# Hypervolume Gradient Ascent for Memetic Building Spatial Design Optimisation

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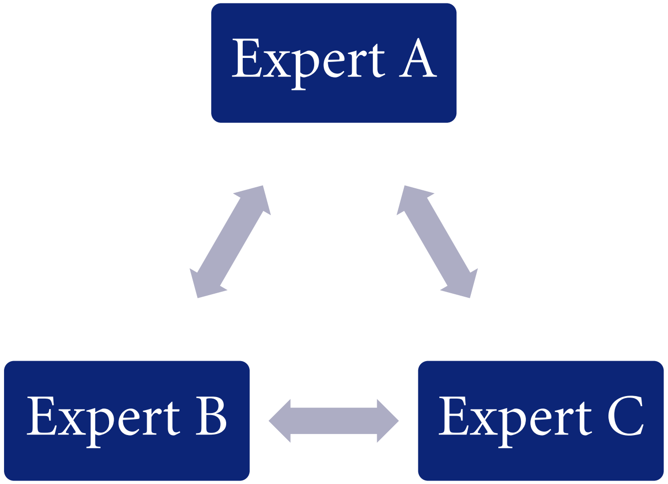
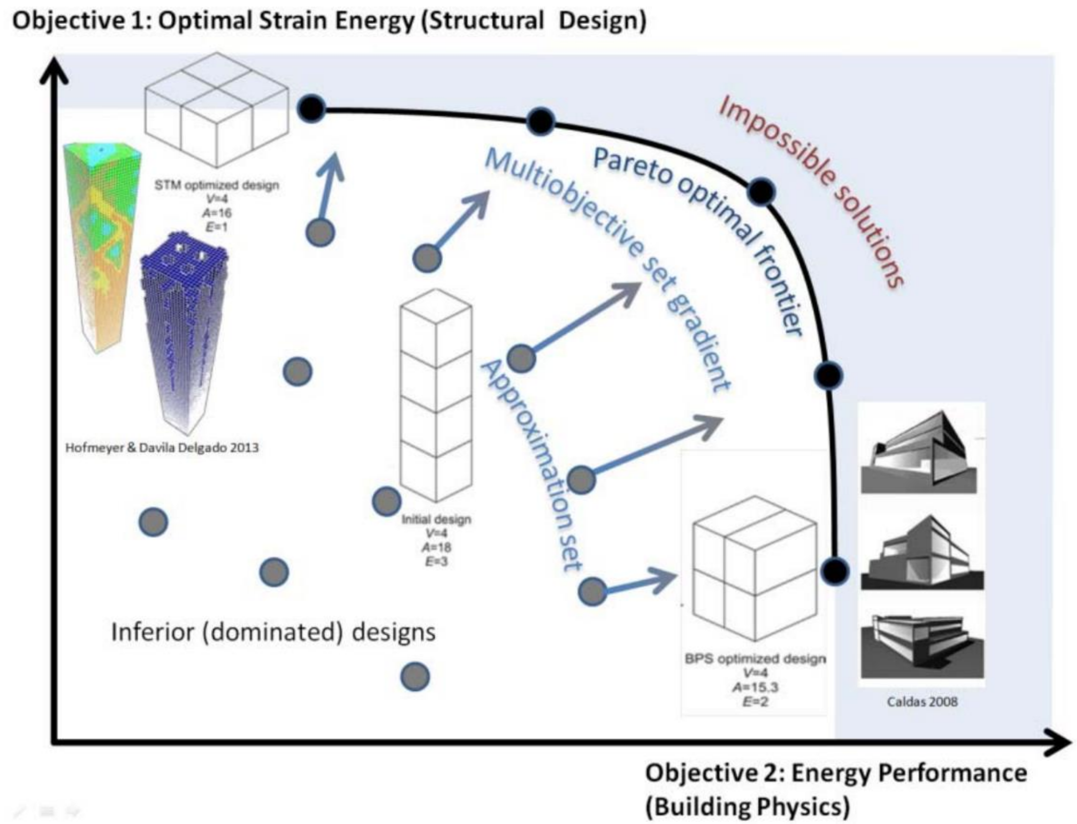
# Traditional building design

- Many disciplines with different experts
  - E.g. Structural, plumbing, HVAC, etc.
- Issues
  - Sequential
  - Limited communication
- Solution: Automation



# Problem description

- Optimise building spatial design (i.e. the shape)
  - Structural performance (compliance)
  - Thermal performance (heating/cooling energy)



# Work so far

- Problem representation and constraint functions [1,2]
- Tested with standard algorithms [2,3]
- Constraint satisfaction penalty functions [2]
- Constraint satisfaction by specialised initialisation and mutation operators [3]
- Improved operators and parameter tuning [4]
- Cooperative superstructure and free representation [5]


