Multi-objective optimization of building's life cycle performance in early design stages

09.13.2019 SBE19 Graz

Hanze Yu, Wei Yang, Qiyuan Li

School of Architecture, Tianjin University, 300072, Tianjin, China

hanzeyu@tju.edu.cn (H. Yu), walker_yang@tju.edu.cn (W. Yang), qiyuan_li@tju.edu.cn (Q. Li).

Contents

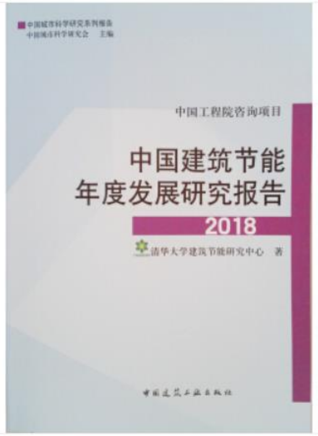
In 2016, China‘s total building energy consumption was 899 million tons of standard coal, accounting for about 20.6% of the country’s total energy consumption.

Jiangsu Nantong Sanjian Group Co. L 2018 *China Building Energy Research Report(2018)* (Beijing: China Building Industry Press)

The resource conversion rate of construction waste is lower than the average level of developed countries. Less than 5% of the construction waste is recycled.

Hao C 2016 Research on the Difficulties in the Development of Urban Construction Waste Resource Industry in China and Its Coping Strategies J. Legal Expo 02 82-83

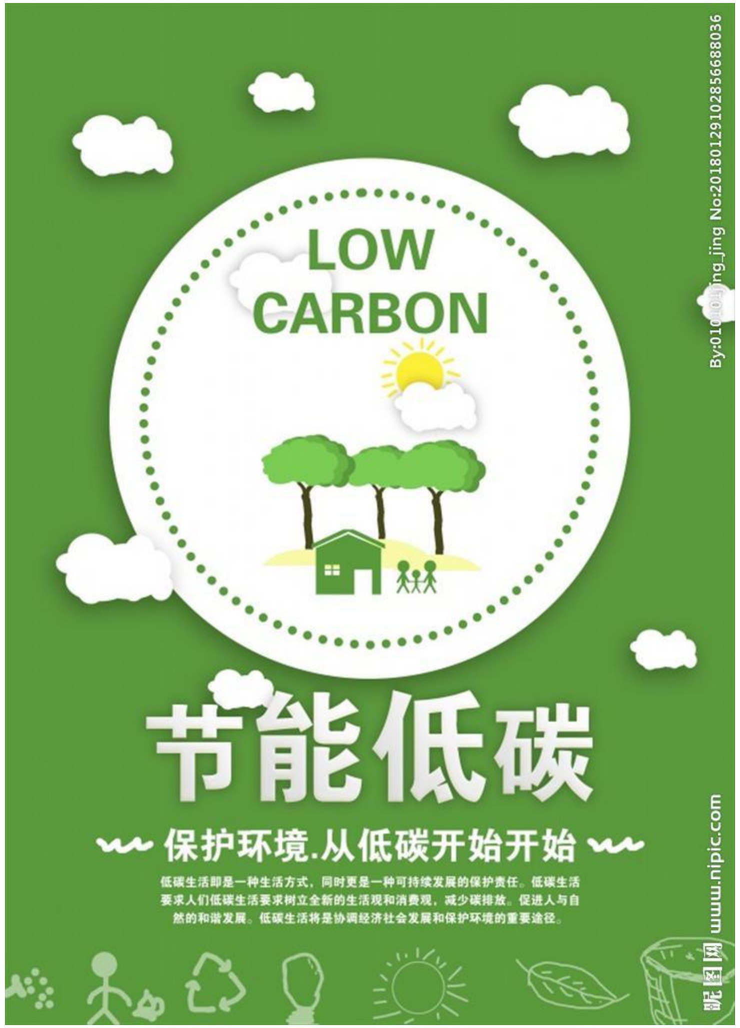
Copyright Getty Images



- China's LCA tool is still under development. The design and decision making functions have not been included.

Efootprint[EB/OL]. http://www.efootprint.net/#/home.

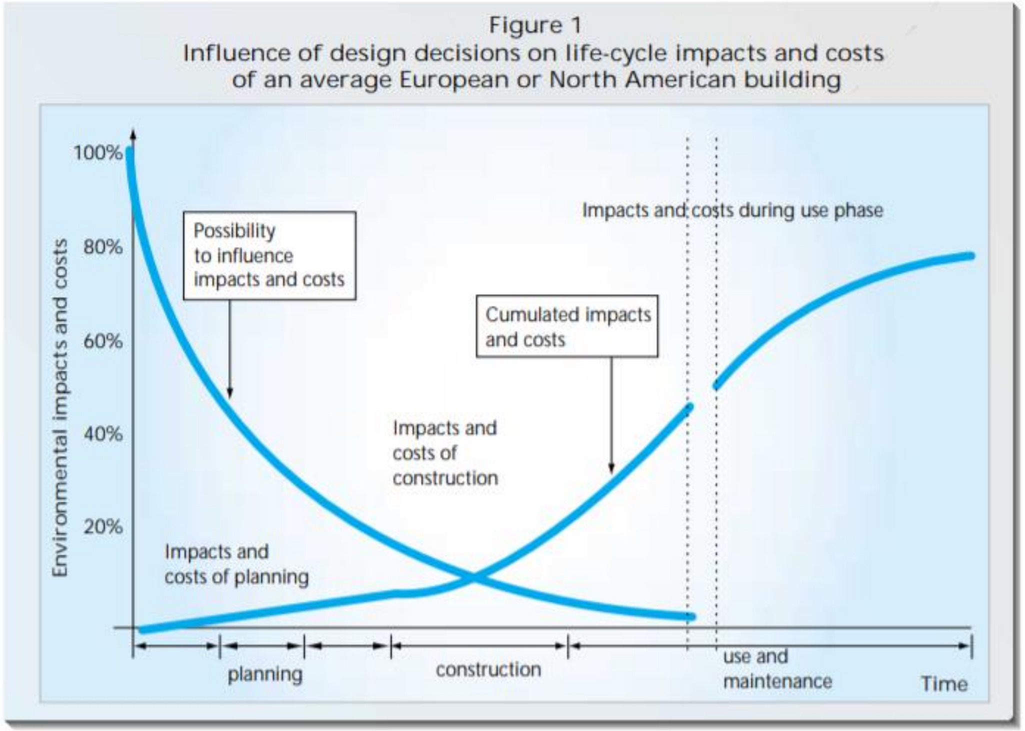
- There are fewer comprehensive considerations for LCA and LCC.



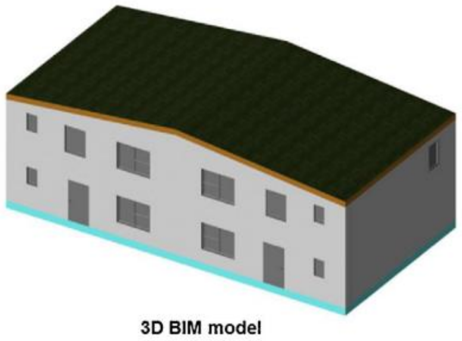
Copyright http://www.nipic.com

Most of the decisions related to building performance occurred in the early stages of design.

Negendahl K 2015 Building performance simulation in the early design stage: An introduction to integrated dynamic models *J. Automation in Construction* **54** 39-53

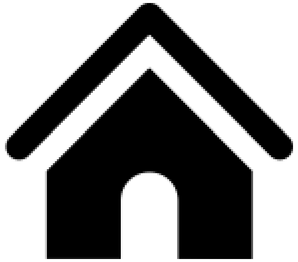


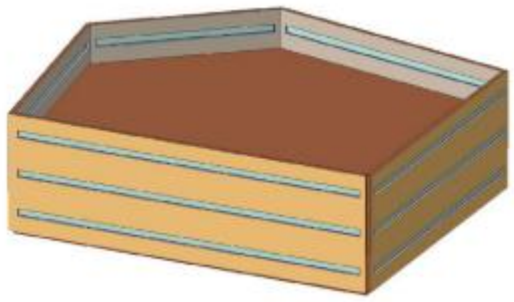
UNEP. Life-cycle analysis of the built environment. UNEP Indust Environ 2003: 17e21.



