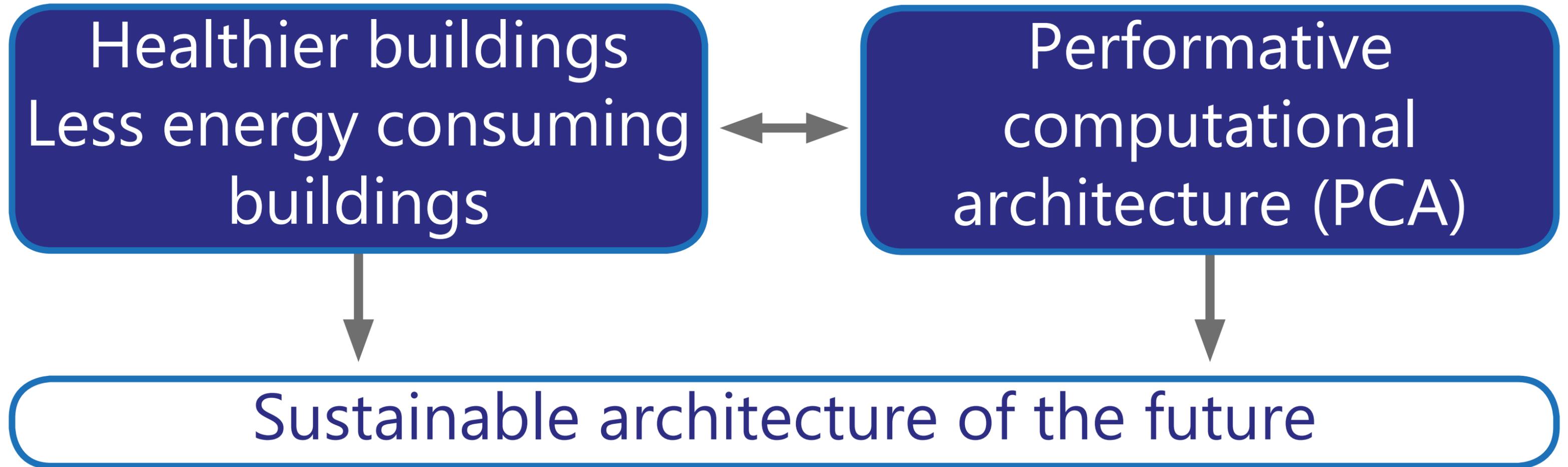


Sun shading of the future

A next generation workflow for applying the performative computational architecture framework to sun shading design, based on an example sun shading system for high-rise office buildings with all-glass exteriors in tropical climates optimised on visual and thermal comfort

Topic framework

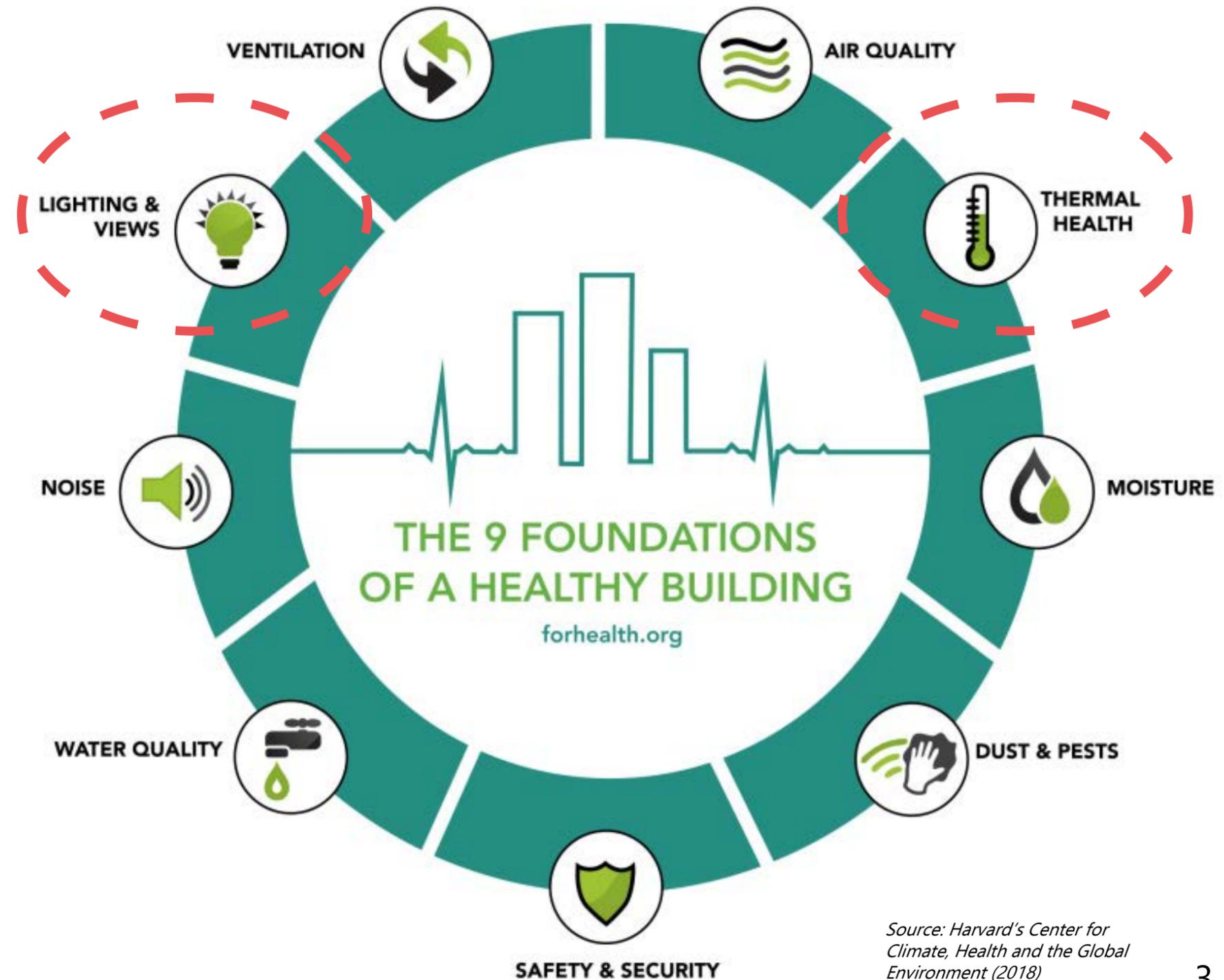


Topic framework

Healthy buildings

Visual comfort

Thermal comfort



Source: Harvard's Center for Climate, Health and the Global Environment (2018)

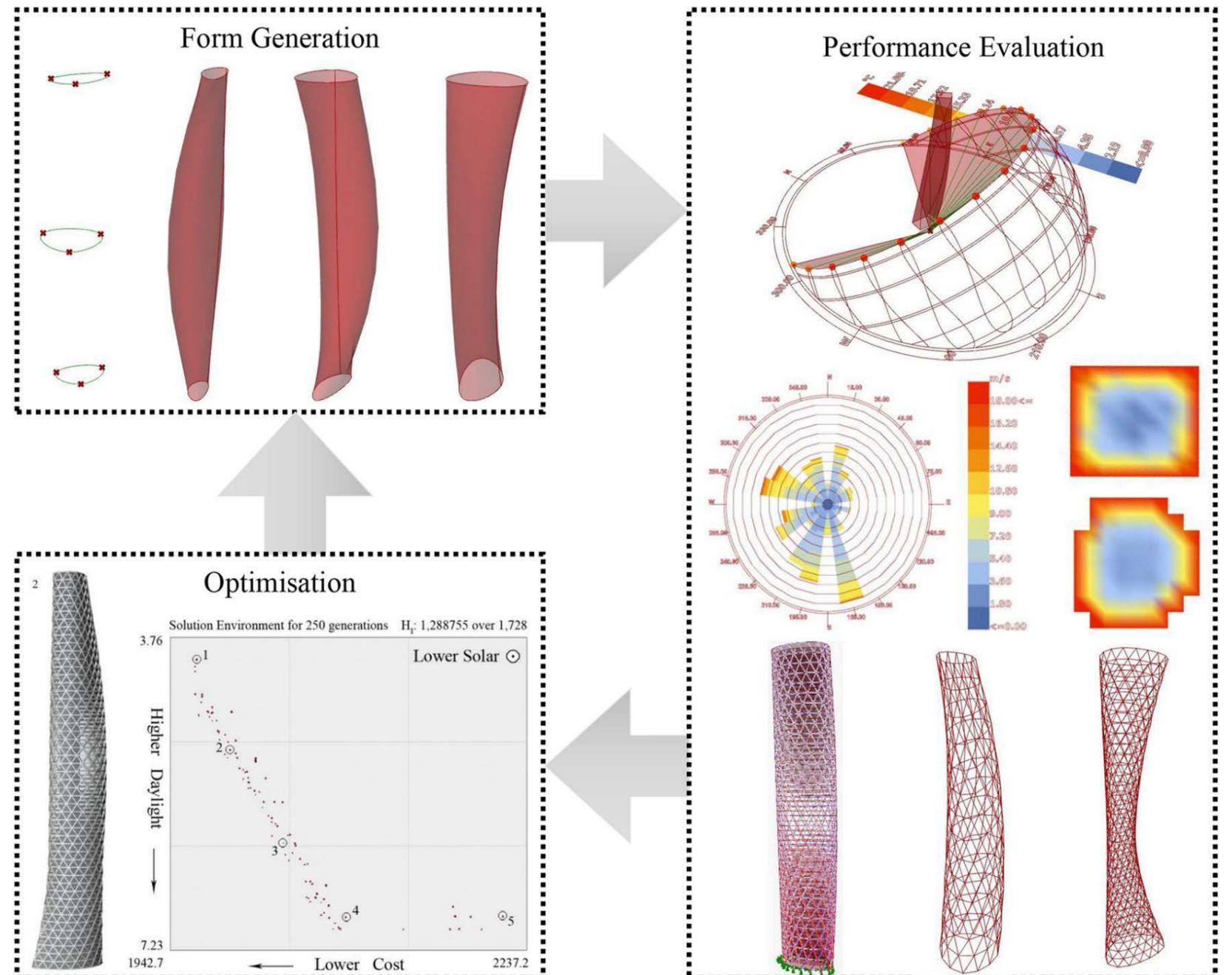
Topic framework

PCA

Parametric modelling

Performance

Optimization



Topic framework

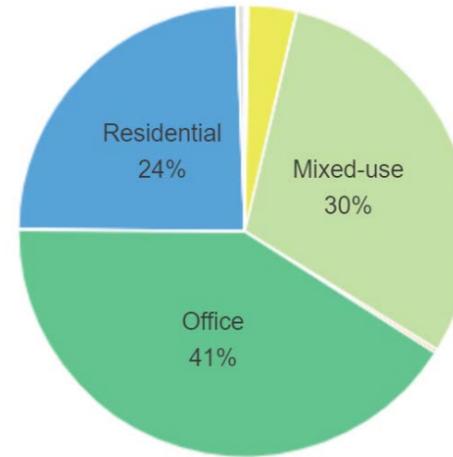
Future architecture

High-rise buildings

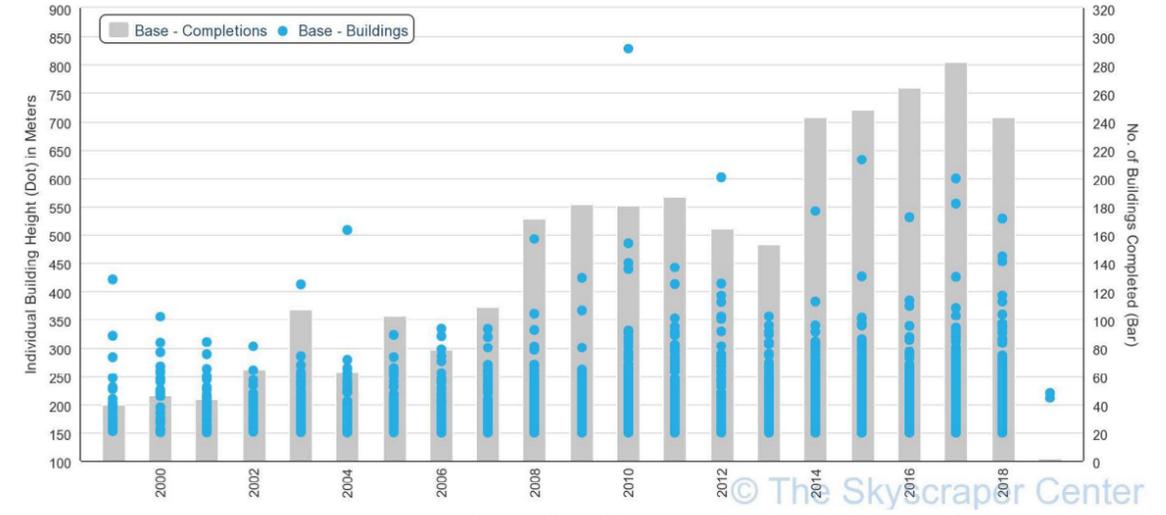
All-glass exteriors

Office function

Tropical climates



Source: Council on Tall Buildings and Urban Habitat, ctbuh.org (2019)



Source: Council on Tall Buildings and Urban Habitat, ctbuh.org (2019)



Source: Google.com (2019)

Research question

“How can the contemporary common Performative Computational Architecture (PCA) workflow for optimising sun shading designs on visual and thermal comfort in high-rise office buildings with all-glass exteriors be advanced to the next generation?”

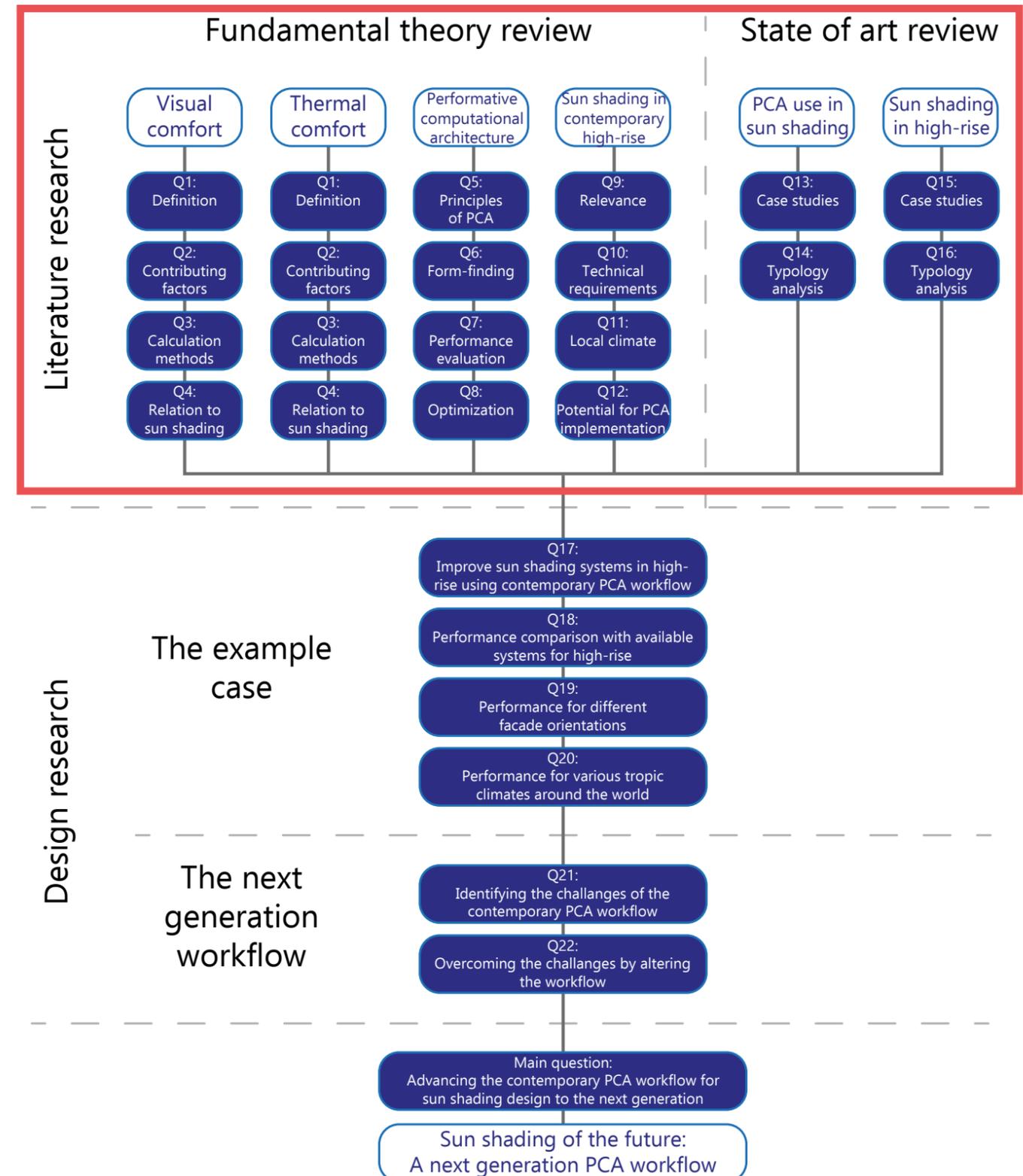
Sub-questions: Literature

Fundamentals:

1. Visual comfort
2. Thermal comfort
3. The PCA framework
4. Sun shading in contemporary high-rise

State of the art:

5. PCA workflow in sun shading design
6. Sun shading in high-rise office buildings with all-glass exterior in tropic climates



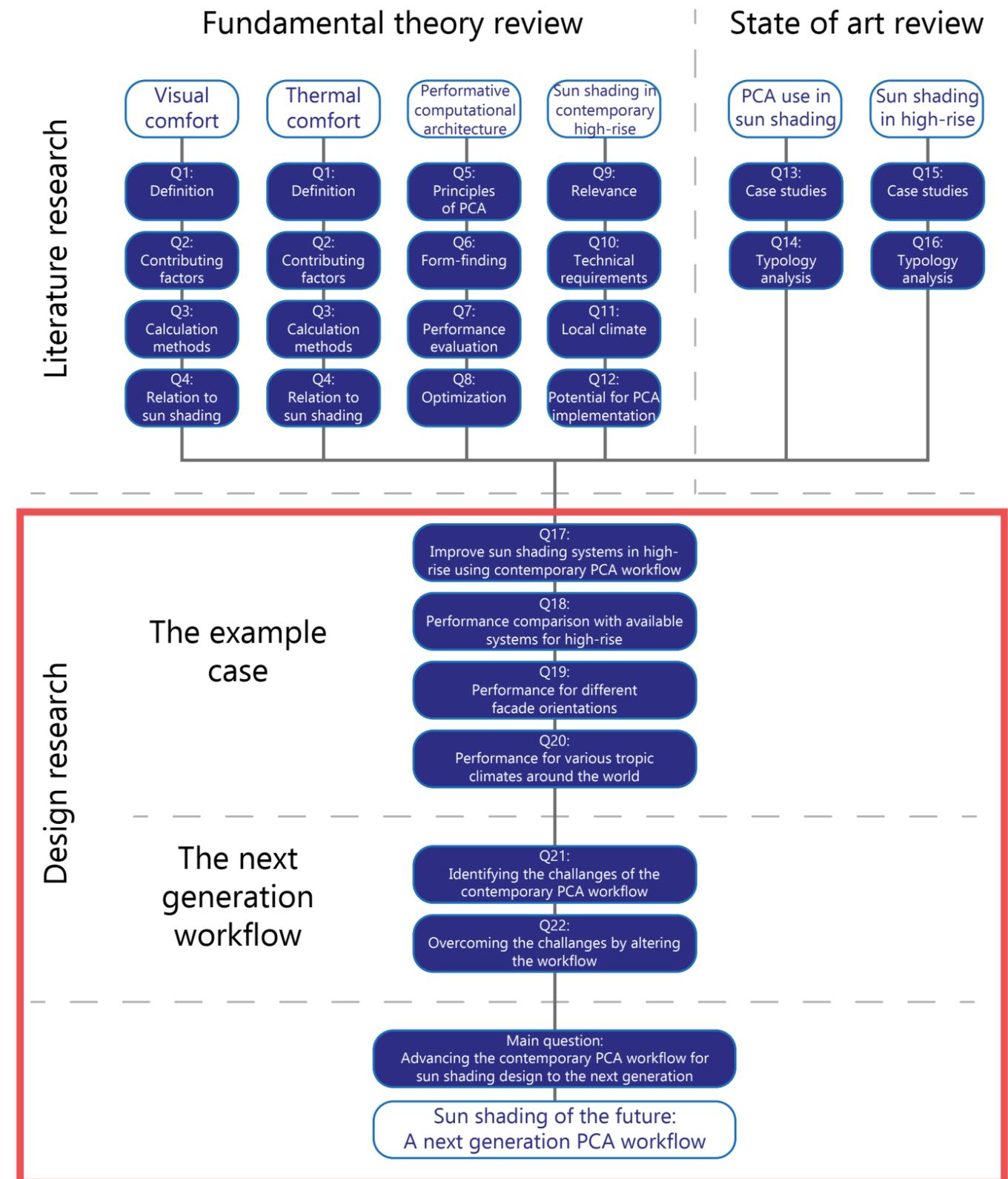
Sub-questions: Practical

Example case:

1. Improve sun shading system using the contemporary common workflow
2. Performance compared to other systems
3. Performance for different orientations
4. Performance for various tropic climates

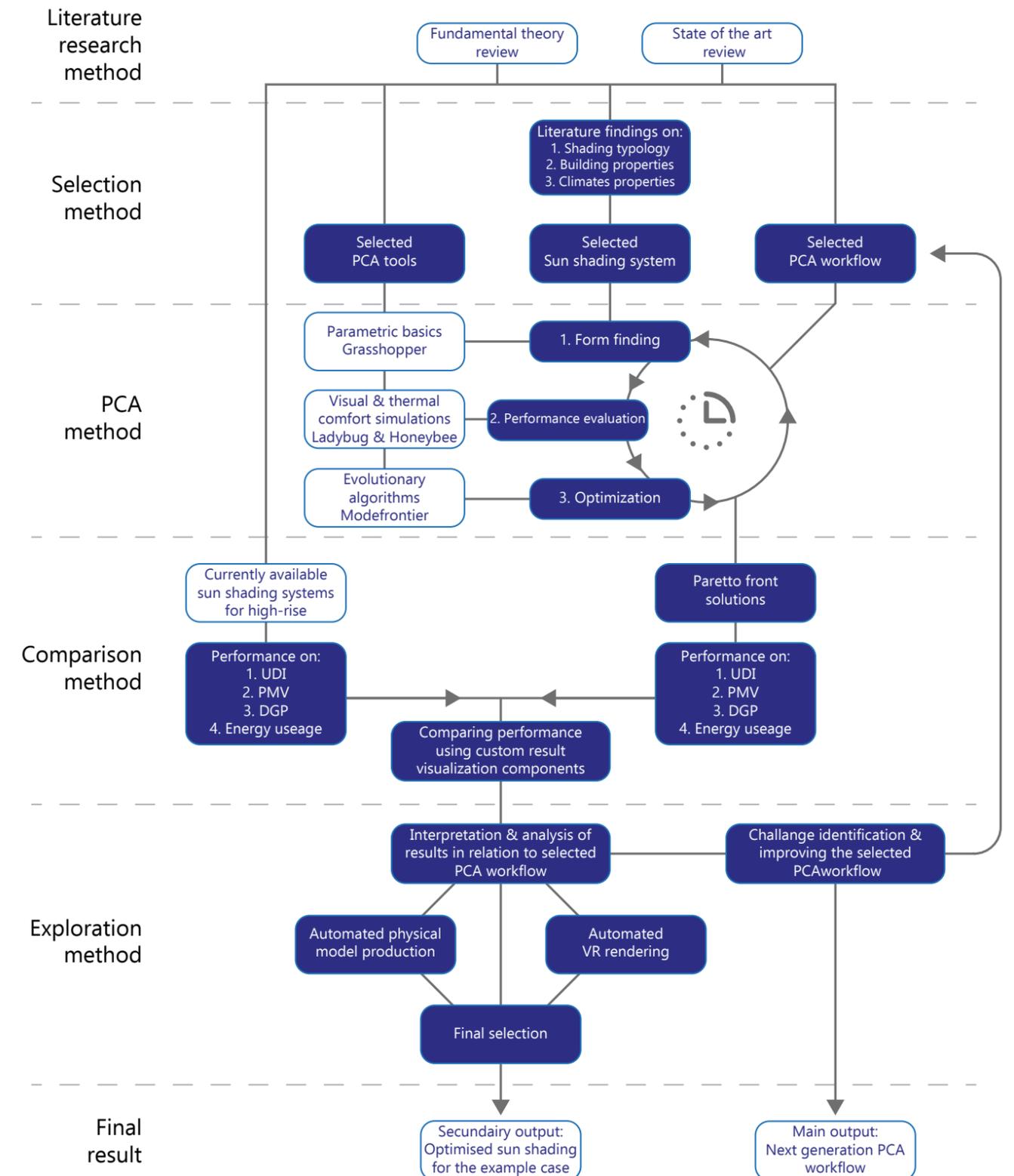
Next generation workflow:

