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Evolutionary methods in automatic floor layout generation

Barbara Strug

Jagiellonian University, Institute of Applied Computer Science

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Outline

1. Problem formulation, motivation and background
2. Evolutionary computations
3. Design representation
4. Evolutionary operators
5. Fitness evaluation
6. Examples and results
7. Open problems - future work

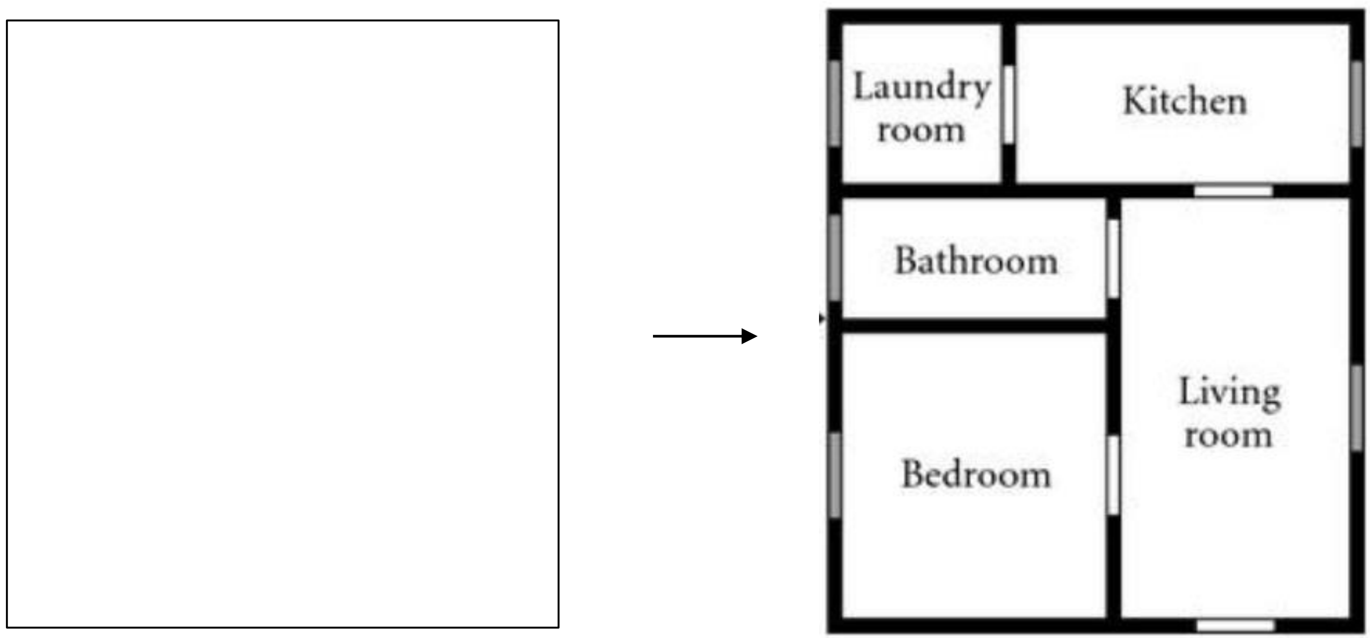
Based mainly on:

Barbara Strug, Ewa Grabska, Grażyna Ślusarczyk: Supporting the design process with hypergraph genetic operators. Adv. Eng. Informatics 28(1): 11-27 (2014)

Grzesiak-Kopeć, Katarzyna, Barbara Strug, and Grażyna Ślusarczyk. 2021. "Evolutionary Methods in House Floor Plan Design" Applied Sciences 11, no. 17: 8229. https://doi.org/10.3390/app11178229