Shadram F and Mukkavaara J 2018 An integrated BIM-based framework for the optimization of the trade-off between embodied and operational energy J. Energy and Buildings 158 1189-205

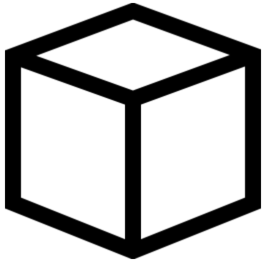
House-like

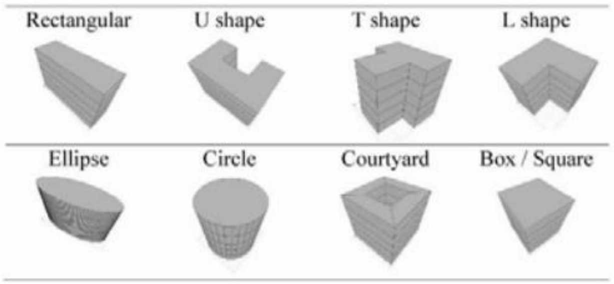




Wang W, Rivard H and Zmeureanu R 2006 Floor shape optimization for green building design Advanced Engineering Informatics 20 363-78

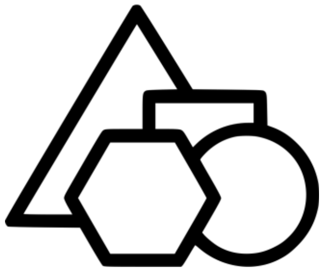
Shoebox

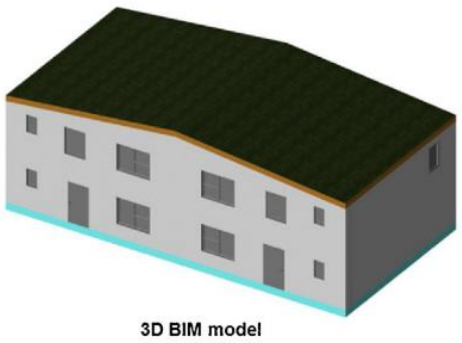


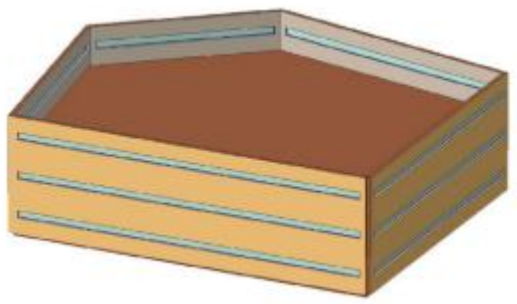


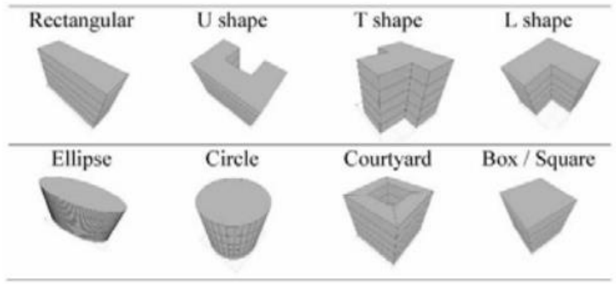
Rashdi W S S W M and Embi M R 2016 Analysing Optimum Building form in Relation to Lower Cooling Load Procedia - Social and Behavioral Sciences 222 782-90

