Multi-objective optimization(MOO) of BIPV envelope design: BIPV Cladding application

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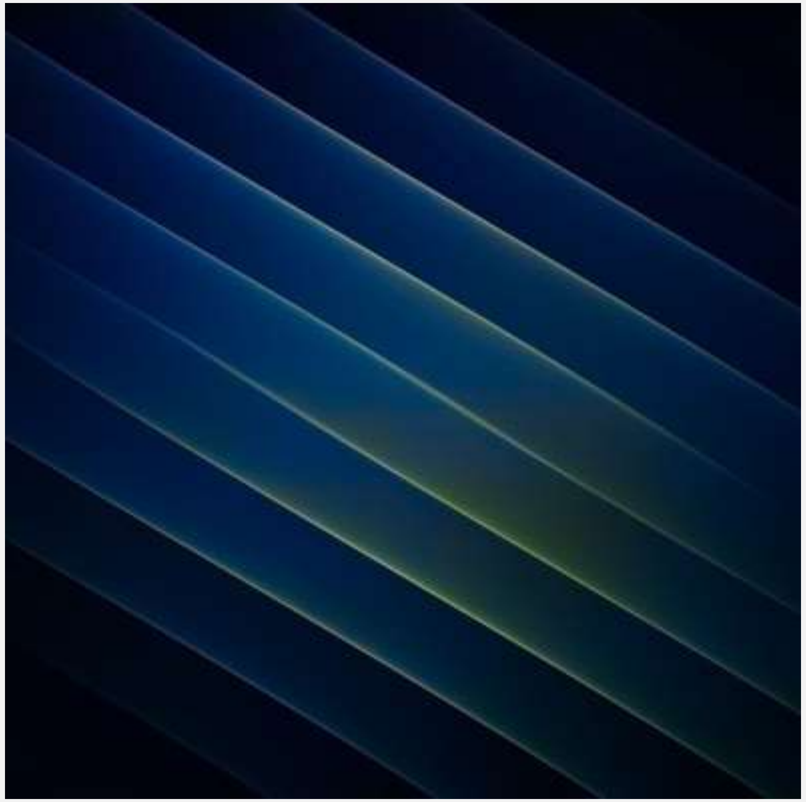

Background

BUILDING SECTOR ACCOUNTS FOR **40% OF THE TOTAL ENERGY USE** WHILE ACCOUNTING FOR **28% OF THE GLOBAL GREENHOUSE GAS** EMISSIONS

THUS, **RENEWABLE ENERGY IN BUILDINGS**

THE **AUSTRALIAN GOVERNMENT** HAS SET TARGETS TO INCREASE RENEWABLE ENERGY BY 255% BY THE END OF 2030.

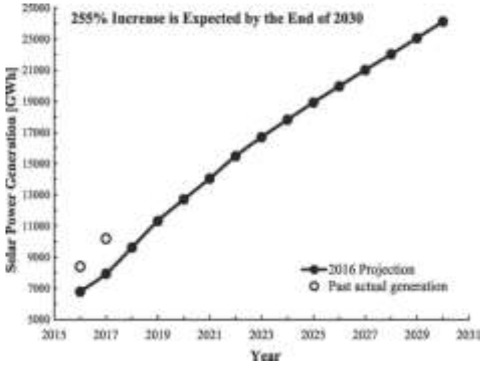

Figure 1: Current and expected renewable power generation in Australia by 2030 (Johnston and Egan, 2016)

BIPV (Building integrated Photovoltaics)

- Dual purpose
  - BIPVs are considered a functional part of the building structure, or they are architecturally integrated into the building's design
  - Source of electrical power
- Aesthetic advantage
- Reduce air conditioning loads
- Offers diffuse natural lighting (e.g. Semi-transparent arrays of spaced crystalline cells)

BIPV Application Types

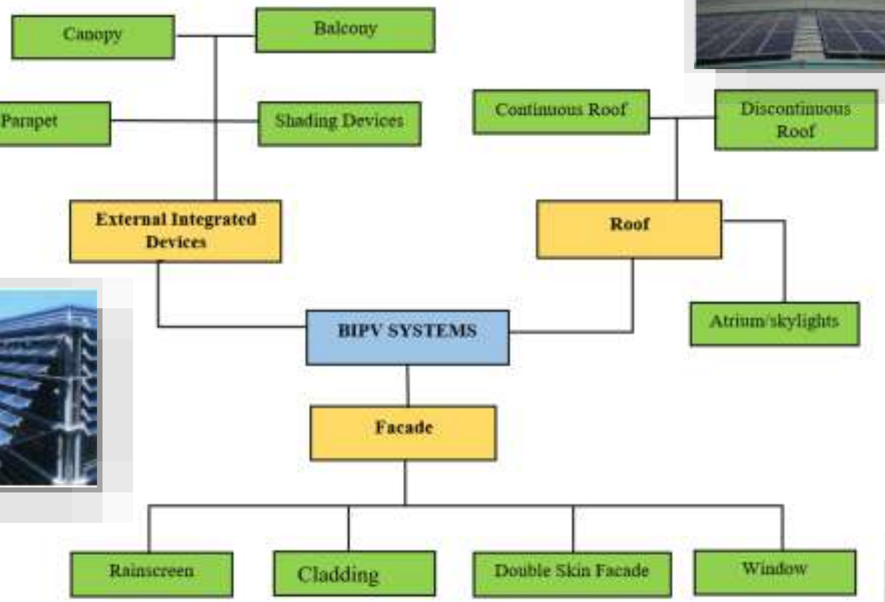

Figure 2:BIPV Application types

Source - *Yunfeng et al. (2016), Hermannsdörfer and Rüb (2005), Bonomo et al. (2019), Munari Probst et al. (2013)*