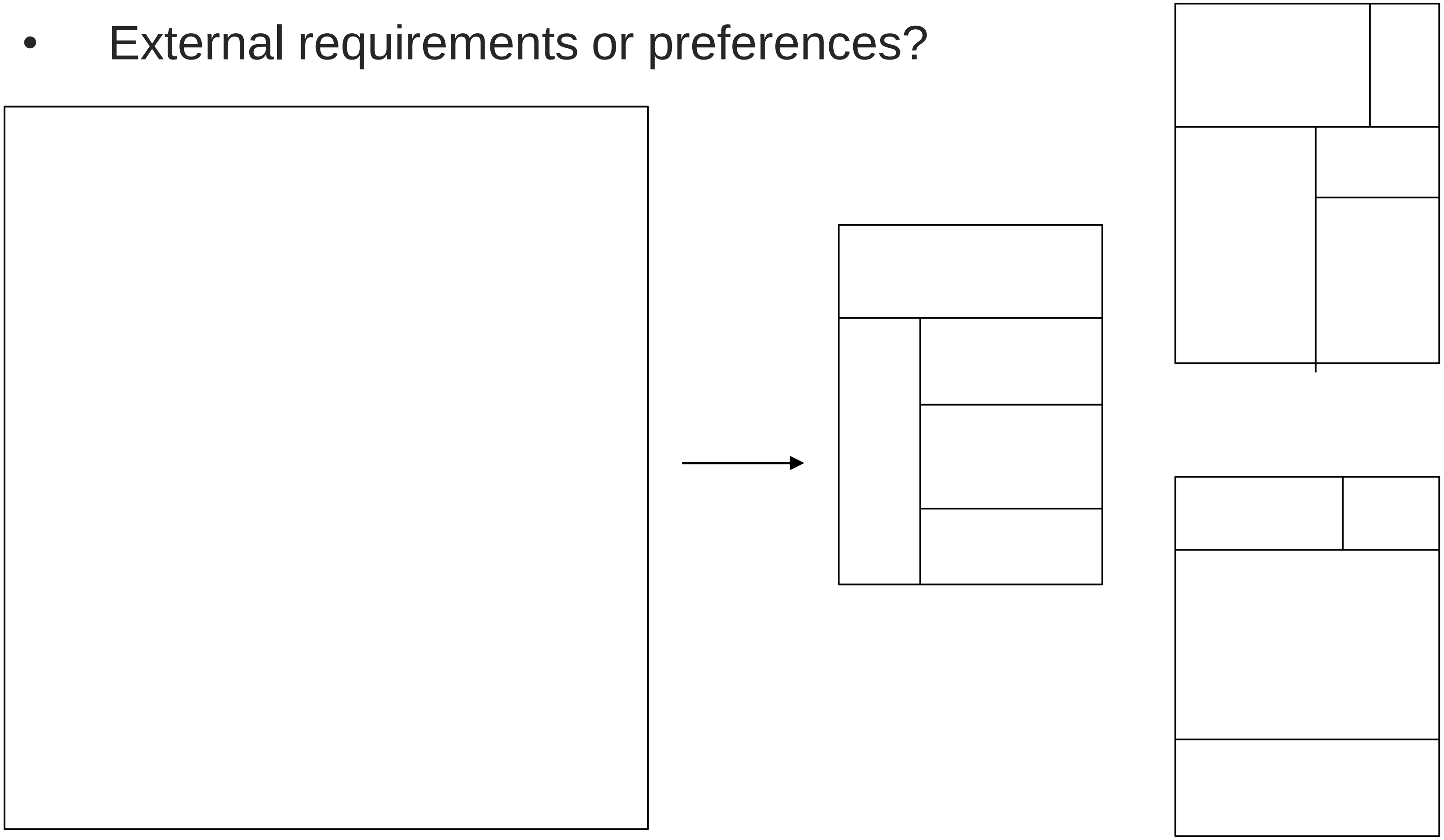
Poblem formulation (I)

- Geometric area as a base for the floor layout
- External knowledge – constraints, requirements
- Preferences



Poblem formulation (II)

- Same geometric area as a base -> different layouts
- External requirements or preferences?



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Optimization problem?

YES

Constraint based optimization problem

Case-based design

Possible well defined numerical boundaries (area, price, use of materials)