[1] S. Boonstra, K. van der Blom, H. Hofmeyer, R. Amor, and M. T. M. Emmerich, “Super-structure and super-structure free design search space representations for a building spatial design in multi-disciplinary building optimisation,” in Electronic proceedings of the 23rd International Workshop of the European Group for Intelligent Computing in Engineering. Jagiellonian University ZPGK, 2016, pp. 1–10.
[2] K. van der Blom, S. Boonstra, H. Hofmeyer, and Emmerich M. T. M., A super-structure based optimisation approach for building spatial designs. in Proceedings of the VII European Congress on Computational Methods in Applied Sciences and Engineering, Papadrakakis M., Papadopoulos V., Stefanou G., Plevris V., Eds.. National Technical University of Athens, 2016, pp. 3409–3422.
[3] K. van der Blom, S. Boonstra, H. Hofmeyer, and M. T. M. Emmerich, “Multicriteria building spatial design with mixed integer evolutionary algorithms,” in Parallel Problem Solving from Nature – PPSN XIV, ser. Lecture Notes in Computer Science, J. Handl, E. Hart, P. R. Lewis, M. López-Ibáñez, G. Ochoa, and B. Paechter, Eds., vol. 9921. Cham: Springer International Publishing, 2016, pp. 453–462.
[4] K. van der Blom, S. Boonstra, H. Hofmeyer, T. Bäck, M. T. M. Emmerich, “Configuring advanced evolutionary algorithms for multicriteria building spatial design optimisation,” in 2017 Congress on Evolutionary Computation (CEC). IEEE, 2017, pp. 1803–1810
[5] S. Boonstra, K. van der Blom, H. Hofmeyer, M. T. M. Emmerich, “Combined super-structured and super-structure free optimisation of building spatial designs,” in 24rd International Workshop of the European Group for Intelligent Computing in Engineering, C. Koch, W. Tizani, J. Ninic, Eds.. University of Nottingham, 2017, pp. 23–34

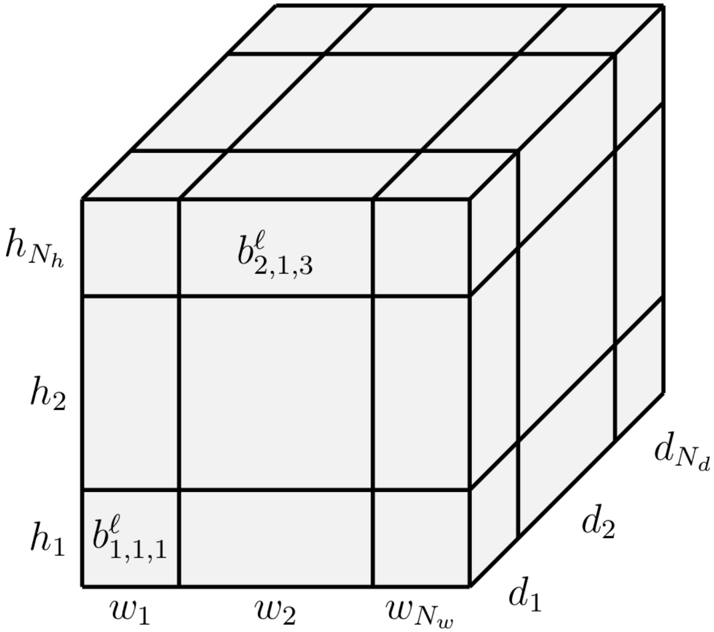
# Contributions

- Hypervolume gradient ascent in the real world

- Challenges:
  - Numerical gradients only
  - Box constraints
  - Repair function

- Memetic algorithm
  - Improve local search
  - Relay or alternate?