Basic geometry

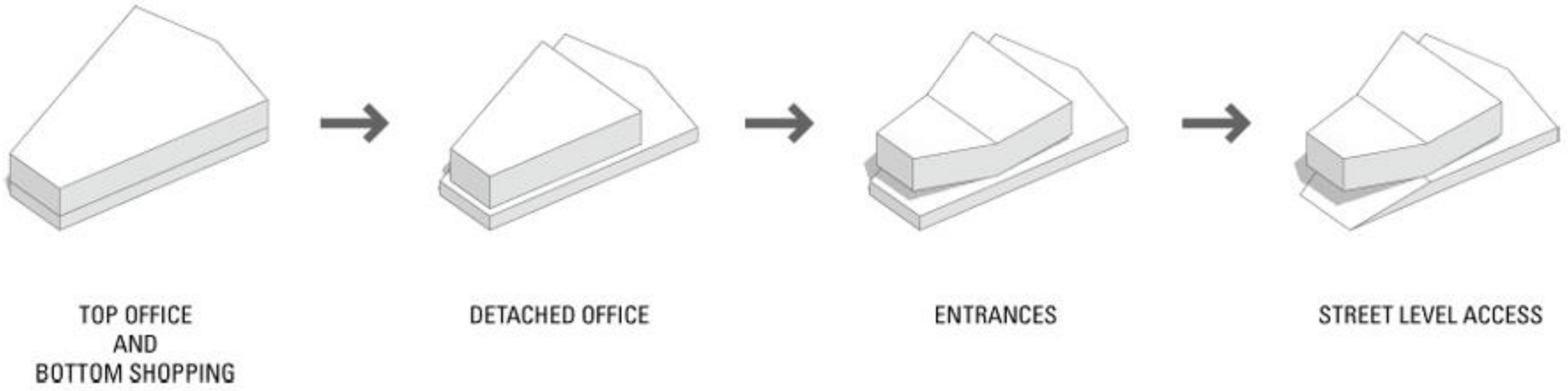






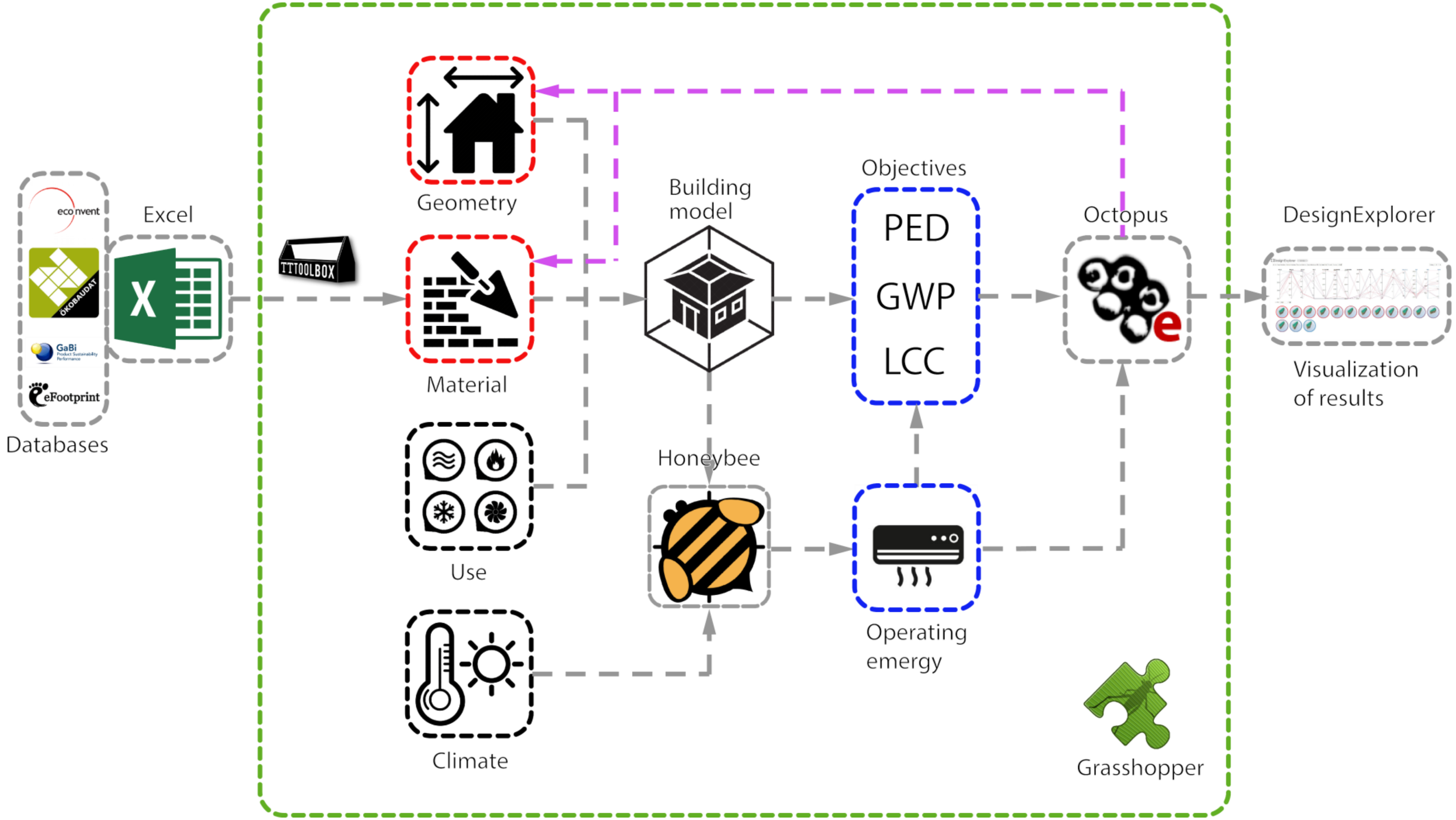


Morphology



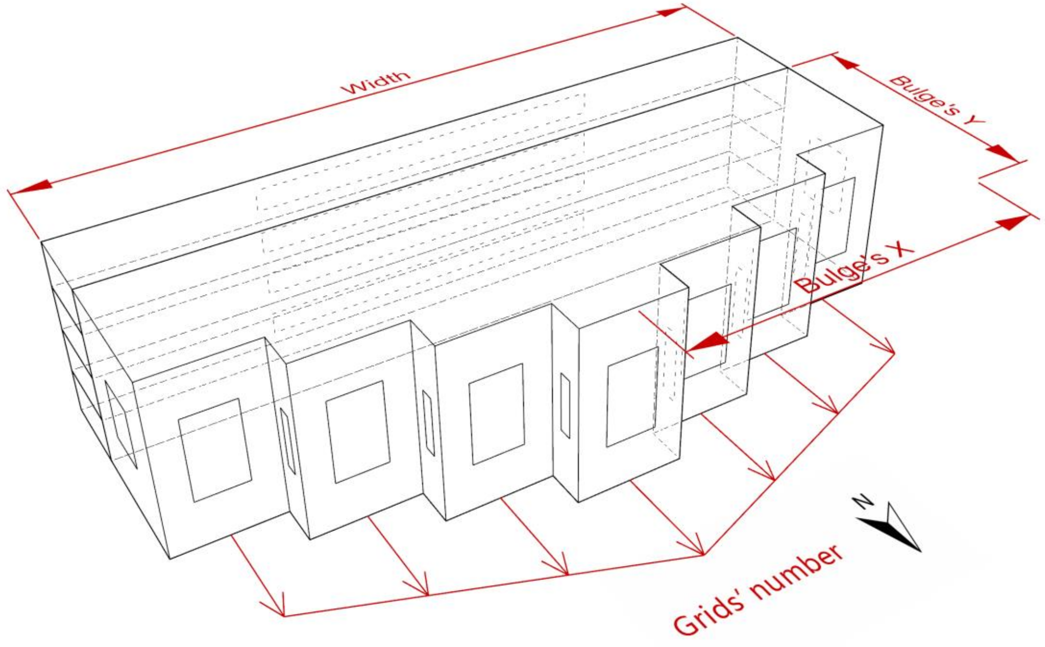
The Cornerstone / JAJA Architects ApS. https://www.archdaily.com/66426/the-cornerstone-jaja-architects-aps?ad_medium=gallery

A simulation-based parametric approach through the use of multi-objective optimization method is framed.



"Dinosaur Museum"

Location	Tianjin, China (39°N)
Floors	4
Area	5200 ㎡
Reference service life	50 years
Cooling	VRF (electricity, cop 3.5)
Heating	Central heating (natural gas, cop 0.88)



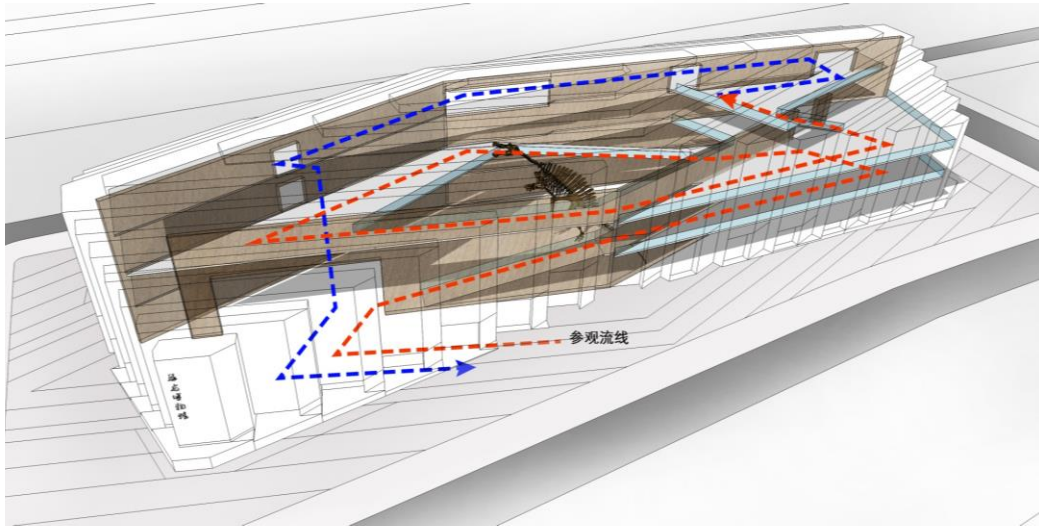
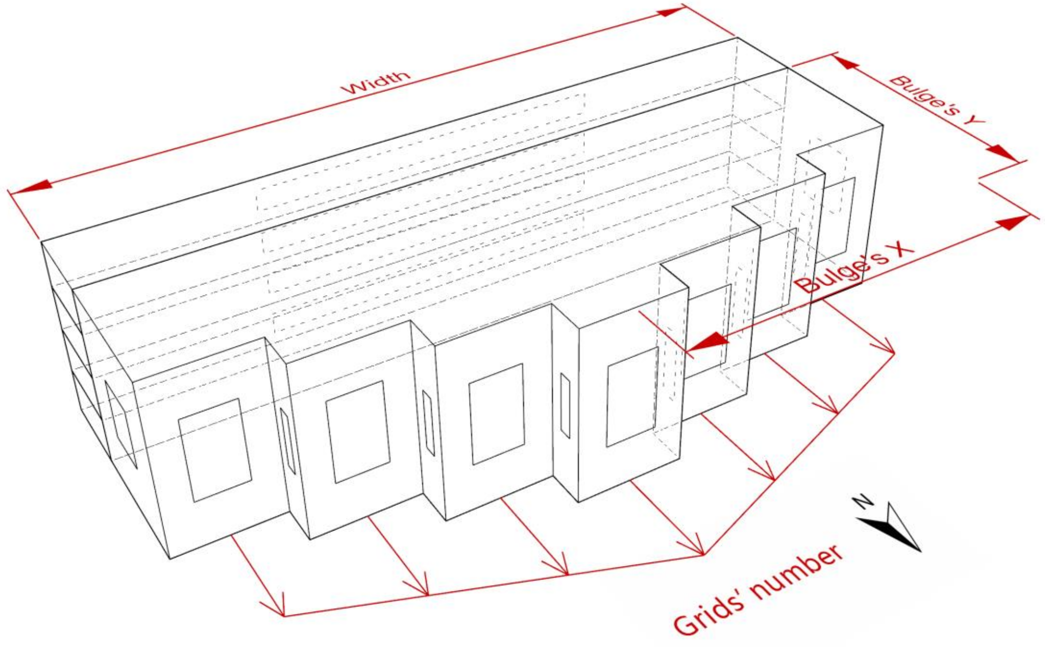


Table 1. Input variables and their ranges for optimization.