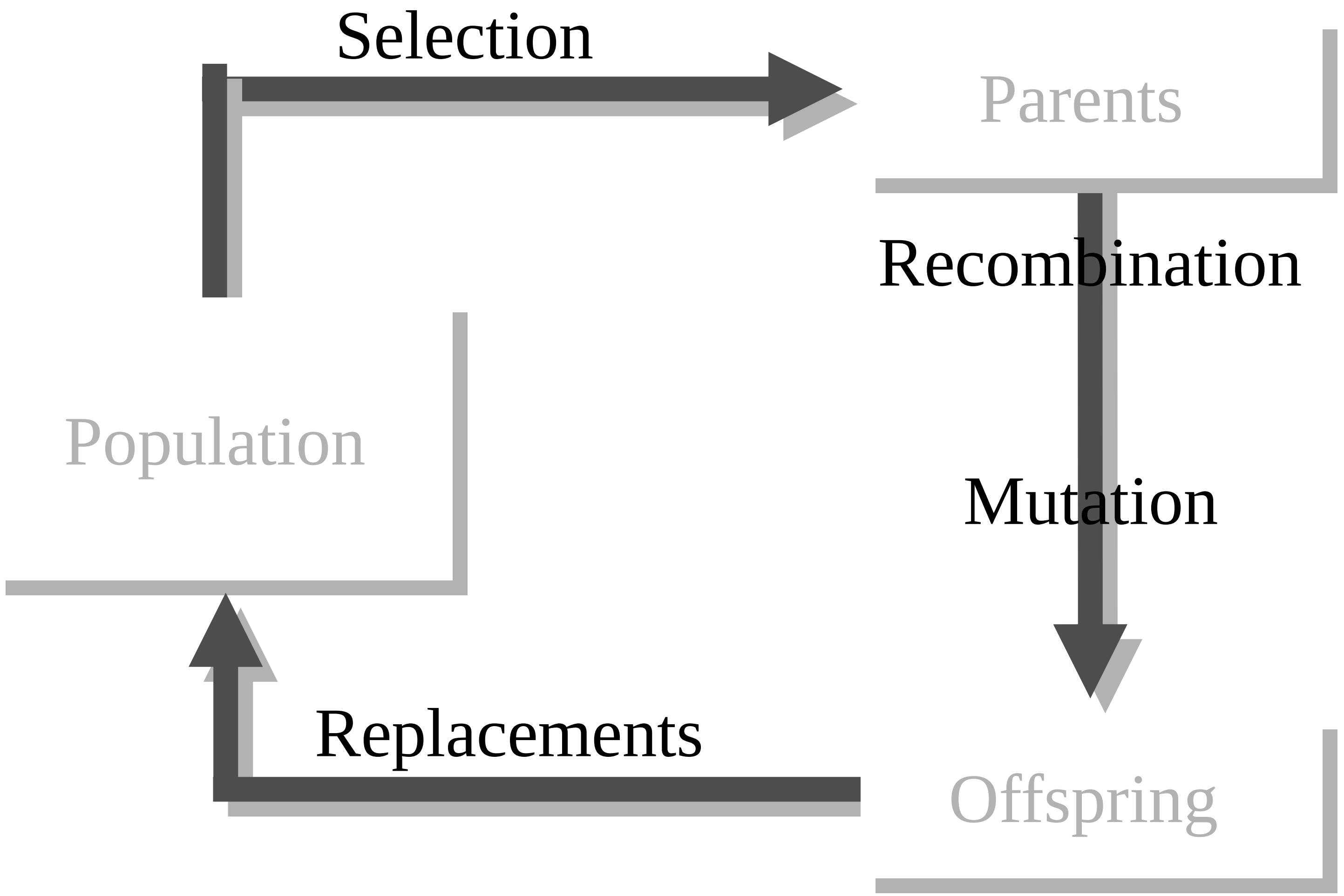
NO

Soft requirements

Personal preferences

Evolutionary computations (I)

Population algorithms

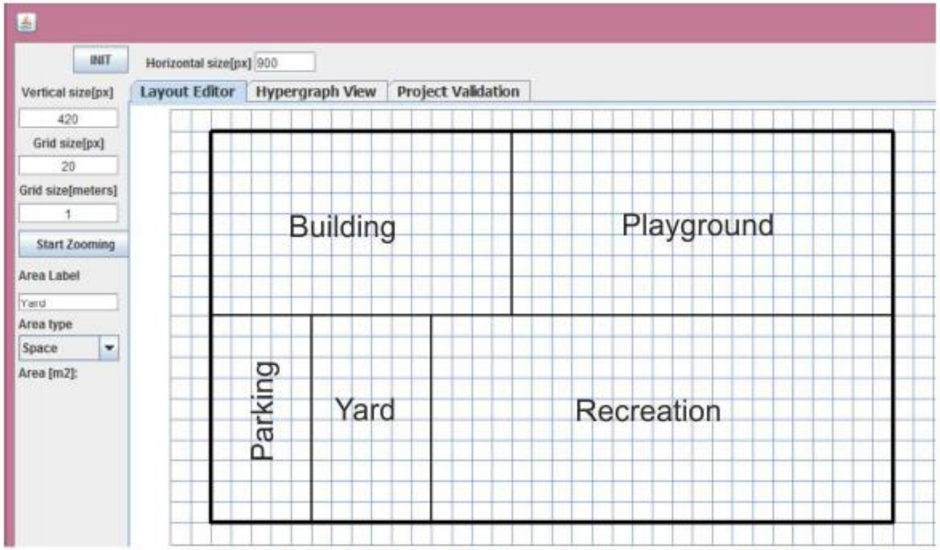


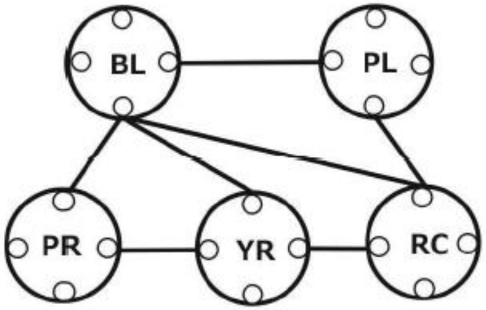
Population algorithms

- Initialization
- Representation
- Recombination and/or mutation
- Fitness evaluation
- Selection