# Problem representation



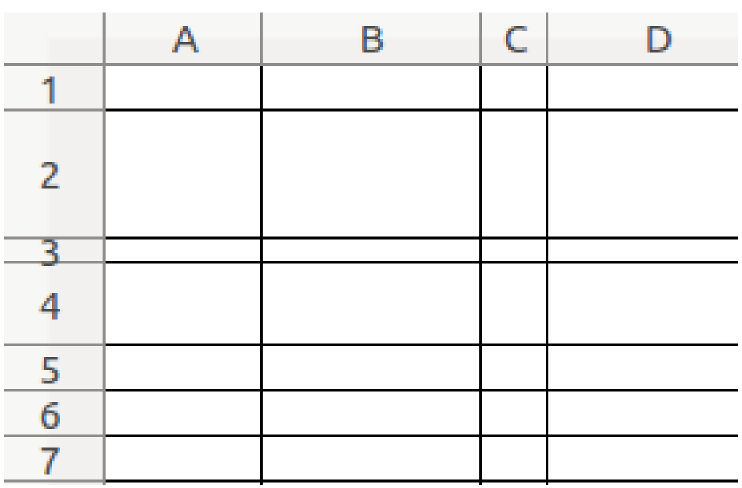

$i \in \{1,2,\ldots,N_w\} \qquad w_i \in \mathbb{R} \geq 0$

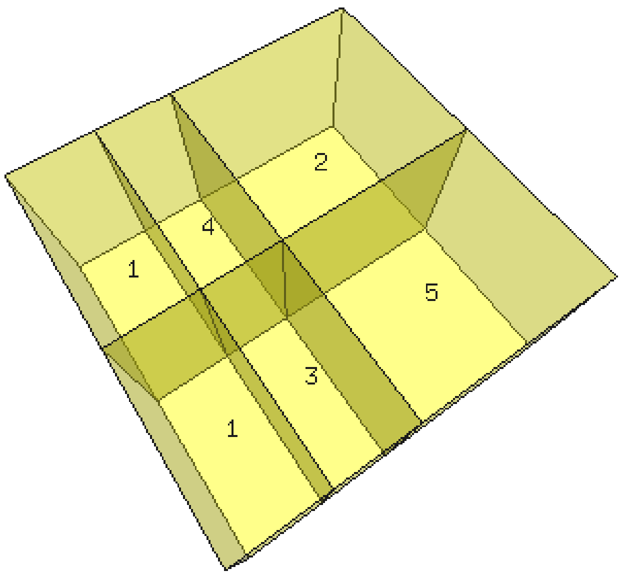
$j \in \{1,2,\ldots,N_d\} \qquad d_j \in \mathbb{R} \geq 0$

$k \in \{1,2,\ldots,N_h\} \qquad h_k \in \mathbb{R} \geq 0$

$\ell \in \{1,2,\ldots,N_{rooms}\}$

$$b^{\ell}_{i,j,k} = \begin{cases} 1 & \text{if cell } (i,j,k) \text{ belongs to room } \ell \\ 0 & \text{otherwise} \end{cases}$$



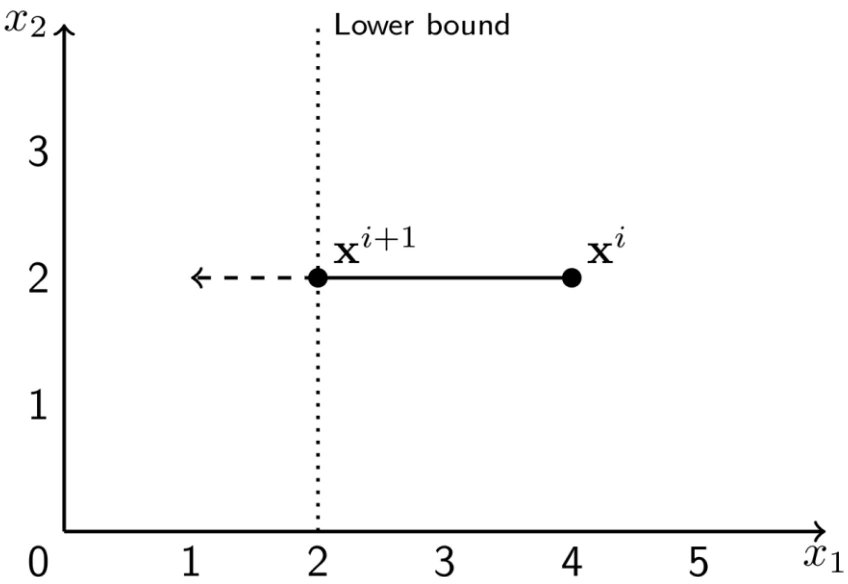
# Constraints on binary variables

- Active – every room has at least one active cell
- No overlap – cell $(x, y, z)$ is active for at most one room
- Cuboid shape – all cells active for a room together form a cuboid (3D rectangle)
- No floating cells – every cell has ground or another cell below it