Categories	Description of variables	Unit	Distribution	Sampling ranges
Building geometry	Width	m	Uniform	(70.0,80.0)
	Bulge's X	%	Uniform	(0,100)
	Bulge's Y	m	Uniform	(40.0,60.0)
	Grid's number	-	Discrete	(3,5,7,9,11,13,15)
Window to wall ratio	North WWR	%	Uniform	(20,40)
	West WWR	%	Uniform	(10,30)
	South WWR	%	Uniform	(20,30)
	East WWR	%	Uniform	(10,30)
Building element	Window	-	Discrete	(1-5)
	Exterior wall	-	Discrete	(1-21)
	Roof	-	Discrete	(1-19)


Width
Bulge's Y
Bulge's X
Grids' number
N

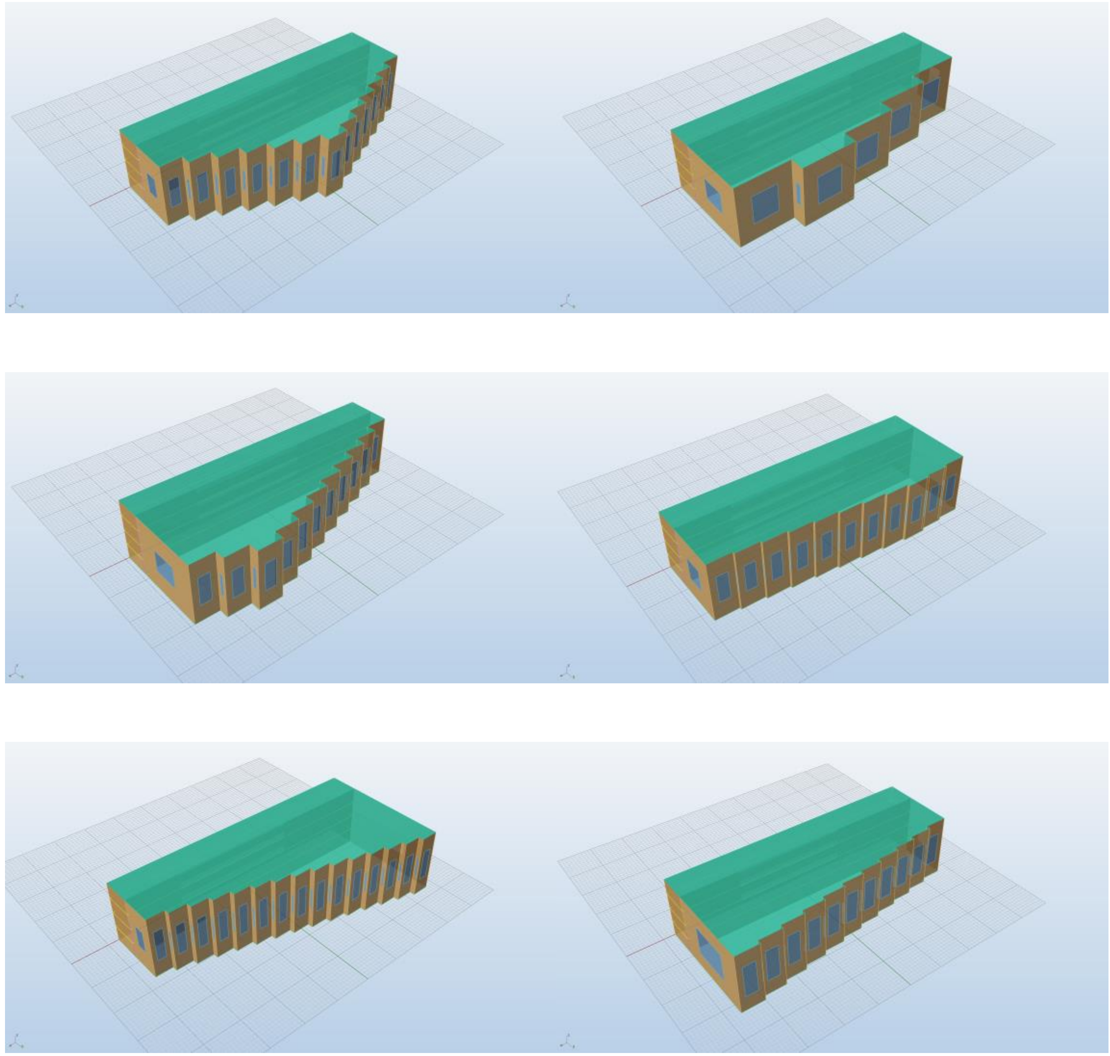


Table 2. Building elements in this case study.

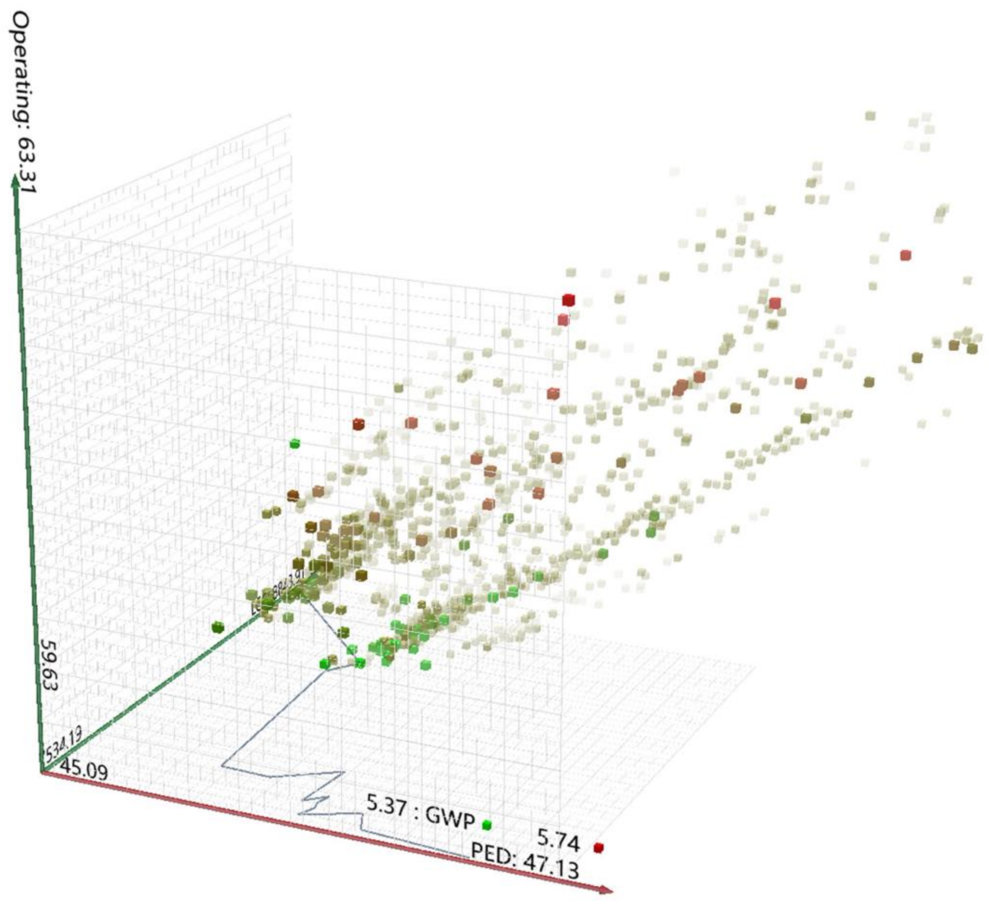
Index number (Window)	Glass type	Frame type	U-value [W/m^2·K]	SHGC	Visible transmittance
1	Double Low-E	Aluminum alloy	2.16	0.4767	0.76
2	Triple Low-E	Aluminum alloy	1.78	0.4759	0.72
3	Triple Low-E (Argon filled)	Aluminum alloy	1.51	0.4721	0.68
4	Double Low-E	Wood-aluminum	1.30	0.4767	0.76
5	Triple Low-E	Wood-aluminum	0.80	0.4759	0.72
Index number (Exterior wall)	**Layers (from outside to inside)**	**Thickness [m]**	**Thermal conductivity [W/m·K]**	**Density [kg/m^3]**	**Specific heat capacity [J/kg·K]**
	Curtain (Stone panel)	0.005	3.5	3300	920
	Curtain (Aluminum frame)	0.02	203	2700	900
	Cement mortar	0.01	0.93	1800	1050
1-11	Rock wool panel	0.05-0.15	0.048	140	1220
12-21	XPS panel	0.04-0.13	0.0384	30	1380
	Autoclaved aerated concrete block	0.2	0.175	500	1050
	Cement mortar	0.01	0.93	1800	1050
Index number (Roof)	**Layers (from outside to inside)**	**Thickness [m]**	**Thermal conductivity [W/m·K]**	**Density [kg/m^3]**	**Specific heat capacity [J/kg·K]**
	Polymer waterproofing membrane	0.002	0.15	580	1680
	Thermal insulation mortar	0.065	0.08	400	1050
	Perlite insulating concrete	0.002	0.435	800	1320
1-11	Rock wool panel	0.1-0.2	0.048	140	1220
12-19	XPS panel	0.08-0.15	0.0384	30	1380
	Reinforced concrete	0.1	1.74	2500	920