Graph representation (CP)

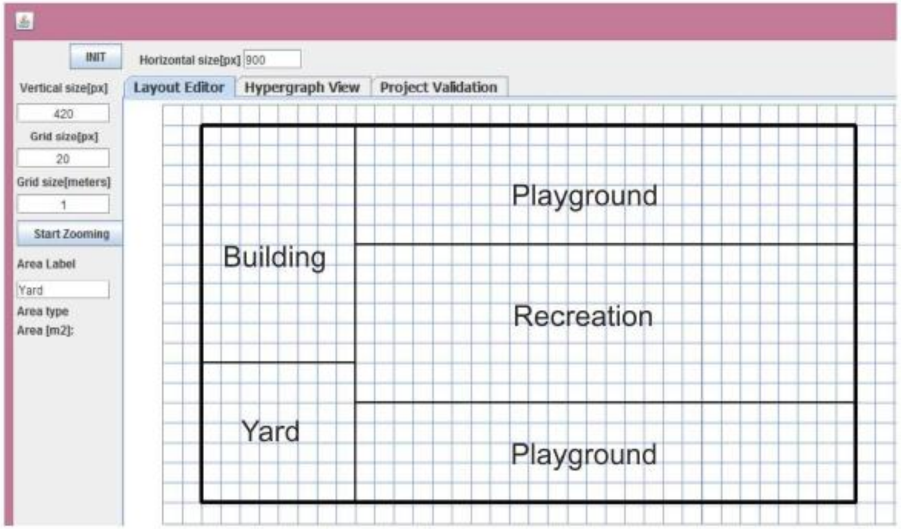
Structural relations between components – graphs
CP-Graph - nodes, edges, bonds
Nodes - components
Edges - relations between components
Bonds - potential connections („placeholders”)
Attributes – semantic information

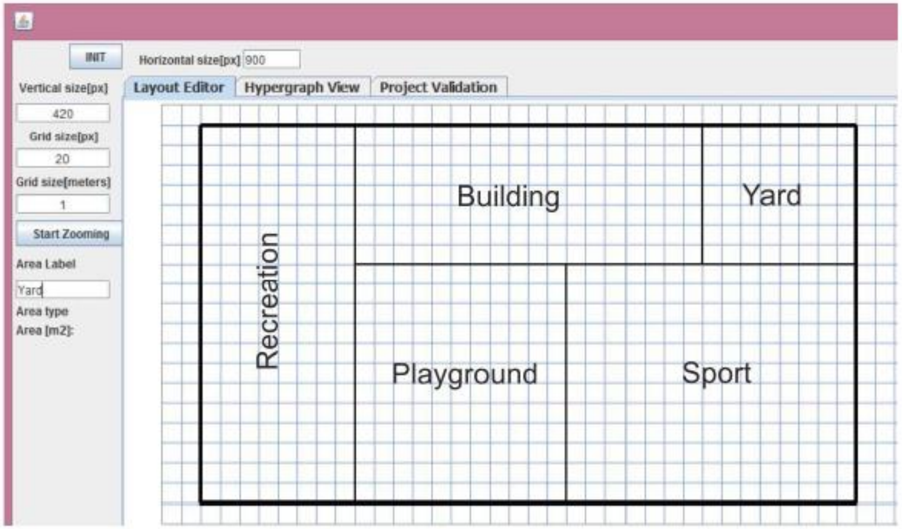


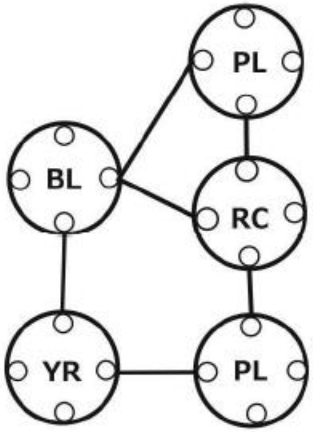


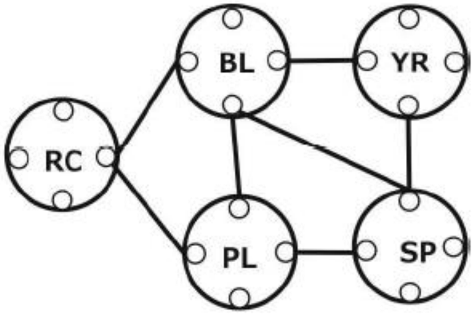
Graph – representa a potential solution of a design task