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BIPV Product Type Categories

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Photovoltaic foils, photovoltaic tiles, photovoltaic modules and solar cell glazing

Figure 3. BIPV Product types

Source - **Shukla et al. (2017)**)

Poly- and Mono-crystalline, Thin film or Amorphous

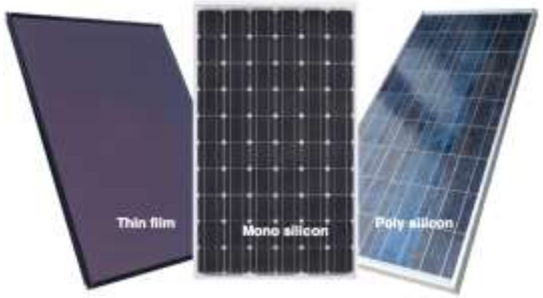


Figure 4. BIPV technologies

Source - Newkirk (2014)

Different transparency levels, different colors, different textures

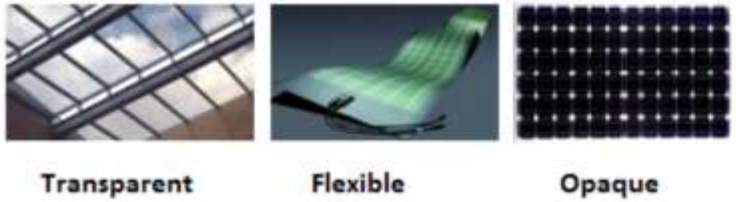


Figure 5. BIPV Product transparency

Source - Dice (2013)

Figure 6. BIPV Product colors and textures

Source - Kwang (2017)

Best PV product depends on **the application**, **building requirements** and **customer requirements**

Building Envelope → Solar building envelope

Physical separation between the interior and exterior environments of a building.

Includes all the components that protect the interior of the building from external elements, provide thermal insulation, and ensure structural integrity

Solar building envelope – controls irradiance thereby building performance

BIPV vs Building Envelope

Why BIPV Envelope Design Optimization ?

- **Sustainable, Energy efficient, Environmentally friendly buildings**
- **Complexity of BIPV envelope design**
  - Different BIPV Application types Vs BIPV Product types
  - Set of parameters that can influence a building's performance is relatively huge and in most of the cases, different parameters induce opposing influences
  - Multiple, and often conflicting, objectives – Energy vs Cost - **No one best solution**
  - Constraints such as construction budget and life cycle cost budget may impact the generation of optimal values
- Trial-and-error → too time consuming

