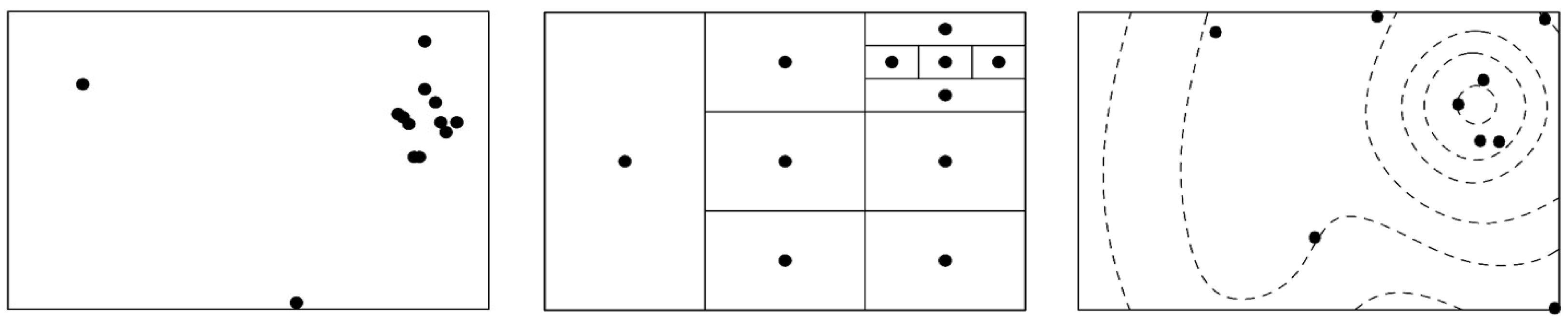
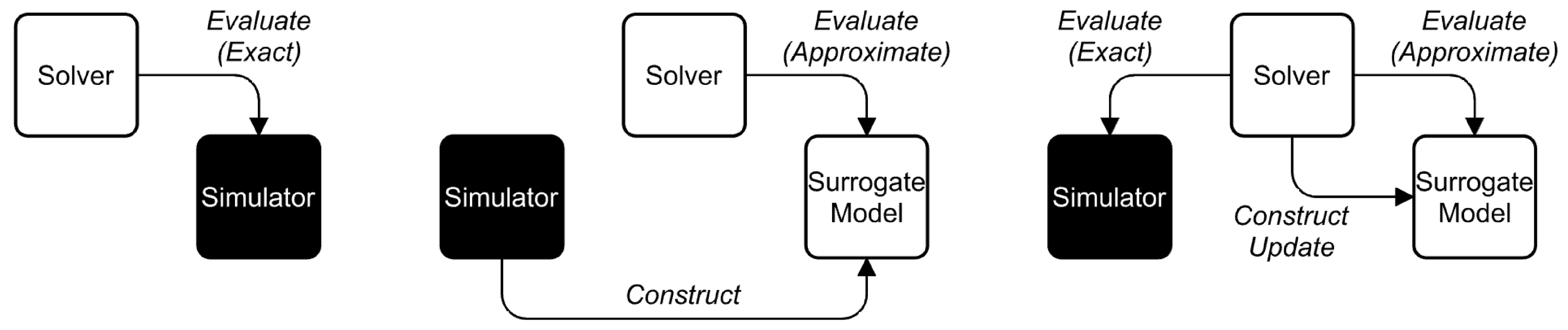
From Randomized Design Exploration to Design Space Cartography–Model-based Optimization for Performance-Informed Architectural Design Processes

