGD/KW_p

Inflation

The inflation rate will be used to escalate operating and maintenance cost, inverter replacement cost, and residual value cost.

2%



BIPV LCC Calculator

NUS National University of Singapore | SERIS Solar Energy Research Institute of Singapore

Step 2: User inputs

System Lifetime

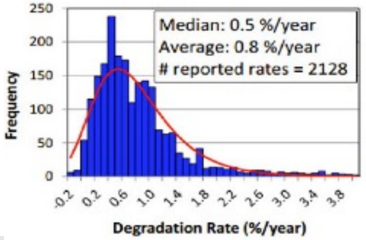
A value according to the building's life expectations or in-line with the output guarantee based on the BIPV module warranty can be used.

25 years

Performance Ratio

The performance ratio is an indication of how well a solar PV system converts available sunlight into electricity. A value of 100% would be a perfect system operating under standardised test conditions (i.e. cell temperature of 25 degrees Celsius, solar irradiance at 1000 W/m^2, and an air mass of 1.5). However, in real life applications there are losses due to DC to AC conversion, cabling or mismatch issues, temperature effects, soiling, reflections etc. A well-designed system in Singapore can achieve a performance ratio between 80-85%. With regards to BIPV, shading implications from near-by buildings need to be taken into account.

75%



System Degradation Rate

: After the first year's specific energy yield (i.e. available irradiance multiplied by the system's performance ratio), the system degrades by a certain % from year to year. It is quite common in temperate climates to assume a degradation rate of 0.5%. For tropical climates, it is recommended to use a degradation rate of ~0.8-1.0%.

1%

BIPV LCC Calculator

Step 2: User inputs

Reduced Solar Heat Gain Coefficient (SHGC)

Integration of BIPV into windows may lead to potential energy savings (i.e. cooling load reduction) and optimal thermal comfort in tropical countries. This can be expressed in a reduced SHGC, a direct indicator of energy efficiency in buildings, compared to single glazing fenestration systems, which typically have a SHGC of ~0.8. The reduction can be as high as 0.4 by using glass-glass BIPV modules, or ~0.2 by using see-through BIPV modules. The benefit calculation is based on a common air-conditioning coefficient of performance of 3.7. Calculated energy savings would only occur in enclosed environments where air conditioning is used.

0.1 reduction

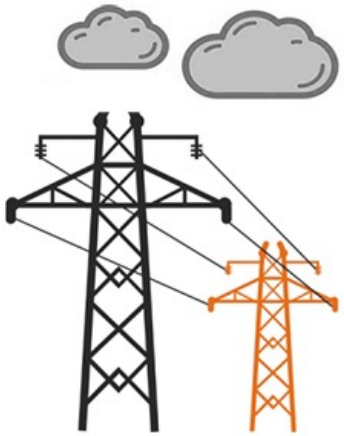
Electricity Price Arrangement (SGD cents/kWh)

The non-contestable client (NCC) or contestable client (CC) option uses the average values of the respective customer group with future electricity price progression based on SERIS' most-likely scenarios, published in the latest Solar Economics Handbook under following link: http://www.solar-repository.sg/solar-economics-handbook.

NCC ▾

BIPV LCC Calculator

Step 2: User inputs



Electricity Grid Emission Factor

This refers to the CO_2 emissions Singapore emits per kWh produced with conventional power stations (424.4 gr, Source: EMA for the year 2016) adjusted by the carbon footprint of the multi-silicon PV technology (28 gr, based on the "Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems" IEA PVPS Task 12, January 2015 report).

396.4 CO_2/kWh

Carbon Tax Price (SGD/tCO_2)

This refer to carbon pricing of 5 SGD per tonne of greenhouse gas (GHG) emissions to be levied by Singapore government starting from 2019 as part of national GHG inventory (UNFCCC). Thereafter carbon tax will be reviewed in 2023 with intention to gradually increase to 10 and 15 SGP /tCO2 by 2030 (FY 2018 Budget Statement). Carbon Tax Savings of BIPV system coupled with avoided CO2 over the system's lifetime will be estimated.