Graph representation (CP – II)





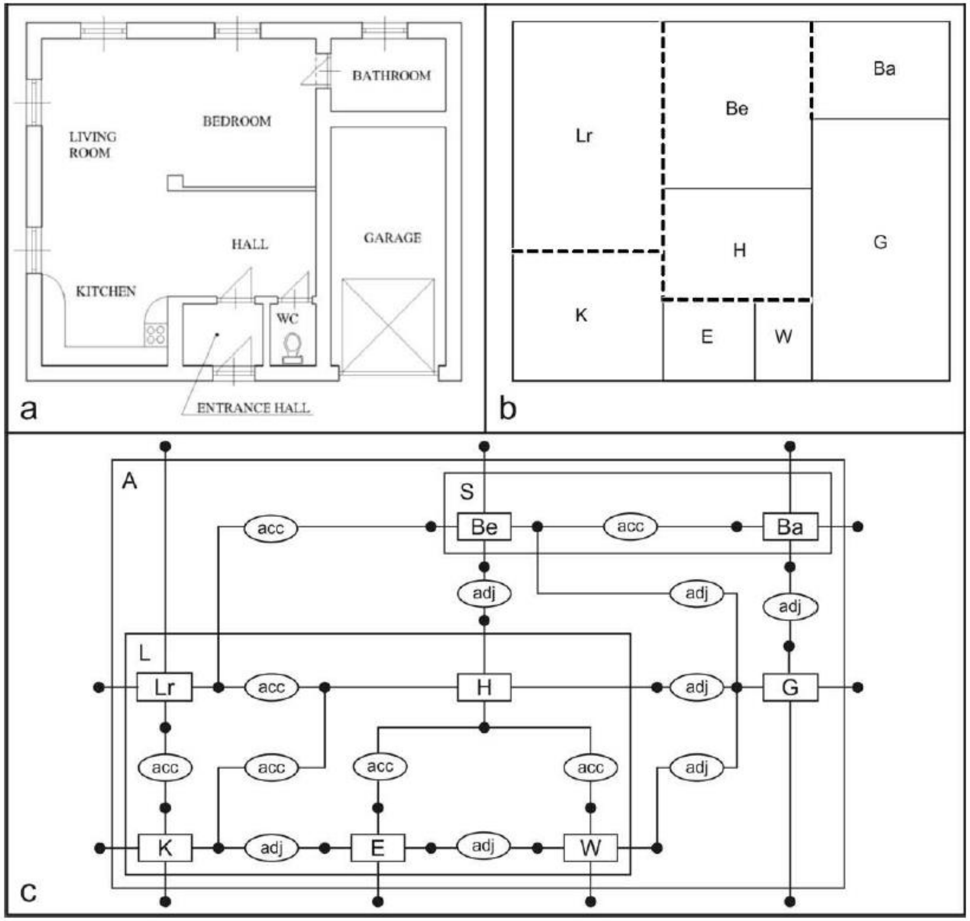




Graph representation (Hypergraph)

Relations between components – hypergraphs (hierarchical or not)

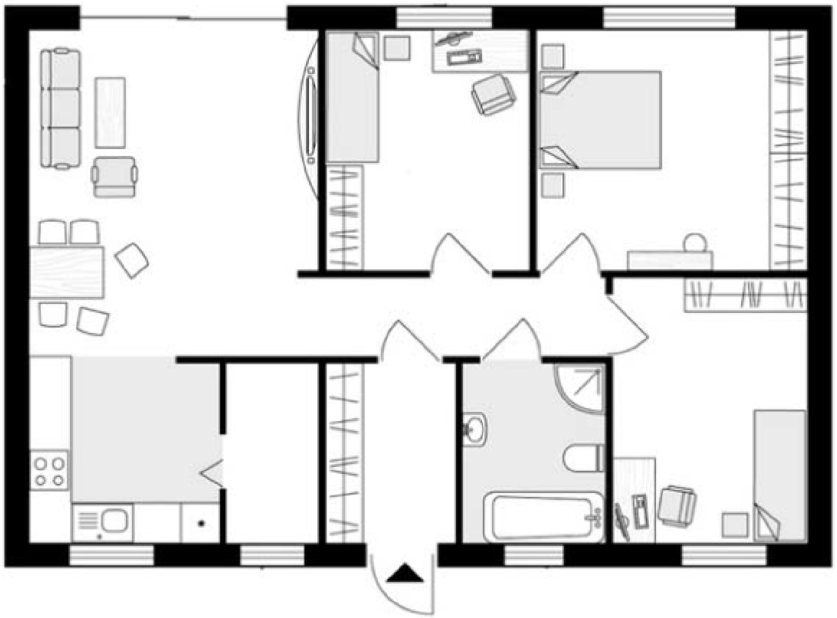
- hypergraph - nodes, hyperedges,
- nodes - walls
- hyperedges - components
  and relations between
  components
- attributes – semantic
  information