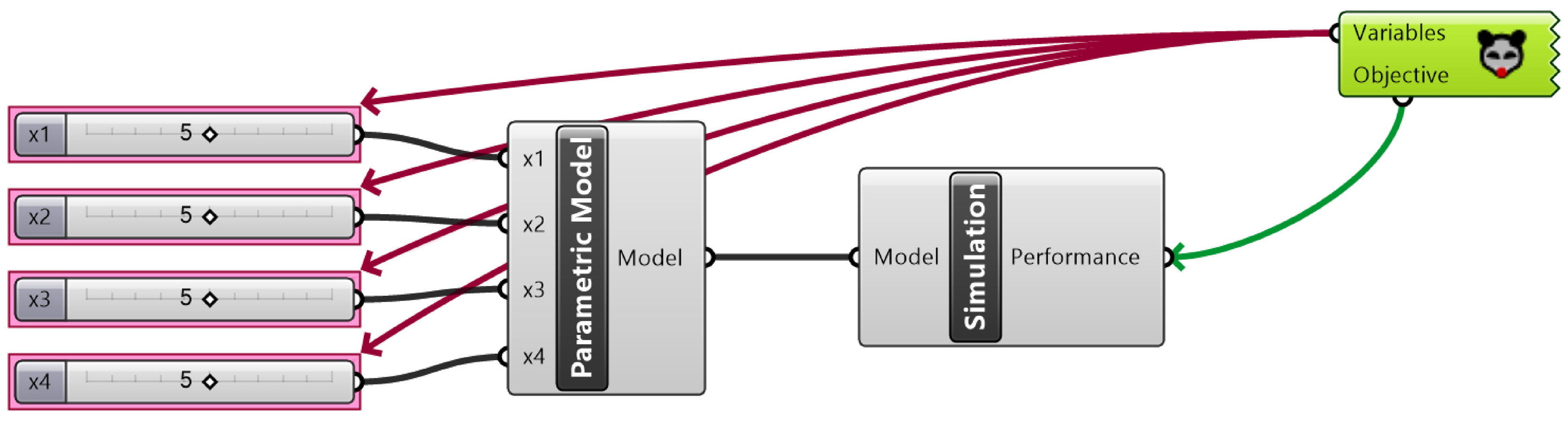
SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

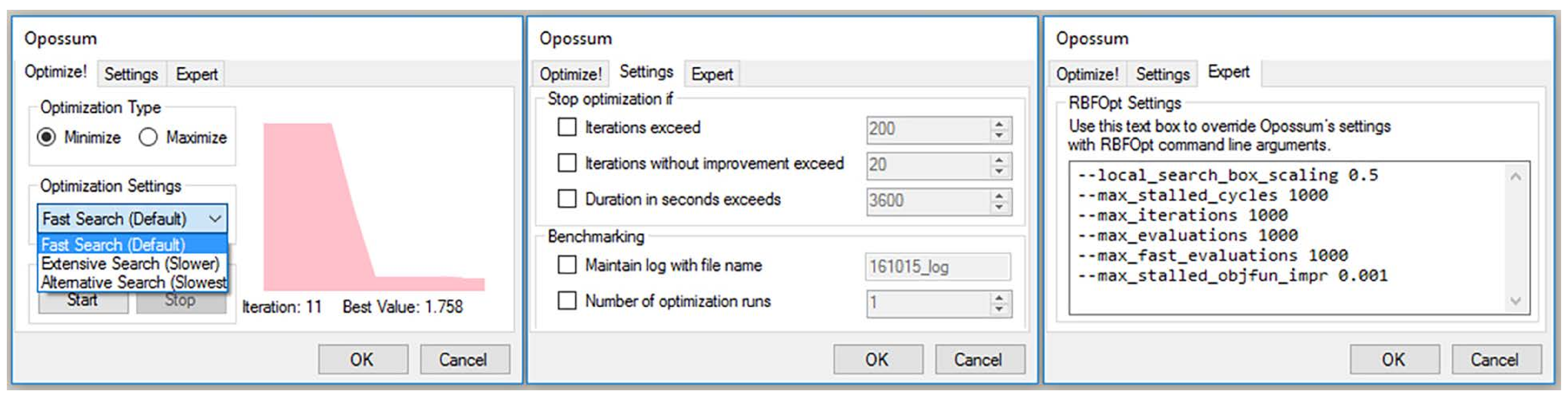


Contemporary architectural design often involves **sophisticated structural and environmental simulations that are time-intensive**. To optimise architectural designs in a reasonable amount of time, it is necessary to employ **state-of-the-art optimisation algorithms**. The diagrams above represent the three classes of simulation-based optimisation algorithms: stochastic **metaheuristics, deterministic direct search and model-based algorithms**.