5 SGD

PREVIOUS CALCULATE

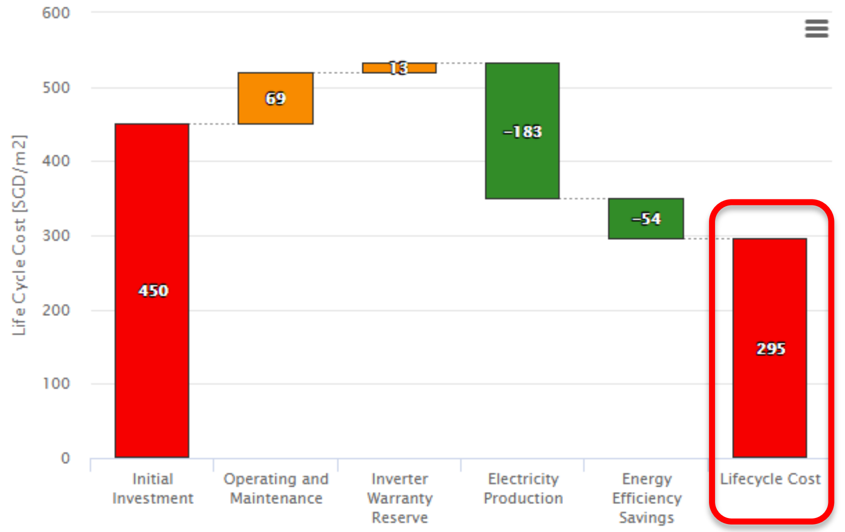
BIPV LCC Calculator

Step 3: Results

Output Fields

Total area (m^2)	2000
Installed capacity (kW_p)	270
Total system cost (SGD)	900,000
Annual operating and maintenance cost (SGD, 1st year)	8,000
Annual inverter replacement reserve (SGD, 1st year)	1485
Specific annual yield (kWh/kW_p, 1st year)	498
First year's energy generation (kWh)	134,549
Annual energy efficiency (kWh)	35,916
Total Life Cycle Cost (SGD)	
Total investment (SGD)	900,000
Operating and Maintenance	137,473
Inverter Warranty Replacement Reserve	25,518
Residual	0
- Benefit from electricity production	-365,737
- Benefit from energy savings	-107,463
Total Life Cycle cost	589,792
Green electricity production over system's lifetime (kWh)	3,887,271
CO_2 savings over the system's lifetime (tonnes)	1,541
Carbon Tax Savings (SGD)	7,704.57
Life Cycle cost per m^2	**294.9**

Life Cycle Cost | Environmental Benefits



How does your LCC/m^2 compare to standard façade material?

Estimated cost of a curtain wall in Singapore (SGD/m^2)	600
Estimated cost of a cladding wall in Singapore (SGD/m^2)	350

BIPV LCC Calculator

Step 3: Results

Life Cycle Cost | Environmental Benefits

Our BIPV system's contribution to the environment is:

Green electricity production over the system's lifetime (kWh): 2,989

In Singapore this can power:

1	0	1,246	157	2
4-room HDB households for one year	Days of all mobile phones charging in Singapore	MRT rides per passenger	LED light bulbs for one year	Households' air-conditioners for one year

Avoided CO_2 over the system's lifetime (tCO_2): 1,172

In Singapore this can power:

183	2,727	601,249	30,062
Motor vehicles driven for one year	Barrel of oil consumed	Litres of gasoline consumed	Tree seedlings grown for 10 years

Myth #3…

“BIPV in Singapore is…”

“… ugly”

Answer:
NO, not anymore !


unveiling the
PERANAKAN
BIPV module

BIPV Singapore Flag @NDP 2024

NUS National University of Singapore | SERIS Solar Energy Research Institute of Singapore