Research Gap

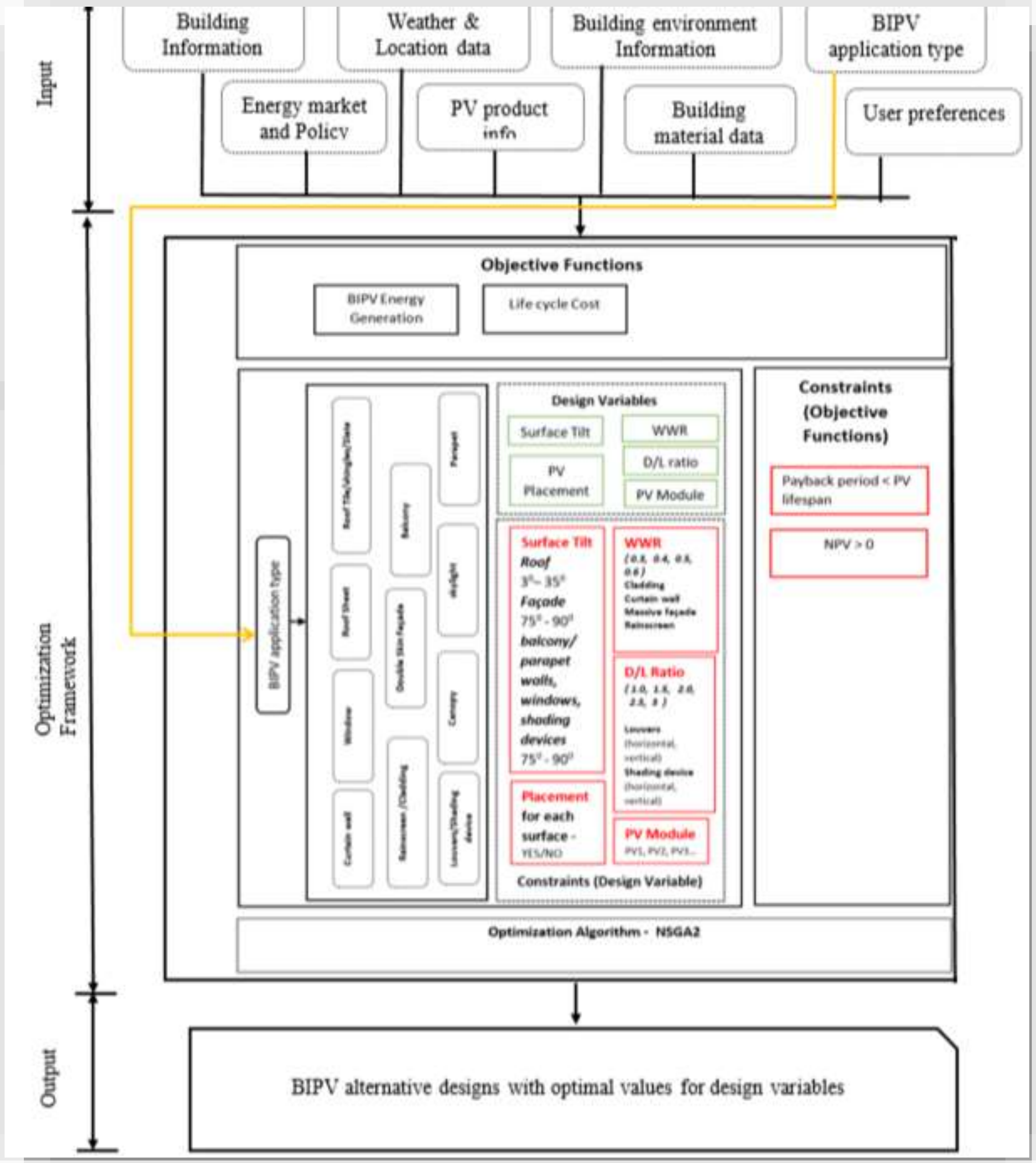
Past studies >

- Evaluation of the potential of BIPV
- BIPV installation
- Development of PV cell materials

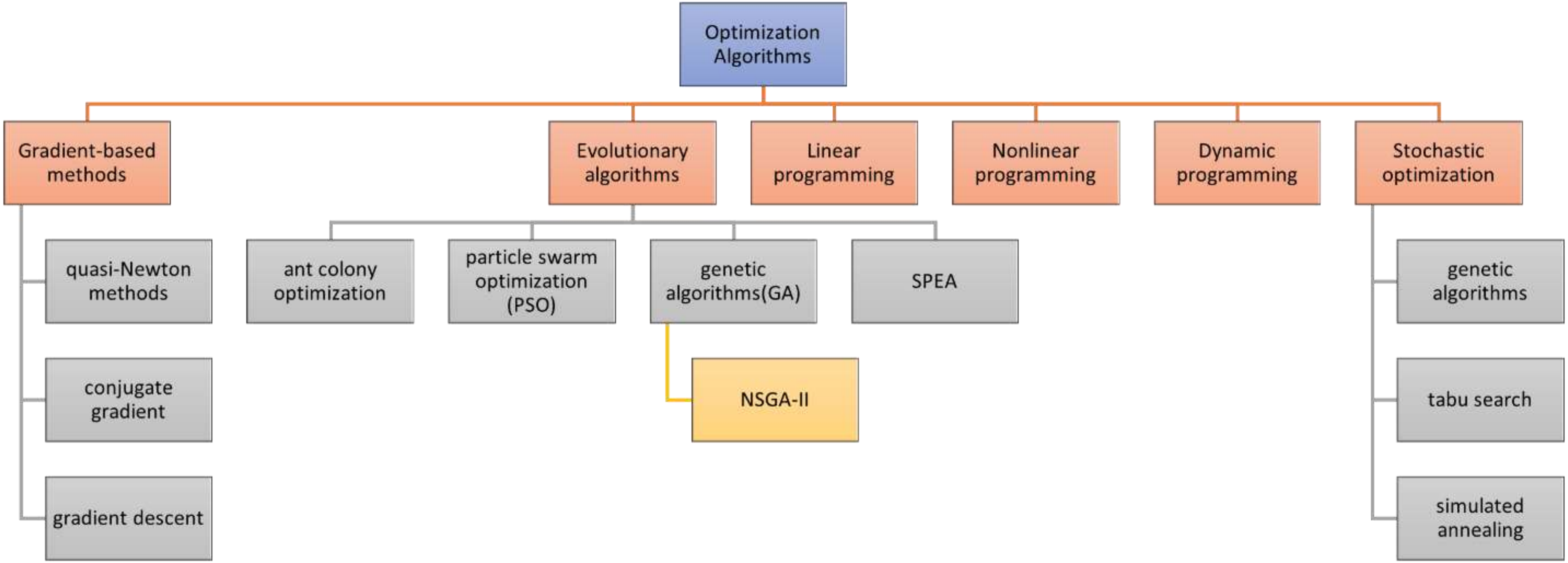
Not much studies focused on optimizing building envelope design to integrate BIPVs and thereupon achieve optimum performance.

- Deficiency in identifying potential and added benefits of BIPV limits the BIPV market growth in Australia.
- Mismatch between the existing optimization models and real-world BIPV problems
  - **Single-objective** optimization studies
  - Past studies have **not considered different PV Modules** as a decision variable in multi-objective BIPV design optimization models.

This study utilized a **building envelope design optimization framework** to optimize BIPV cladding performance at the **conceptual building design stage** by generating the **optimal BIPV product** and envelope parameters.