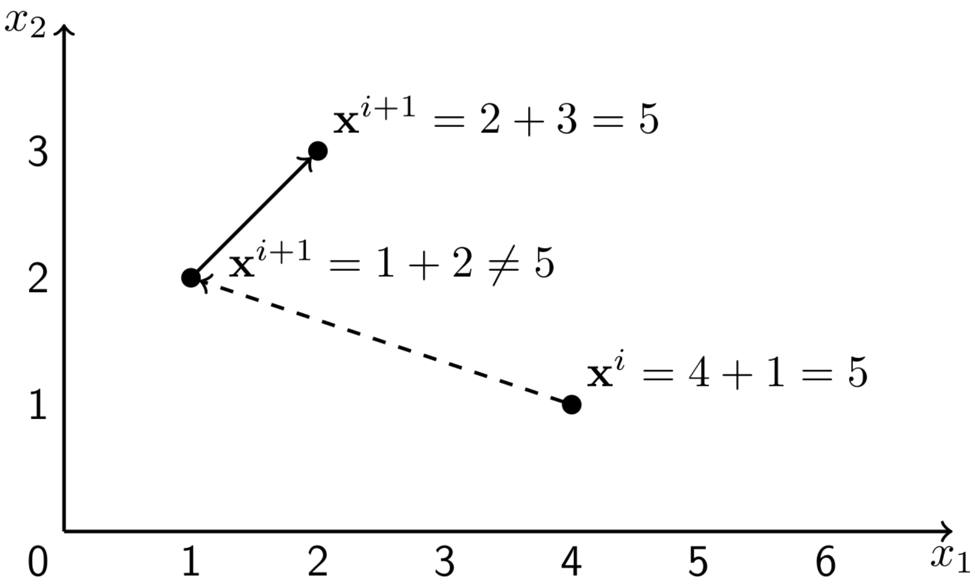
# Problem specific challenges

- Gradients can only be found numerically
- Constraints on variables

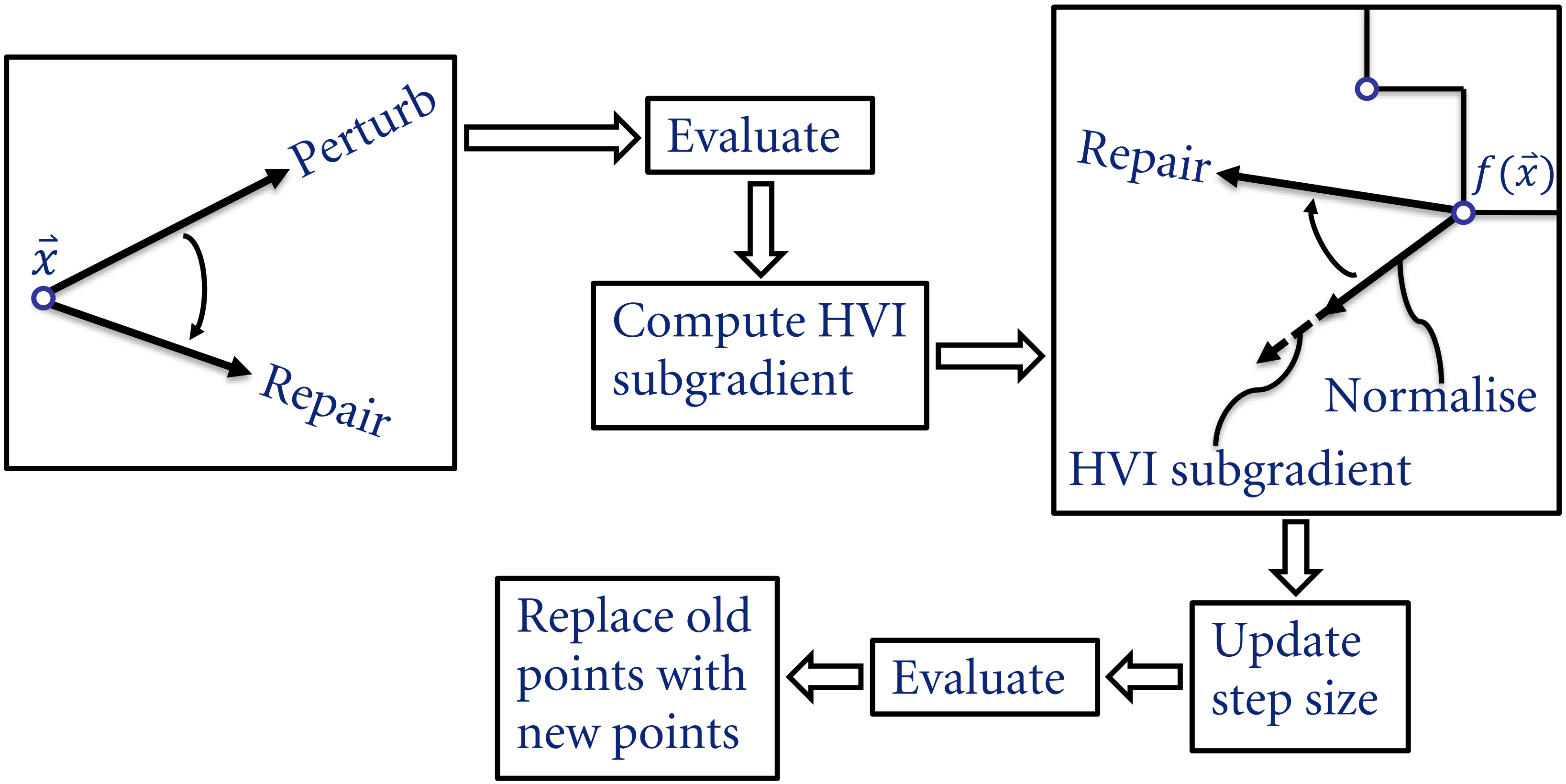
Box constraint




Rescale



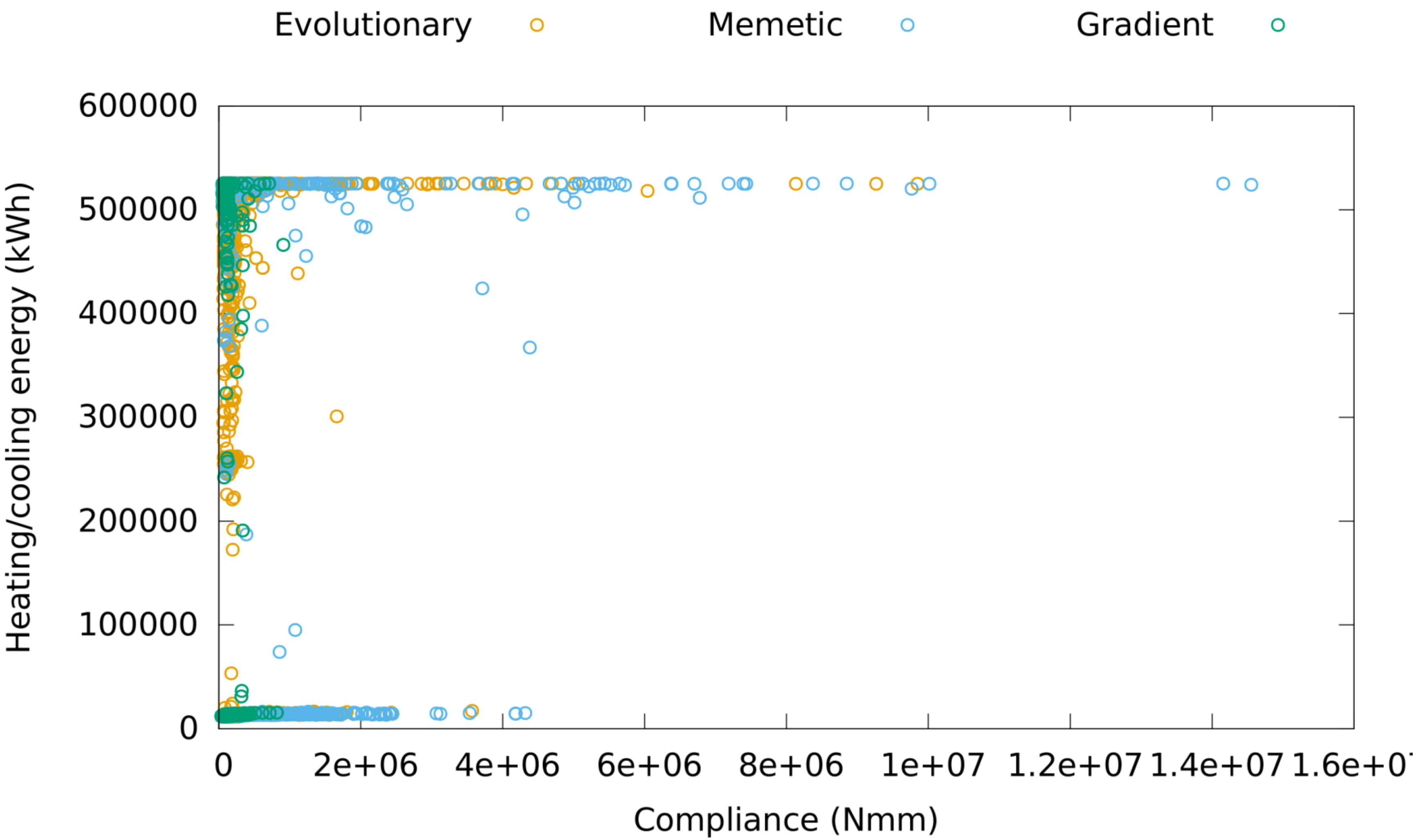