Singapore flag printed over 3 PV panels in collaboration with REC

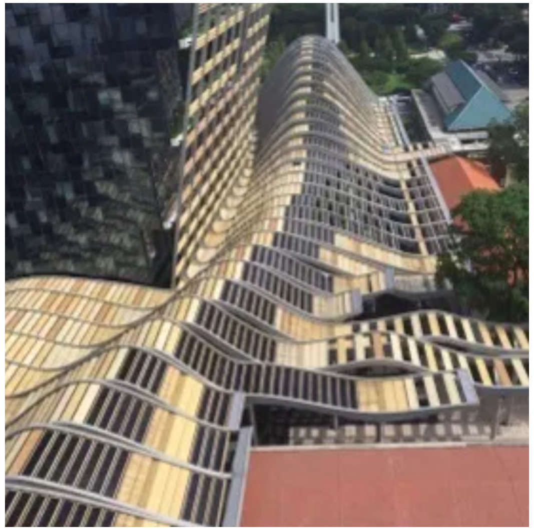
BIPV at the new PSA Tuas Port

NUS National University of Singapore | SERIS Solar Energy Research Institute of Singapore

Novel “urban solar” applications

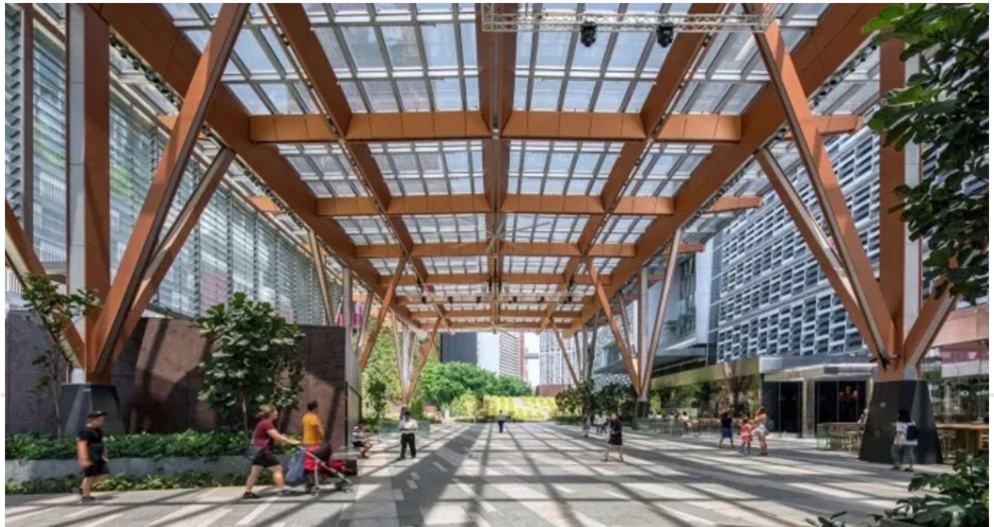
Project examples from Singapore

South Beach Tower



CleanTech One

Waterfront Promenade (Marina Bay)



Tanjong Pagar Center

Source: bipv.sg

Patented modules & systems for BIPV

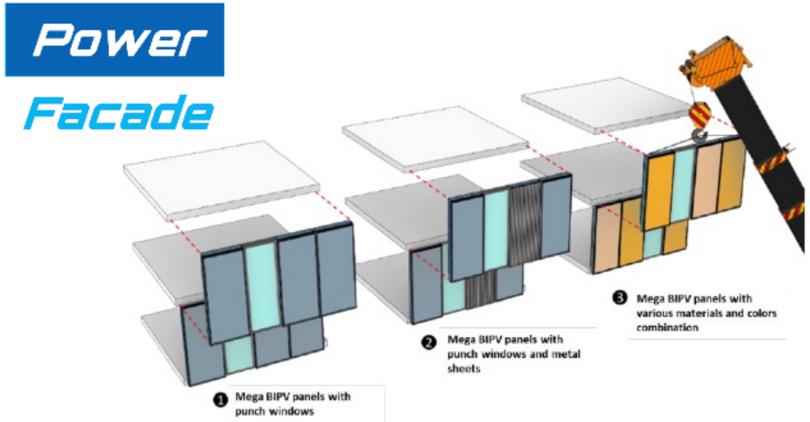
Applicable for BIPV (building-integrated PV and BAPV (building-applied PV)