5. Identify the challenges
6. Developing the new workflow



Research methodology

1. Literature research phase
2. Selected sun shading system
3. The contemporary common PCA workflow
4. Example case: Form-finding
5. Example case: Performance evaluation
6. Example case: Optimisation
7. Performance comparison
8. Exploration of the example case
9. The next generation workflow



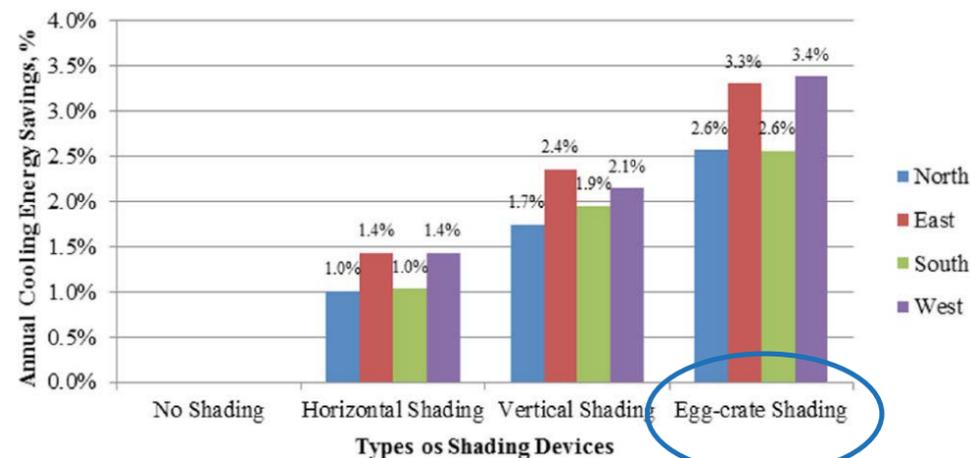
Selected sun shading system

Shading typology:

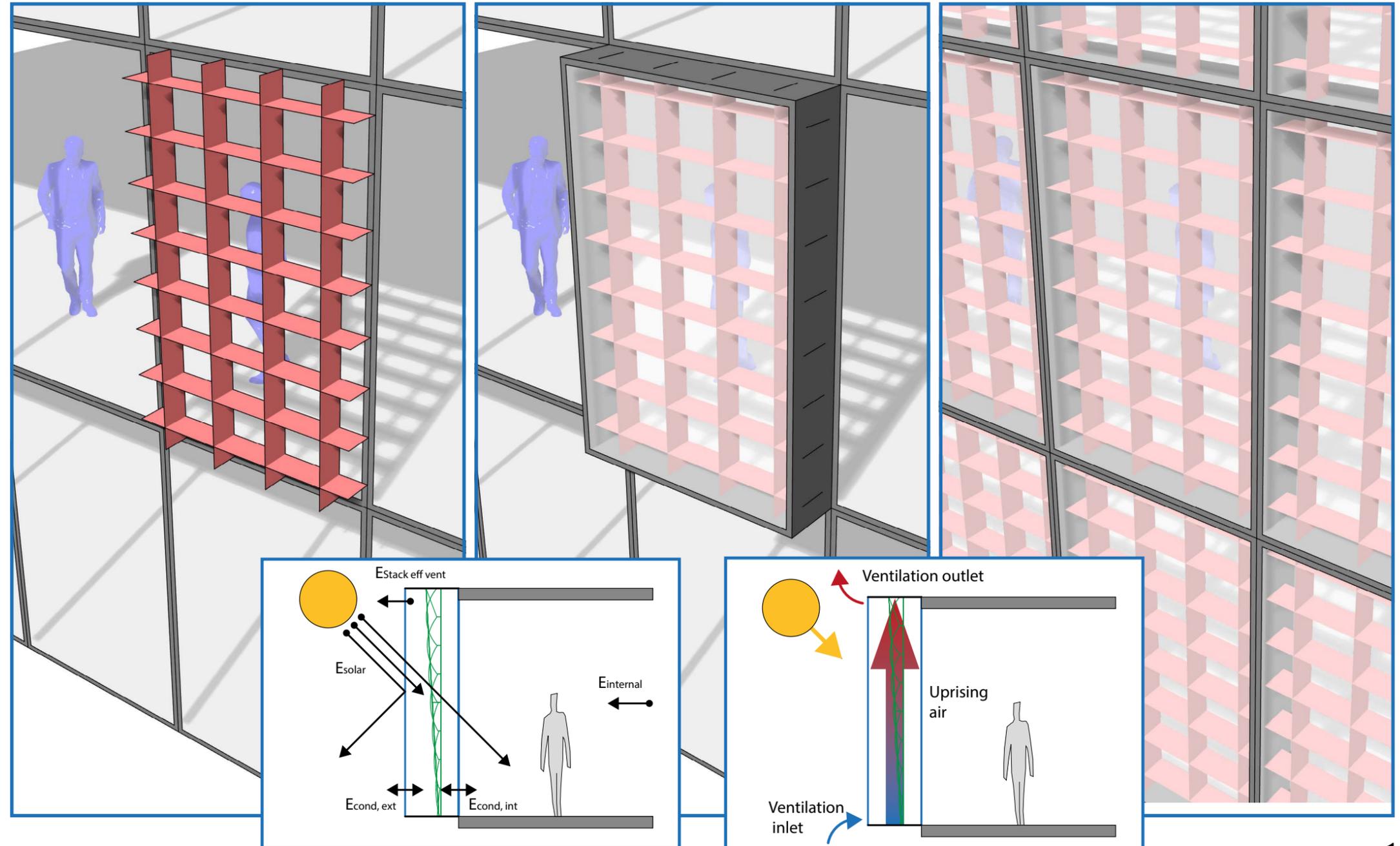
Egg-crate shading system
 Double skin integrated

Substantial potential:

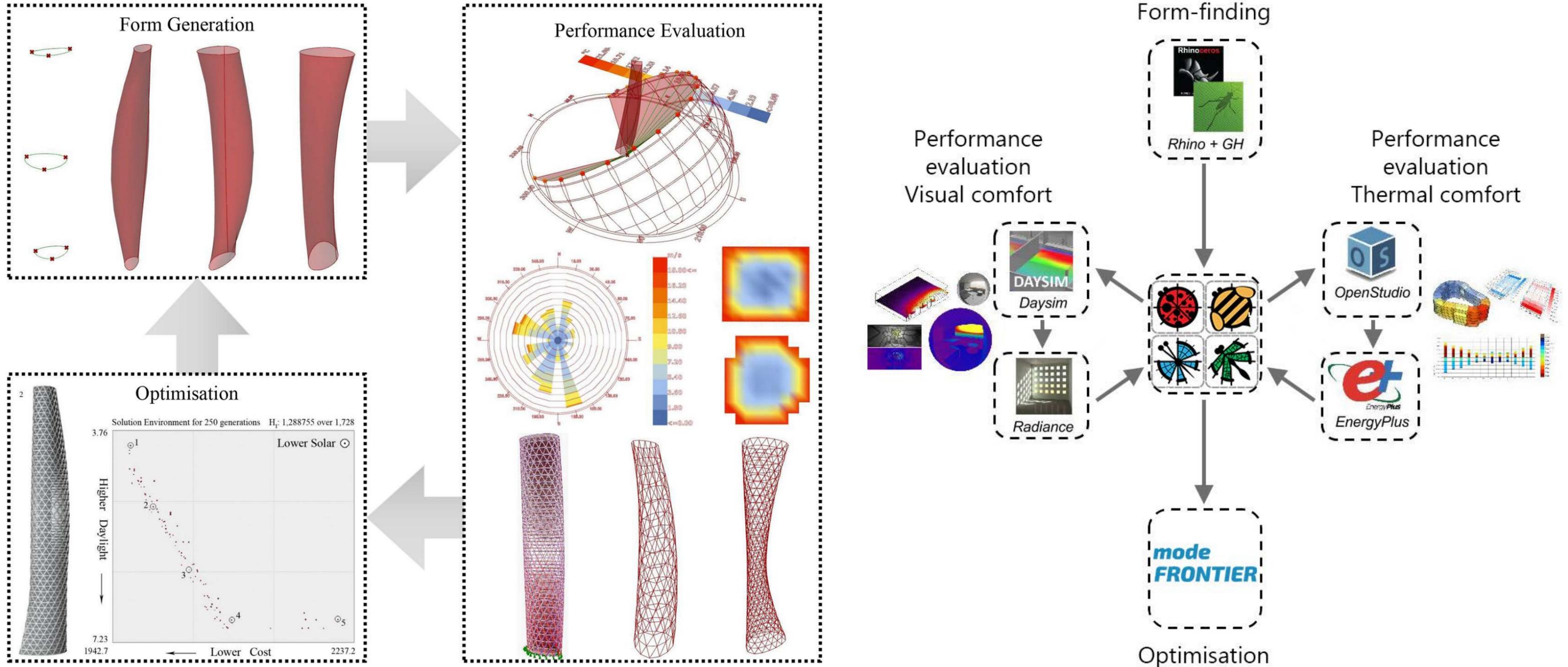
Proven in relevant literature
 Building properties
 Climate properties



Source: Lau et al. (2016)



The contemporary common PCA workflow



Source: Ekici et al., 2019

Source: Food4rhino.com (2019),
edited by author

The contemporary common PCA workflow

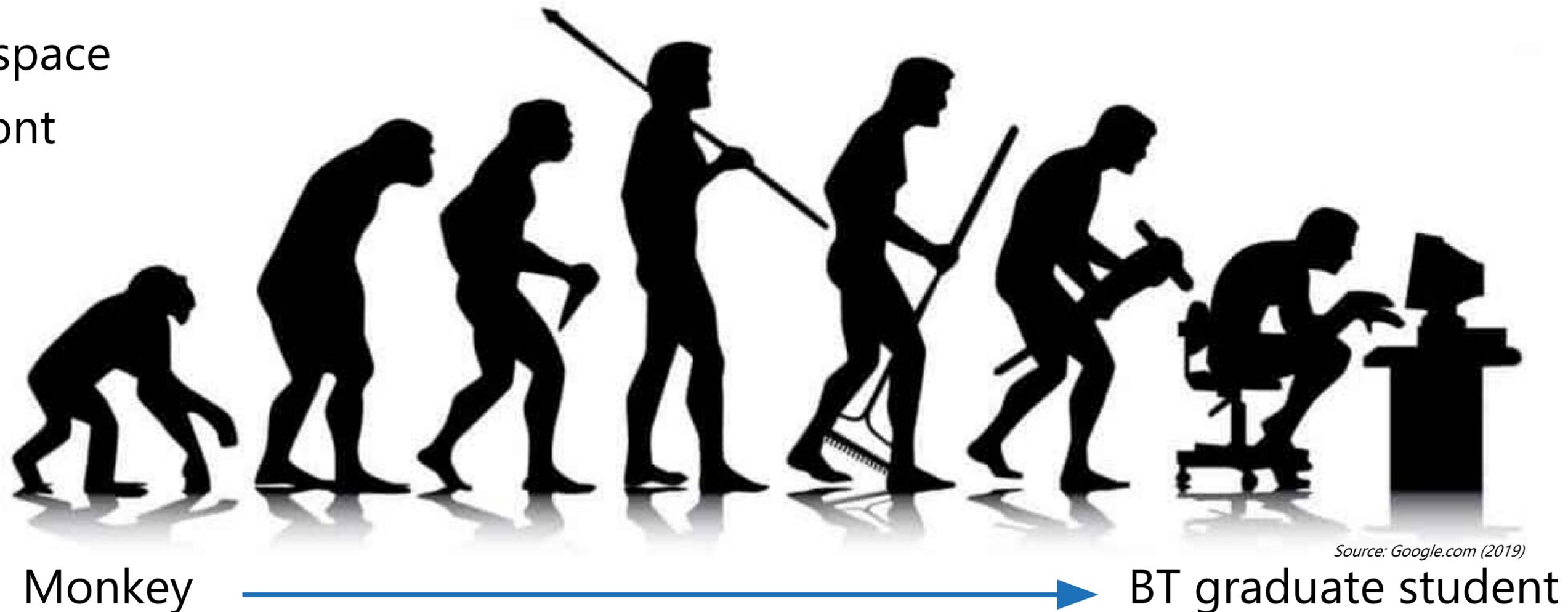
Evolutionary search algorithms:

Darwin's evolution theory

Natural selection

Solution space

Pareto front



The contemporary common PCA workflow

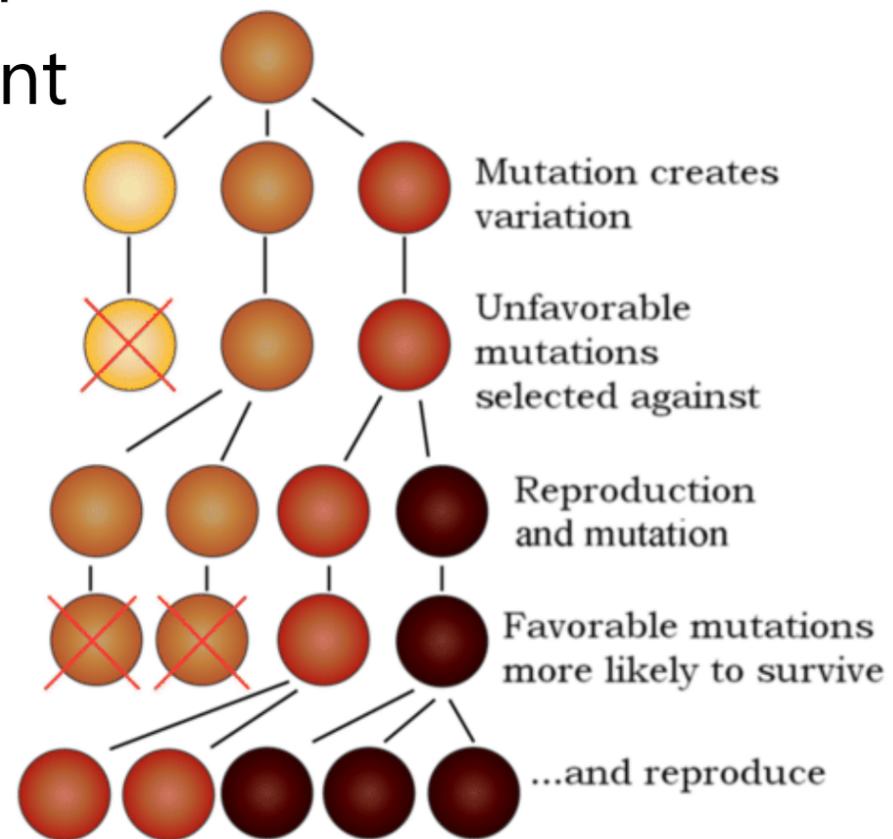
Evolutionary search algorithms:

Darwin's evolution theory

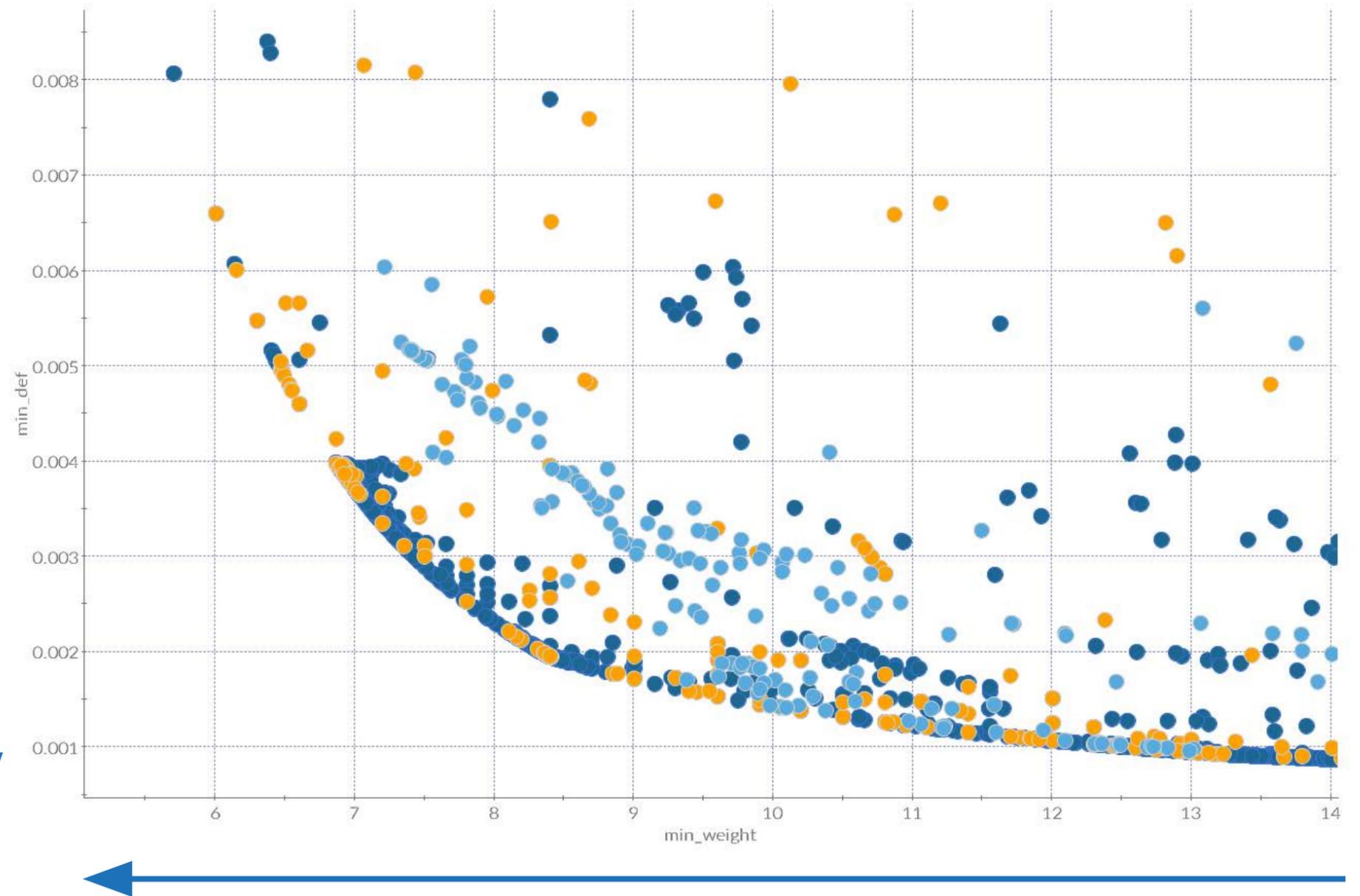
Natural selection

Solution space

Pareto front

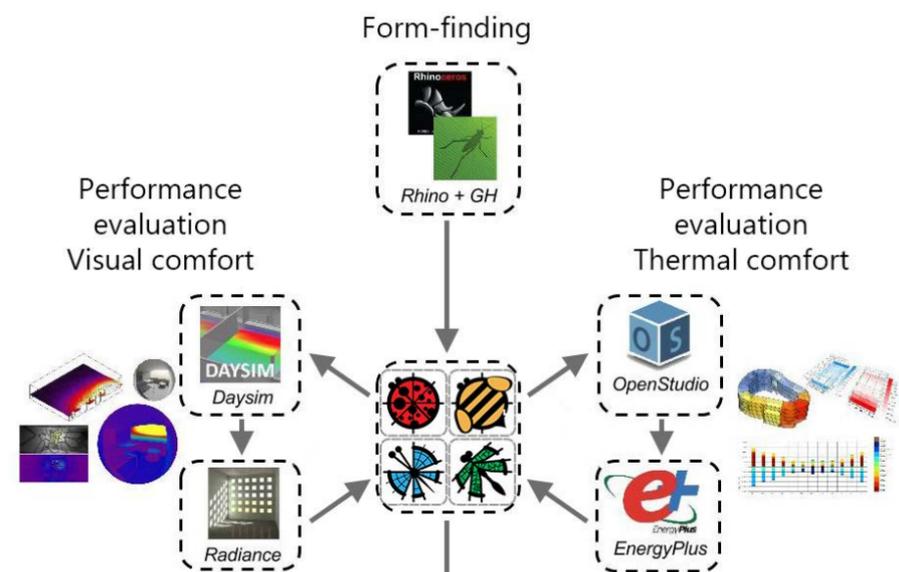
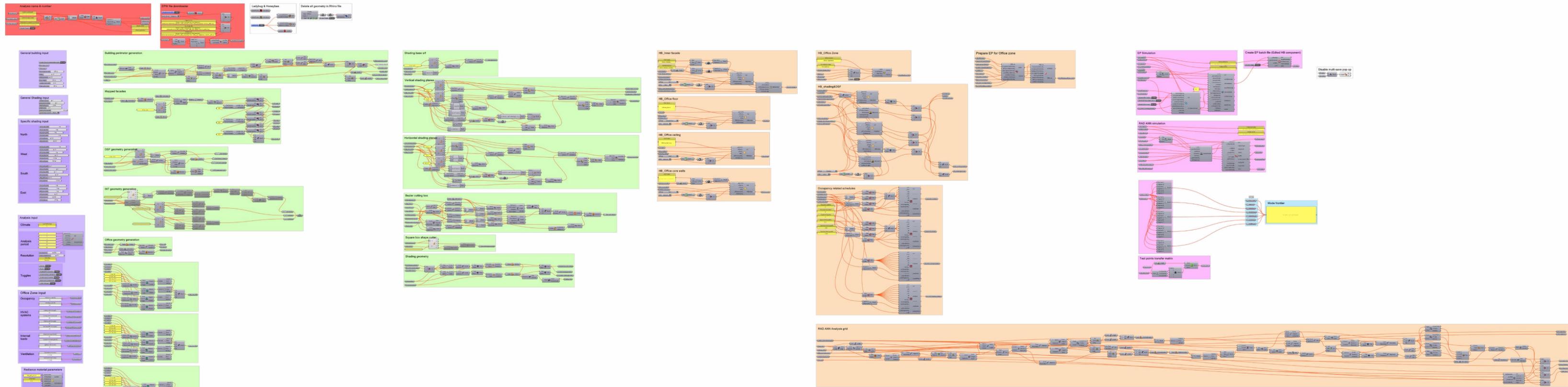


Source: Google.com (2019)

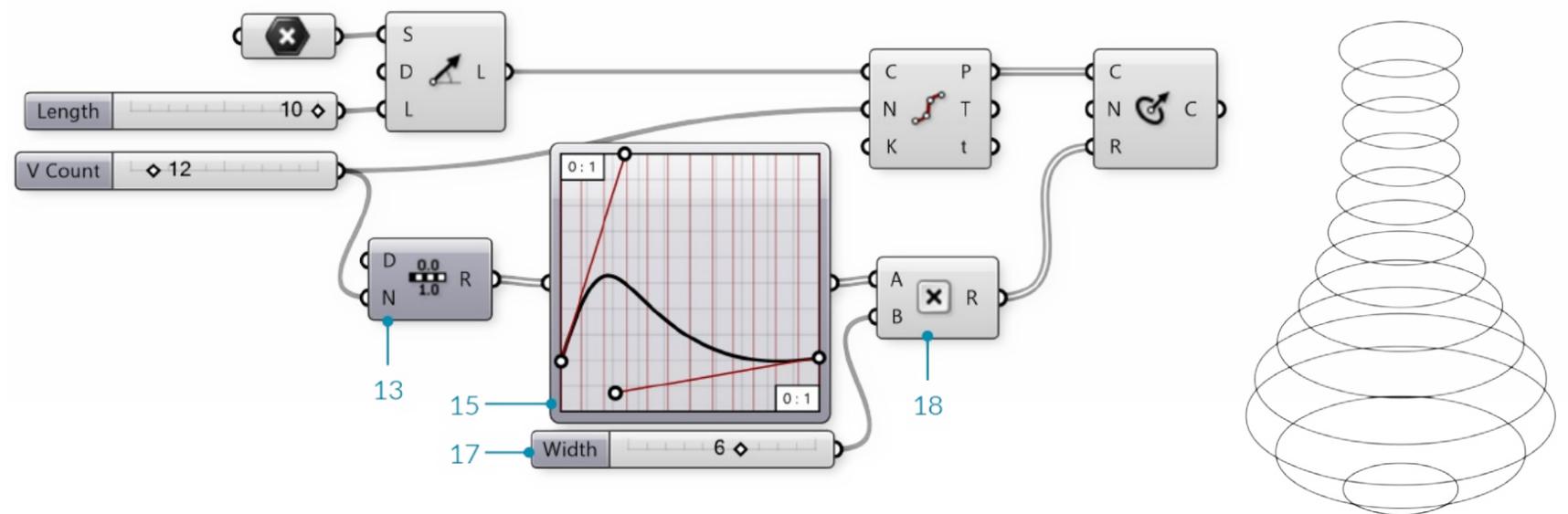


Source: Esteco.com (2019)