Table 3. Environmental data of materials used.

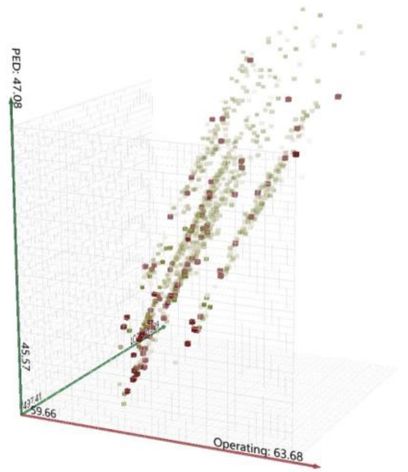
Categories	Components	Unit	PED [MJ]	GWP [kg CO2 eq]	Database	Initial cost [Yuan]	Initial cost's unit	RSL [a]
Insulation material	Rock wool panel	kg	14.96	1.13	Ecoinvent	474.61	m^3	30
	XPS panel	m^3	3020.1	96.37	ÖKOBAUDAT	747.2	m^3	30
Structure	Autoclaved aerated concrete block	kg	4.00	0.47	Ecoinvent	463.93	m^3	> 50
	Reinforced concrete	kg	0.50	0.13	Ecoinvent	743.66	m^3	> 50
Cladding	Stone panel (Curtain)	m^2	535.76	35.92	ÖKOBAUDAT	805.56	m^2	30
	Aluminum frame (Curtain)	kg	48.22	11.12	ÖKOBAUDAT	340.44	m^2	30
	Cement mortar	kg	1.47	0.18	ÖKOBAUDAT	49.23	m^2(10mm thickness)	20
	Polymer waterproofing membrane	kg	4.18	0.08	ÖKOBAUDAT	5.69	m^2	30
	Thermal insulation mortar	kg	2.05	0.29	ÖKOBAUDAT	33.72	m^2	30
	Perlite insulating concrete	kg	14.58	1.23	Ecoinvent	366.26	m^3	30
Window	Double Low-E(A)	m^2	1792.07	131.54	Gabi	756.78	m^2	30
	Triple Low-E(A)	m^2	2362.21	172.58	Gabi	963.61	m^2	30
	Triple Low-E(A) (Argon filled)	m^2	2387.27	174.53	Gabi	1313.61	m^2	30
	Double Low-E(WA)	m^2	3301	180	Gabi	3104	m^2	30
	Triple Low-E(WA)	m^2	3520.52	193.91	Gabi	3311	m^2	30
Energy	Electricity	kW·h	14.98	1.18	CLCD	0.9	kW·h	-
	Natural gas	m^3	15.49	0.28	CLCD	- [a]	-	-

[a] There is a starting fare 12Yuan/m^2 on the whole building and 0.25Yuan/kWh fee for the actual cost.