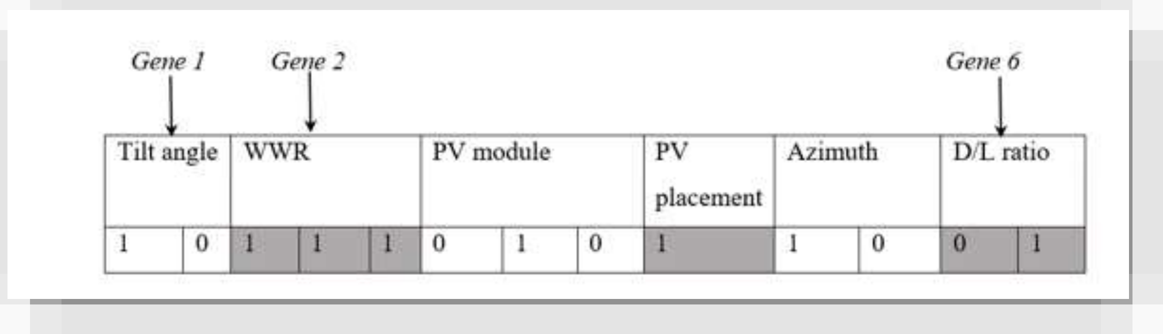


Multi-Objective Optimization Algorithms (MOOAs)

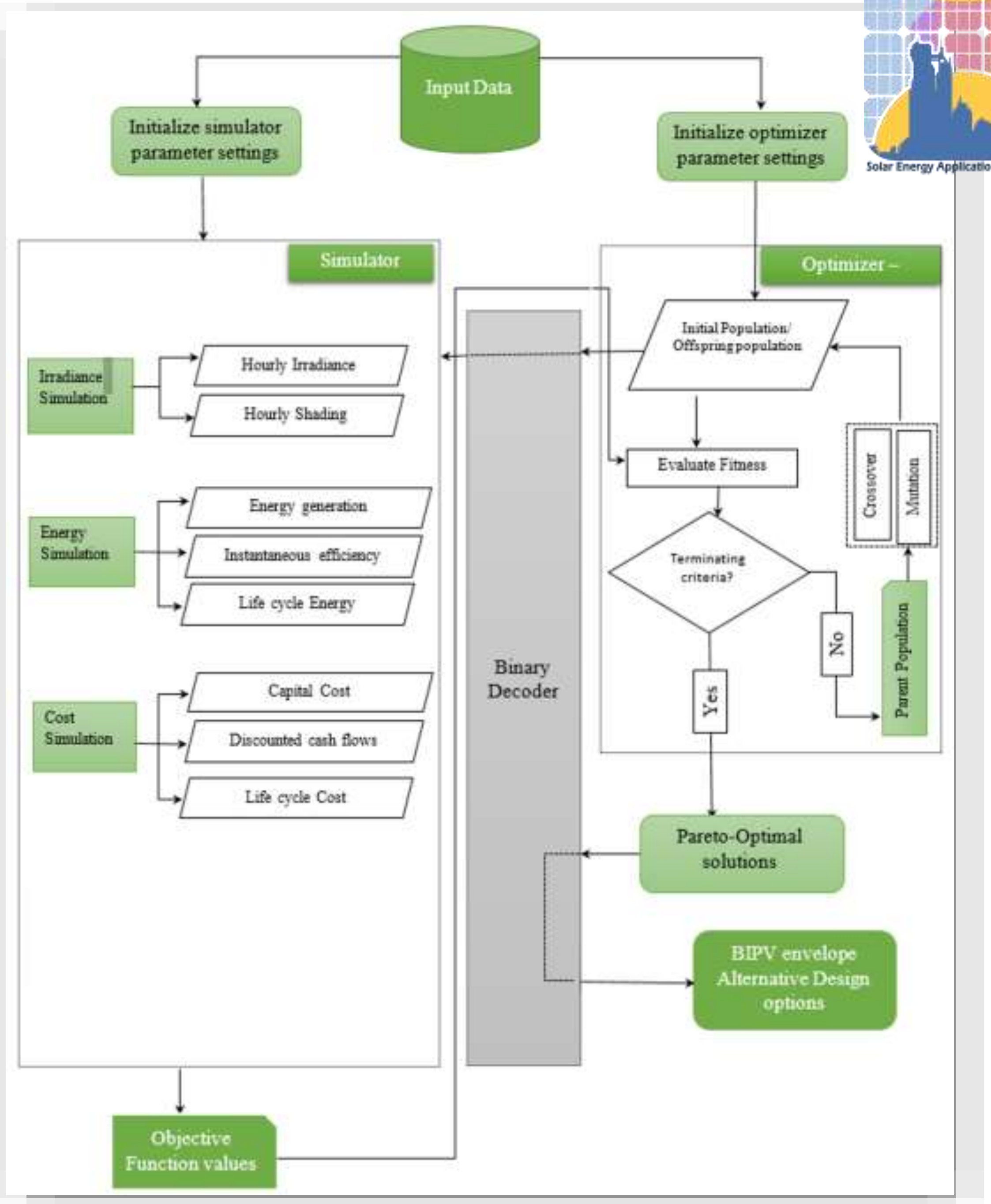


Multi-Objective Optimization (MOO)