Innovations:

- ➢ Patented methodology for colourful designs (“Peranakan PV”)
- ➢ Demonstrated the potential of aesthetically appealing solar modules, with relative efficiency losses up to only ~6%
- ➢ Testbed underway, in collaboration with NUS Baba House and NUS Centre for the Arts

New spin-off: Power Facade

- ➢ Commercialising 2 SERIS patents:
  - ▪ BIPV modules mimicking building materials (e.g. brick, marble, wood)
  - ▪ Unitised, pre-fabricated BIPV walls

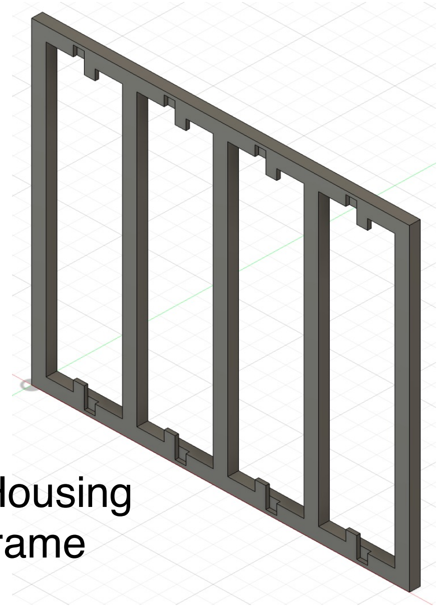


Next frontier: Pixel PV concept

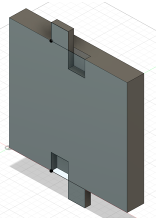
Rather than using large (> $2m^2$) panels, can we instead use small modules (~30x30cm) acting as "pixels"?

Advantages:

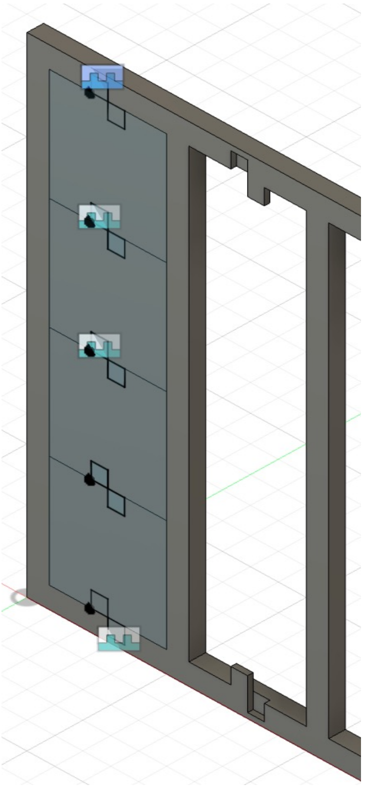
- Reduce customisation costs for aesthetic PV
- Architects may be more willing to adopt this as it provides more design flexibility
- Potentially more shading resistant (major source of loss for BIPV especially in dense urban environments)