# Numerical HIGA-MO



# Experiment

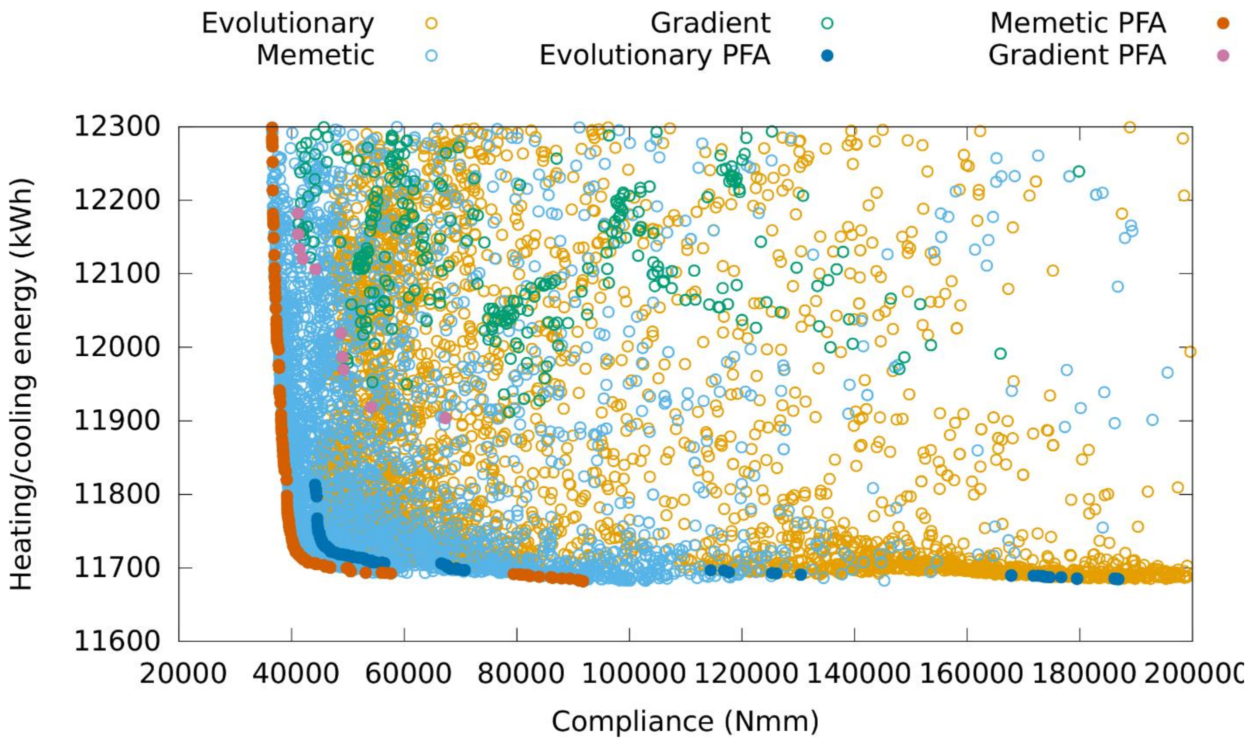
- Compare
  - Evolutionary (SMS-EMOA + problem specific operators)
  - Hypervolume indicator gradient ascent (HIGA)
  - Memetic: Evolutionary + HIGA in relay (switch half way)
- Setup
  - 2 objectives
  - 81 binary variables
