Multicriteria Building Spatial Design with Mixed Integer Evolutionary Algorithms

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Background

Building spatial design involves multiple disciplines with conflicting objectives. Traditional design procedures require cooperation between experts from different disciplines to ensure a design that is effective for each discipline. Cooperation between experts is prone to overlooking discipline specific intricacies. Pareto optimisation is a tool to help find a balance between different disciplines in design problems. This work presents an effort to optimise building spatial designs with objective functions from two conflicting disciplines: **energy performance** and **structural performance**.

Supercube representation

Building spatial designs are represented by a supercube as shown in Fig. 1.

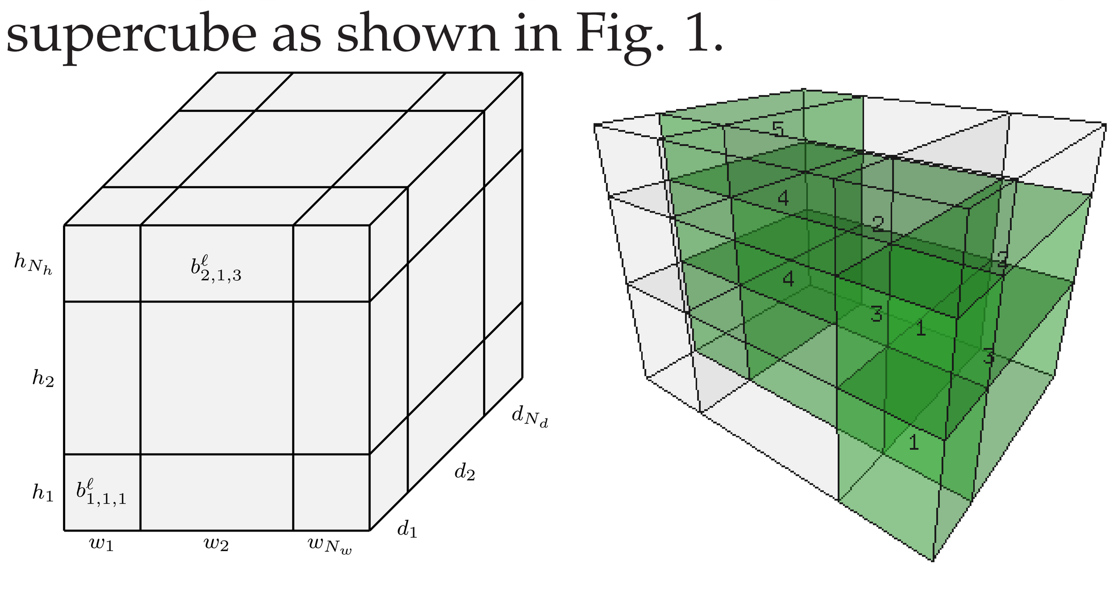

Figure 1: Left: Supercube grid represetation. **Right**: Building spatial design.

Discrete variables: (all binary)

$$b^{\ell}_{i,j,k}, i \in \{1,\ldots,N_w\}, j \in \{1,\ldots,N_d\},$$
$$k \in \{1,\ldots,N_h\}, \text{ and } \ell \in \{1,\ldots,N_{spaces}\}$$

Continuous variables:

$$w_i, i \in \{1,\ldots,N_w\}, d_j, j \in \{1,\ldots,N_d\},$$
$$\text{and } h_k, k \in \{1,\ldots,N_h\}$$

Energy performance is measured as the total outside surface area of the building spatial design, excluding the floor surface of the ground level.
A black box simulator is used to compute the structural performance measured by the compliance.

Constraints

These constraints are defined in MINLP form:

- Spaces should not overlap with each other
- Spaces should have a cuboid (3D rectangle) shape
- Vertical gaps (e.g. floating parts, archways, cantilevered parts) are not allowed
- The number of spaces is constant

For example the last constraint is described by Eq. 1. Equations of the other cosntraitns may be found in [1].

$$\forall_{i,j,k} \sum_{\ell=1}^{N_{spaces}} b^{\ell}_{i,j,k} \leq 1 \qquad (1)$$

Standard Algorithms

NSGA-II [3] and SMS-EMOA [4] are used in their standard form except for the following:

- **Function evaluation**: Only when no constraints are violated. In case of constraint violations a large penalty value based on the number of violations is returned.
- **Offspring generation**: After traditional offspring generation the volume of the offspring individual is repaired by rescaling supercube dimensions.

A constant volume is maintained during optimisation of the building spatial design to avoid the possibility of objectives largely being optimised by taking extreme values for the continuous variables.
The volume of a building spatial design is found with Eq. 2 and must be close to the desired volume V_0. When the current volume V_c is not within 1% of V_0 the building spatial design is scaled by a factor $\alpha = V_0/V_c$ as in Eq. 3.

$$\sum_{i=1}^{N_w}\sum_{j=1}^{N_d}\sum_{k=1}^{N_h} b_{i,j,k} w_i d_j h_k = V_0 \qquad (2)$$

$$\forall_i : w_i = \sqrt[3]{\alpha w_i}$$
$$\forall_j : d_j = \sqrt[3]{\alpha d_j} \qquad (3)$$
$$\forall_k : h_k = \sqrt[3]{\alpha h_k}$$

Smart SMS-EMOA

Smart SMS-EMOA aims to improve navigation through the constrained search space by adapting SMS-EMOA as follows:

- **Initialisation**: Spaces are initialised to the lowest empty cell in a randomly selected pillar.
- **Mutation**: Expand or contract a single random surface of a random space by a single cell width. In case of constraint violation try a random different move.
- **No recombination**

The volume of offspring individuals is repaired in the same manner as presented for the standard algorithms. Penalties are no longer necessary since the used operators ensure no constraints are violated.