- Generations
- Chromosome



- Population Size
- Selection
- Crossover
- Mutation



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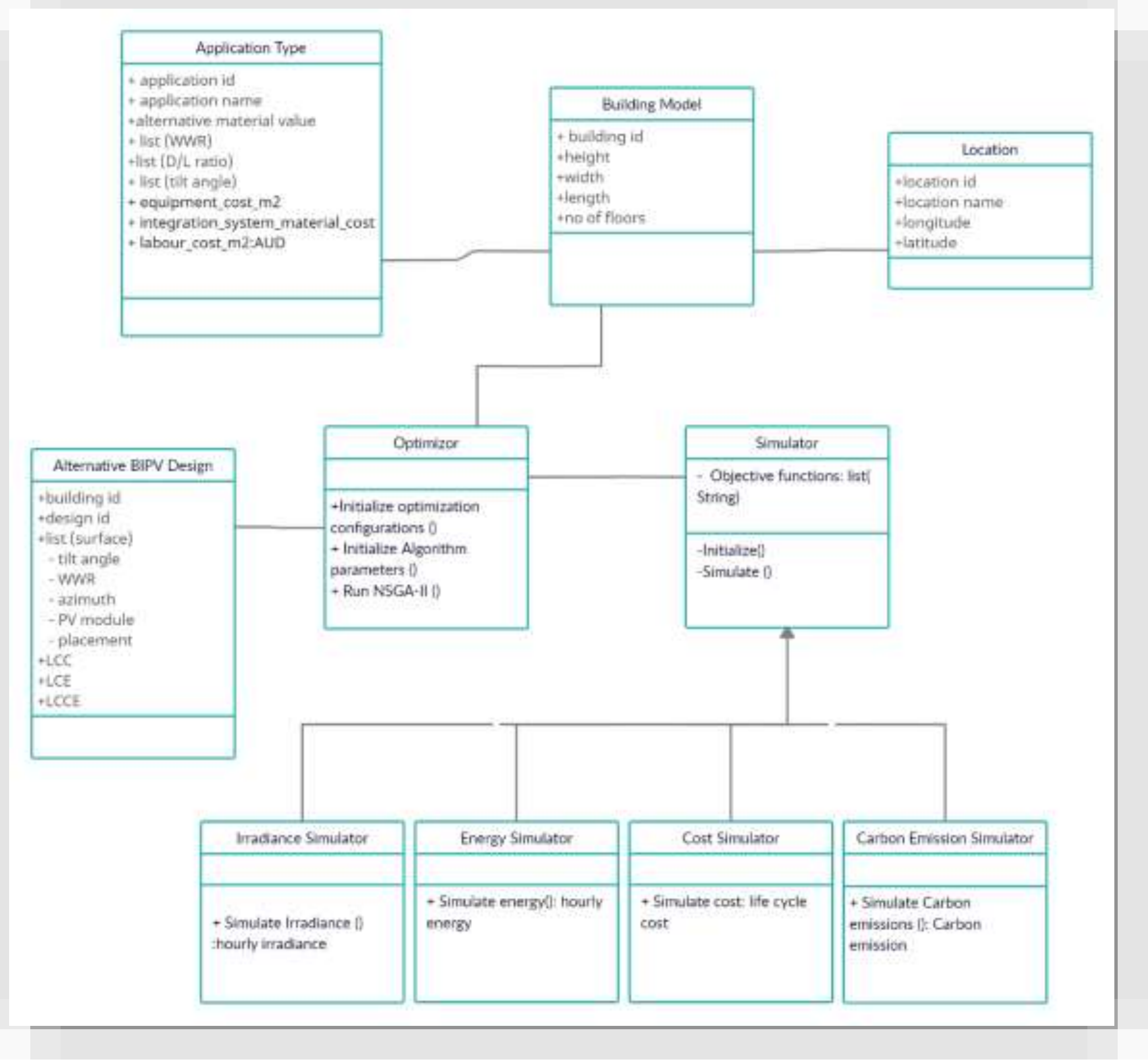
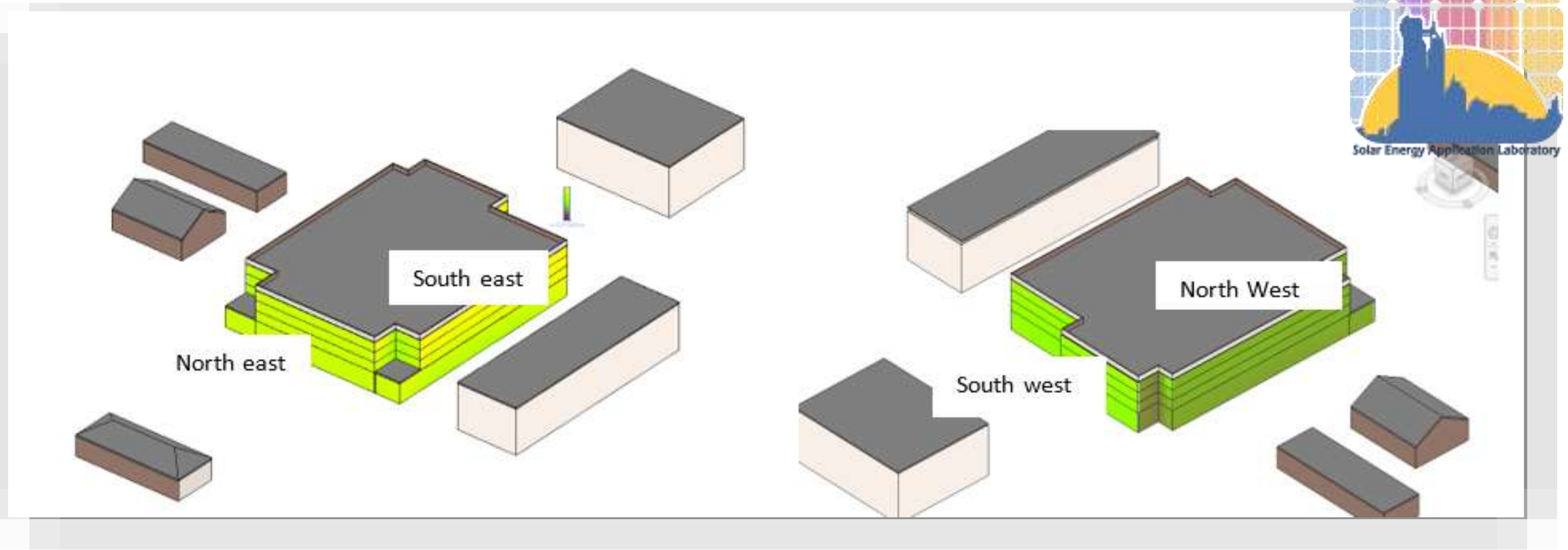