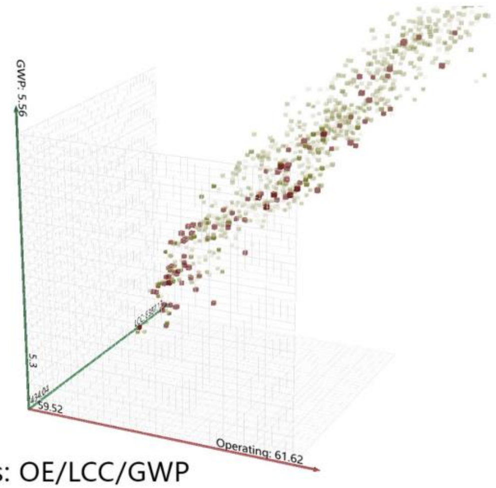
The scatter charts of all scenarios



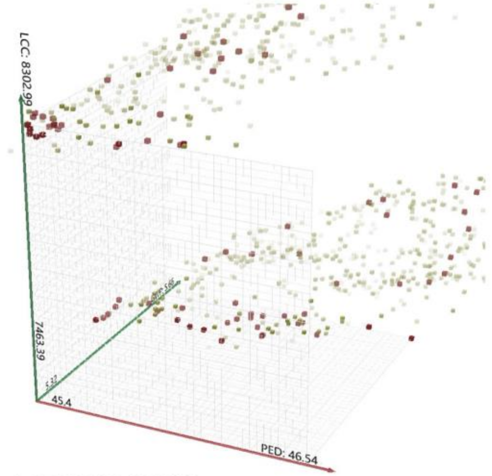
Objectives: OE/LCC/PED/GWP



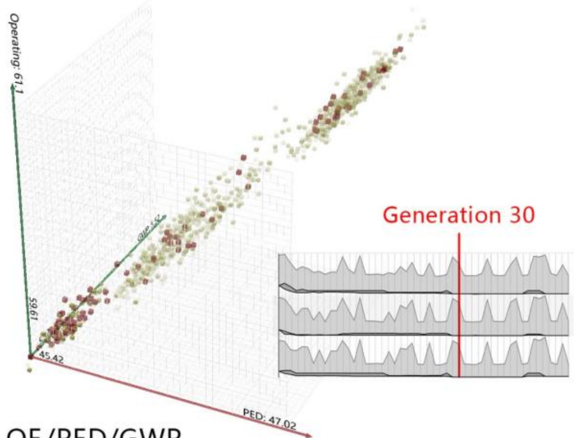
Objectives: OE/LCC/PED



Objectives: OE/LCC/GWP

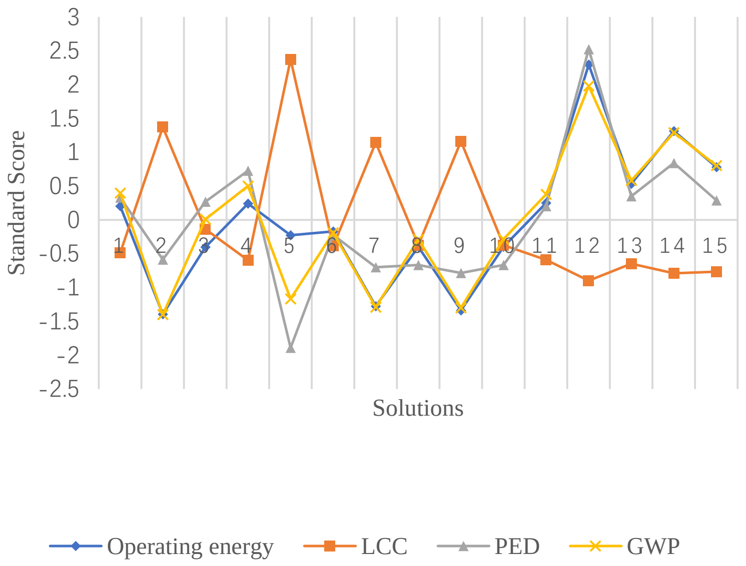


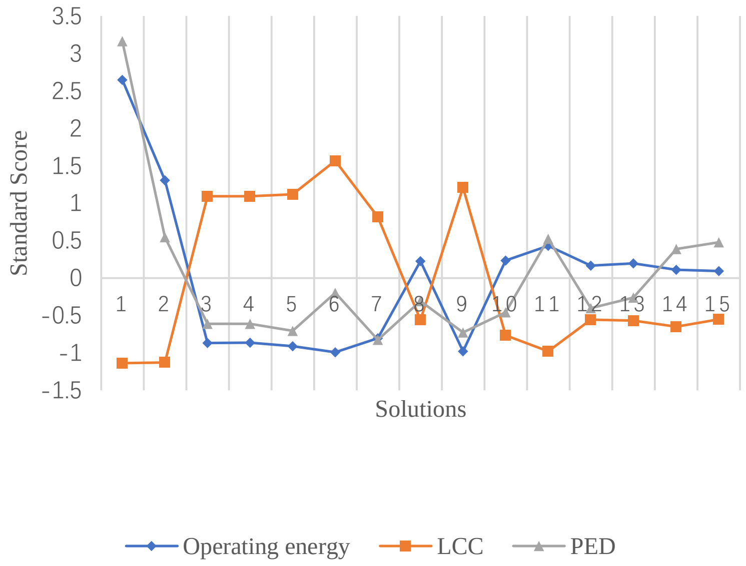
Objectives: LCC/PED/GWP

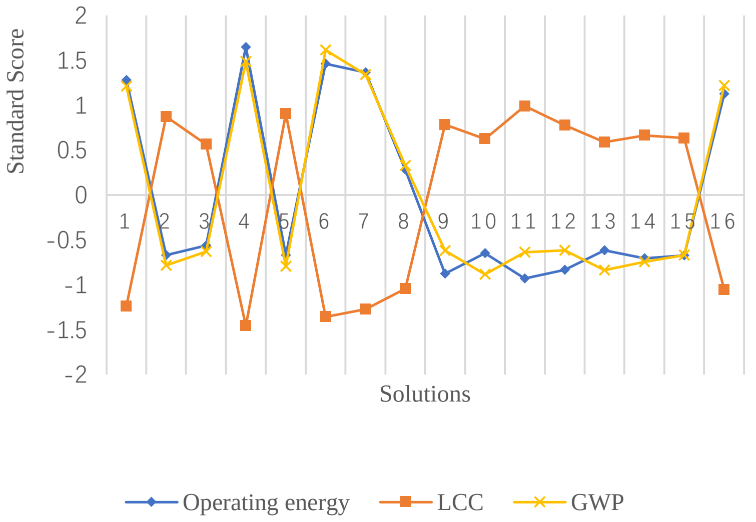


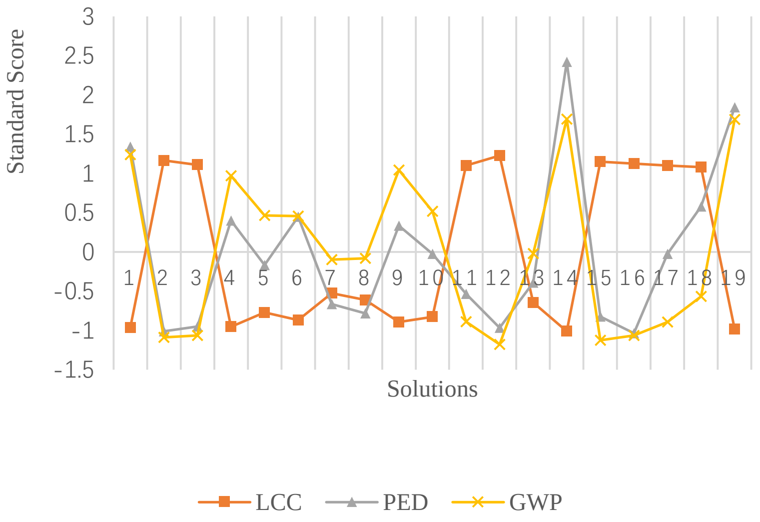
Objectives: OE/PED/GWP

The standardized Pareto optimal solution sets

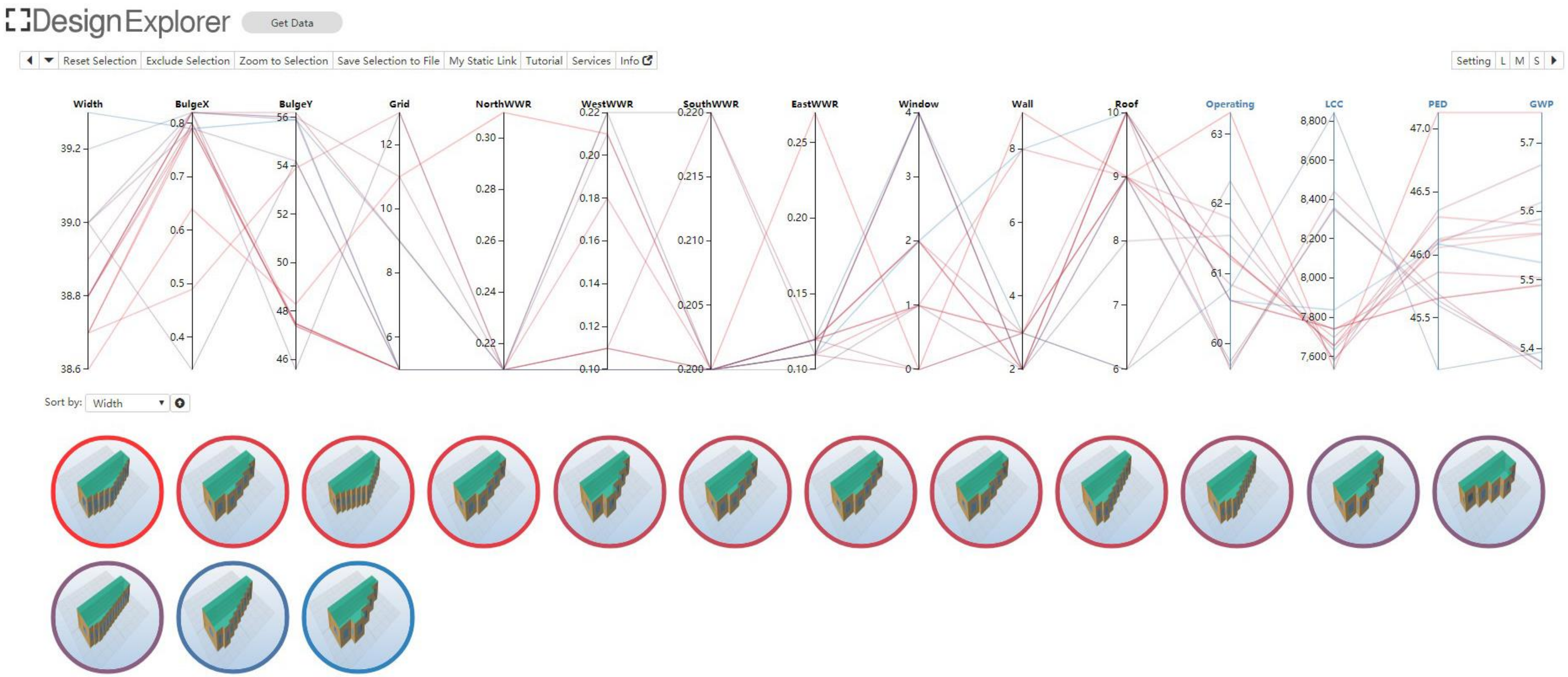




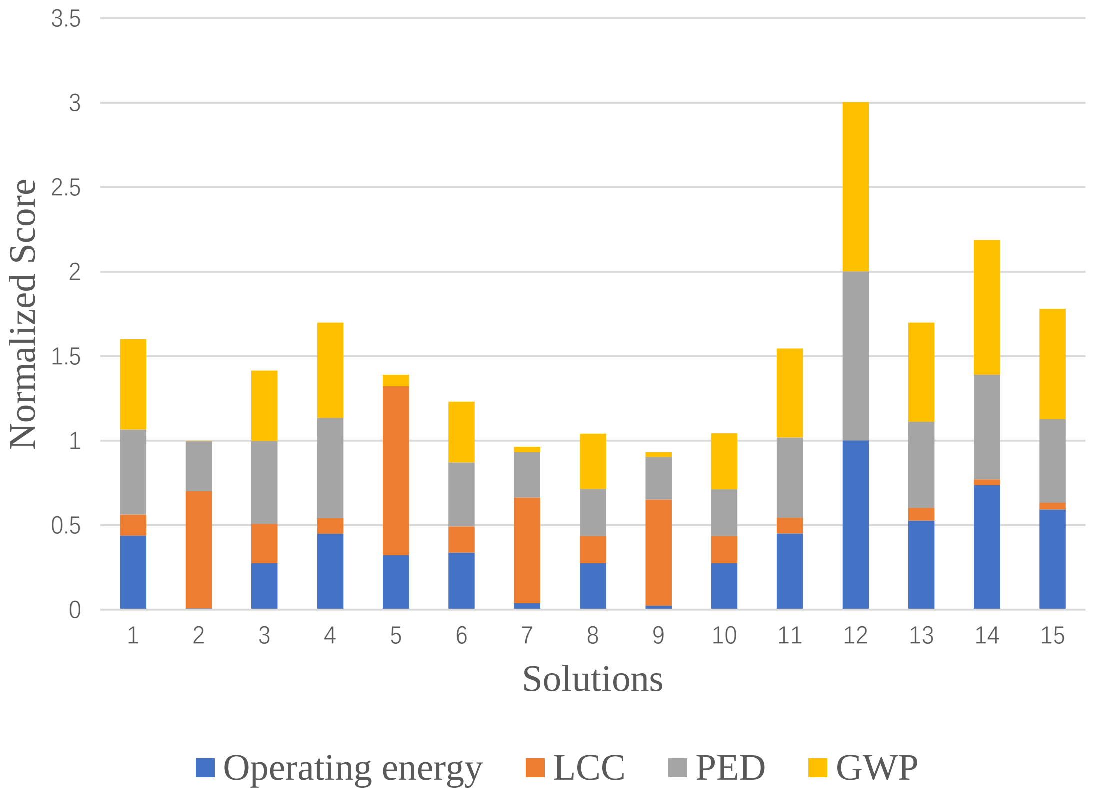


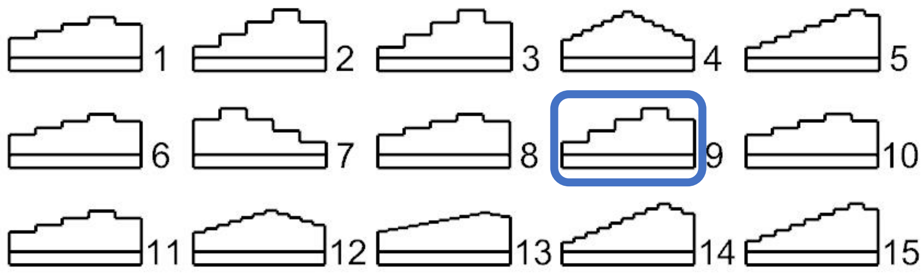


Pareto optimal solution set of OE/LCC/PED/GWP scenario