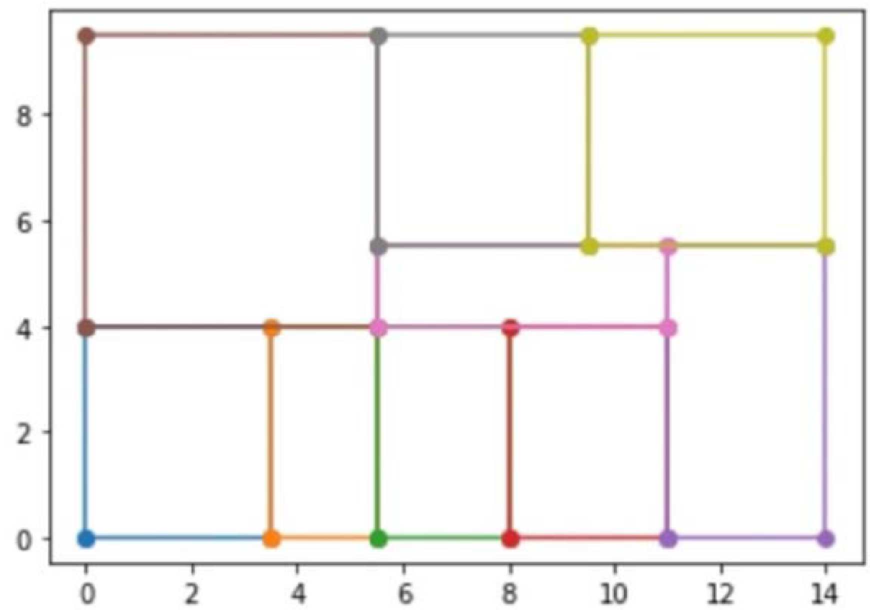


Hypergraph – representa
a potential solution of a
design task

Vector representation

No structural information

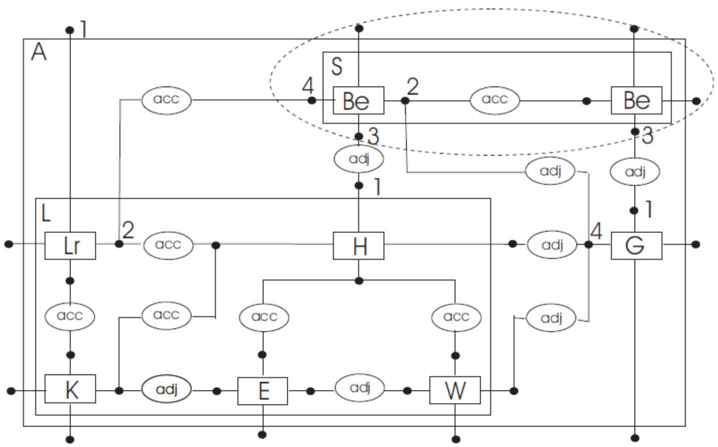


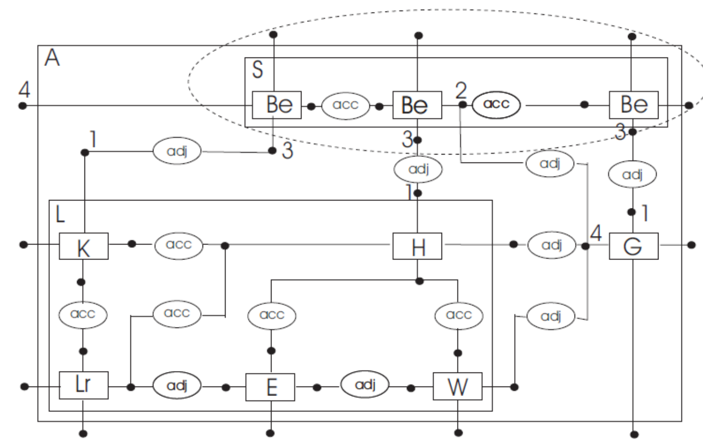


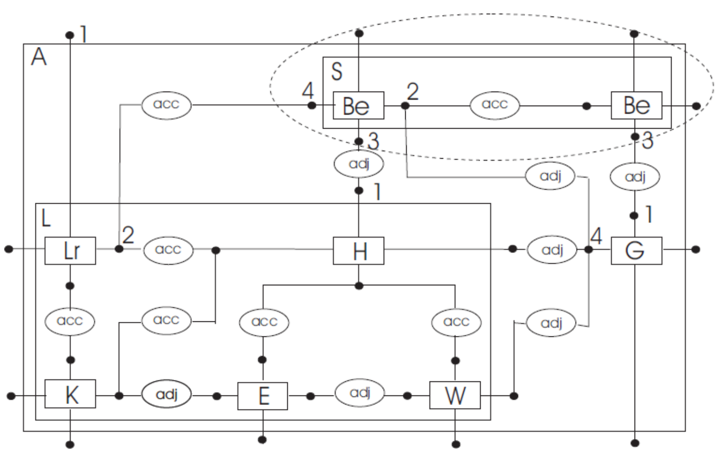

```
points = [(0.0,0.0),(3.5,0.0),(5.5,0.0),(8.0,0.0),(11.0,0.0),
          (14.0,0.0),(11.0,4.0),(8.0,4.0),(5.5,4.0),(3.5,4.0),
          (0.0,4.0),(5.5,5.5),(9.5,5.5),(11.0,5.5),(14.0,5.5),