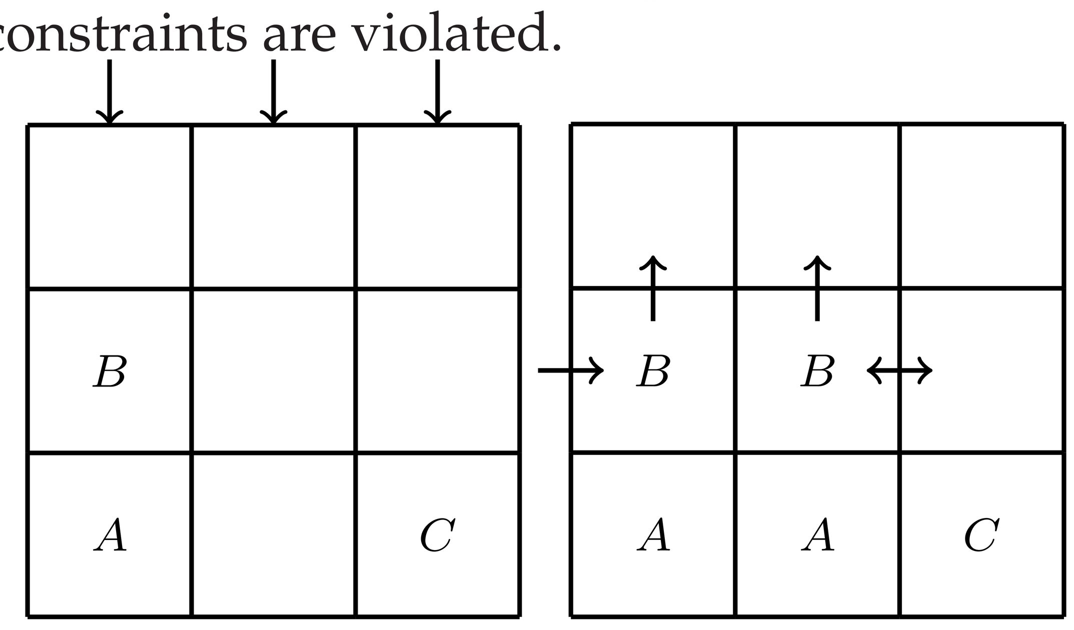

Figure 2: Left: Assigning a single cell to each space in a randomly selected pillar to initialse. **Right**: Mutation with possible mutation directions for space B

Experimental Result

Experiments were conducted to compare the performance of standard versions of the NSGA-II and SMS-EMOA algorithms as well as the smart SMS-EMOA algorithm presented here. The comparison was made on problems of different size, varying in number of cells represented by the supercube and number of spaces to encode.

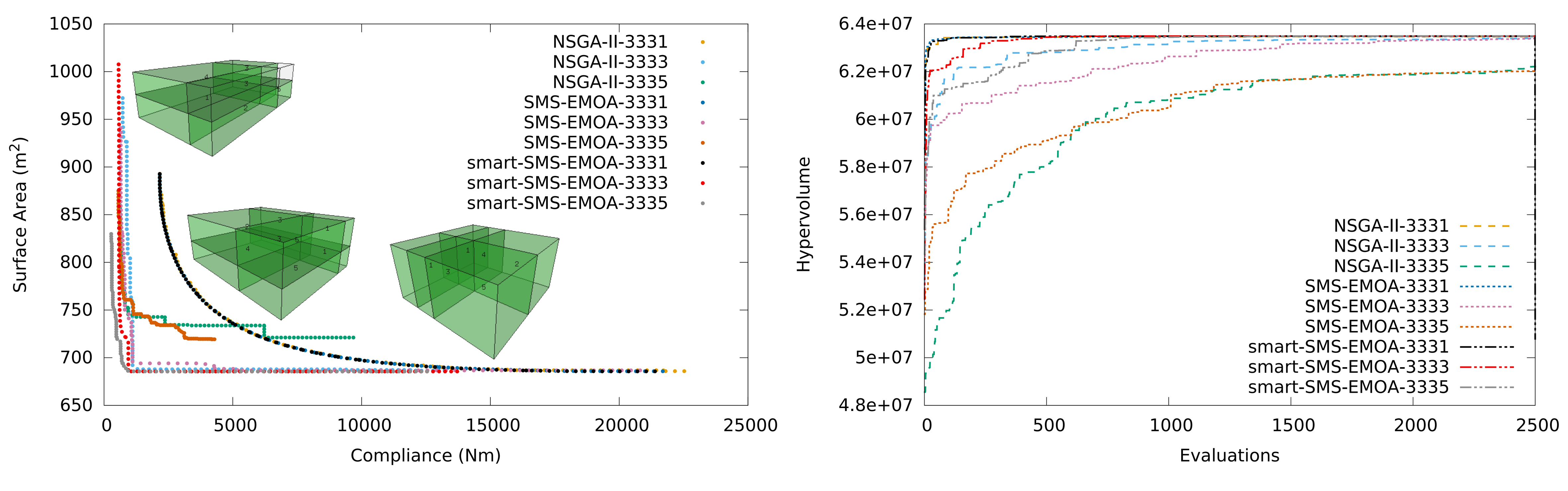

Figure 3: Results over five runs. **Left**: Median attainment curves. **Right**: Average hypervolume growth.

Conclusion

- First approximate Pareto Fronts of building spatial designs are produced, which are always convex
- An improved understanding of the design space is achieved
- Standard algorithms have difficulty navigating constrained landscapes
- A problem specific constraint handling mutation operator is introduced
- Smart mutation improves convergence to and precision of the Pareto front

References

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