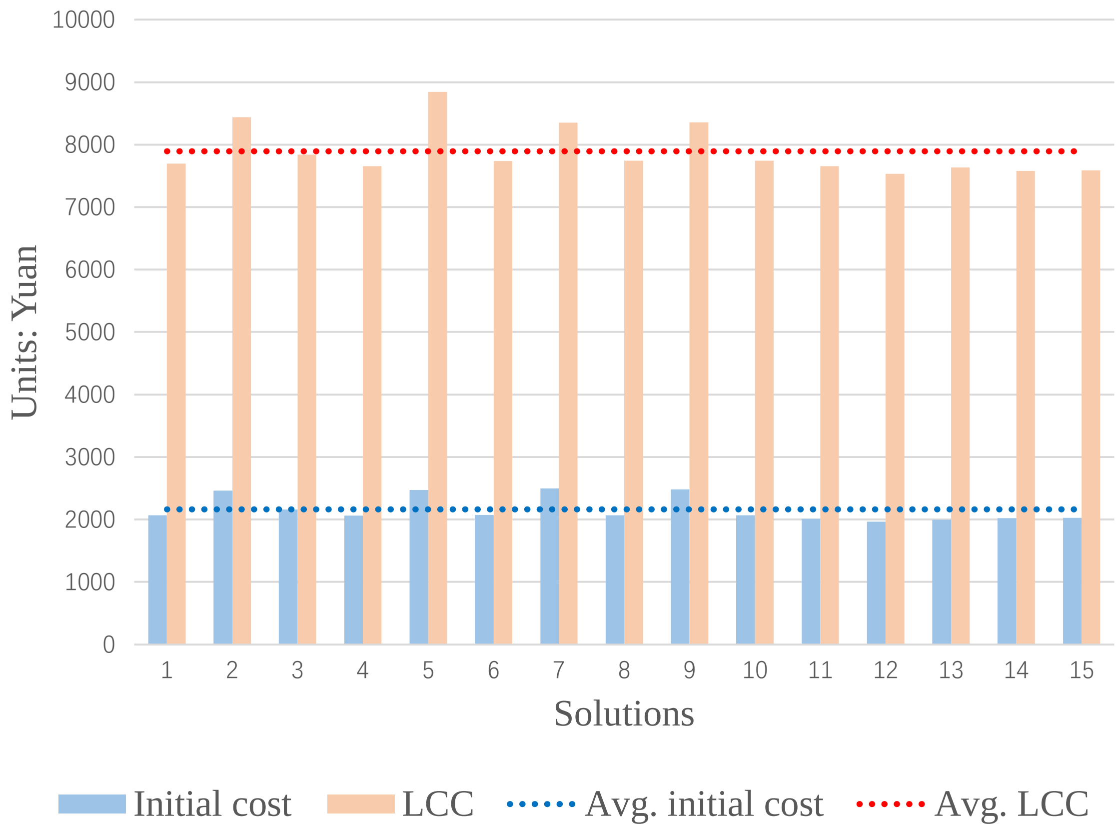


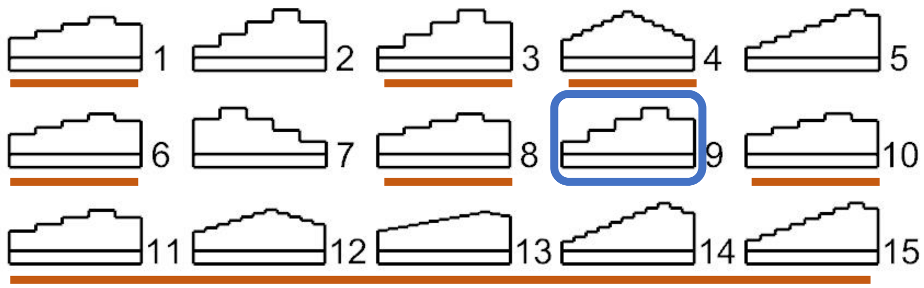
Manual comparison



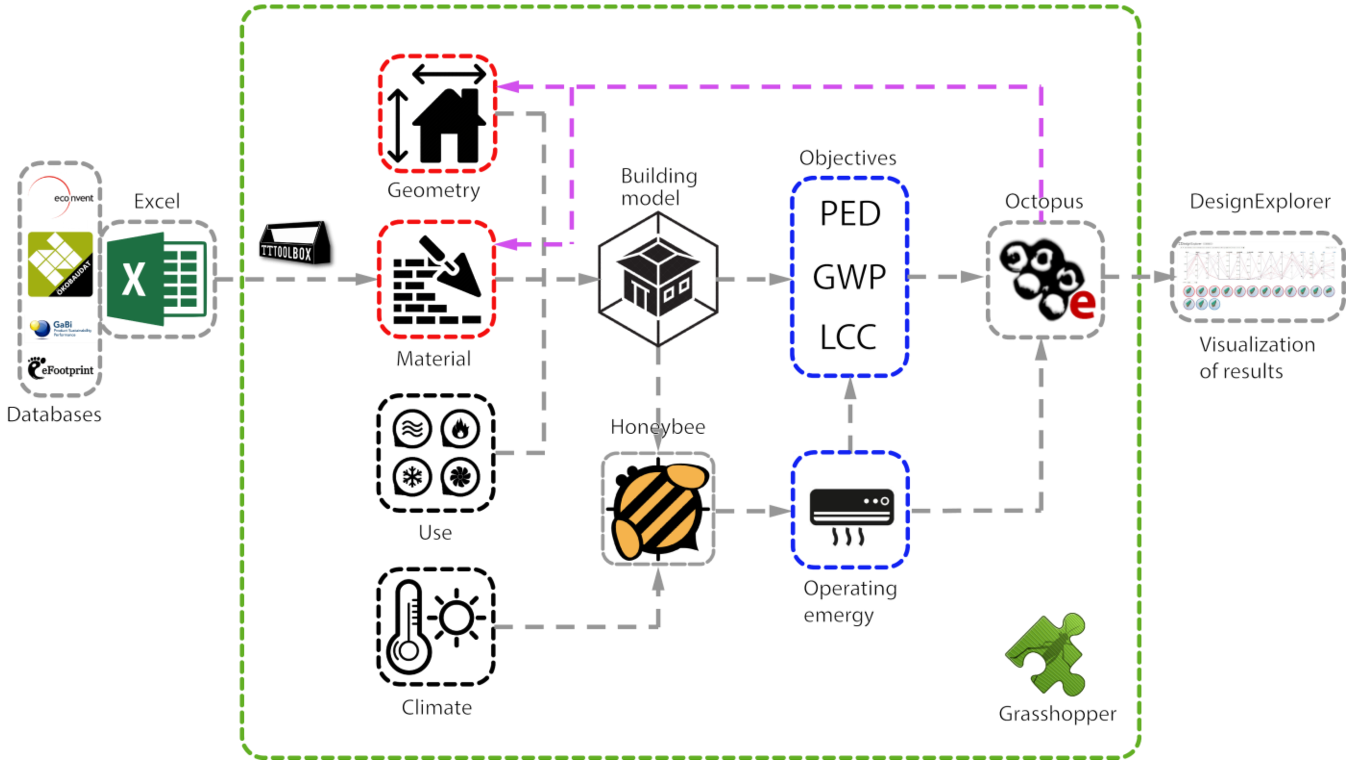


Manual comparison





- A simulation-based parametric approach with geometry and material parameters through the use of multi-objective optimization method in building’s early design stages is framed.

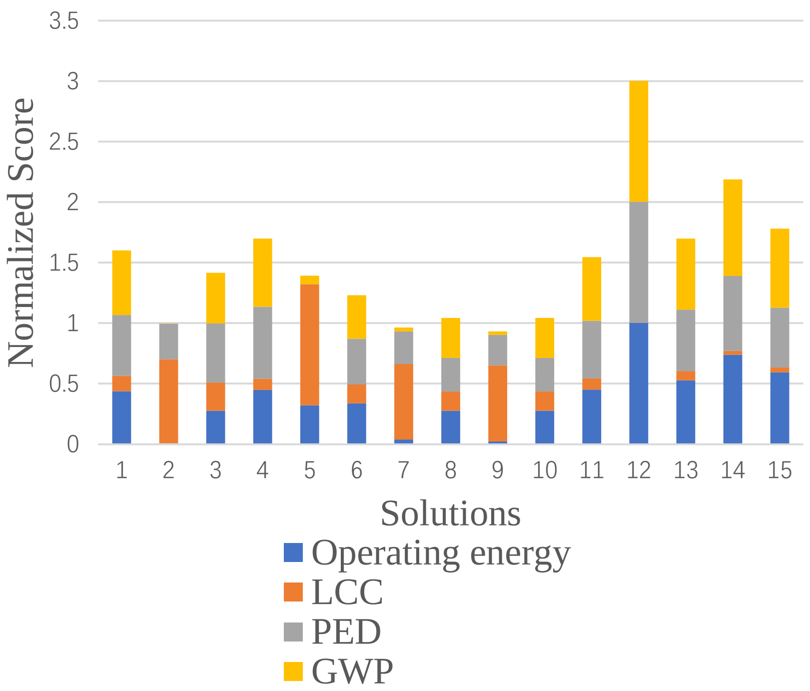


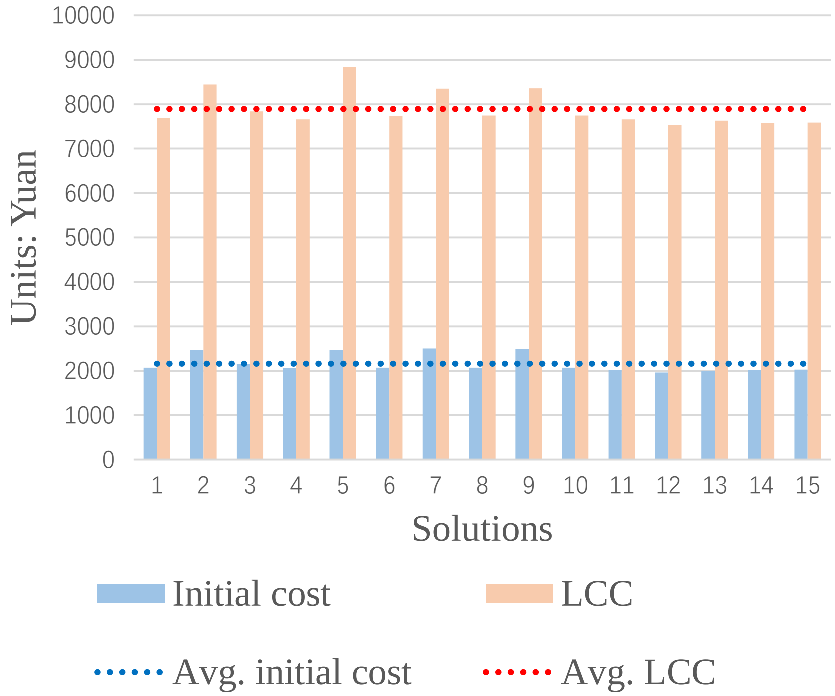
- The optimization objectives should be considered comprehensively; an incomplete set will result in poorly behaviour of the unselected objectives.

Avg.	OE (kWh/m2/a)	LCC (Yuan/m2)	PED (GJ/m2)	GWP (t CO_2 eq/m2)
All	61.02059	7893.475	45.96541	5.524817
NoGWP	60.75454	7966.238	45.88587	5.590589
NoPED	60.27762	8001.24	46.58854	5.398821
NoOE	61.54994	7843.206	45.73808	5.461123
NoLCC	59.60561	8652.74	45.41734	5.320213

Limits

- The geometry model is only for this project and cannot be reused.
- The explanation of results can change from normalization to indicators of each objectives; the average values can be changed to benchmarks.





Thank you for your attention!

09.13.2019 SBE19 Graz

Hanze Yu, Wei Yang, Qiyuan Li

School of Architecture, Tianjin University, 300072, Tianjin, China

hanzeyu@tju.edu.cn (H. Yu), walker_yang@tju.edu.cn (W. Yang), qiyuan_li@tju.edu.cn (Q. Li).