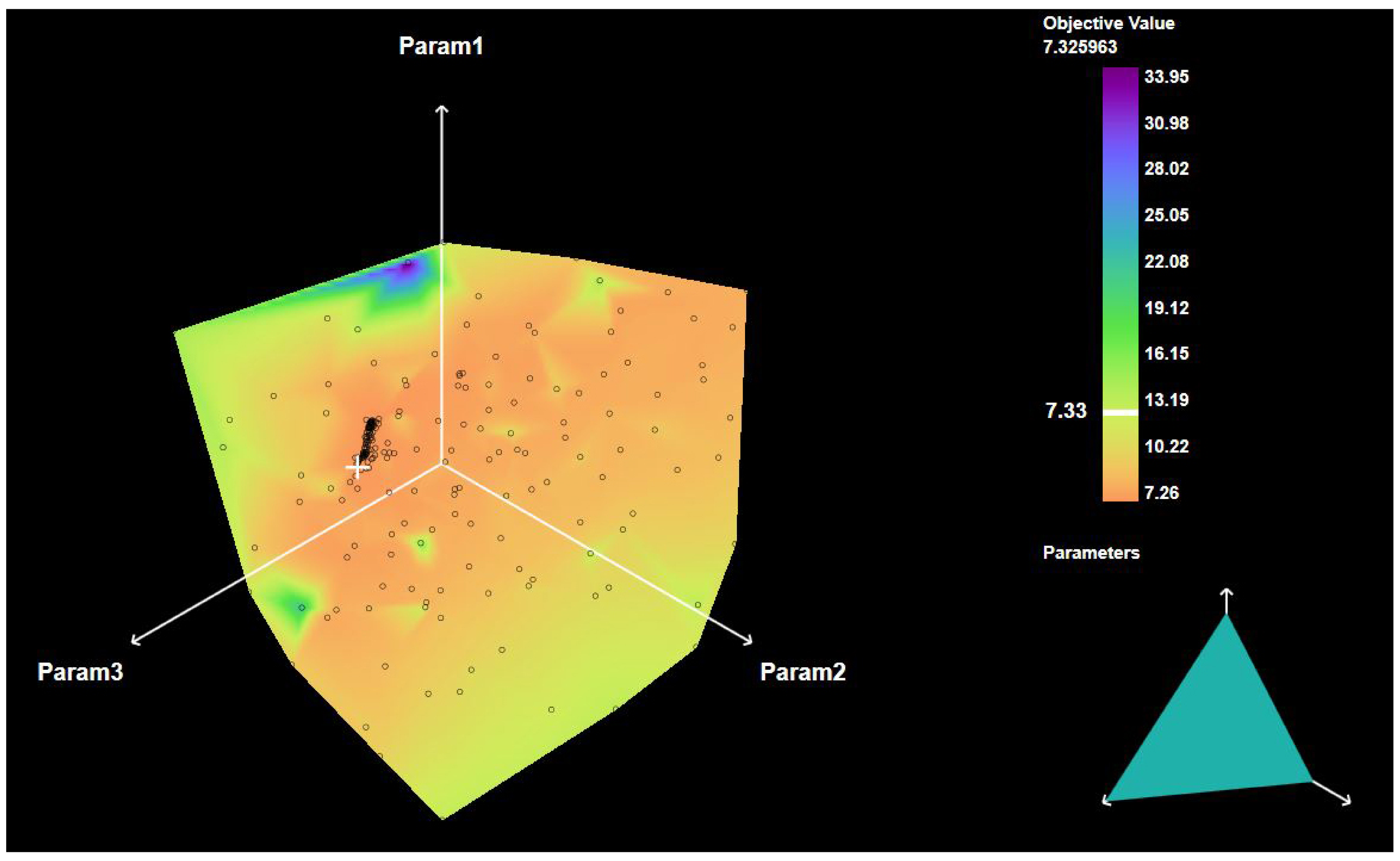


Model-based algorithms employ surrogate models (estimates of the implicit mathematical formulations of simulation-based problems) to guide the search for good solutions. Surrogate models accelerate optimisation, since they are **much faster to calculate** than the underlying simulations. One optimisation steps consist of (1) **searching the model for a promising solution** to evaluate, (2) **simulating the found solution** and (3) **updating the model** based on the simulation results.