Programming Architecture

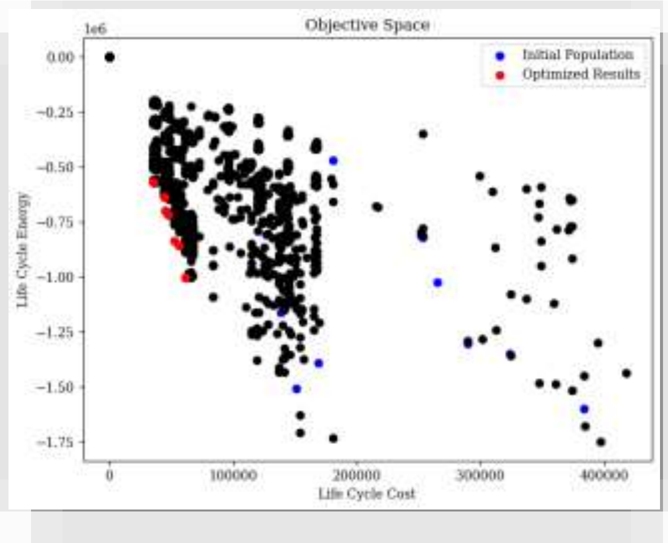
- **Object-Oriented Programming (OOP)**
- **Class Diagram**

Case study – BIPV Cladding design



Design variable	Values
BIPV products	16 products
WWR	0.3, 0.4, 0.5, 0.6
PV placement	YES/NO
Façade Tilt angle	75, 80, 85, 90 degrees
Objective function	**Aim**
LCC	Minimization
LCE	Maximization
Constraints	**Values**
NPV	> 0
Payback period	< PV life span

Optimal alternative designs



Non-dominated solutions

	South East façade tilt (degrees)	South East façade PV placement	South East façade WWR	South East façade No of PVs	North East façade tilt (degrees)	North East façade PV placement	North East façade WWR	North -East facade No of PVs	PV Type	PV Color	PV Life Span	LCC (AUD)	LCE (kW)	Payback Period (years)	NPV	Capital Cost (AUD)	LCOE	Total PV area (m^2)	Life cycle saving (AUD)
ALT 1	90	x	NA	0	75	YES	0.3	313	501	gray	25	53107.27	1003426	14.8818	13674.35	44170.61	0.061	225.3	66781.63
ALT 2	90	x	NA	0	75	YES	0.6	179	401	blue	25	30371.25	573844	12.7018	11566.85	25260.51	0.061	128.8	41938.11
ALT 3	90	x	NA	0	75	YES	0.5	224	204	black/ blue/ custom	25	39945.44	718107	14.4691	10766.17	32551.72	0.065	161.2	50711.61
ALT 4	90	x	NA	0	80	YES	0.4	268	201	black	25	45472.04	839572	14.646	12252.49	37820.2	0.062	192.9	57724.53
ALT 5	90	x	NA	0	75	YES	0.3	313	505	blue	25	53107.27	1003426	14.8818	13674.35	44170.61	0.061	225.3	66781.63
ALT 6	90	x	NA	0	75	YES	0.6	179	512	bronze	25	30371.25	573844	12.7018	11566.85	25260.51	0.061	128.8	41938.11
ALT 7	90	x	NA	0	75	YES	0.6	179	914	silver	25	30371.25	573844	12.7018	11566.85	25260.51	0.061	128.8	41938.11
ALT 8	90	x	NA	0	75	YES	0.5	224	507	orange	25	39945.44	718107	14.4691	10766.17	32551.72	0.065	161.2	50711.61
ALT 9	90	x	NA	0	75	YES	0.4	268	510	gold	25	47791.86	859163	15.3065	10965.3	38945.8	0.065	192.9	58757.17
ALT 10	90	x	NA	0	75	YES	0.5	224	913	silver	25	39945.44	718107	14.4691	10766.17	32551.72	0.065	161.2	50711.61