The example case: Form-finding

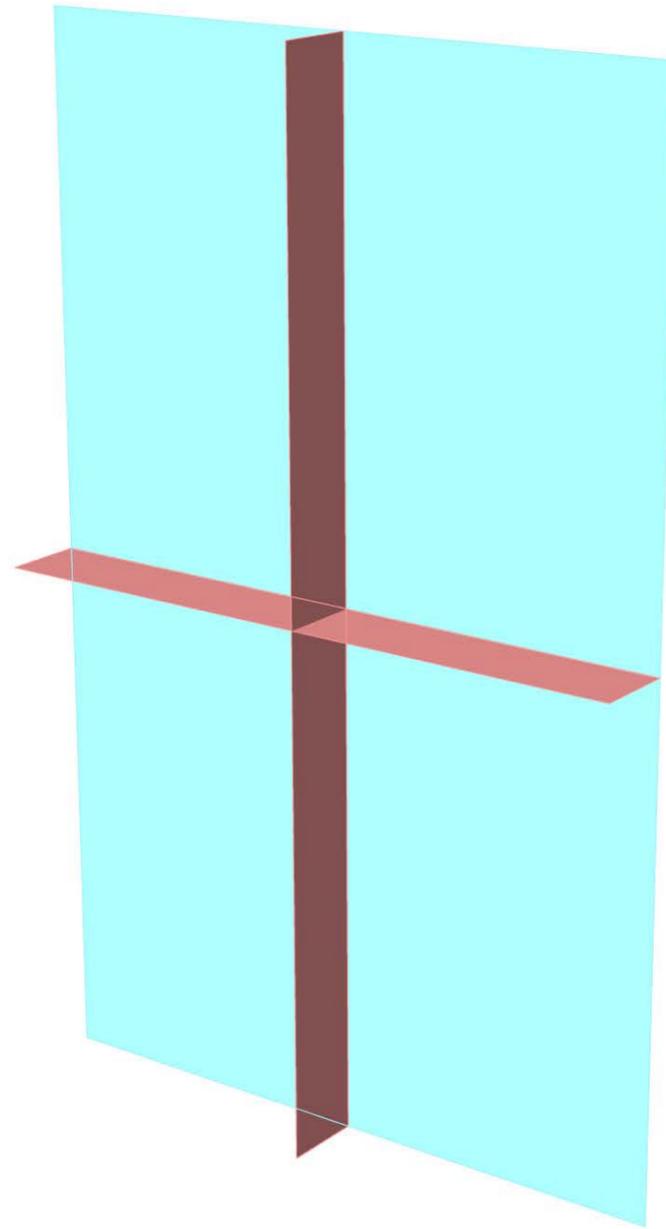


Source: Food4rhino.com (2019)



Source: Grasshopper manual, grasshopper3d.com (2019)

The example case: Form-finding



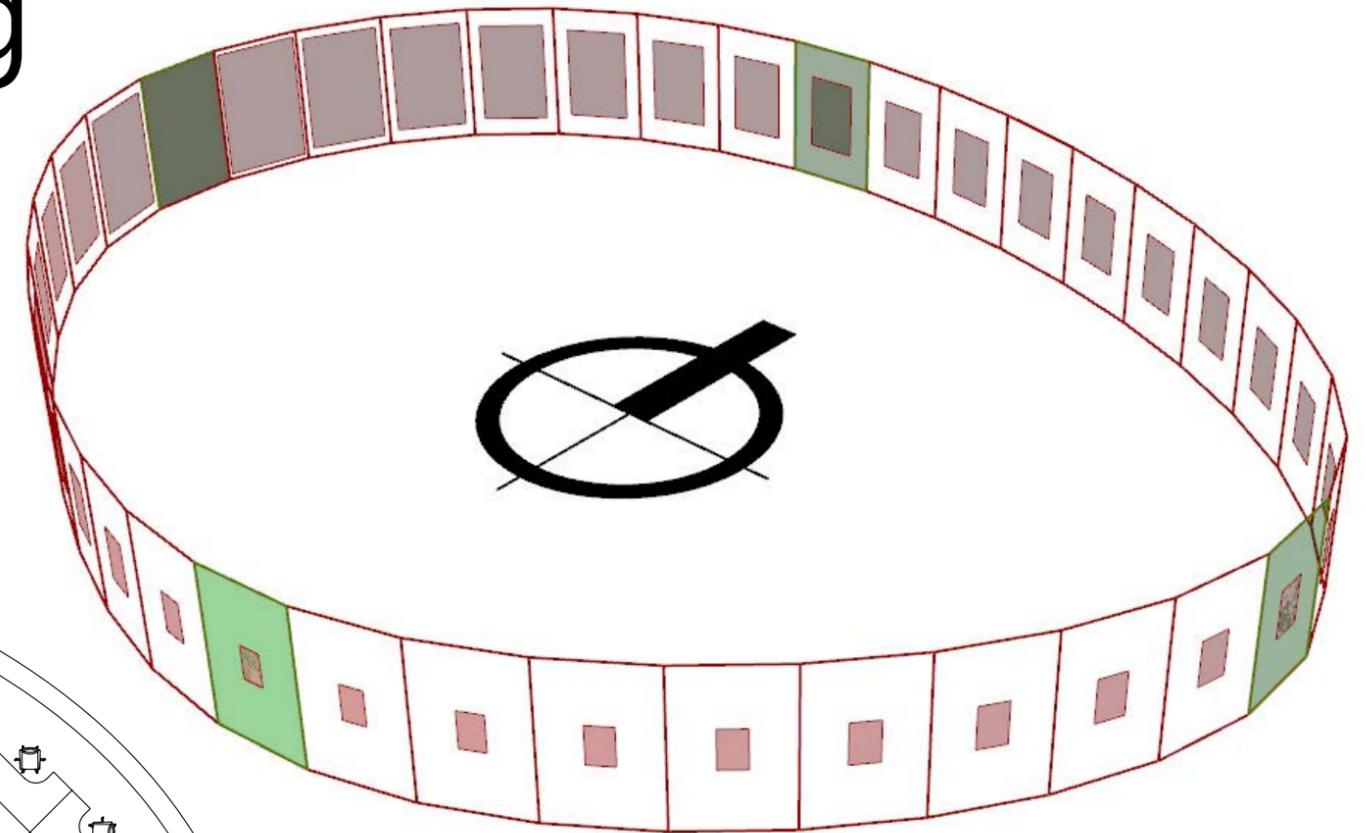
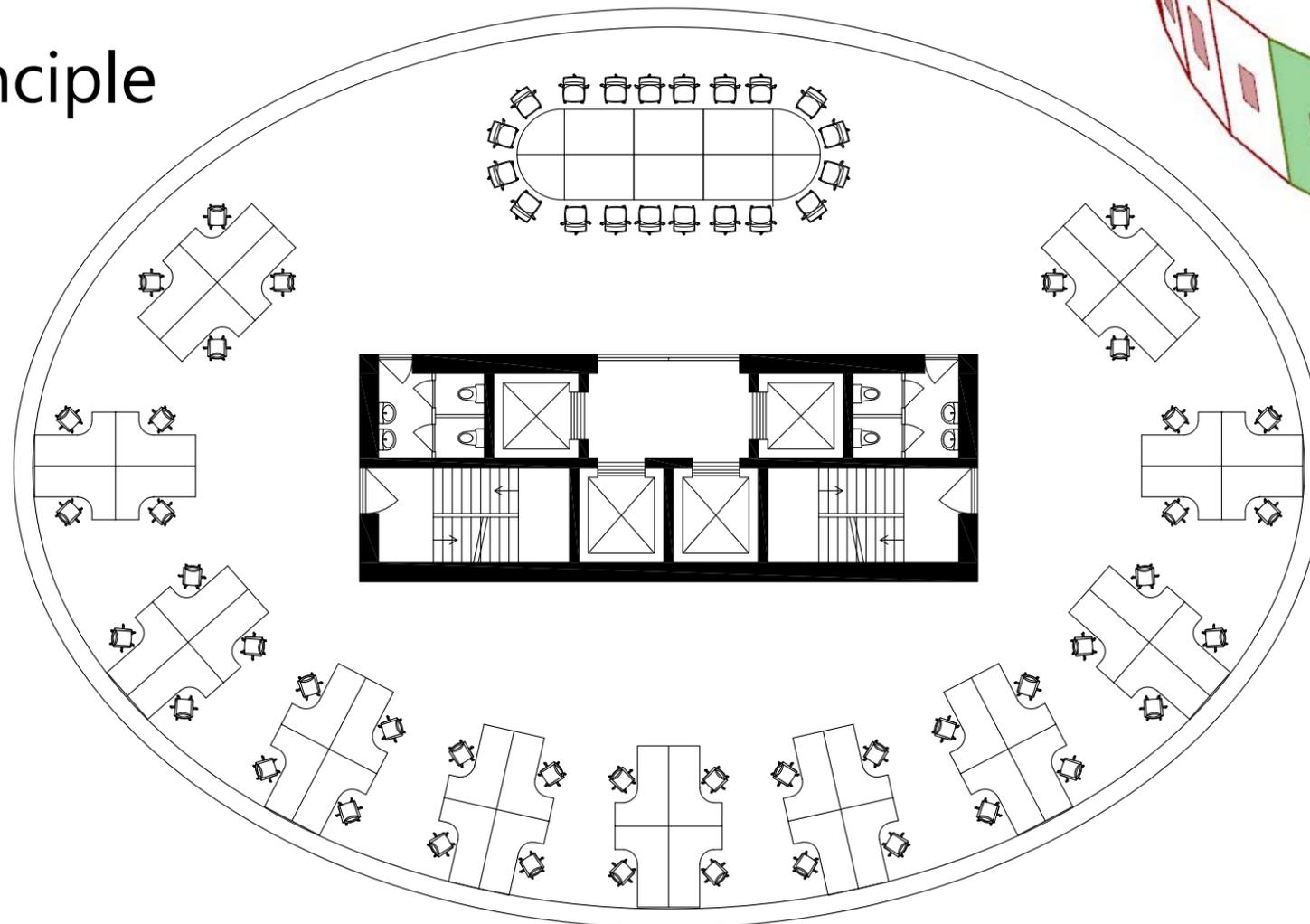
The example case: Form-finding

The building design:

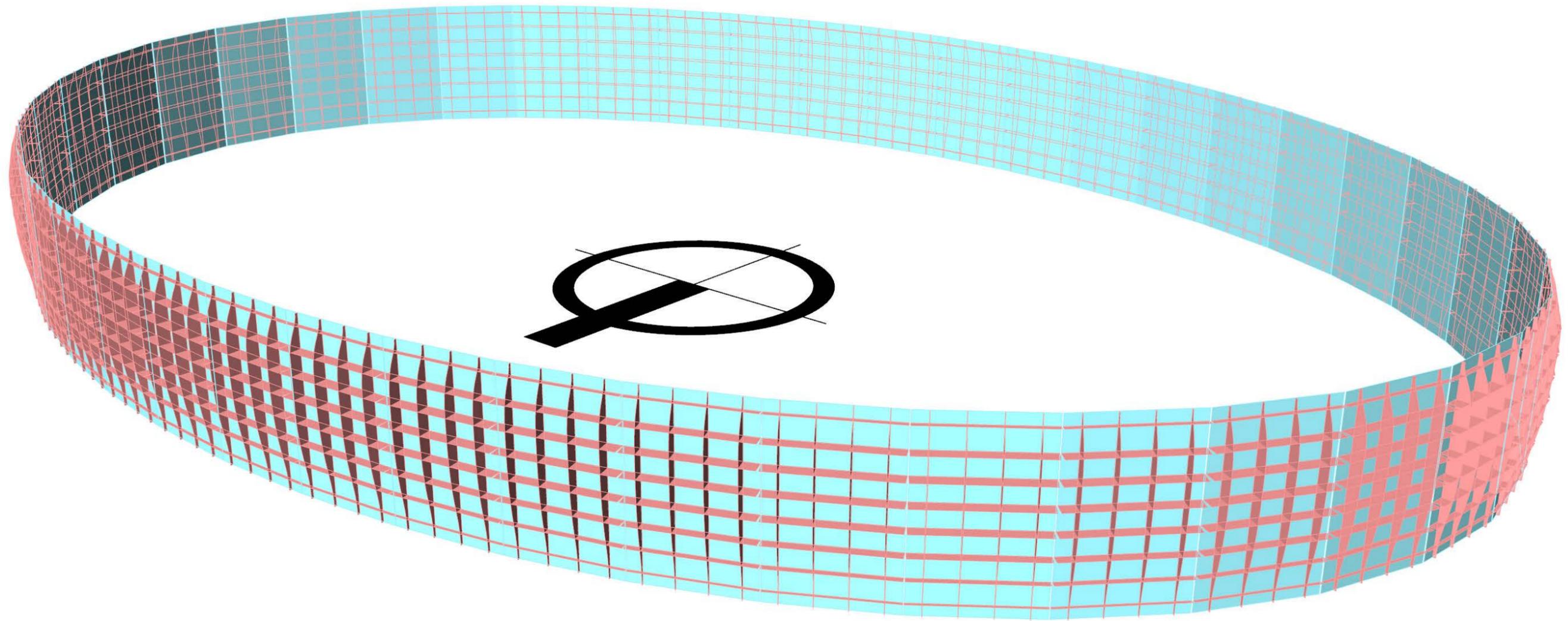
Open office floorplan

Entire floor

Interpolation principle



The example case: Form-finding



The example case: Performance evaluation

Three tropic climates:

1. Singapore:

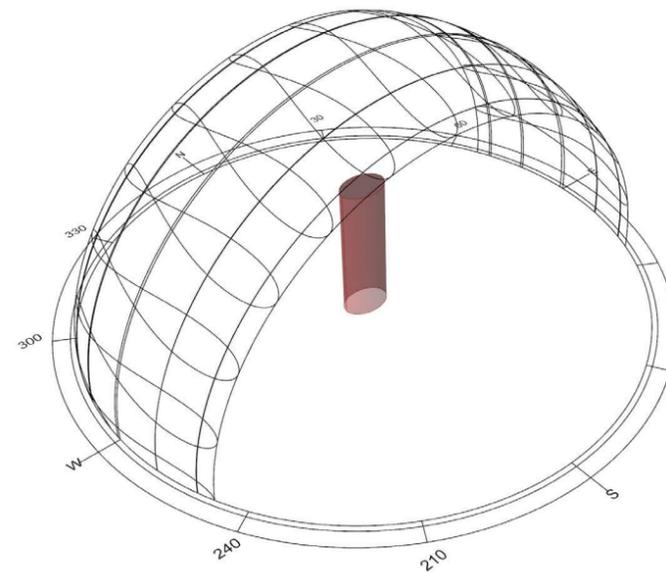
Tropical rainforest climate

2. Abu Dhabi:

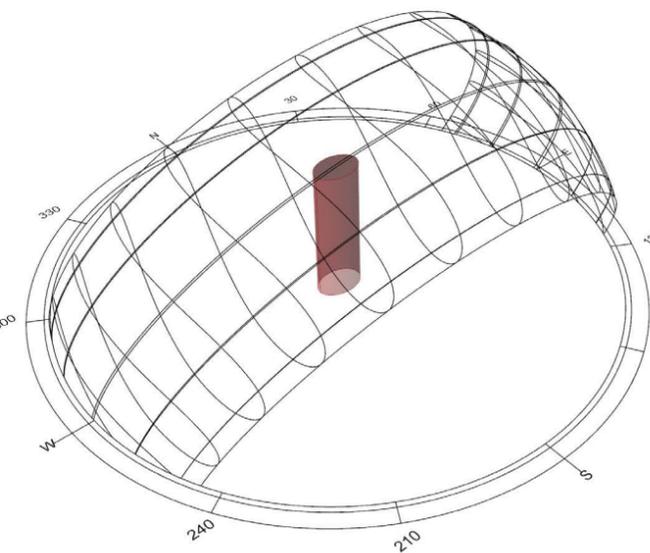
Hot desert climate

3. Brisbane:

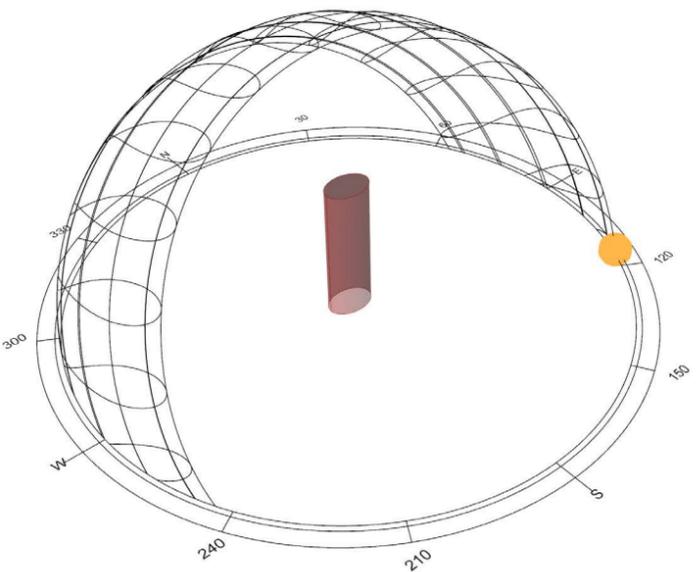
Humid sub-tropical climate



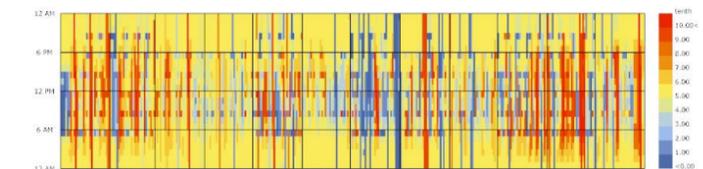
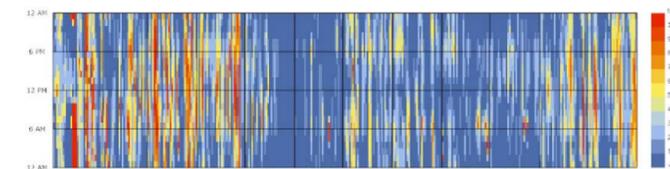
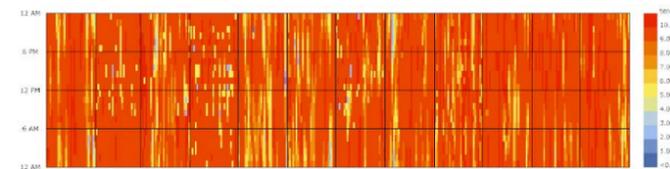
Singapore June/December



Abu Dhabi June/December

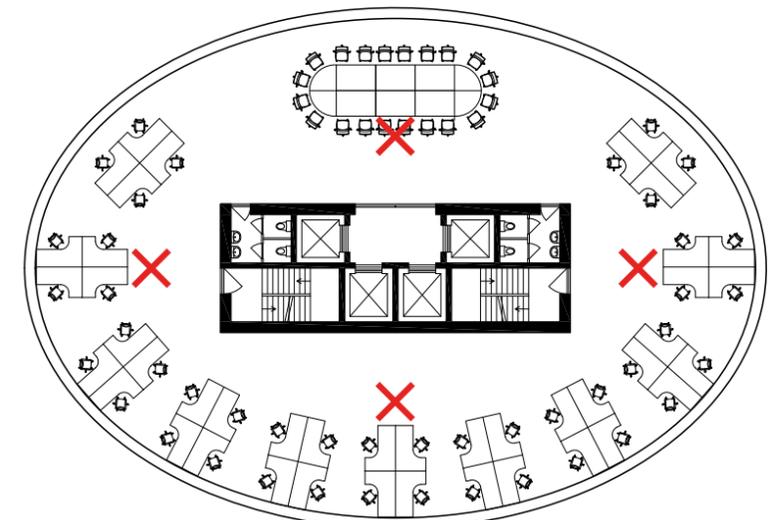
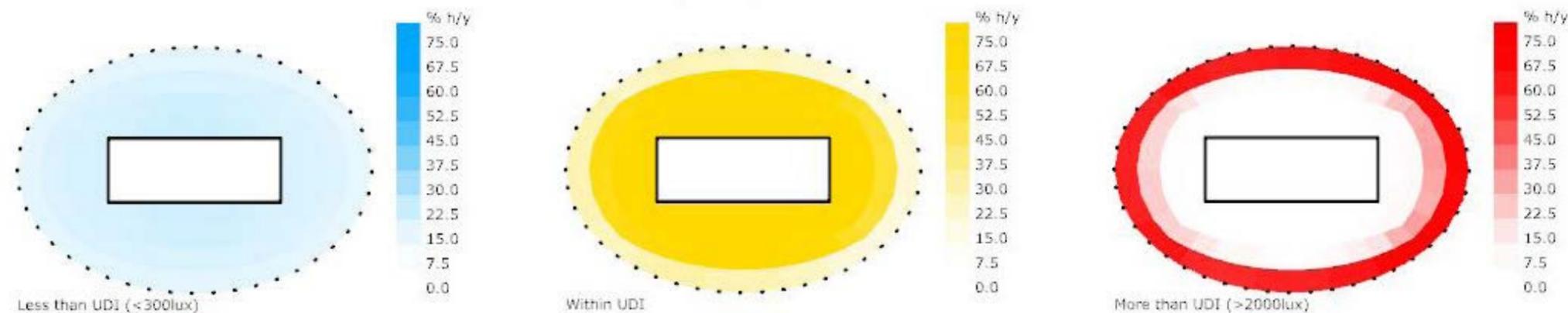
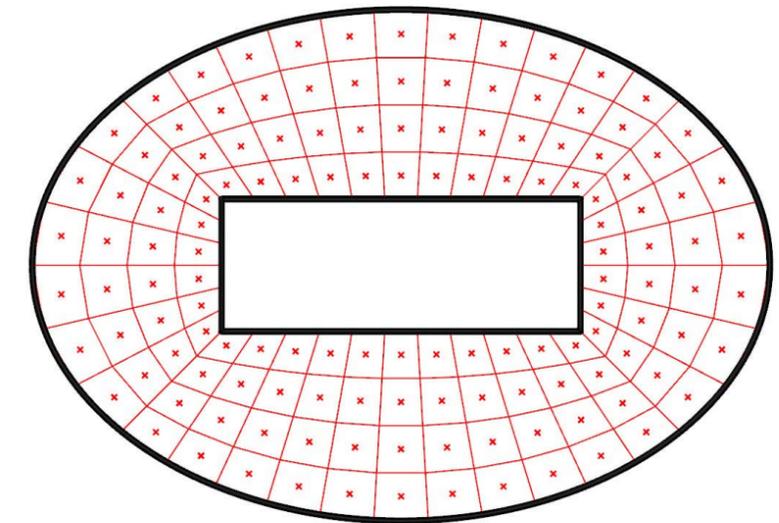
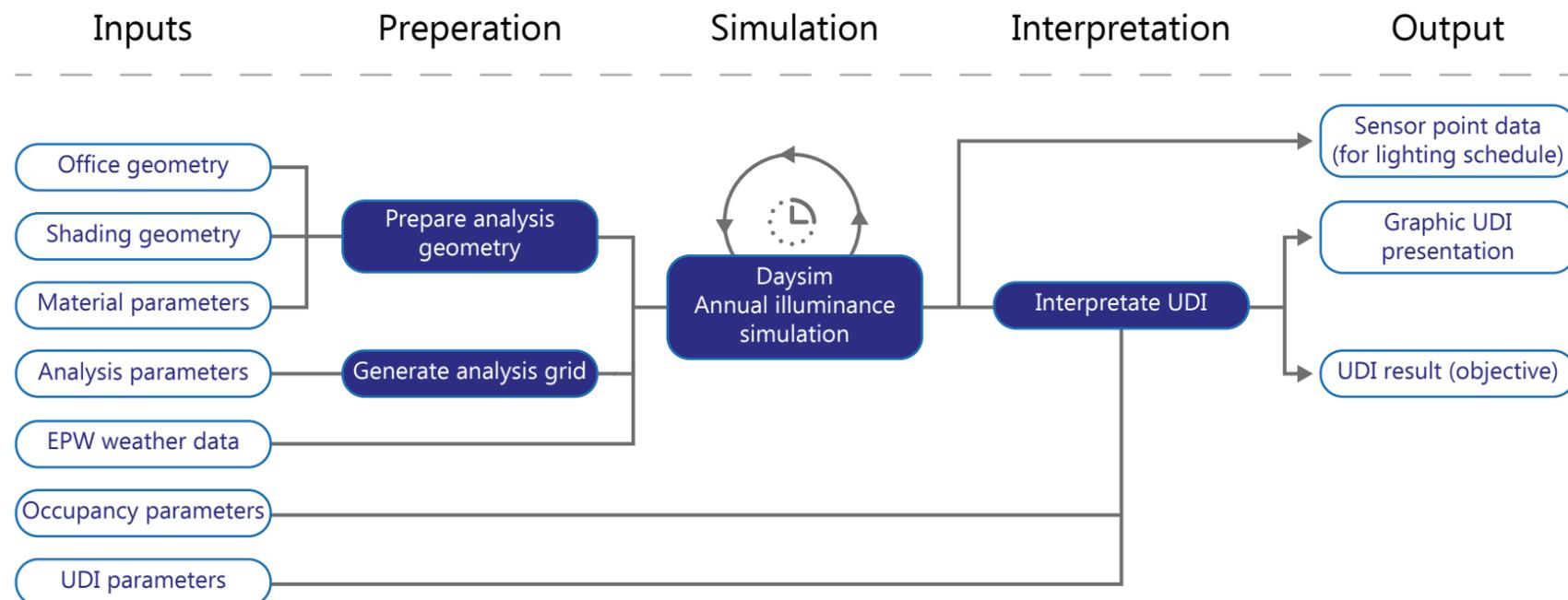