Housing frame



Pixel casing

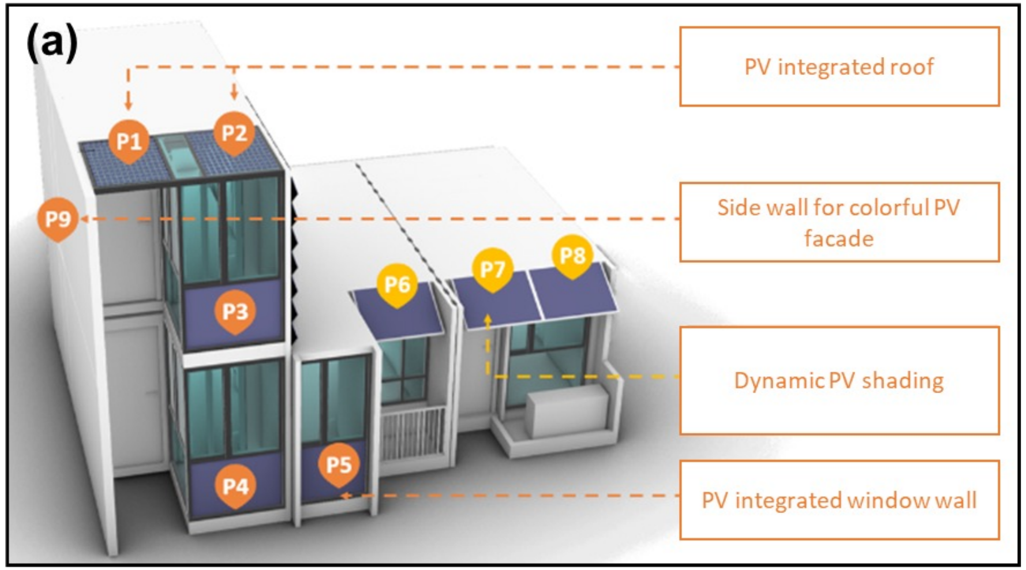


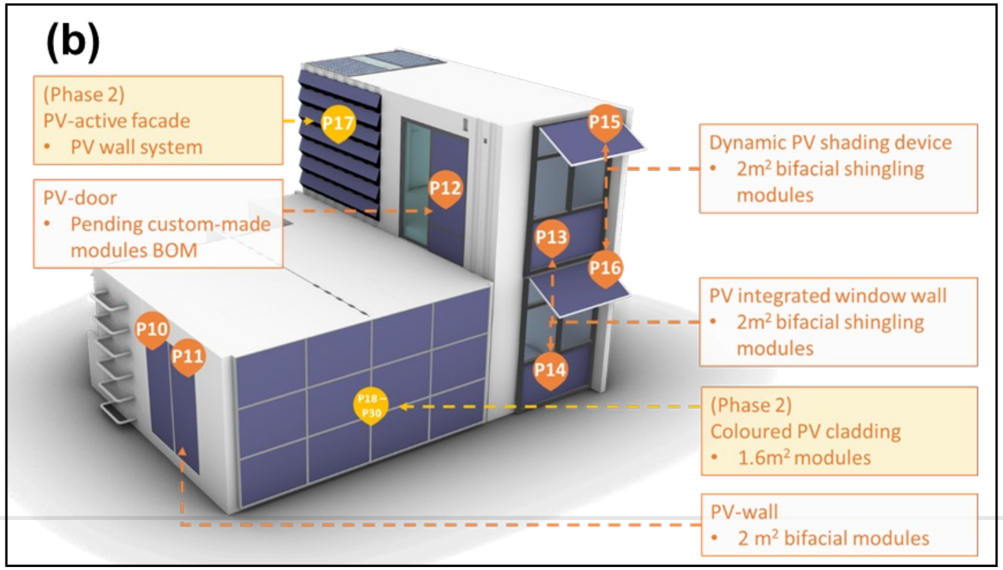
3x1 pixel cabinet

Prefabricated prefinished volumetric construction

- For high-rise residential buildings, prefabricated prefinished volumetric construction (PPVC) has gradually become the preferred method due to cost reduction and an improved construction environment

- The early integration of BIPV elements during the prefabrication step presents an opportunity to reduce installation costs.