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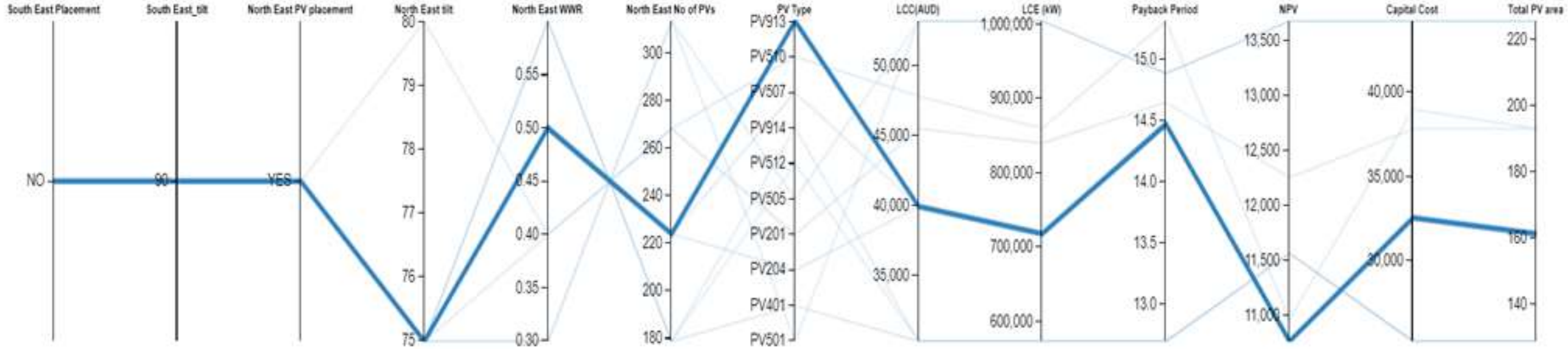
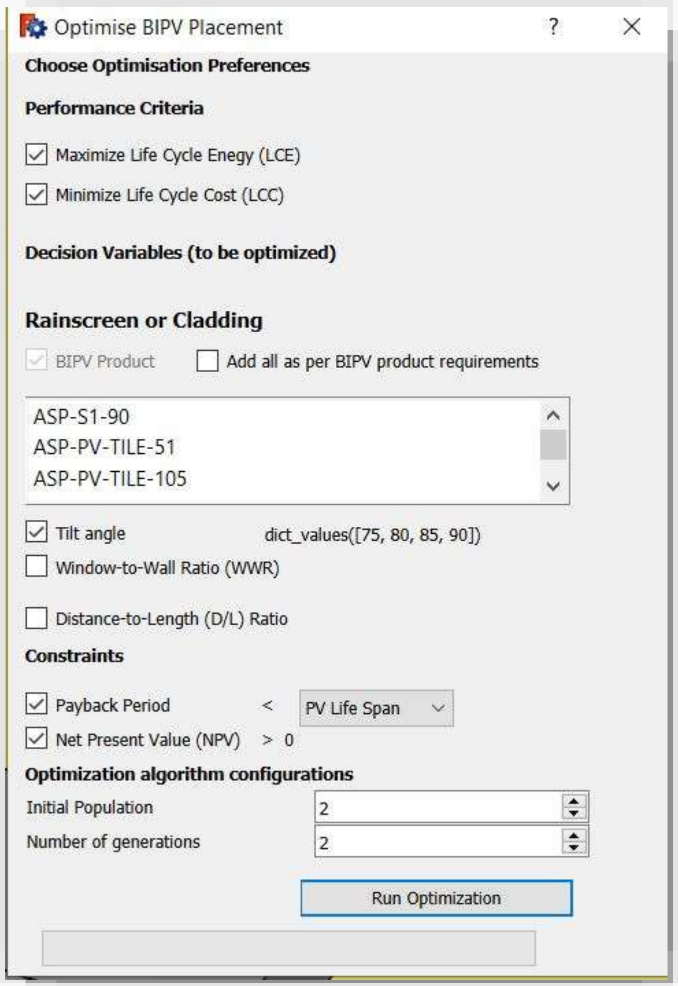
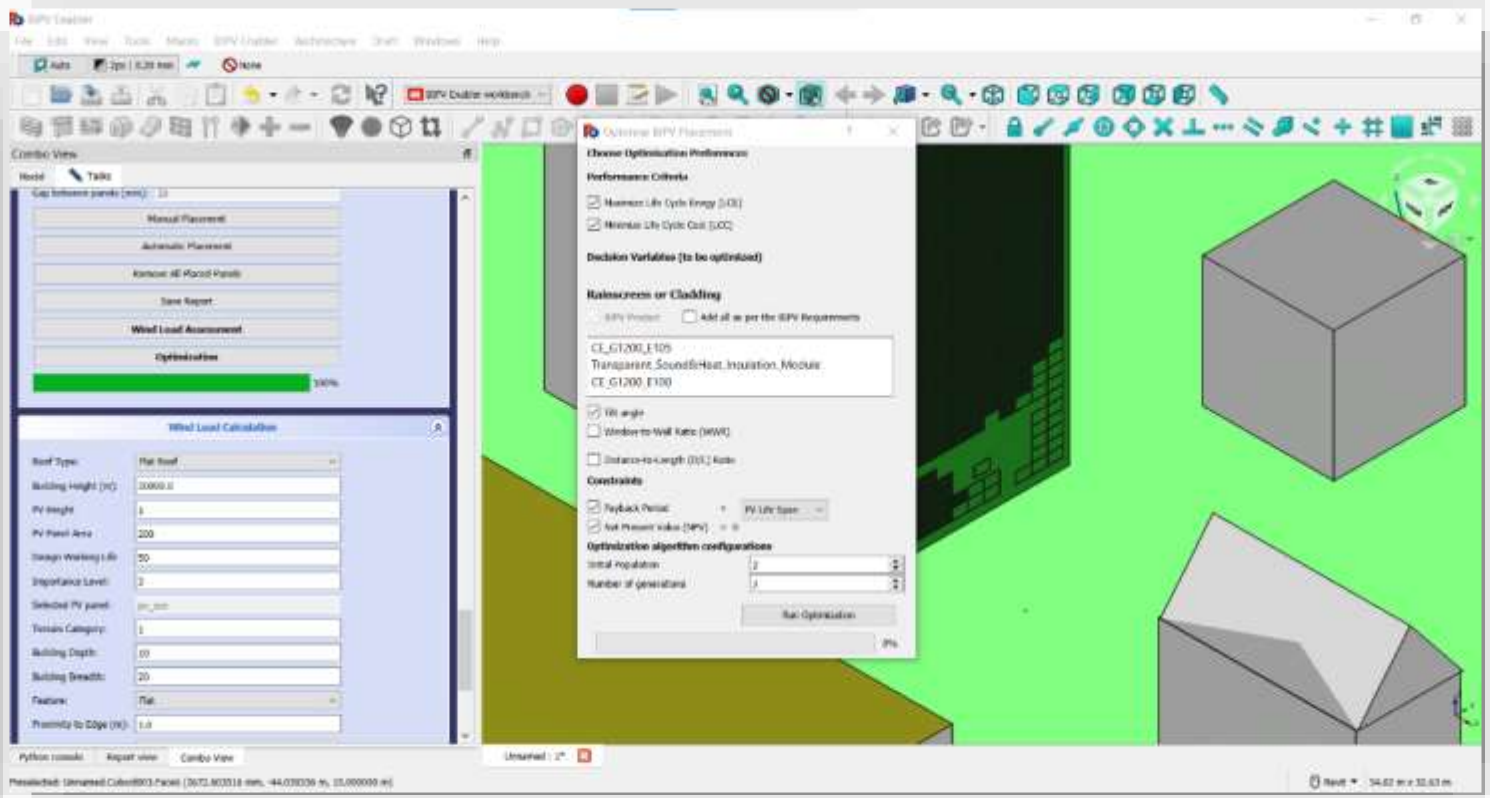
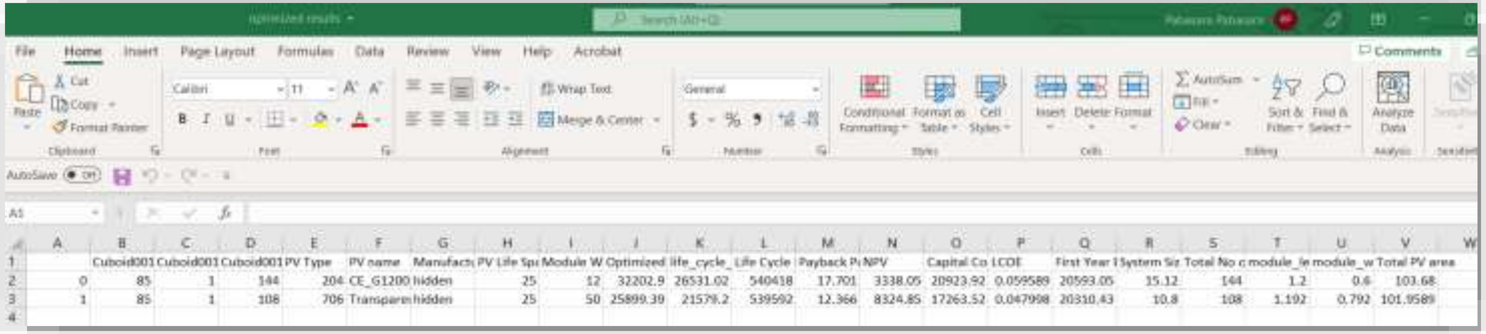