  - 9 continuous variables
  - 10,000 evaluations

# Results – overview objective space



# Pareto Front

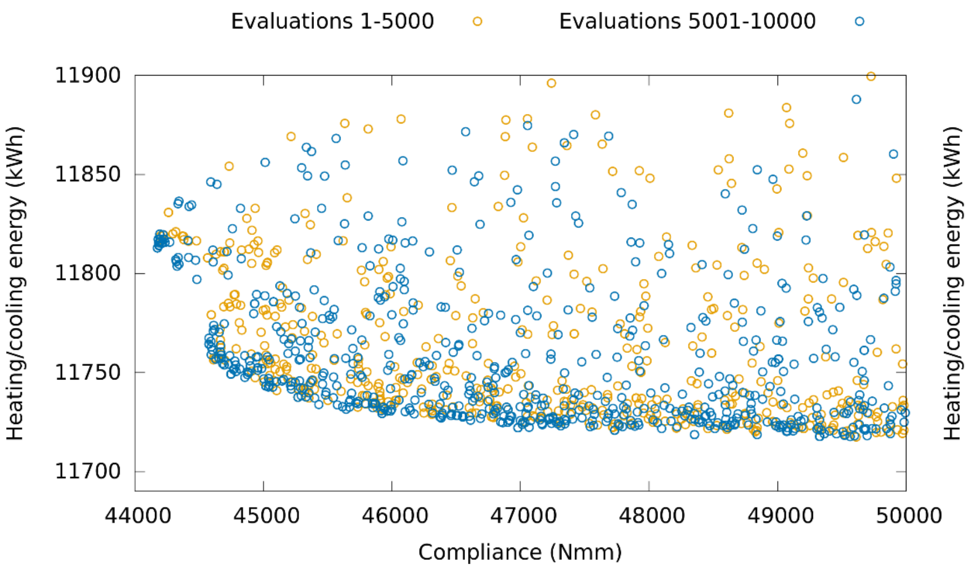
- Gradient only is not sufficient
- In this example: Memetic ≻ Evolutionary before gradient search starts (in discrete space)