Next frontier: Fire resistant and lightweight PV

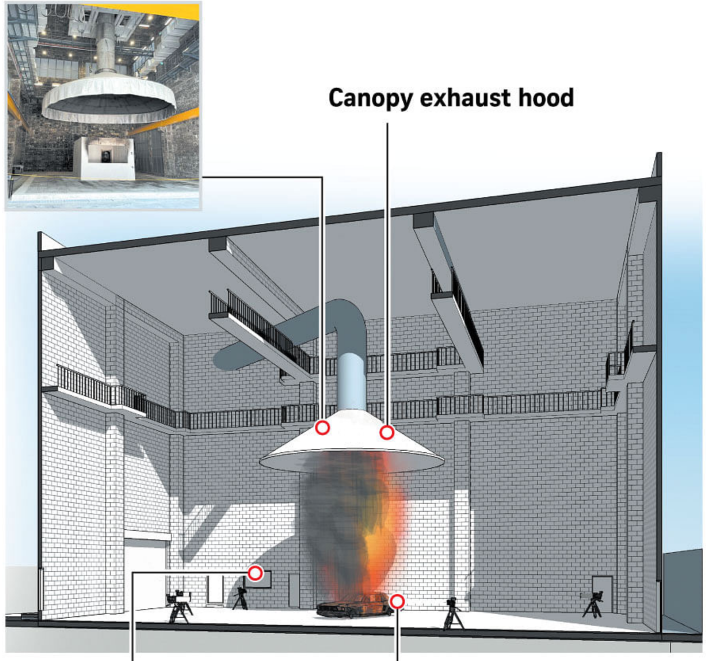
SCDF's Fire Research Center with an
8m cone calorimeter for large scale tests

How the Fire Research Centre works

FIRE RESEARCH CENTRE (FRC)

LARGE-CONE CALORIMETER

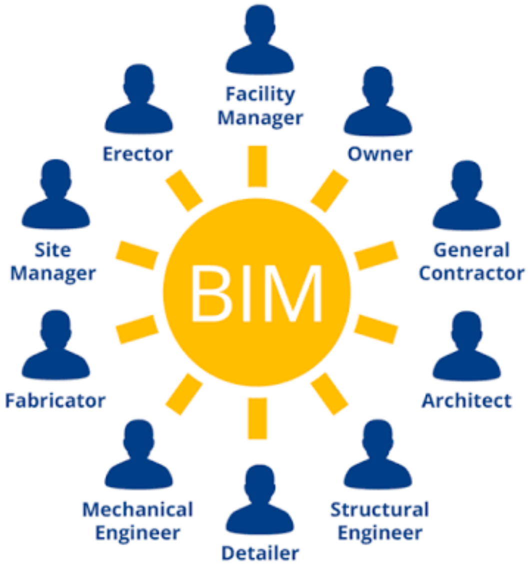
A calorimeter is a device used to measure the amount of heat energy evolved in a combustion process.



Enclosed control room
The operational statuses of the scrubber system are monitored in here

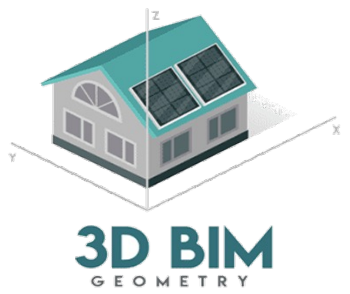
Burning area

Building Information Modeling (BIM)

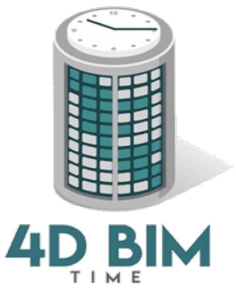


Building Information Modeling (BIM) is a collaborative and data-driven process that entails creating and managing digital representations of a building's physical and functional characteristics, progressing from geometric modeling (3D) to time scheduling (4D), cost estimation (5D), energy simulation for sustainability (6D), and encompassing management and operation aspects (7D).

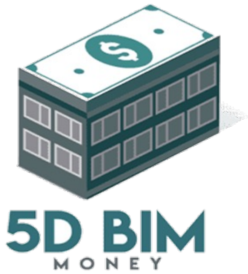
3D (Geometry)



4D (Time)