South East Placement	South East_tilt	North East PV ...	North East tilt	North East WWR	North East No ...	PV Type	LCC(AUD)	LCE (kW)	Payback Period	NPV	Capital Cost	LCOE	Total PV area
NO	90	YES	75	0.3	313	PV501	53107.2791	1003426	14.8818	13674.35	44170.61	0.061512924	225.36
NO	90	YES	75	0.6	179	PV401	30371.25668	573844	12.7018	11566.85	25260.51	0.061512955	128.88
NO	90	YES	75	0.5	224	PV204	39945.44621	718107	14.4691	10766.17	32551.72	0.065770773	161.28
NO	90	YES	80	0.4	268	PV201	45472.04484	839572	14.646	12252.49	37820.2	0.06294833	192.96
NO	90	YES	75	0.3	313	PV505	53107.2791	1003426	14.8818	13674.35	44170.61	0.061512924	225.36
NO	90	YES	75	0.6	179	PV512	30371.25668	573844	12.7018	11566.85	25260.51	0.061512955	128.88

Optimal design variables







MOO in BIPVEnabler tool

Future Directions

- The study can be extended to include more variables or objective functions such as building shape, PV area, thermal impact and embodied carbon emissions
- Research is needed to study the conflicts which arise when technical, aesthetic and social design requirements clash in design development or optimization investigations
- Improve time complexity
- Further research will extend it to integrated whole building design
- The framework can be converted into a plug-in for existing building modelling platforms such as Rhino and grasshopper
- Conversion of BIPV products into digital models based on Industry Foundation Classes (IFCs) and the digitalization of BIPV project design

Acknowledgement

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