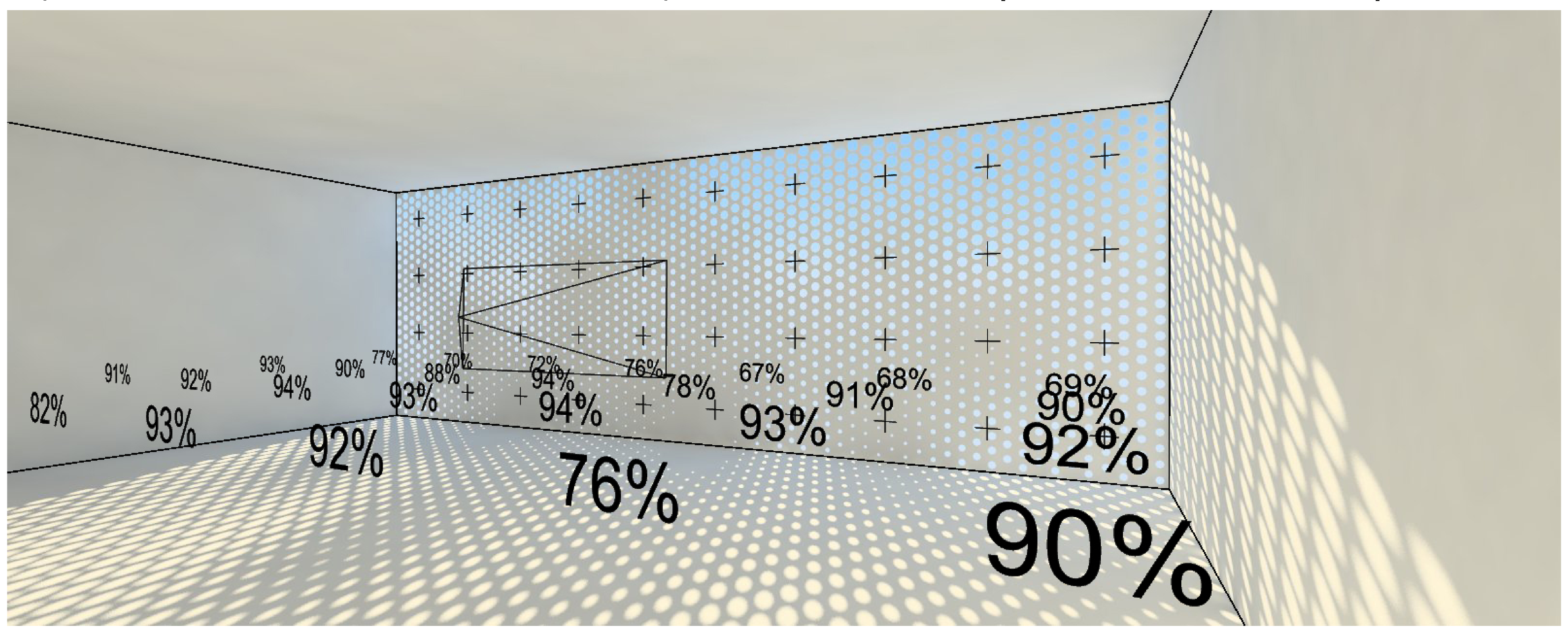




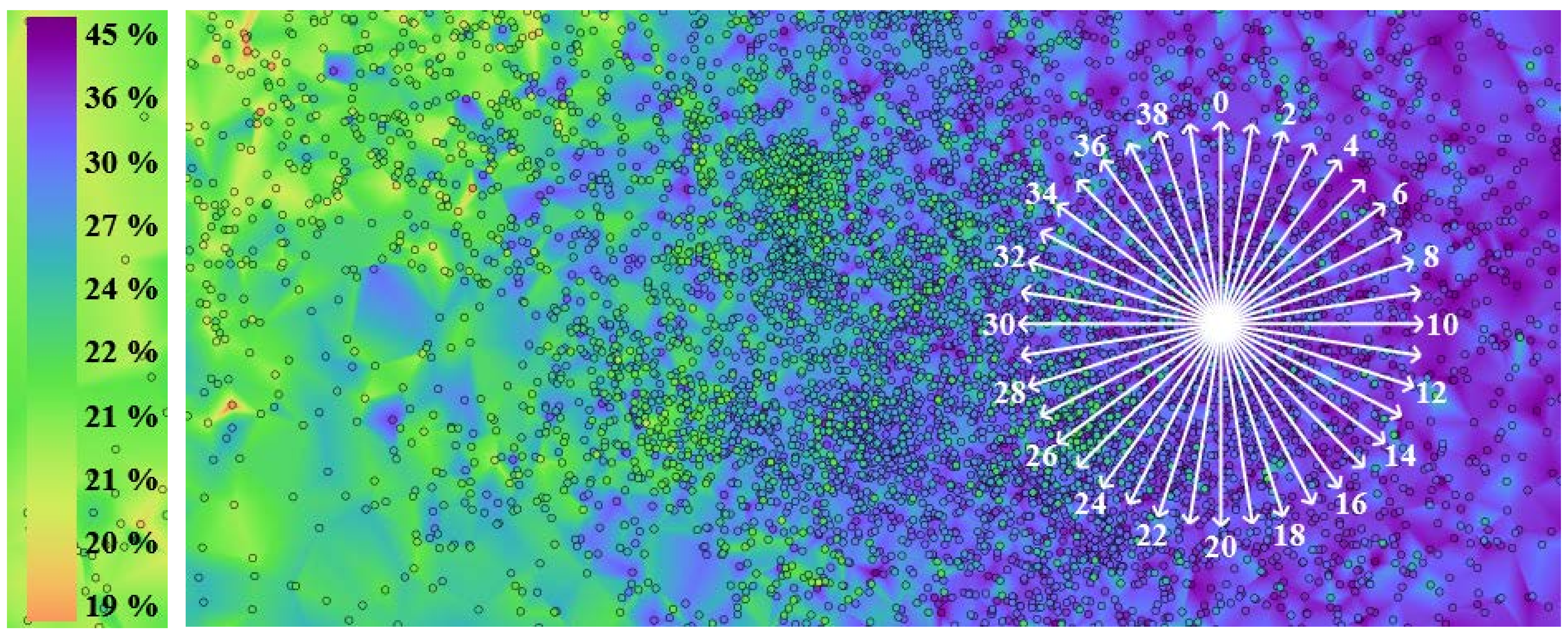
Opossum follows the look and behavior of existing optimisation tools for architects. Opossum's GUI consists of three tabs: The first tab lets users choose between minimisation and maximisation, **select one of three pre-sets** of parameters, and start and stop the optimisation. The second tab lets users **define stopping conditions** based on the number of iterations or the elapsed time and conduct and log multiple optimisation runs. The third tab accepts **command line parameter for RBFOpt**.



Opossum 2.0 will feature an **interactive visualisation of the surrogate model**, a so-called **Performance Map**. This visualisation will (1) **provide insights** into the nature of optimisation problems, (2) **represent the predicted performance** of unexplored designs, (3) **display designs** that are estimated to perform well and (4) **identify promising areas** for further exploration.