Brisbane June/December



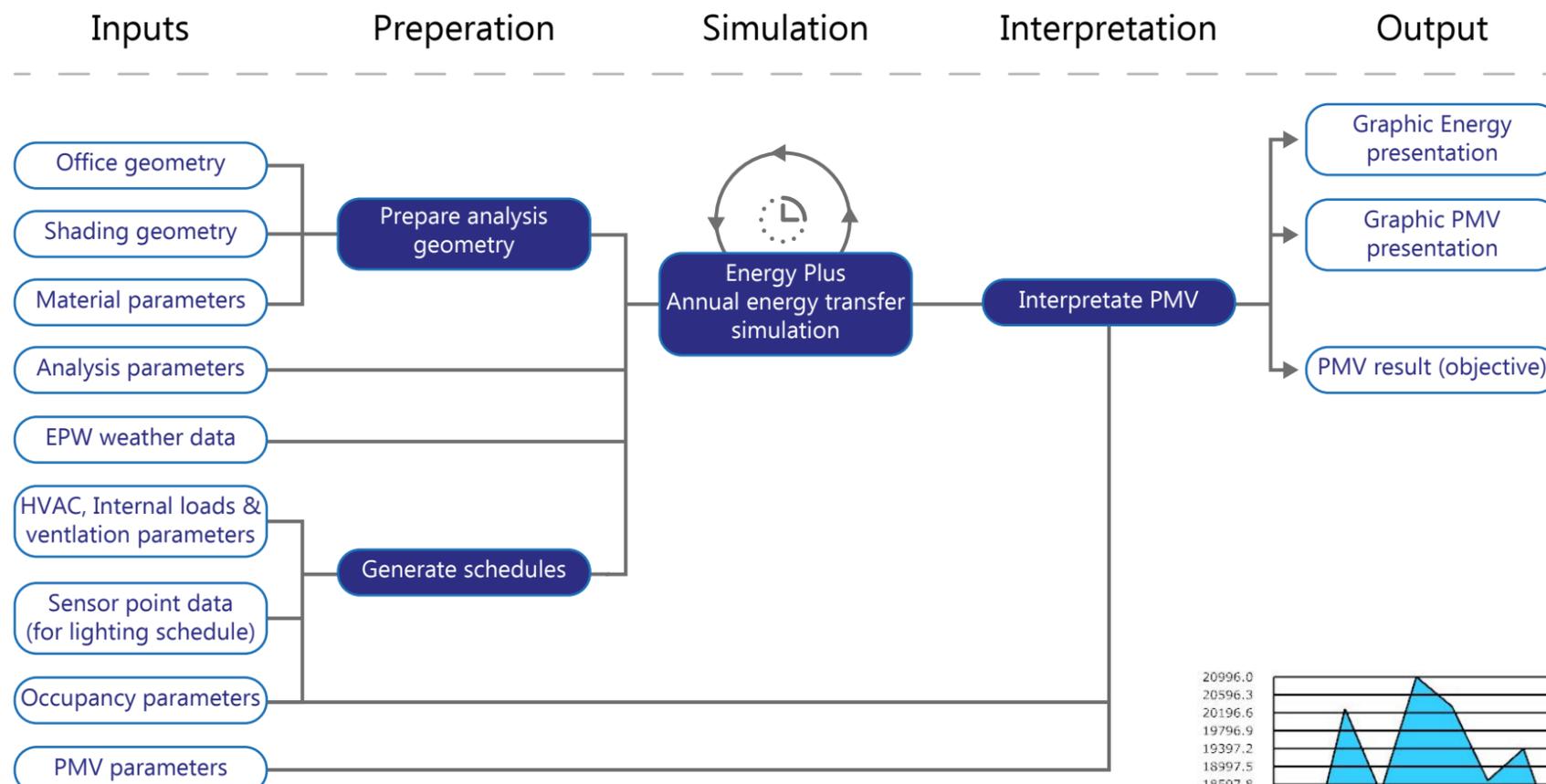
Performance evaluation: Useful Daylight Index (UDI)

Percentage of floor area receiving between 300 and 2000 lux for at least 75% of the annual occupation hours

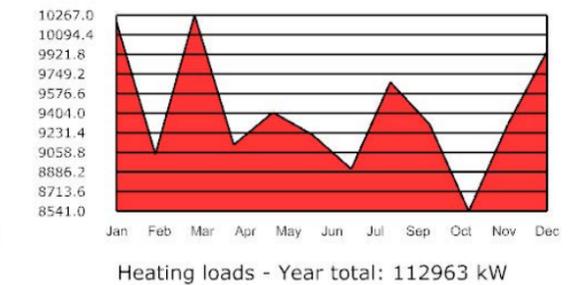
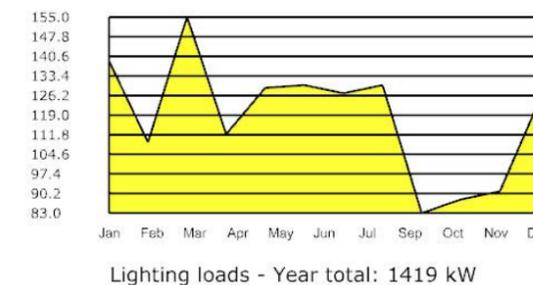
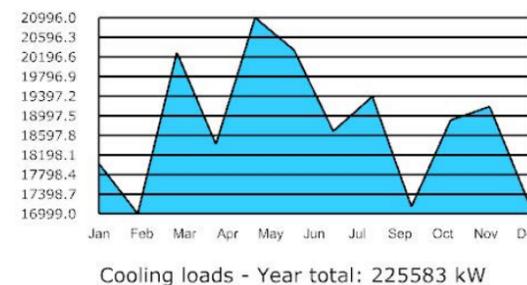
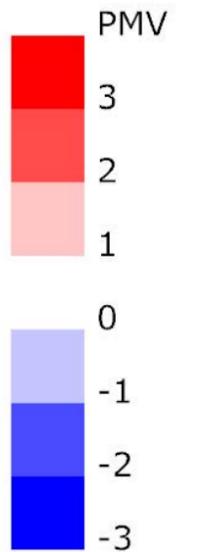


Performance evaluation: Predicted Mean Vote (PMV)

Sum of annual hourly exceedances of the PMV comfort zone (between -0,5 and 0,5)



00:00	-2.1	-1.89	-1.32	-0.75	-0.11	0.31	0.59	0.42	0.07	-0.77	-1.39	-2.13
23:00	-1.76	-1.55	-1.06	-0.57	0.05	0.4	0.63	0.49	0.18	-0.58	-1.16	-1.79
22:00	-1.44	-1.26	-0.82	-0.4	0.2	0.49	0.67	0.55	0.29	-0.4	-0.96	-1.51
21:00	-1.36	-1.12	-0.61	-0.25	0.34	0.6	0.76	0.63	0.39	-0.25	-0.85	-1.43
20:00	-1.21	-0.92	-0.4	-0.09	0.5	0.78	0.9	0.74	0.5	-0.09	-0.71	-1.31
19:00	-0.99	-0.68	-0.19	0.12	0.73	1.01	1.11	0.92	0.62	0.04	-0.56	-1.1
18:00	-0.74	-0.38	0.1	0.35	0.93	1.16	1.27	1.11	0.82	0.22	-0.39	-0.87
17:00	-0.42	-0.06	0.33	0.51	1.07	1.26	1.38	1.26	1.04	0.47	-0.18	-0.65
16:00	-0.18	0.11	0.44	0.6	1.11	1.29	1.41	1.32	1.15	0.68	0.03	-0.4
15:00	-0.07	0.13	0.47	0.6	1.08	1.23	1.37	1.29	1.18	0.77	0.17	-0.26
14:00	-0.1	0.09	0.42	0.5	1.0	1.14	1.28	1.23	1.14	0.78	0.22	-0.23
13:00	-0.24	0.01	0.27	0.36	0.87	1.05	1.18	1.14	1.06	0.69	0.16	-0.27
12:00	-0.39	-0.15	0.09	0.28	0.77	0.99	1.11	1.08	0.96	0.58	0.03	-0.35
11:00	-0.62	-0.38	-0.1	0.2	0.7	0.96	1.08	1.03	0.86	0.44	-0.19	-0.53
10:00	-0.93	-0.77	-0.35	0.09	0.58	0.9	1.03	0.95	0.73	0.21	-0.48	-0.85
09:00	-1.27	-1.15	-0.66	-0.11	0.36	0.8	0.92	0.79	0.49	-0.18	-0.81	-1.2
08:00	-1.51	-1.41	-1.06	-0.41	0.05	0.62	0.75	0.54	0.09	-0.75	-1.14	-1.47
07:00	-1.68	-1.63	-1.4	-0.81	-0.38	0.37	0.55	0.2	-0.35	-1.11	-1.35	-1.66
06:00	-2.55	-2.48	-2.23	-1.57	-0.88	0.06	0.34	-0.07	-0.65	-1.64	-2.0	-2.5
05:00	-2.53	-2.45	-2.15	-1.5	-0.96	-0.18	0.2	-0.07	-0.55	-1.51	-1.94	-2.49
04:00	-2.5	-2.4	-2.04	-1.38	-0.83	-0.12	0.26	0.03	-0.42	-1.37	-1.87	-2.46
03:00	-2.46	-2.34	-1.89	-1.24	-0.67	-0.01	0.34	0.12	-0.29	-1.22	-1.78	-2.42
02:00	-2.38	-2.25	-1.7	-1.09	-0.5	0.09	0.41	0.22	-0.16	-1.06	-1.65	-2.35
01:00	-2.22	-2.08	-1.49	-0.92	-0.33	0.2	0.48	0.31	-0.03	-0.9	-1.49	-2.21
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec



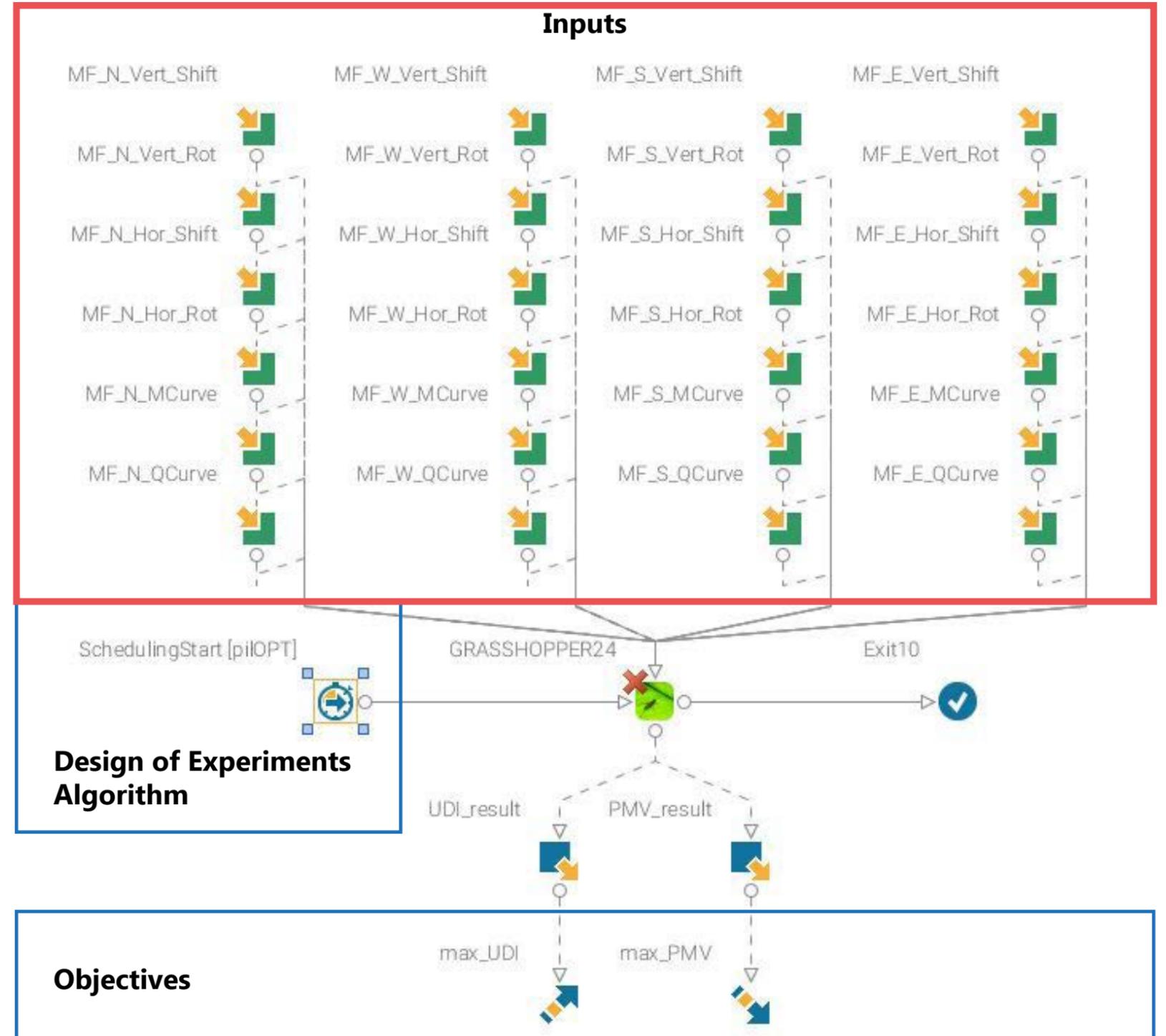
The example case: Optimisation

Fixed inputs:

- 1 Amount vertical (4)
- 2 Amount horizontal (8)
- 3 Extrusion depth (250)
- 4 DSF cavity depth (500)

Variable inputs:

- 1 Shift vertical (-3 to 3)
- 2 Shift horizontal (-5 to 5)
- 3 Rotation vertical (-60 to 60)
- 4 Rotation horizontal (-60 to 60)
- 5 Midpoint (0.5 to 0.9)
- 6 Q-value (0.2 to 0.9)



The example case: Optimisation

DOE & Algorithm:

Uniform Latin Hypercube

Generation size: 50

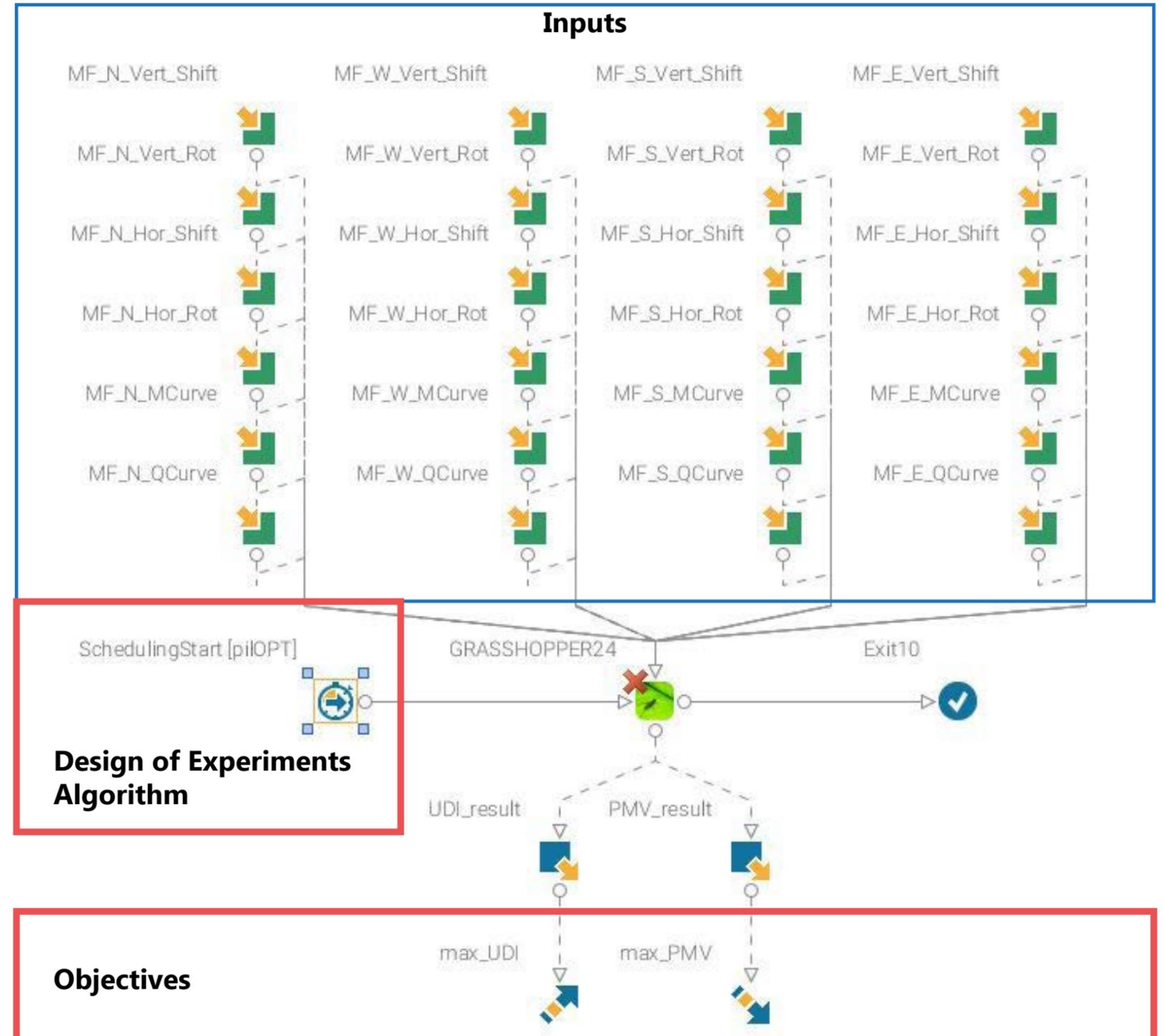
Time limit: 72h

PilOpt algorithm

Objectives:

Minimize annual PMV sum

Maximize UDI score



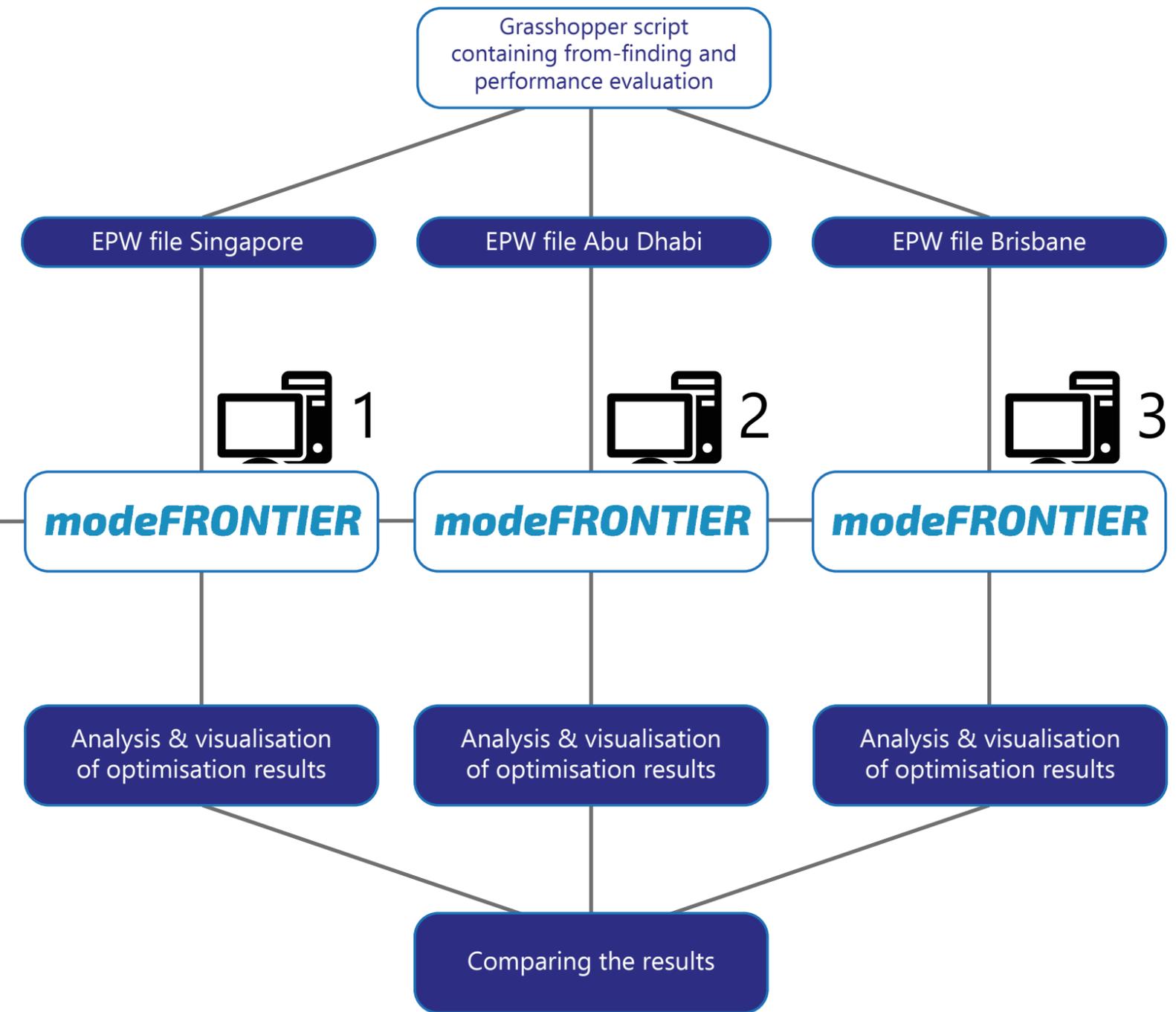
The example case: Optimisation



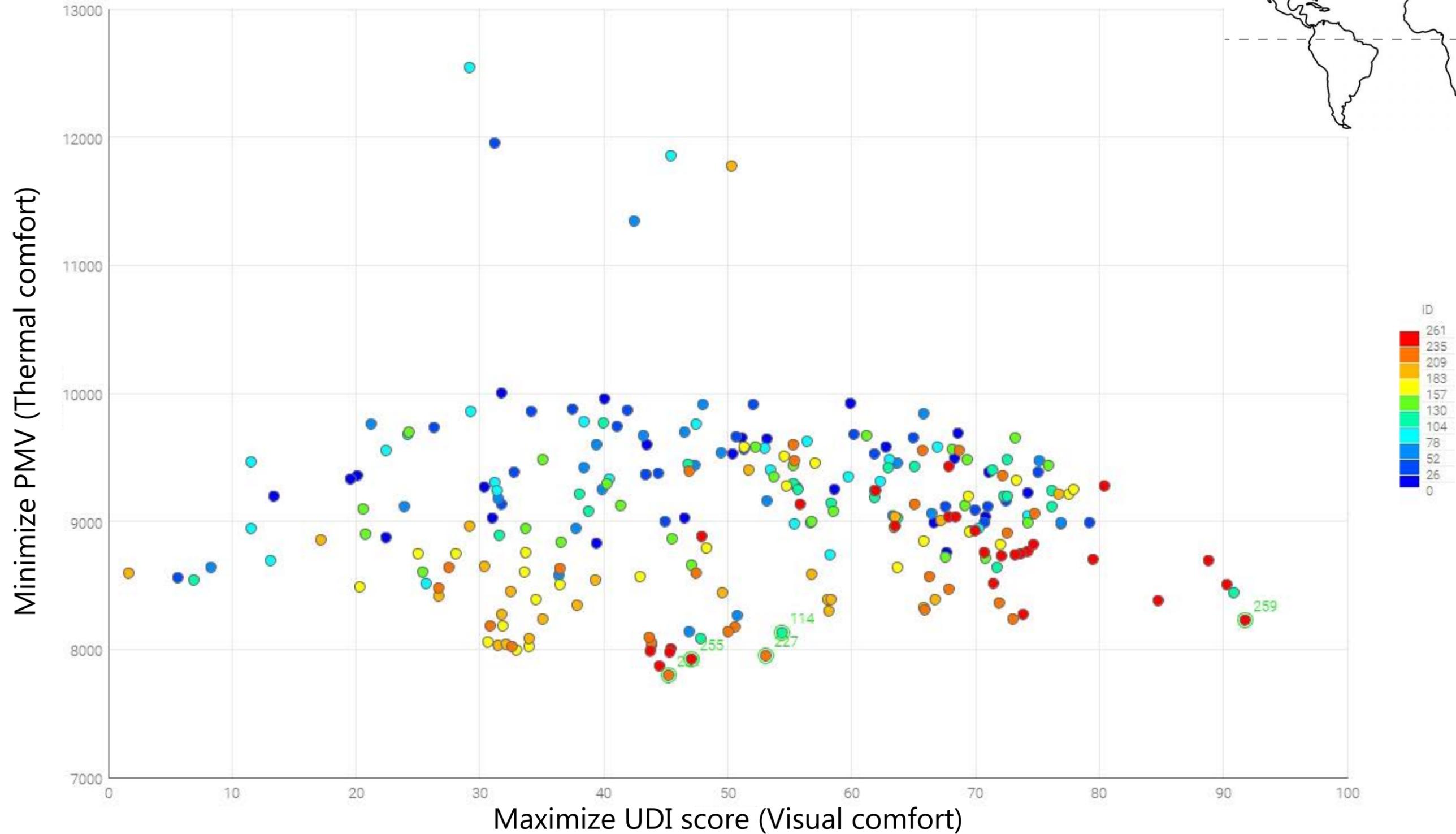
Settings for:
1. Input parameters
2. Objectives
3. Design of experiments
4. Search algorithm