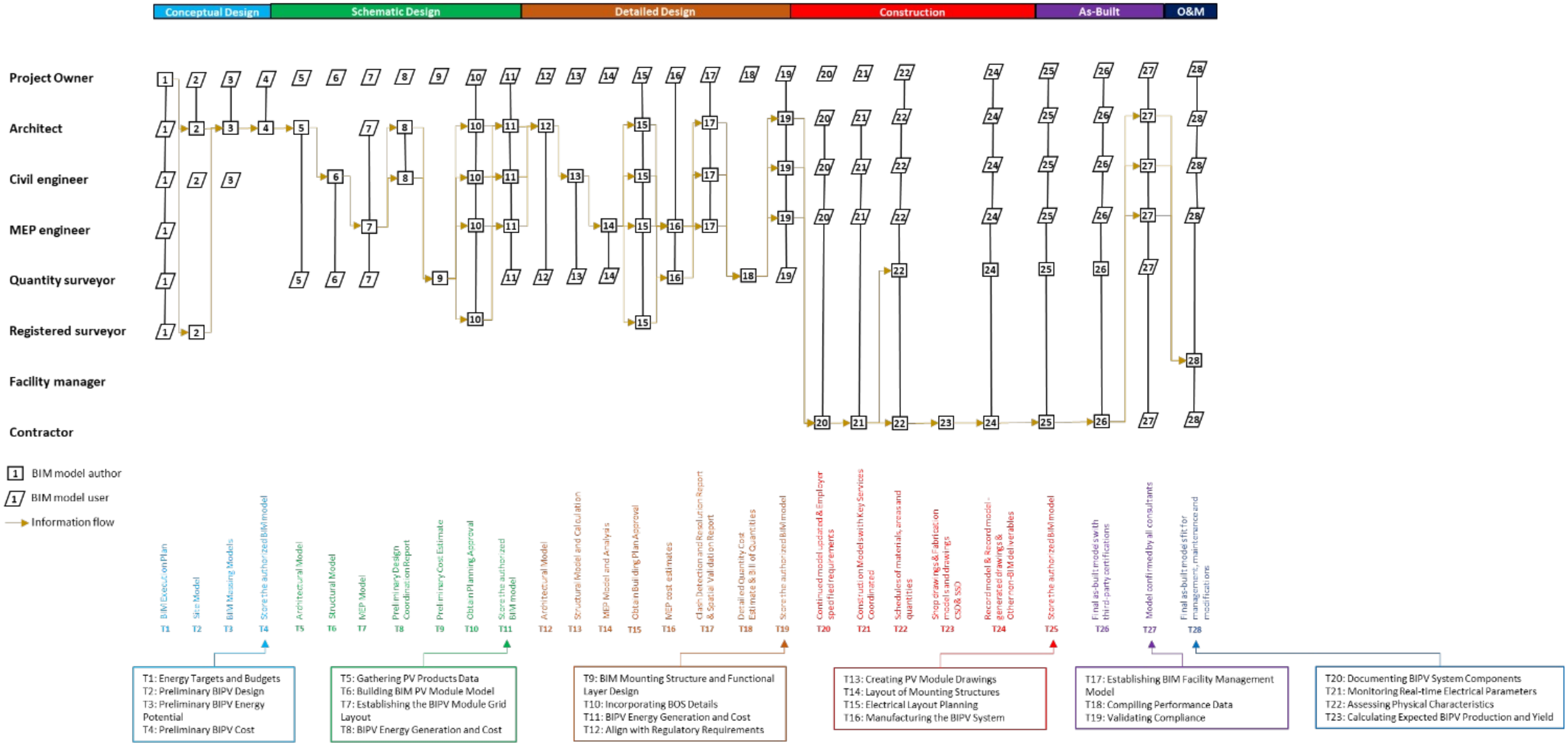
5D (Cost)



6D (Energy)

7D (Operation)

BIM – BIPV framework



Potential NEEDLE MOVER: Solar canopies

"Solar Architecture" is needed to change the way how BIPV is deployed in Singapore

Lingang Songjiang Tech City and its 1.5-km^2 rooftop PV installation, in Pudong, Shanghai.
(Photo source: https://zhuanlan.zhihu.com/p/400462291)

Potential for SG: tbd (but huge)

Similar concept, albeit without PV, at the ITE Central building in Ang Mo Kio

Many thanks for your attention!

thomas.reindl@nus.edu.sg

More information at:

www.seris.sg
www.solar-repository.sg

We are also on:

SYSTEM CERTIFICATION ISO 9001 SGS

UKAS MANAGEMENT SYSTEMS 0005

Accredited Laboratory SAC-SINGLAS LA-2012-0526-E