          (14.0,9.5),(9.5,9.5),(5.5,9.5),(0.0,9.5)]

individual = {'R1':[0,1,9,10],'R2':[1,2,8,9],'R3':[2,3,7,8],
              'R4':[3,4,6,7], 'R5':[4,5,14,13], 'R6':[10,8,17,18],
              'R7':[8,6,13,11], 'R8':[11,12,16,17], 'R9':[12,14,15,16]}
```

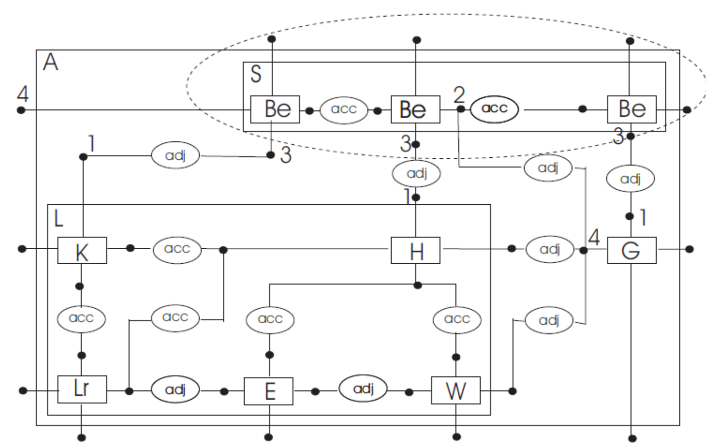
Operators (Hypergraph)

Crossover - The exchange of subgraphs between two different designs





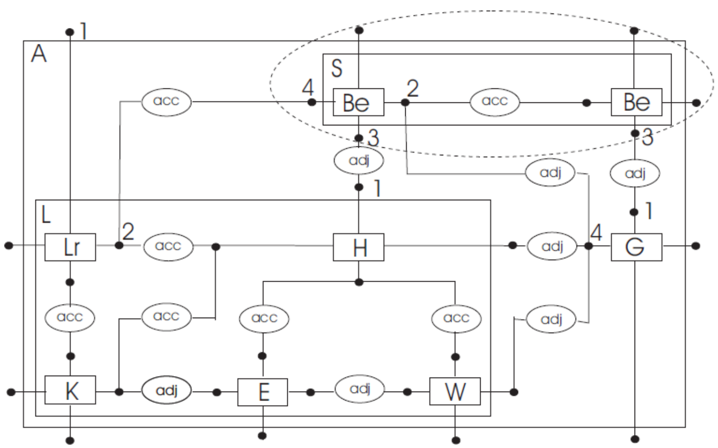


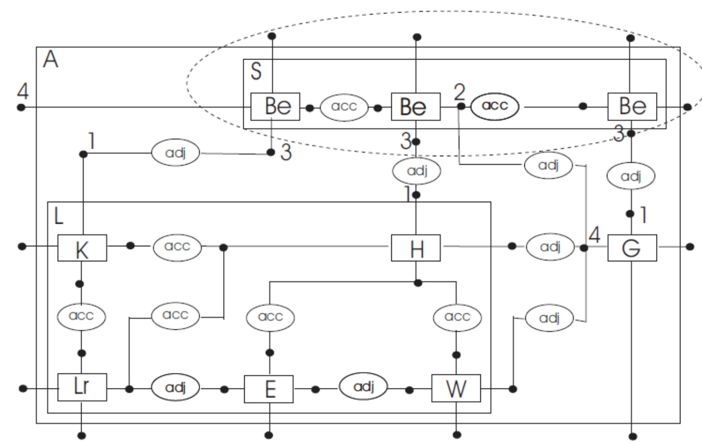


Operators (Hypergraph)