Results after 72 hours:

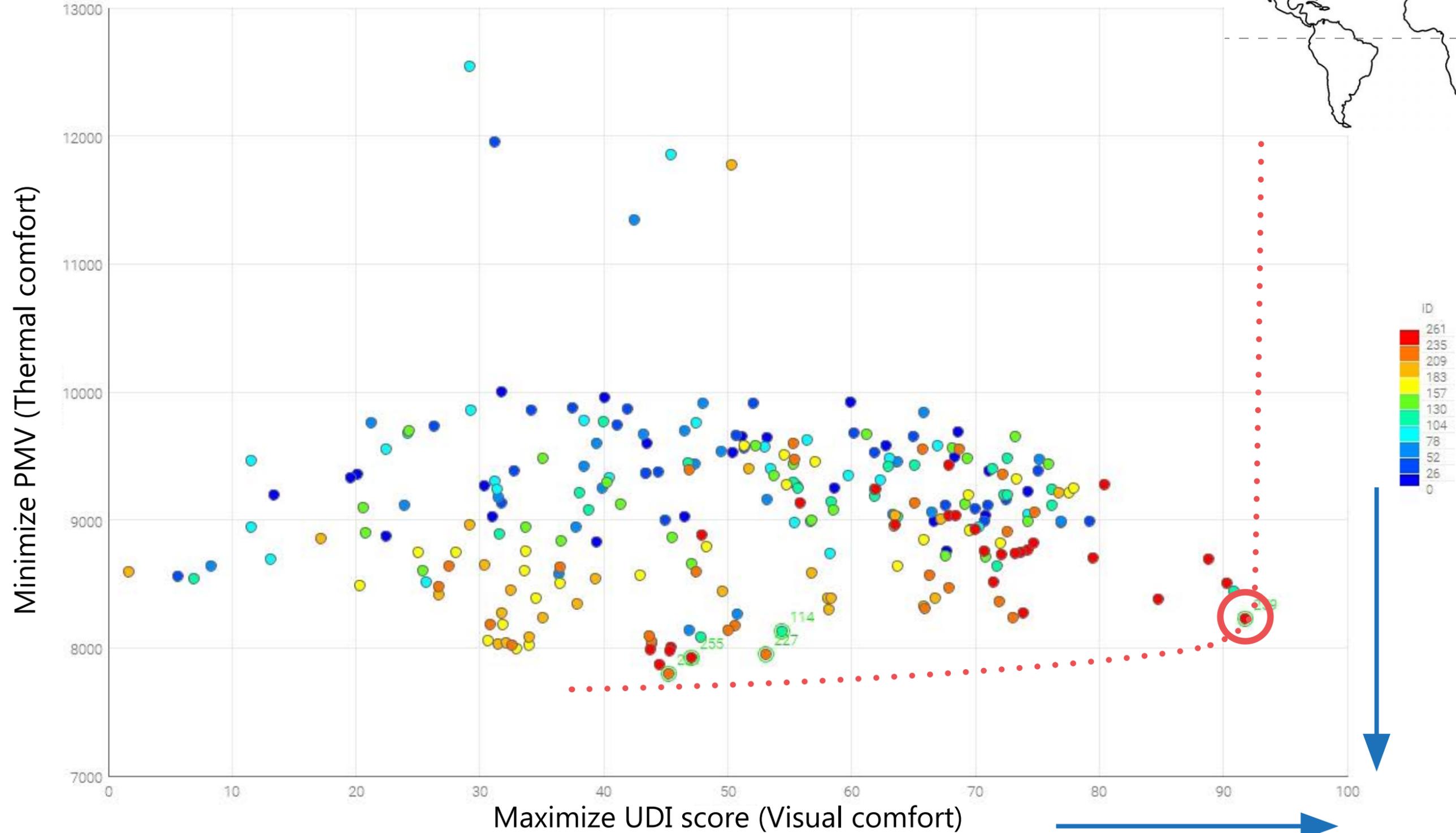
Singapore: 30 evaluations
Abu Dhabi: 261 evaluations
Brisbane: 188 evaluations



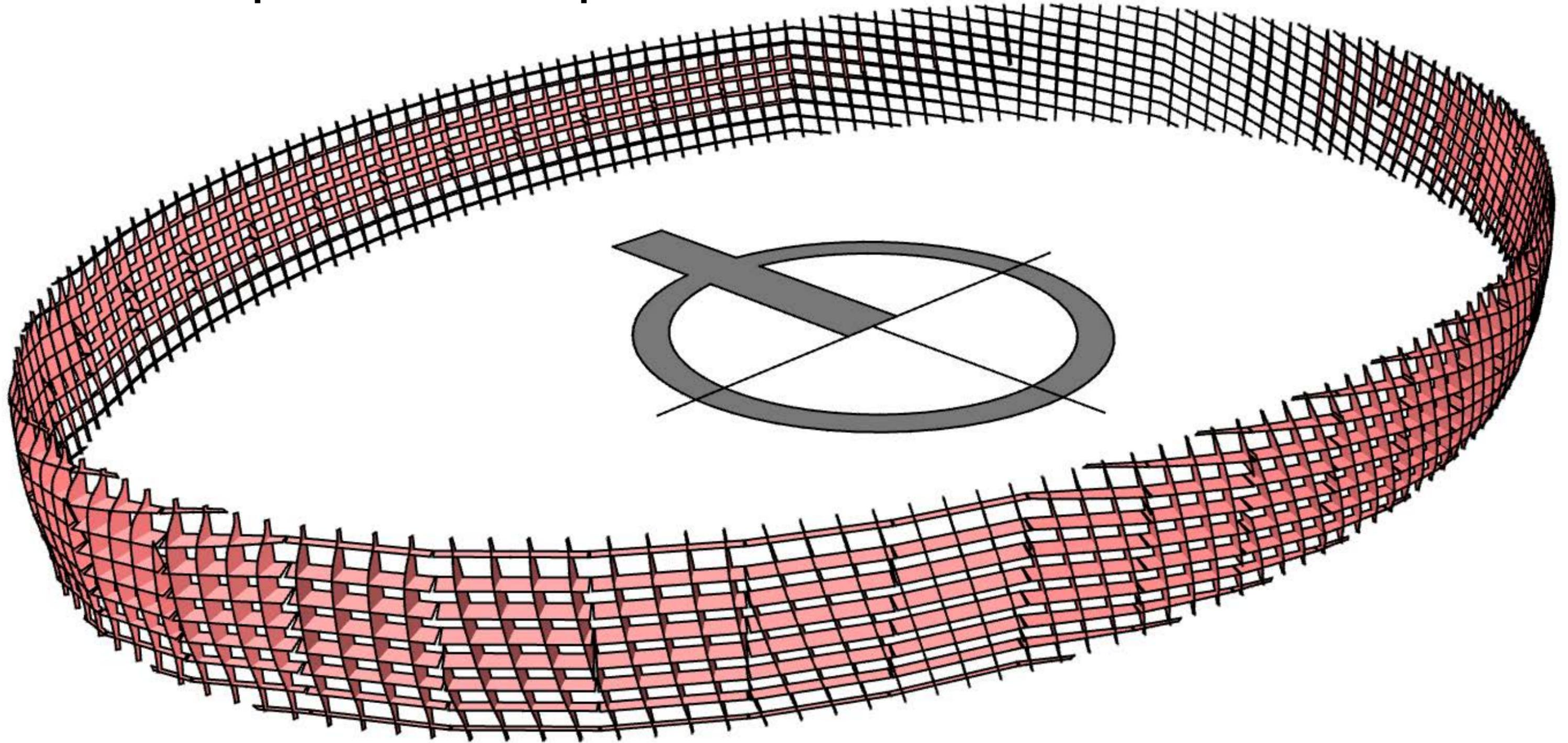
The example case: Optimisation



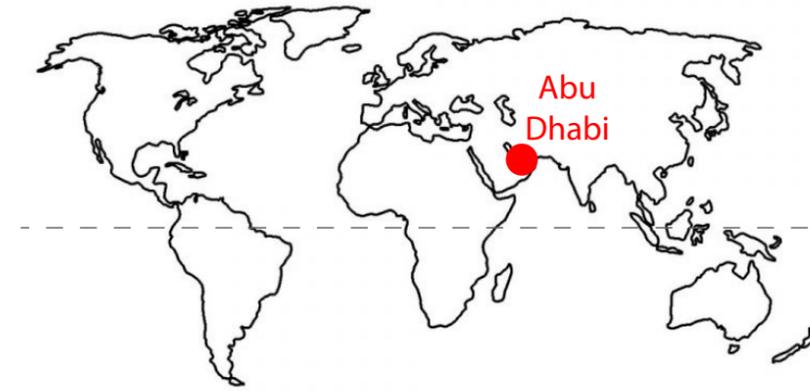
The example case: Optimisation



The example case: Optimisation



The example case: Optimisation



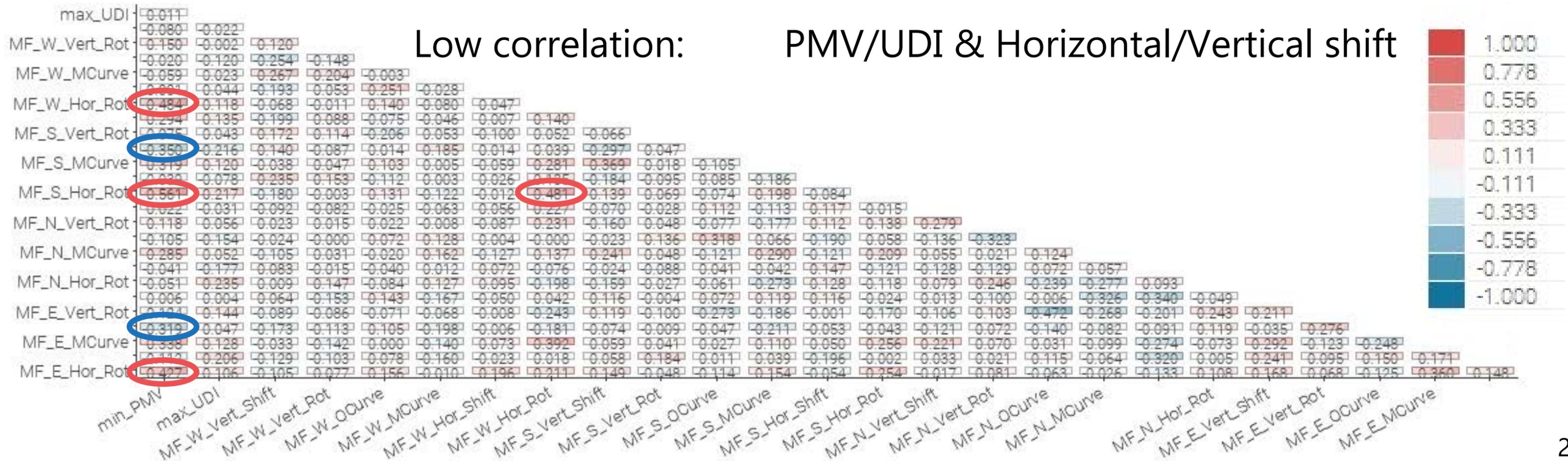
Pearson correlation:

Positive correlation: PMV & Horizontal rotation

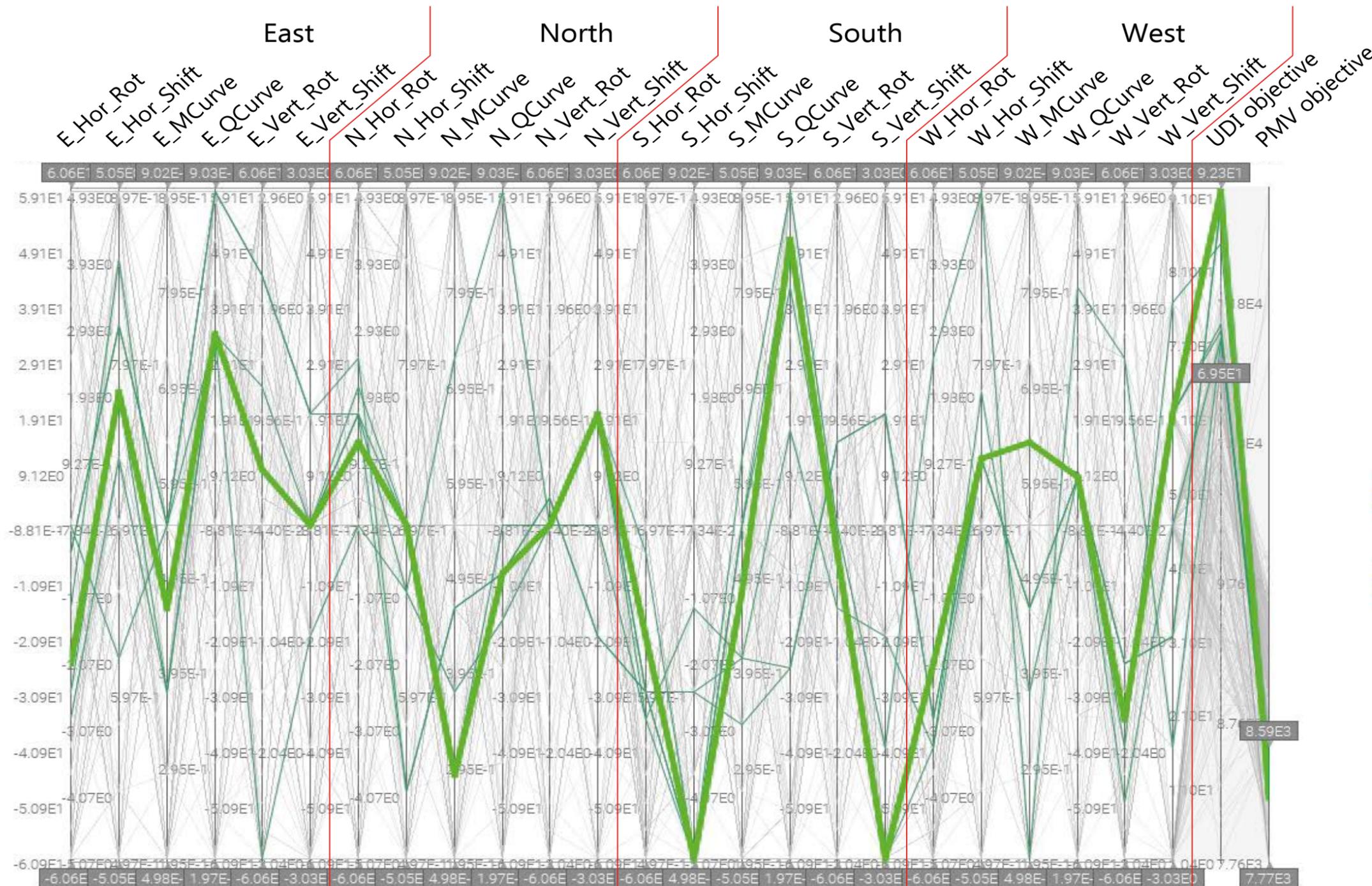
Negative correlation: PMV & Q-value curve

Positive correlation: Hor. rot. West & Hor. rot. South

Low correlation: PMV/UDI & Horizontal/Vertical shift

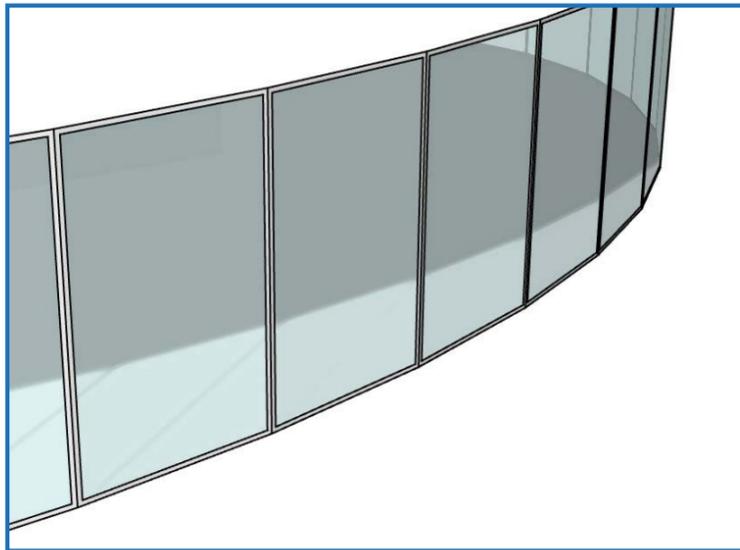


The example case: Optimisation

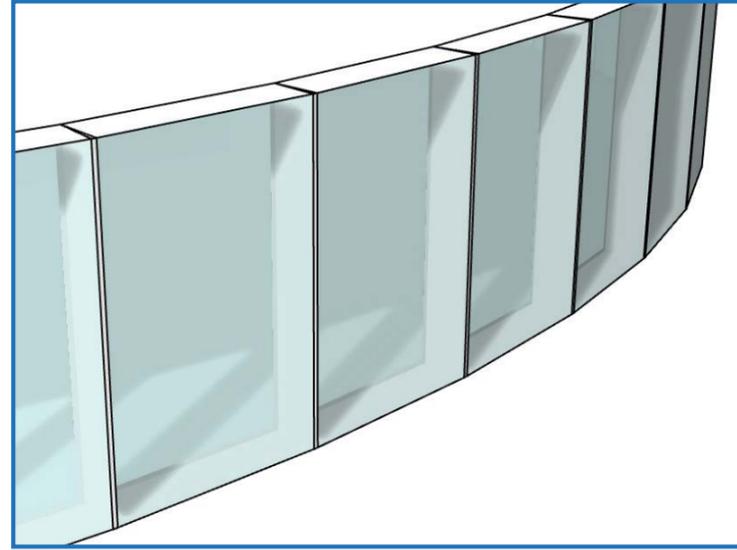


- Parallel Coordinates:**
- South: Closed shading**
 - High M-value curve
 - High Q-value curve
 - Low Horizontal rotation
 - North: Open shading**
 - Low M-value curve
 - Low Q-value curve
 - High Horizontal rotation

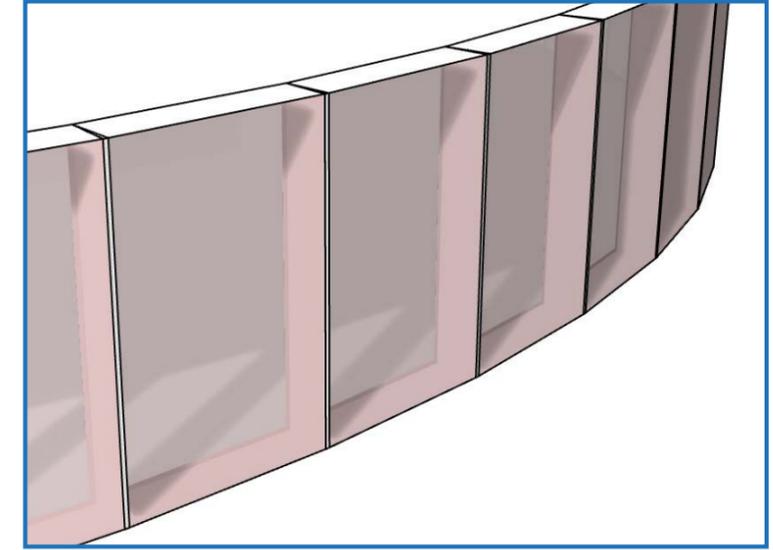
Performance comparison



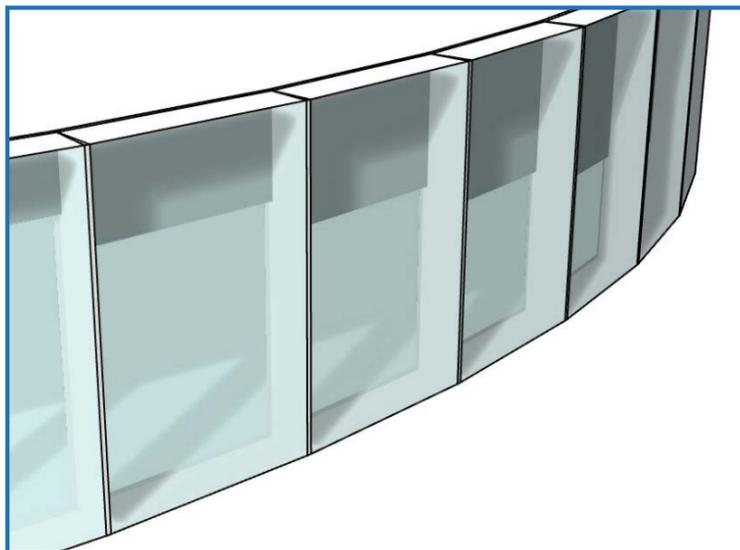
Simulation 1: Reference 1
Single skin facade



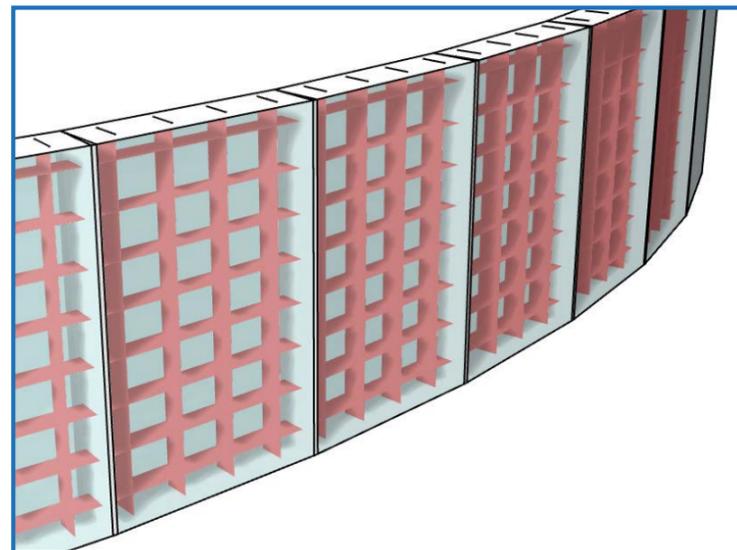
Simulation 2: Reference 2
"Empty" double skin facade