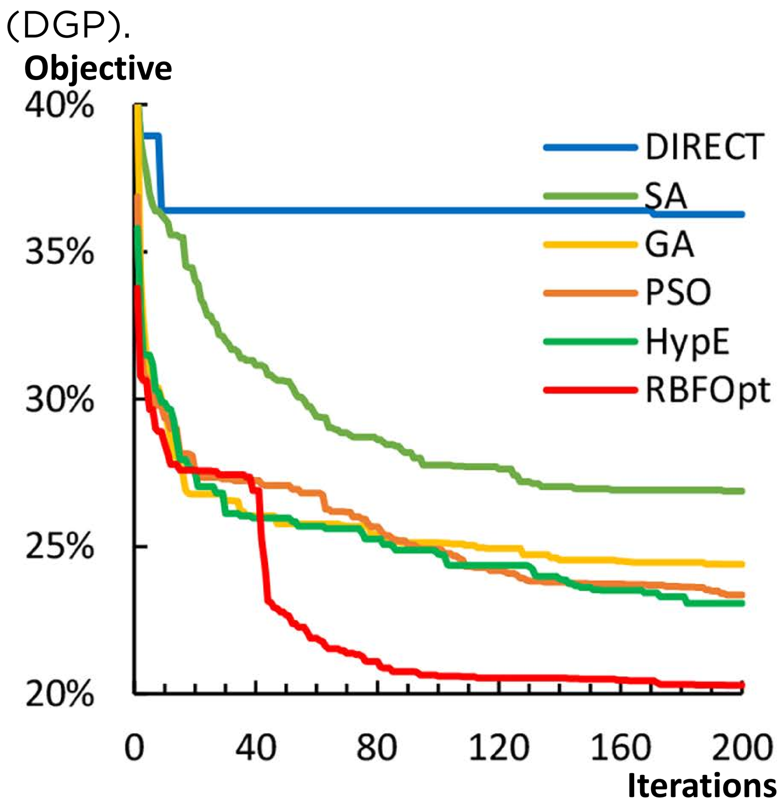


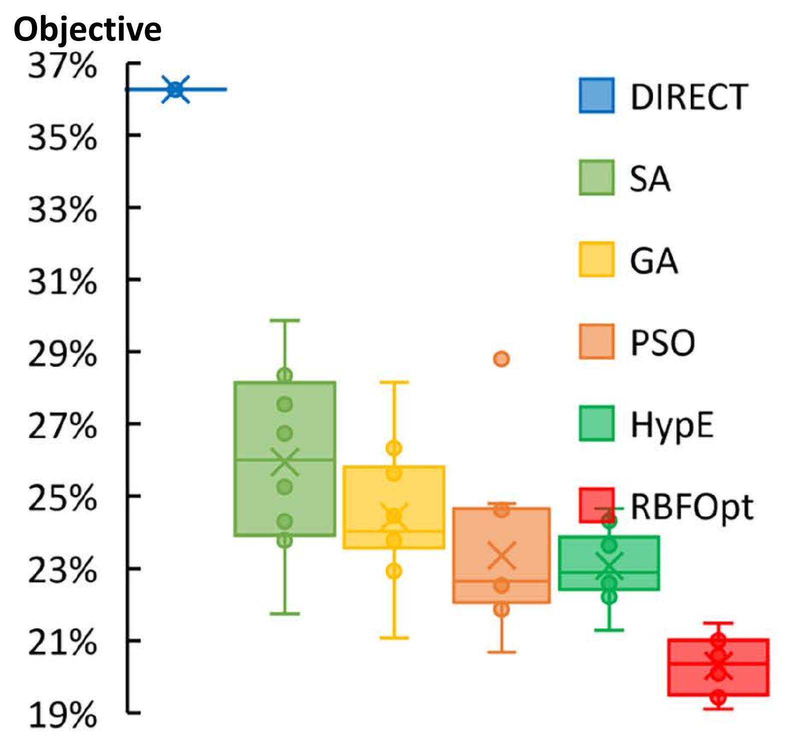
We consider an individual room in Singapore. For the façade, we propose a porous screen with a grid of 1.692 circular openings. A grid of forty "attractor points" controls the openings, with weights in the range [0.0, 1.0]. This formulation results in a problem with forty continuous variables. The objectives of the optimisation are to (1) **maximise Useful Daylight Illuminance** (UDI) while (2) **minimising Daylight Glare Probability** (DGP).