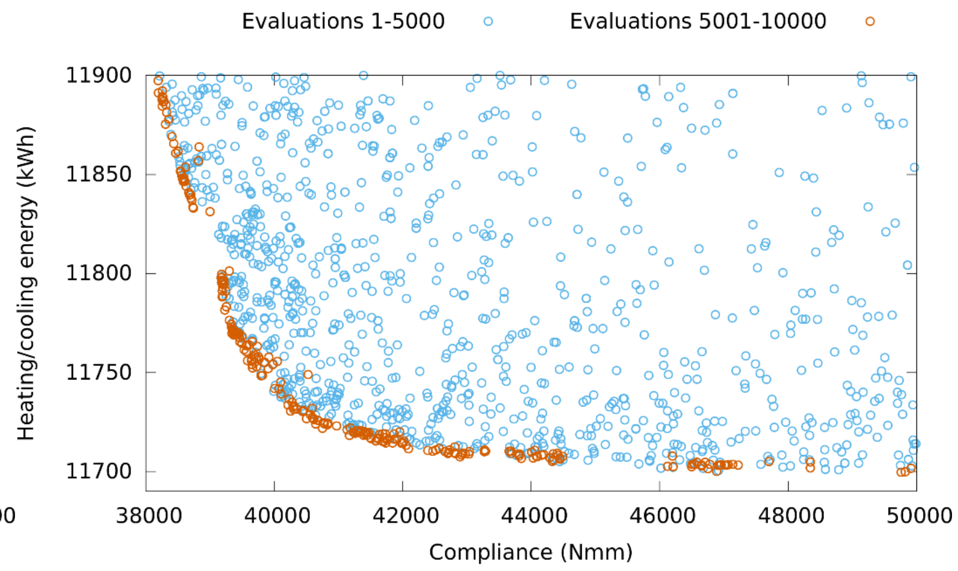
# Local search effectiveness

- Chaotic search vs. search focused on the PF

Evolutionary

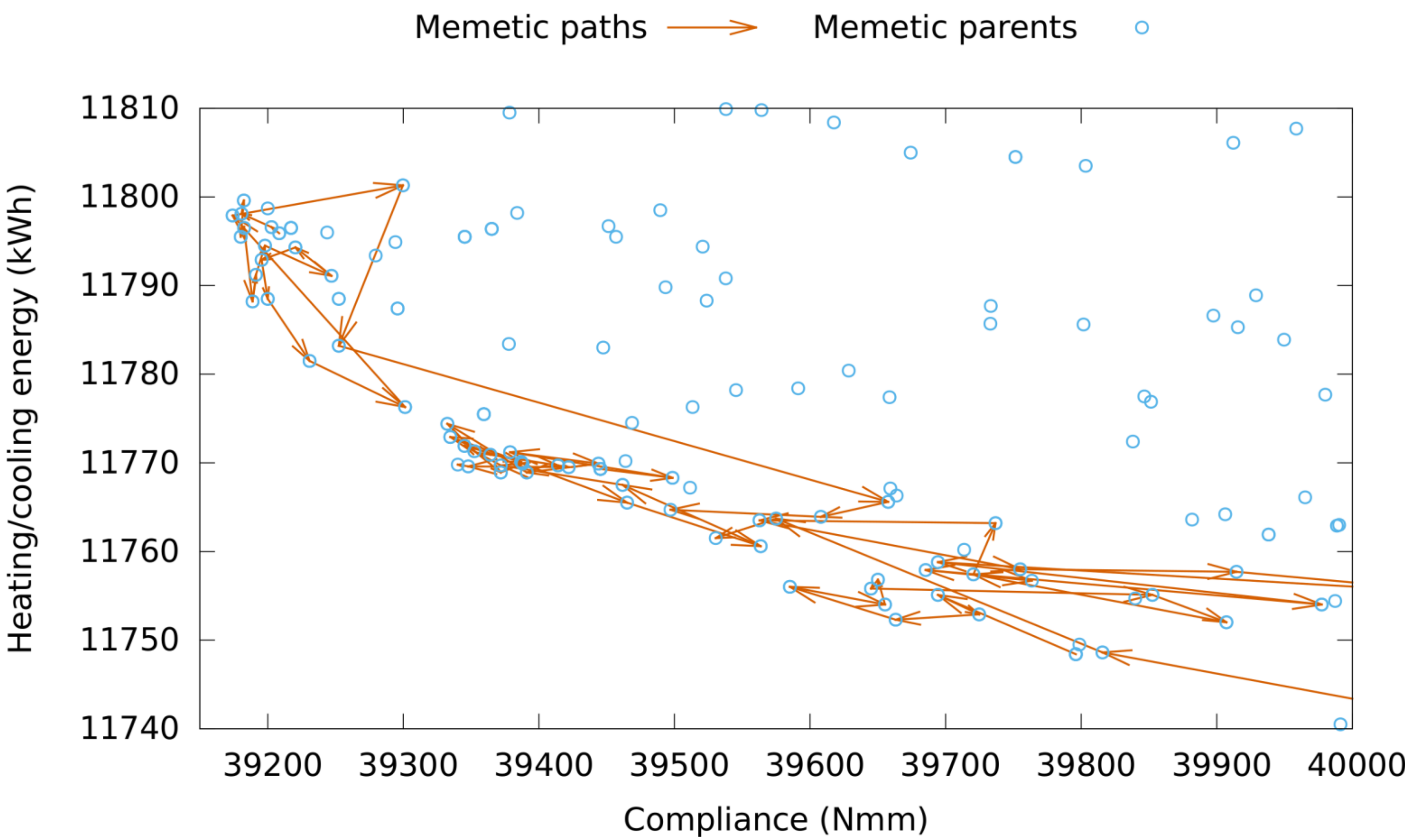



Memetic



# Local search zoomed in

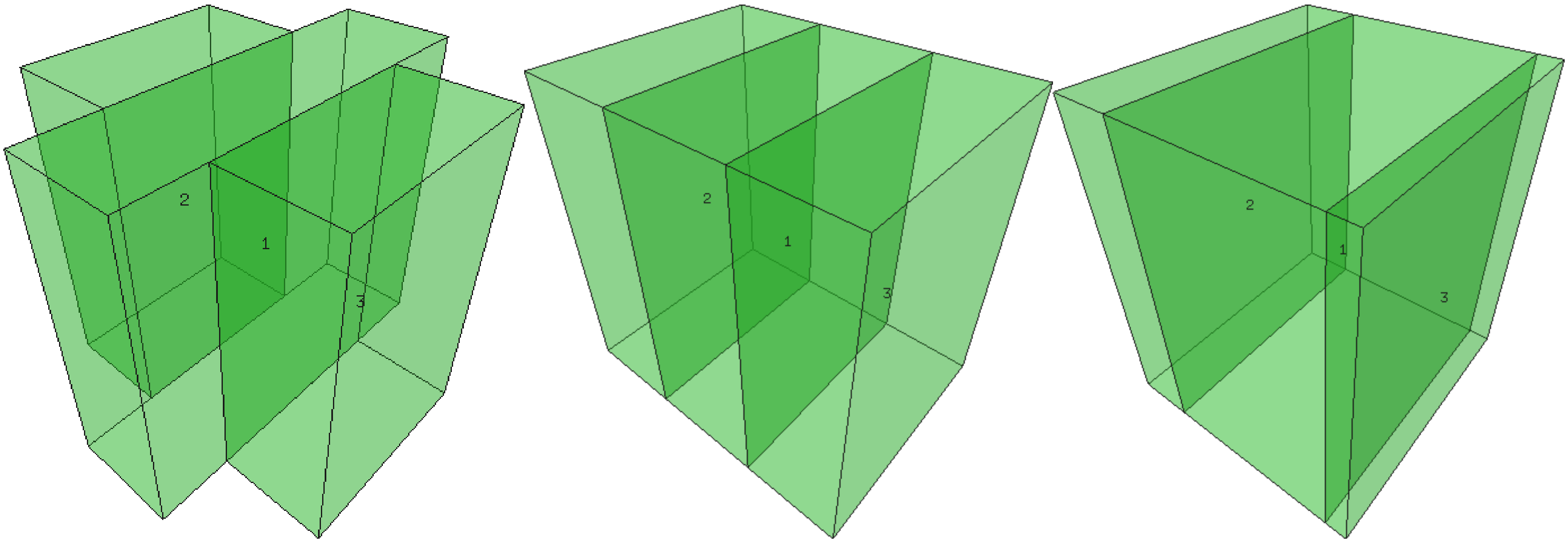
- Gradient search improves the PF



# Visualisation

- Trade-off between objectives

Structural Kneepoint Thermal



# Conclusion

- Optimising buildings spatial design performance
  - Structural
  - Thermal
- Memetic approach combining
  - Evolutionary
  - Hypervolume gradient ascent
- HIGA-MO in the real world
  - Box constraints
  - Repair functions
  - Etc.

# Future work

- More executions to improve confidence in current observations
- Investigate influence of settings, e.g. step size
- Detailed analysis of the influence of the different constraints on HIGA-MO and what can be done to alleviate any problems resulting from this
- Local search of binary space?
- Datamining on solutions

# Questions?

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