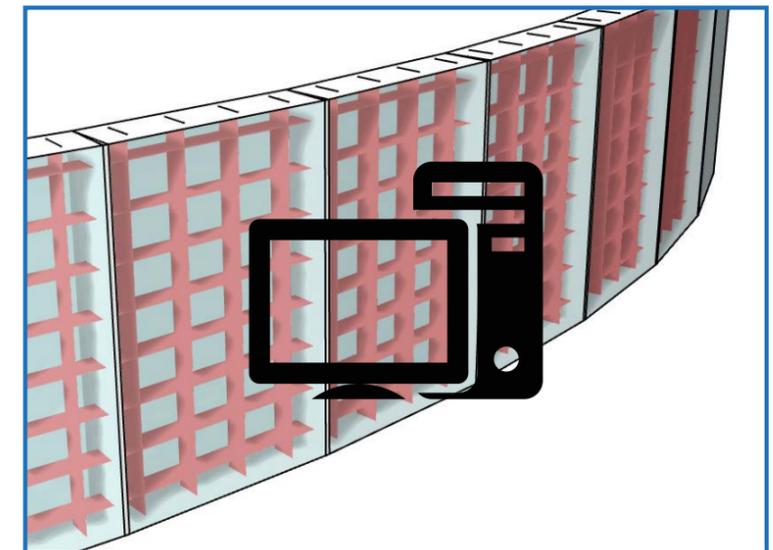
Simulation 3: Alternative A
Solar reflective glazing



Simulation 4: Alternative B
Default dynamic screen shading

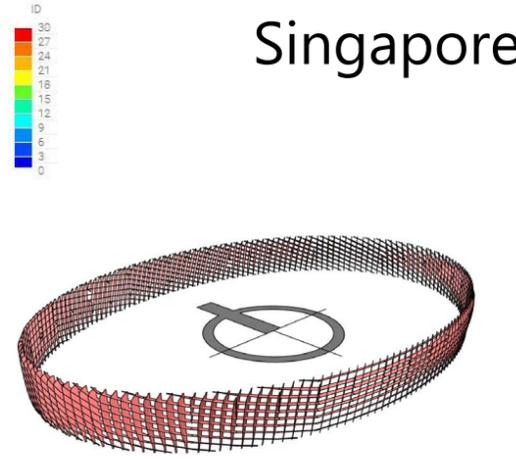
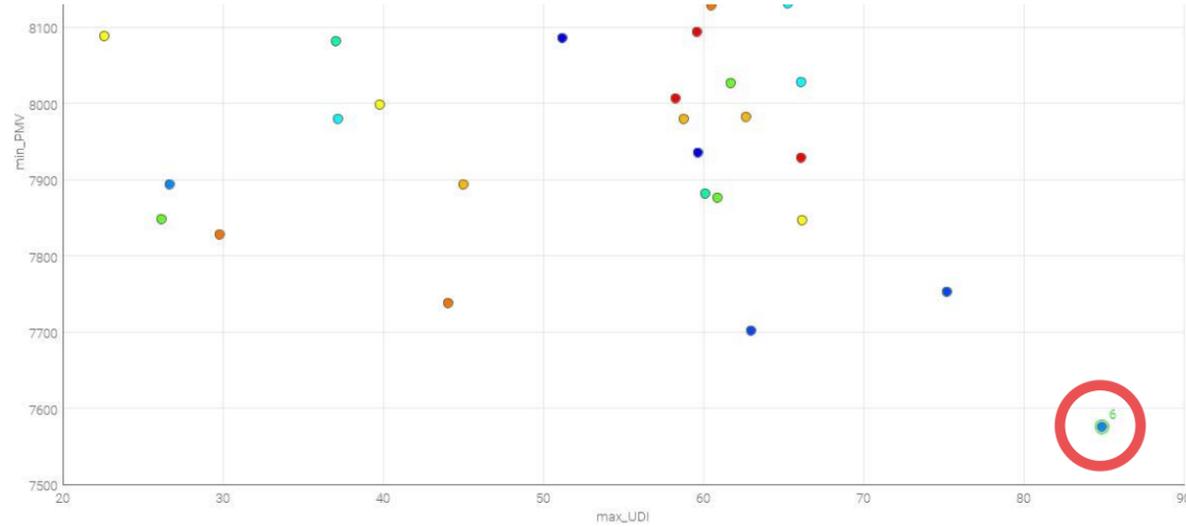


Simulation 5: Alternative C
"Default" egg-crate shading

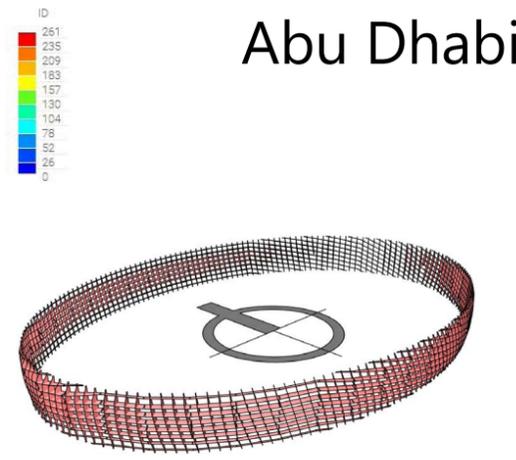
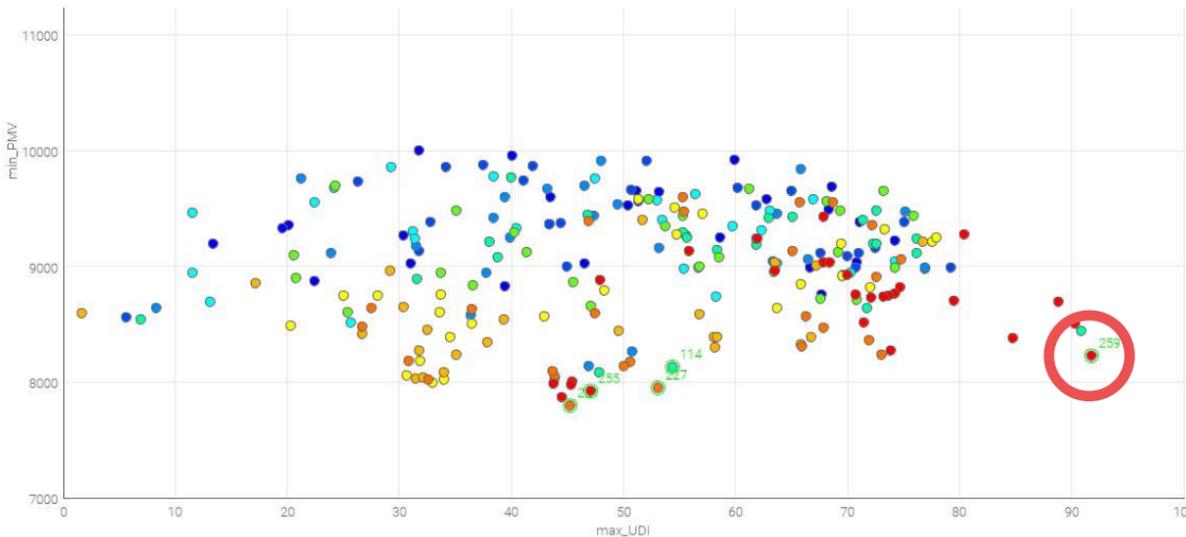


Simulation 6: Optimised
By conventional approach

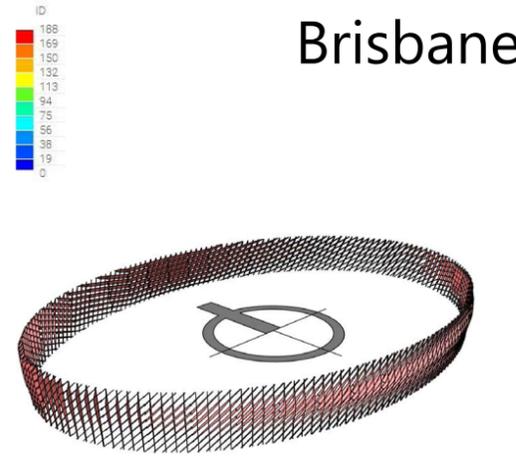
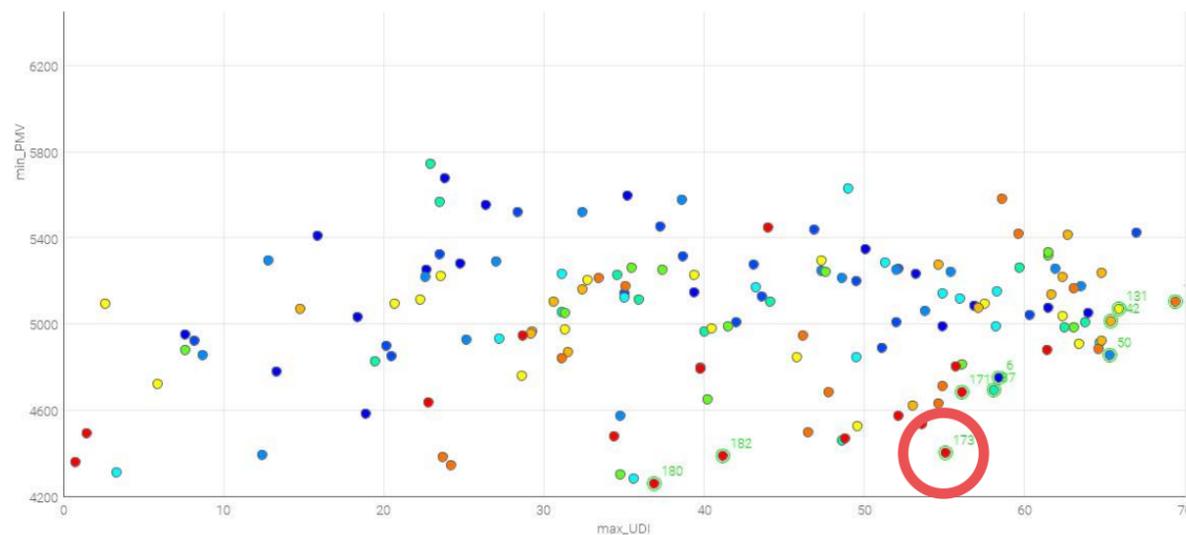
P5 - Graduation - Building Technology - Sun shading of the future - Shane Prins



	Sim 1: Single skin facade	Sim 2: Empty double skin facade	Sim 3: Solar reflective glazing	Sim 4: Dynamic screen sun shading	Sim 5: Default egg-crate sun shading	Sim 6: Optimized egg-crate sun shading
Primary						
PMV score	11587	9833	8417	9865	7375	7575
UDI score	19.2%	39.9%	63.3%	31.9%	82.1%	84.9%
Secondary						
Lighting	1.426 kWh	1.680 kWh	3.447 kWh	10.381 kWh	2.437 kWh	
Heating	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	
Cooling	227.471 kWh	215.556 kWh	206.193 kWh	217.731 kWh	198.032 kWh	
Total	228.897 kWh	217.236 kWh	209.640 kWh	228.112 kWh	200.469 kWh	



	Sim 1: Single skin facade	Sim 2: Empty double skin facade	Sim 3: Solar reflective glazing	Sim 4: Dynamic screen sun shading	Sim 5: Default egg-crate sun shading	Sim 6: Optimized egg-crate sun shading
Primary						
PMV score	14031	11980	10063	9650	8311	8231
UDI score	16.3%	41.8%	69.1%	0.0%	77.8%	91.8%
Secondary						
Lighting	479 kWh	676 kWh	4.109 kWh	14.214 kWh	1.407 kWh	
Heating	280 kWh	268 kWh	267 kWh	248 kWh	266 kWh	
Cooling	177.938 kWh	161.805 kWh	148.341 kWh	147.623 kWh	134.865 kWh	
Total	178.695 kWh	162.749 kWh	152.717 kWh	162.085 kWh	136.538 kWh	



	Sim 1: Single skin facade	Sim 2: Empty double skin facade	Sim 3: Solar reflective glazing	Sim 4: Dynamic screen sun shading	Sim 5: Default egg-crate sun shading	Sim 6: Optimized egg-crate sun shading
Primary						
PMV score	9072	7251	5761	5696	4460	4401
UDI score	14.2%	40.0%	54.4%	0.0%	70.1%	55.1%
Secondary						
Lighting	1.477 kWh	1.921 kWh	5.911 kWh	13.365 kWh	4.135 kWh	
Heating	5.530 kWh	5.533 kWh	5.678 kWh	5.615 kWh	5584 kWh	
Cooling	98.345 kWh	87.656 kWh	79.384 kWh	81.433 kWh	70.335 kWh	
Total	103.875 kWh	95.110 kWh	90.973 kWh	100.413 kWh	80.054 kWh	

Singapore

Default
7375
82.1%

Optimised
7575
84.9%

30 evaluations

Singapore	Sim 1: Single skin facade	Sim 2: Empty double skin facade	Sim 3: Solar reflective glazing	Sim 4: Dynamic screen sun shading	Sim 5: Default egg-crate sun shading	Sim 6: Optimized egg-crate sun shading
Primary						
PMV score	11587	9833	8417	9865	7375	7575
UDI score	19.2%	39.9%	63.3%	31.9%	82.1%	84.9%
Secondary						
Lighting	1.426 kWh	1.680 kWh	3.447 kWh	10.381 kWh	2.437 kWh	
Heating	0 kWh	0 kWh	0 kWh	0 kWh	0 kWh	
Cooling	227.471 kWh	215.556 kWh	206.193 kWh	217.731 kWh	198.022 kWh	
Total	228.897 kWh	217.236 kWh	209.640 kWh	228.112 kWh	200.469 kWh	

Abu Dhabi

Default
8311
77.8%

Optimised
8231
91.8%

261 evaluations

Abu Dhabi	Sim 1: Single skin facade	Sim 2: Empty double skin facade	Sim 3: Solar reflective glazing	Sim 4: Dynamic screen sun shading	Sim 5: Default egg-crate sun shading	Sim 6: Optimized egg-crate sun shading
Primary						
PMV score	14031	11980	10063	9650	8311	8231
UDI score	16.3%	41.8%	69.1%	0.0%	77.8%	91.8%
Secondary						
Lighting	479 kWh	676 kWh	4.109 kWh	14.214 kWh	1.407 kWh	
Heating	280 kWh	268 kWh	267 kWh	248 kWh	266 kWh	
Cooling						
Total	178.695 kWh	162.749 kWh	152.717 kWh	162.085 kWh	136.538 kWh	

Brisbane

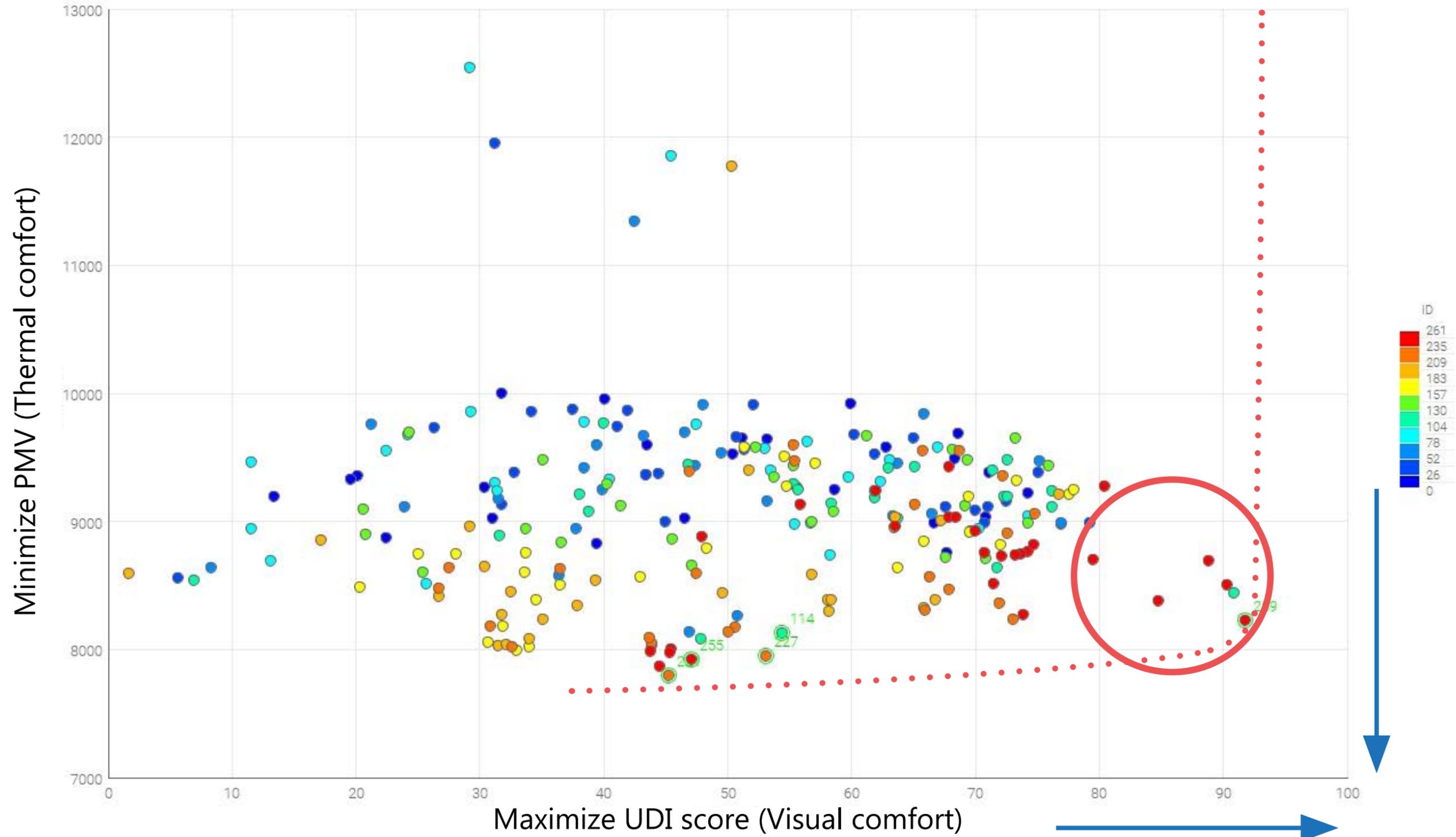
Default
4460
70.1%

Optimised
4401
55.1%

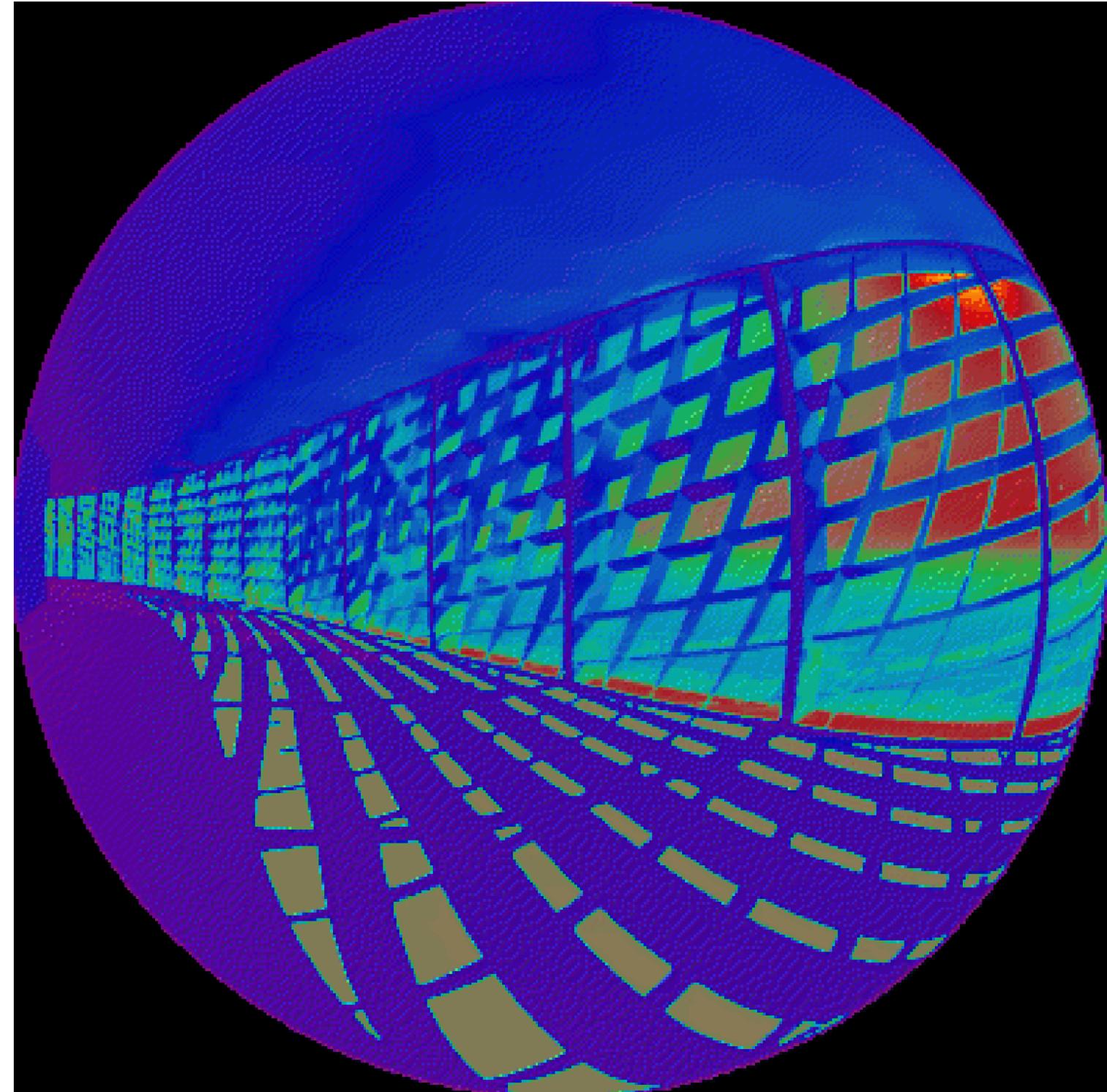
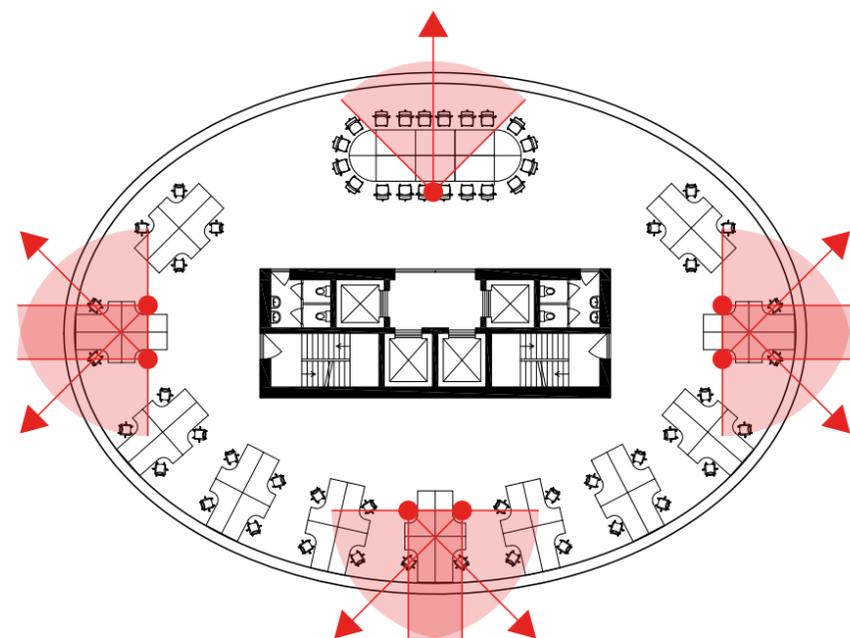
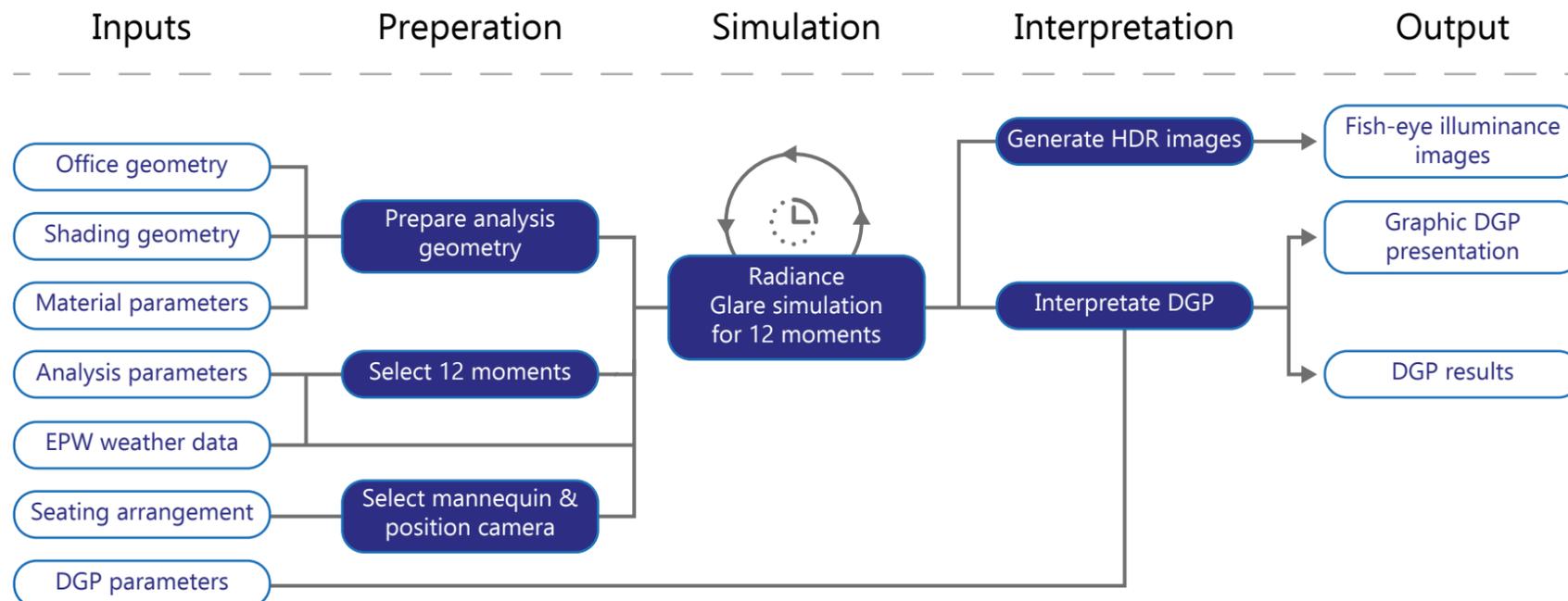
188 evaluations