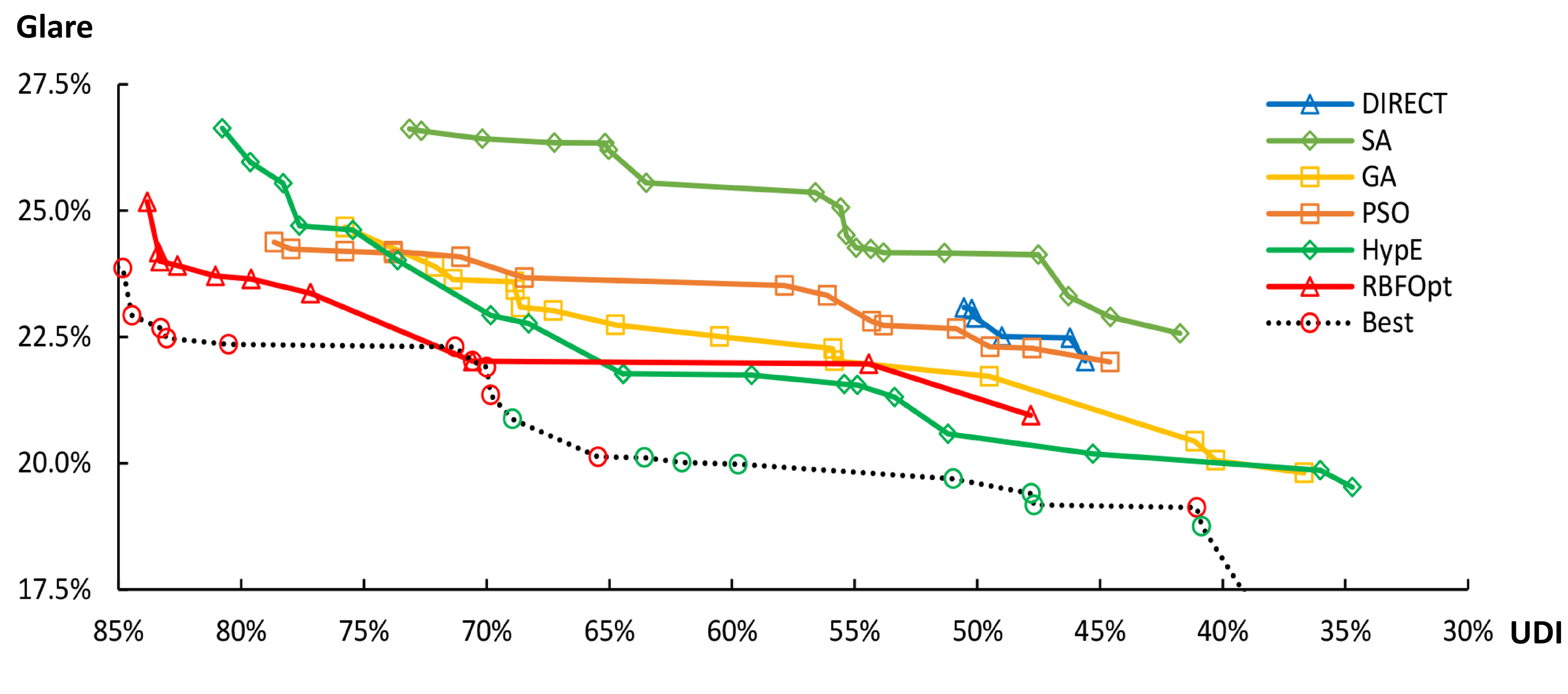
Performance Map of the optimisation problem described on the Left, with the objective: *min f(x) = (1.0 – u(x) + g(x)) / 2*

The map indicates a noisy objective function with a general trend that **better solutions are open towards the top and closed towards the bottom**. There are many solutions around 22% and **several isolated optima at 19%**.





DIRECT and SA perform poorly, while the remaining metaheuristics perform similarly and improve the objective by around 40%. **Opossum's RBFOpt is the best-performing solver** with an improvement of 50%. Note RBFOpt's rapid progress after 40 evaluations: Here it starts **profiting from the surrogate model**. The box plot on the right indicates the range of objective values found by the solvers in five runs. DIRECT is fully deterministic. Of the remaining algorithms, **RBFOpt is the most stable**.



RBFOpt and HypeE have found the closest approximations of the Pareto front. The diagonal fronts indicate a tradeoff between maximising daylight and minimising glare, although large improvements of daylight quality can be achieved by accepting small increases in glare. This improvement is especially noticeable for RBFOpt. HypE suggests a steep tradeoff between daylight and glare, while **RBFOpt indicates that the tradeoff is less dramatic.**

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