Brisbane	Sim 1: Single skin facade	Sim 2: Empty double skin facade	Sim 3: Solar reflective glazing	Sim 4: Dynamic screen sun shading	Sim 5: Default egg-crate sun shading	Sim 6: Optimized egg-crate sun shading
Primary						
PMV score	9072	7251	5761	5696	4460	4401
UDI score	14.2%	40.0%	54.4%	0.0%	70.1%	55.1%
Secondary						
Lighting	1.477 kWh	1.921 kWh	5.911 kWh	13.365 kWh	4.135 kWh	
Heating	5.530 kWh	5.533 kWh	5.678 kWh	5.615 kWh	5584 kWh	
Cooling						
Total	103.875 kWh	95.110 kWh	90.973 kWh	100.413 kWh	80.054 kWh	

Exploration of the example case: Further simulation



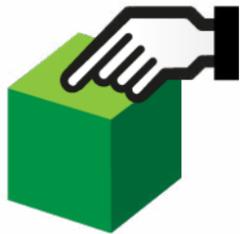
Exploration of the example case: Further simulation



Exploration of the example case: Physical models



Grasshopper

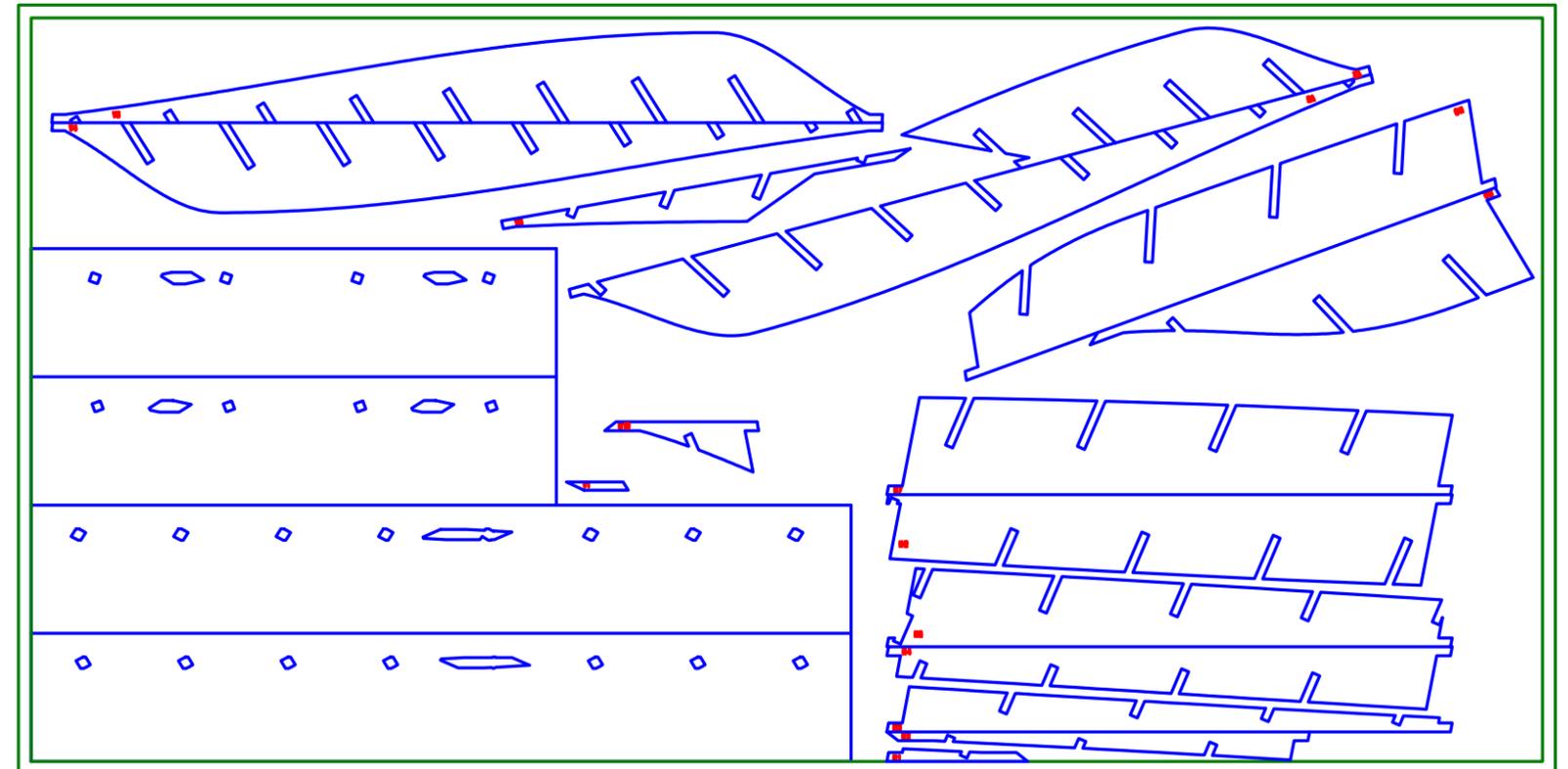
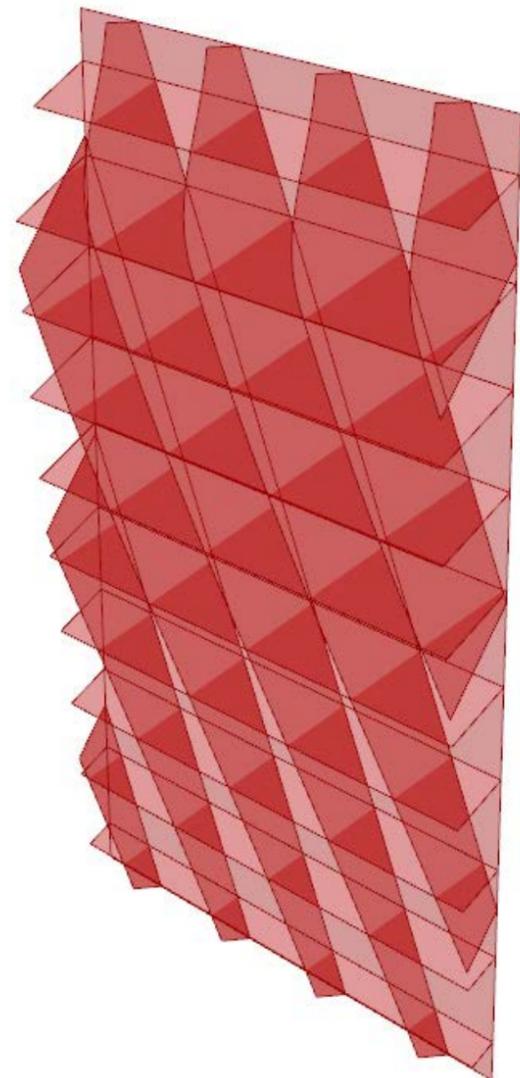


Fab tools



AutoCAD

Logo sources: Google.com (2019)



Exploration of the example case: Physical models



Exploration of the example case: VR rendering



Grasshopper



Dynamo

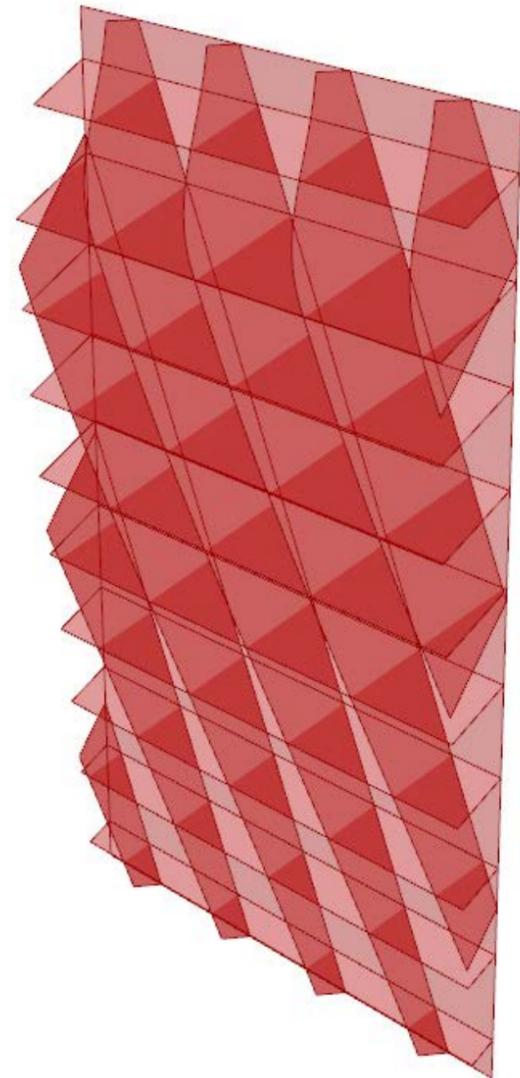


Revit



Autodesk cloud

Logo sources: Google.com (2019)



source: Google.com (2019)

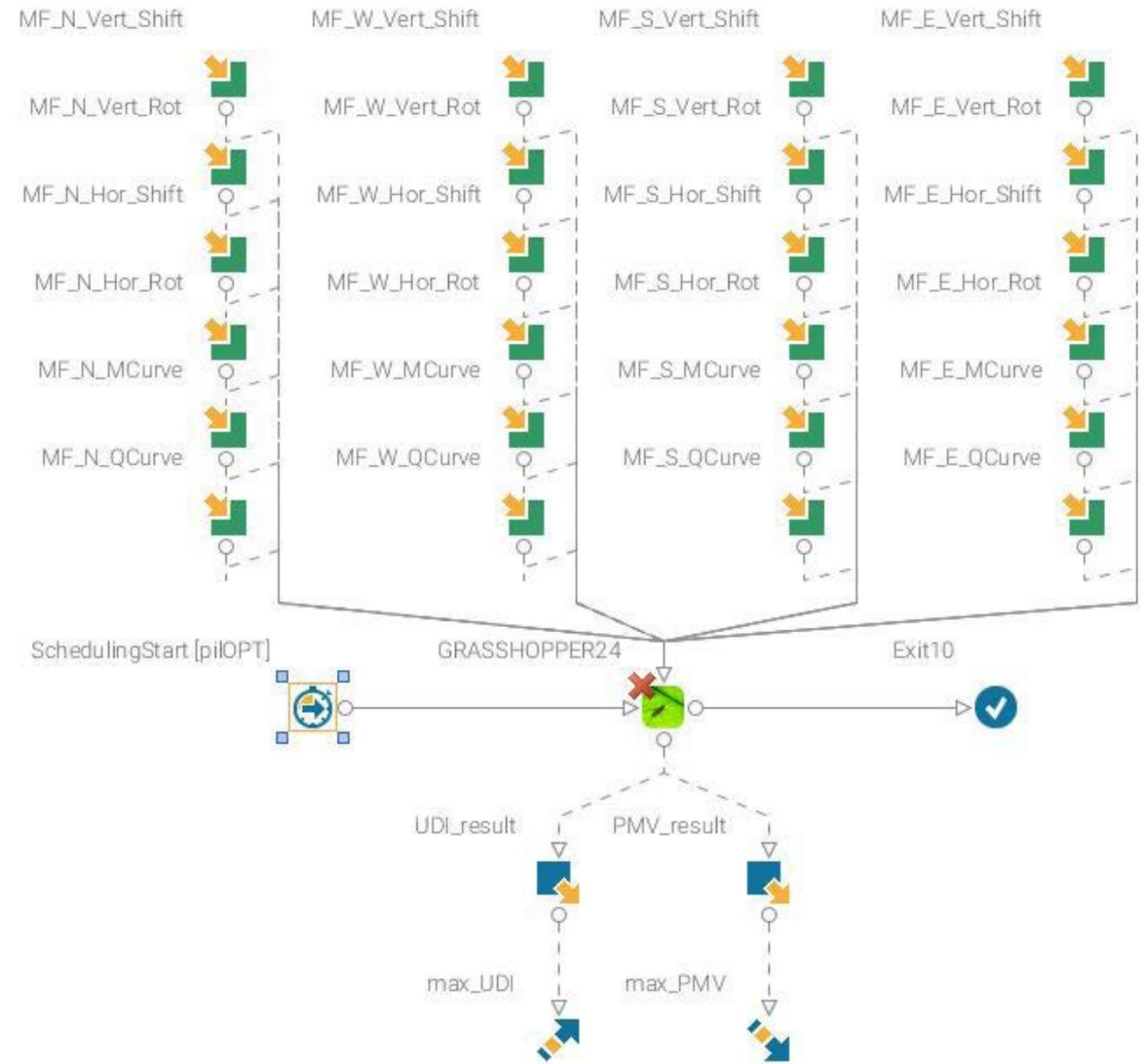
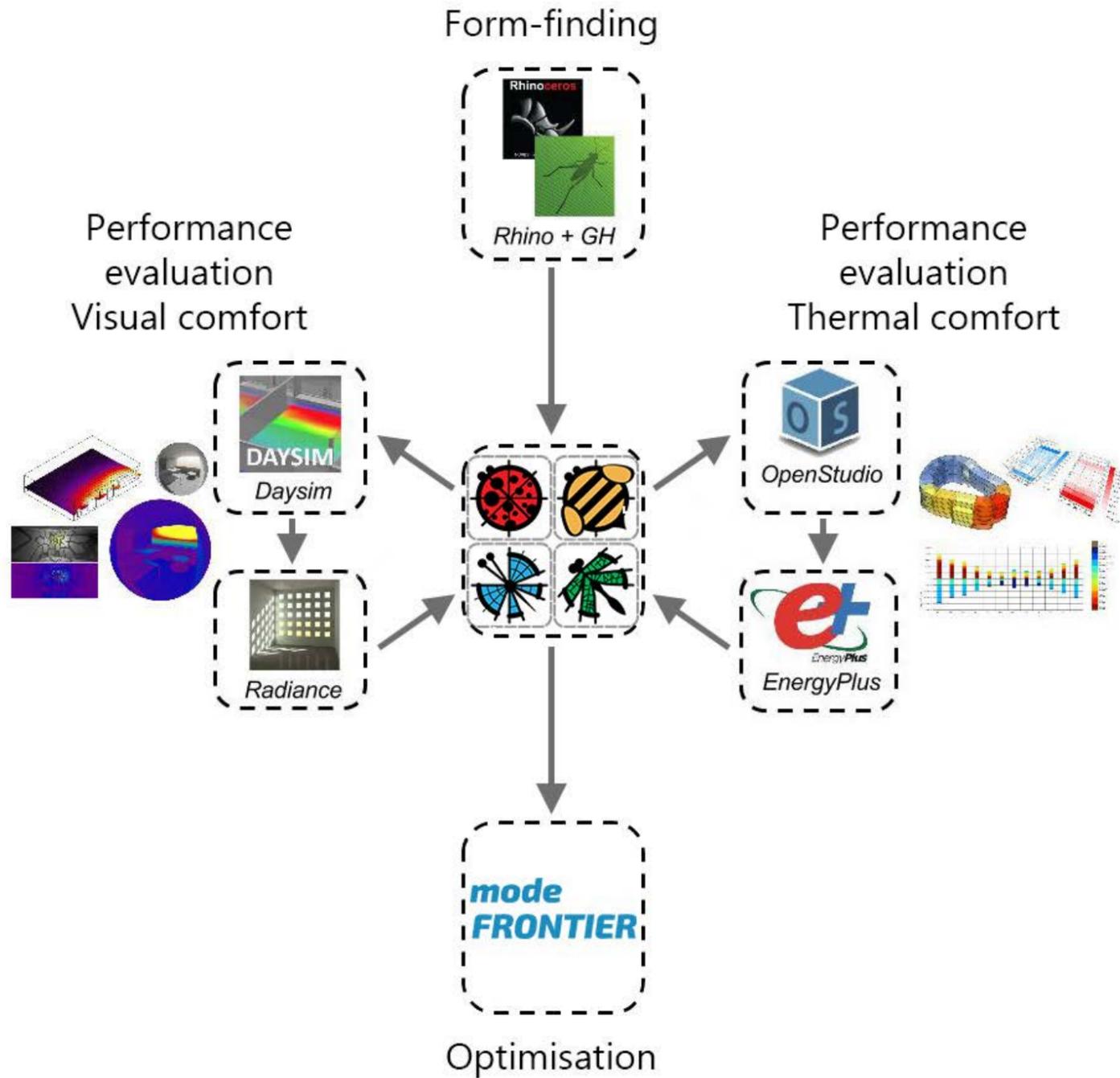
Exploration of the example case: VR rendering



Exploration of the example case: VR rendering

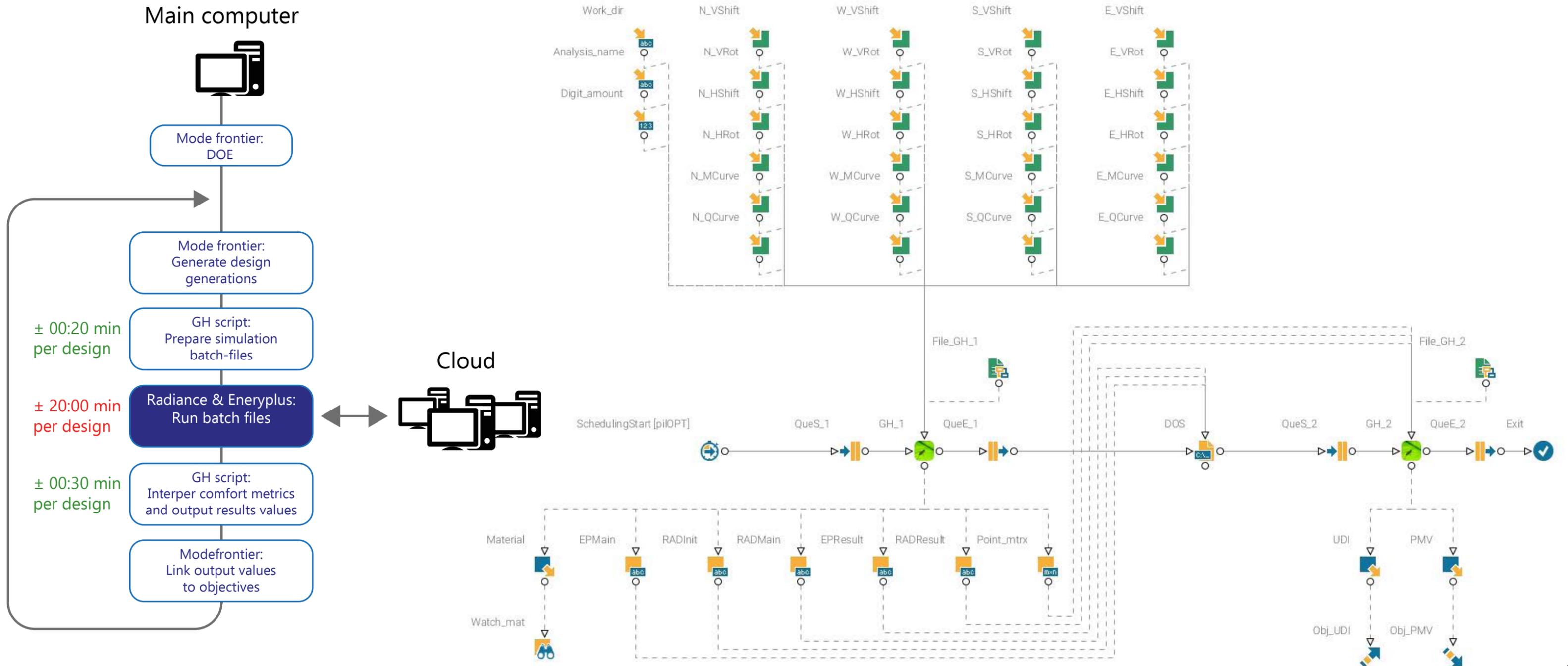


The contemporary common PCA workflow



Source: Food4rhino.com (2019), edited by author

The next generation workflow



The next generation workflow

Optimisation
Scheduling
4 concurrent
processes

Preparation
1 concurrent
proces

Execution
4 concurrent
processes

Interpretation
1 concurrent
proces

Core features:

Convenience inputs

Embedded GH files

Analysis directories

DOS core

Queue nodes



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Optimisation
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Core features:

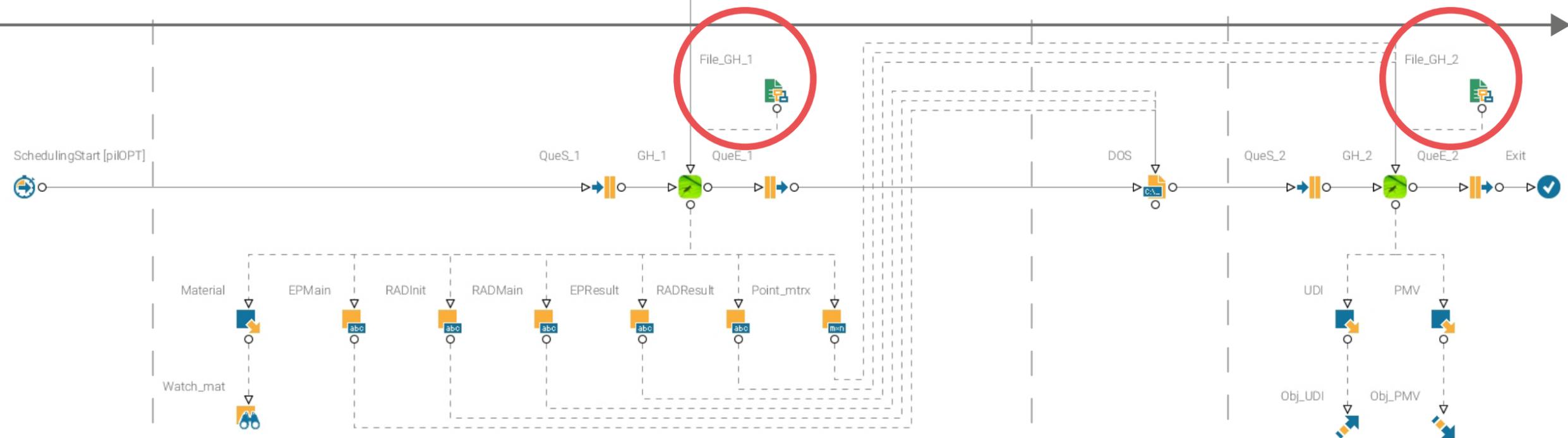
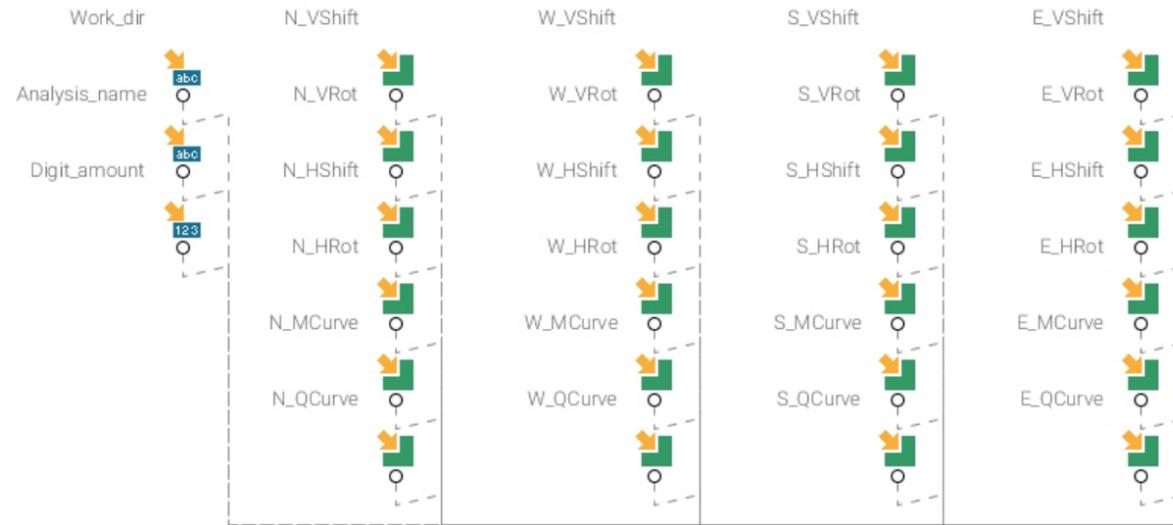
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Core features:

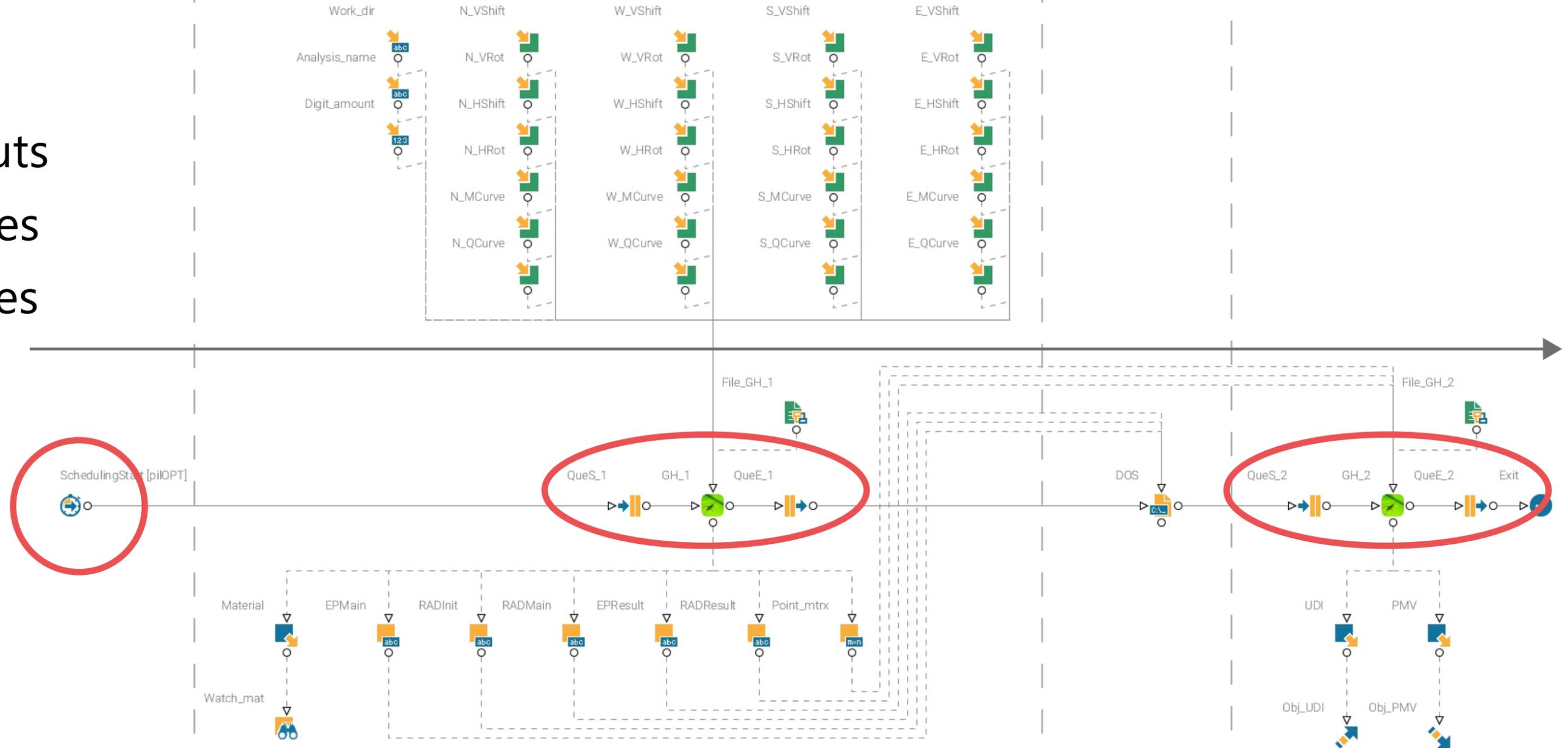
Convenience inputs

Embedded GH files

Analysis directories

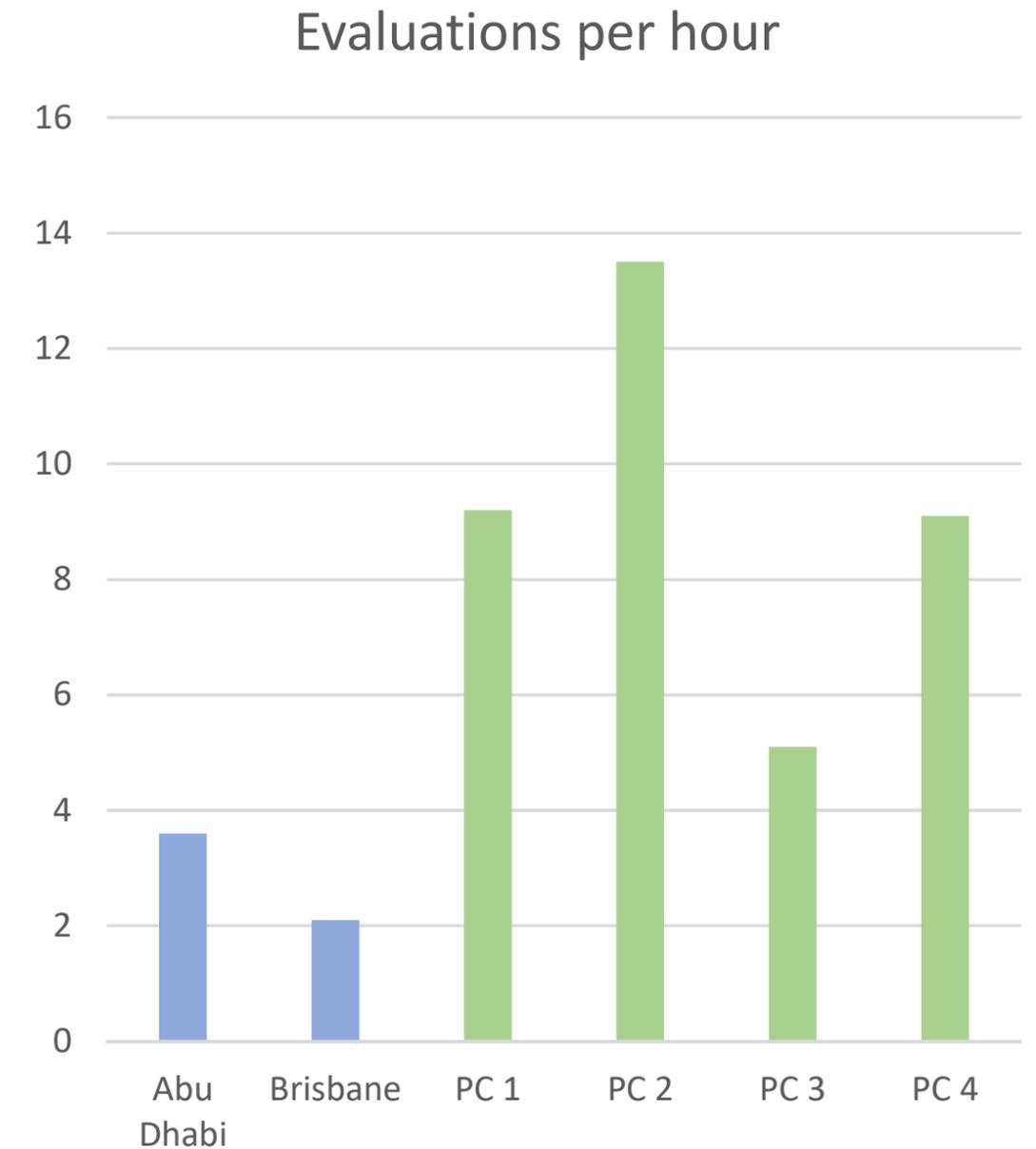
DOS core

Queue nodes

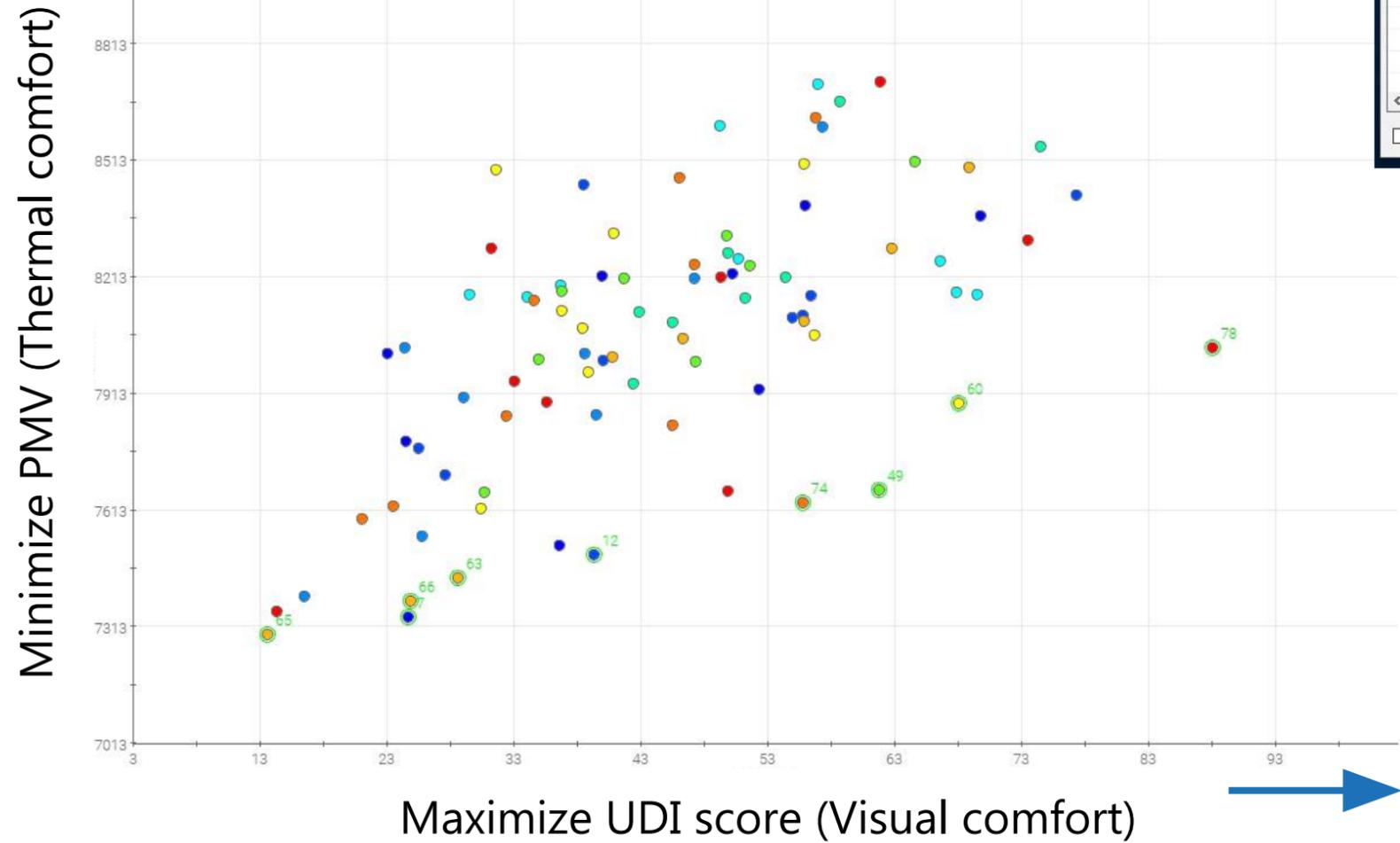


The next generation workflow

<i>Optimisation run</i>	Total evaluations	Total time	Evaluations per hour	Hardware specifications	Number of concurrent processes
Conventional workflow					
<i>Climate of Abu Dhabi</i>	261	72:00 h	3.6	(PC 2) 6 cores @ 3.3 Ghz	1
<i>Climate of Brisbane</i>	188	72:00 h	2.1	(PC 3) 4 cores @ 4.0 Ghz	1
Next generation workflow					
<i>Computer 1</i>	46	05:00 h	9.2	8 cores @ 3.4 Ghz	10
<i>Computer 2</i>	36	02:40 h	13.5	6 cores @ 3.3 Ghz	8
<i>Computer 3</i>	6	01:10 h	5.1	4 cores @ 4.0 Ghz	6
<i>Computer 4</i>	86	09:30 h	9.1	4 cores @ 4.0 Ghz	4



The next generation workflow



Grasshopper breakpoint

The "Honeybee_createHBZones (createHBZones)" object expired during a solution.
Instancelid: 0c35d7c9-3150-44cf-a6cf-7ca726b0ad5d

Grasshopper breakpoint

The "Honeybee_Set EnergyPlus Zone Loads (setEPZoneLoads)" object expired during a solution.
Instancelid: a135c73e-d6c5-4e8d-b4d3-9d27a2bb02fc

Rhino encountered a problem and needs to close.

Please send this confidential error report now.

Include the file you were editing or reading when Rhino closed

Your email:

What were you doing when Rhino closed?

Send Now Don't Send Help

Component Exception

Honeybee_Annual Daylight Simulation
[annualDaylightSimulation]

An exception was thrown during a solution:
Component: Honeybee_Annual Daylight Simulation
c_UUID: 903d2b5b-483d-4499-86be-4226acd16dac
c_POS: {X=11218, Y=1416}

Collection was modified; enumeration operation may not execute.

Don't show again OK

Message: Invoke() takes no arguments (1 given)

Traceback:
line 470, in <module>,
"C:\Users\GuestVR\modeFRONTIER\6\prefs\plugins\customnodes\grasshopper\supportfiles\win\run.py"

OK

Conclusions

Fundamental theory review:

Visual & Thermal comfort
 PCA & high-rise shading design

State of the art:

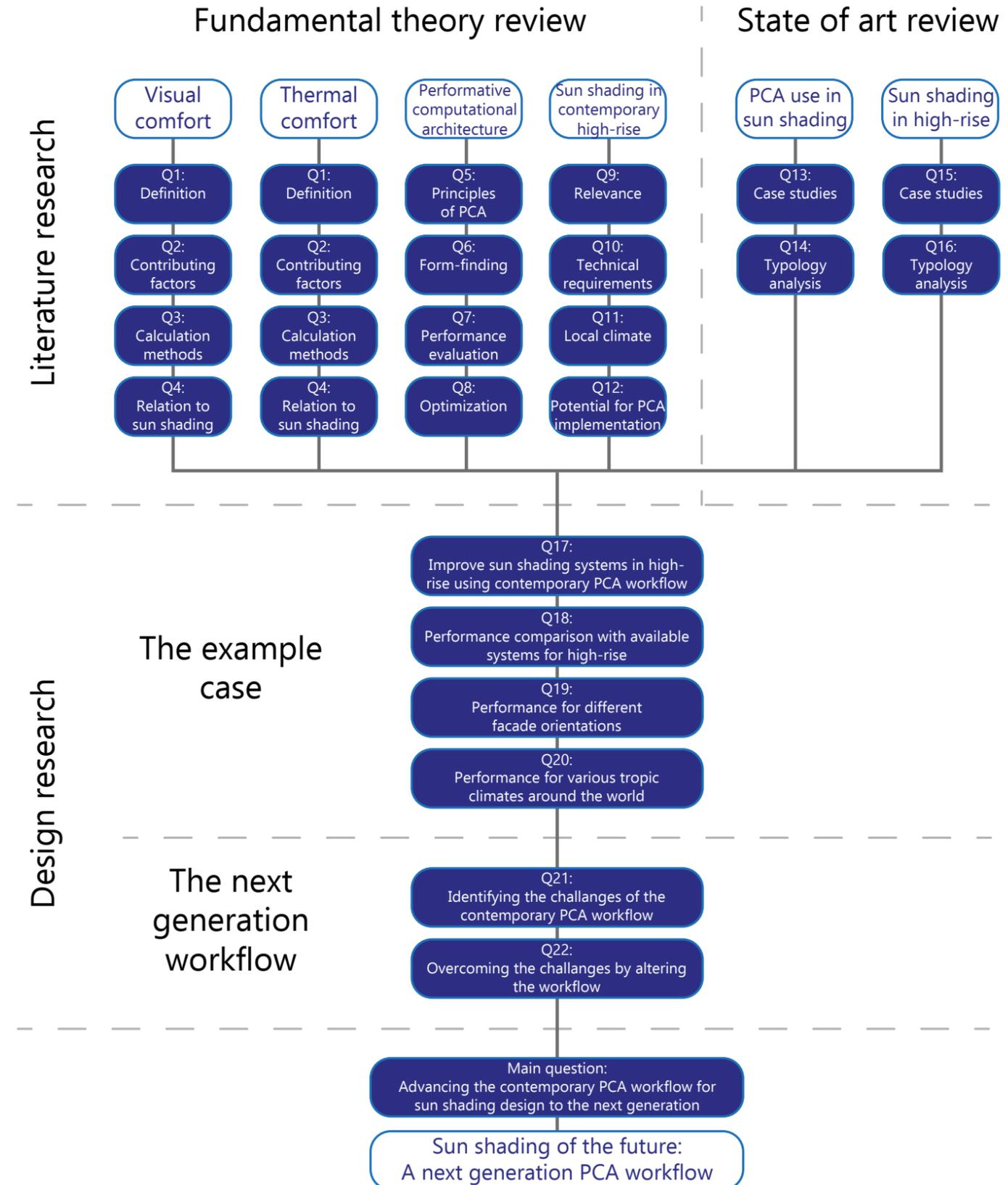
PCA workflow shading design
 Sun shading in high-rise

Example case:

Performance comparison

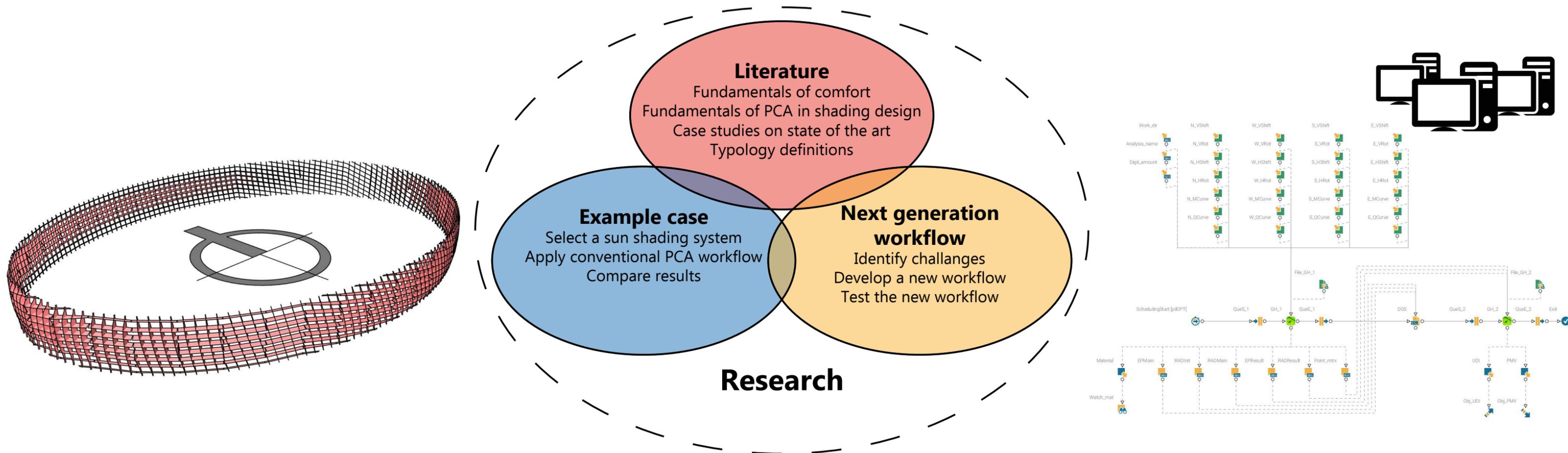
Next generation workflow:

Challenge identification
 Development



Conclusions

“How can the contemporary common Performative Computational Architecture (PCA) workflow for optimising sun shading designs on visual and thermal comfort in high-rise office buildings with all-glass exteriors be advanced to the next generation?”



Conclusions

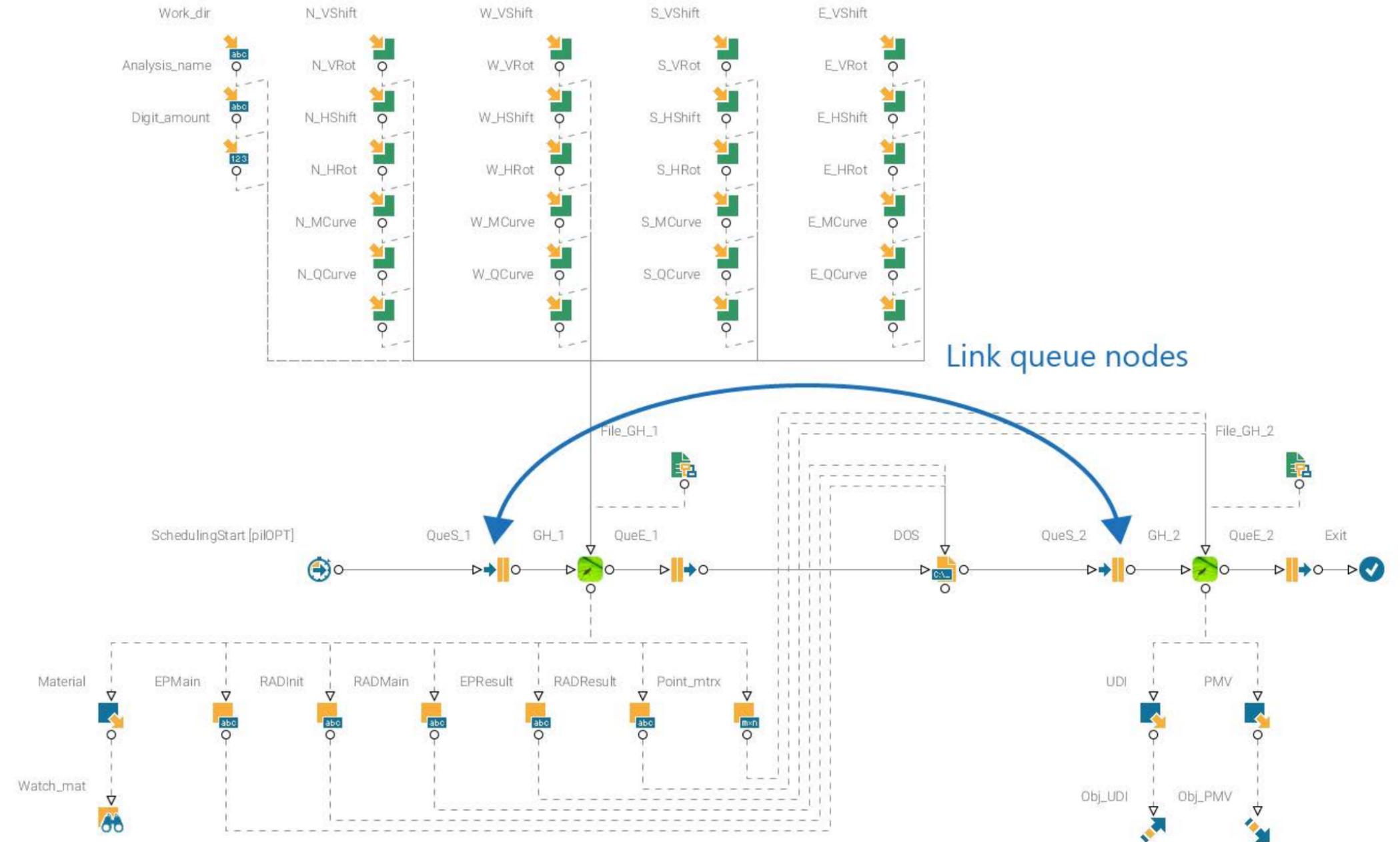
Recommendations & Further development:

Linking the queue nodes

Address minor issues

Further testing on the render-farm

Further testing on a Volta grid in the VR-lab



Sun shading of the future

A next generation workflow for applying the performative computational architecture framework to sun shading design, based on an example sun shading system for high-rise office buildings with all-glass exteriors in tropical climates optimised on visual and thermal comfort