The exchange of subgraphs between two different designs

Limitations/problems
- embedding transformation (Ref*)
- computational complexity
- need for specialized algorithm(s)



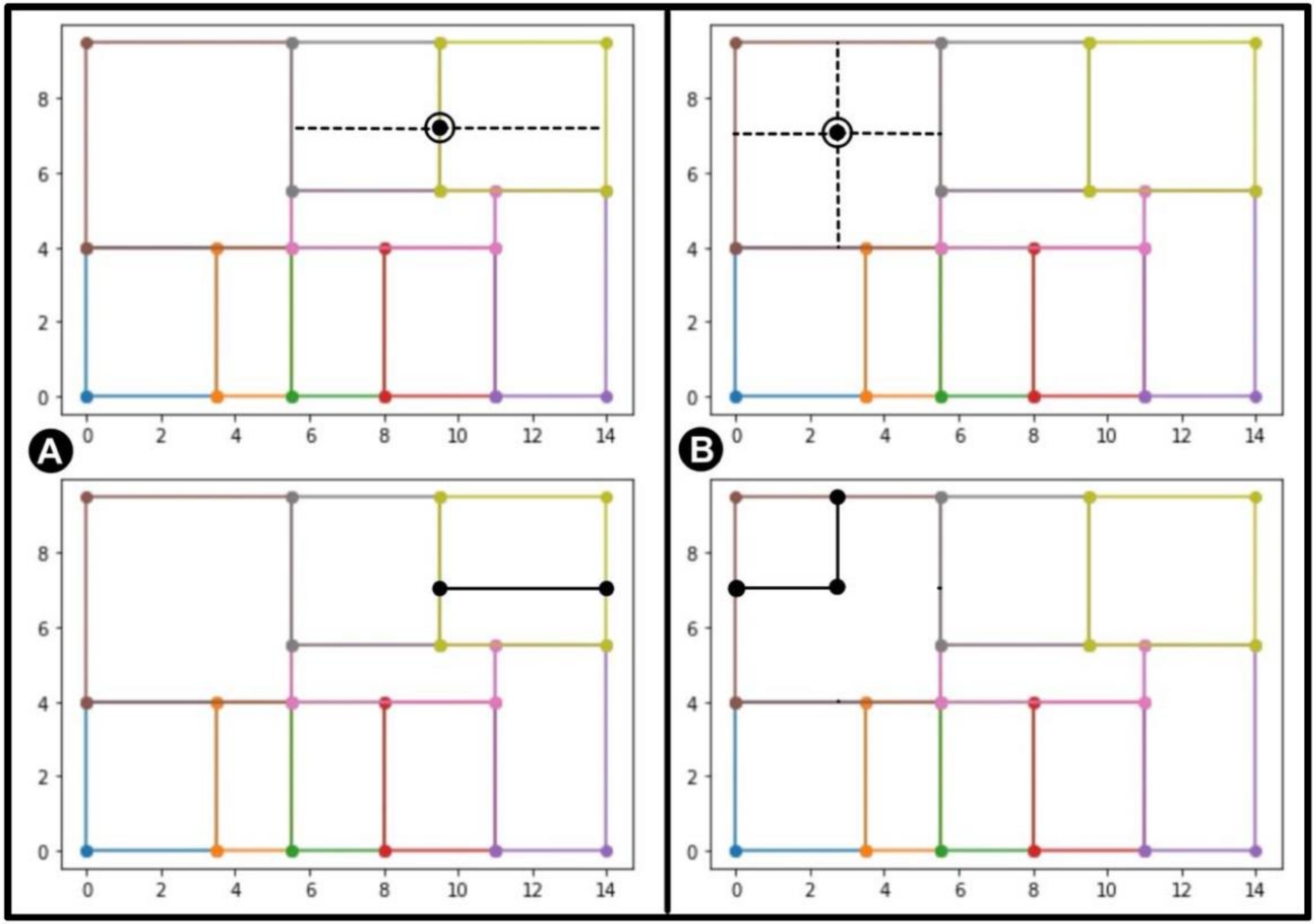


(*) *Grazyna Slusarczyk Barbara Strug , Anna Paszynska, Ewa Grabska, Wojciech Palacz ,Semantic-driven Graph Transformations in Floor Plan Design. Comput. Aided Des. 158: 103480 (2023)*

Operators (Vector)

Mutation only

adding a point
deleting a point
moving a point



Operators (Vector)

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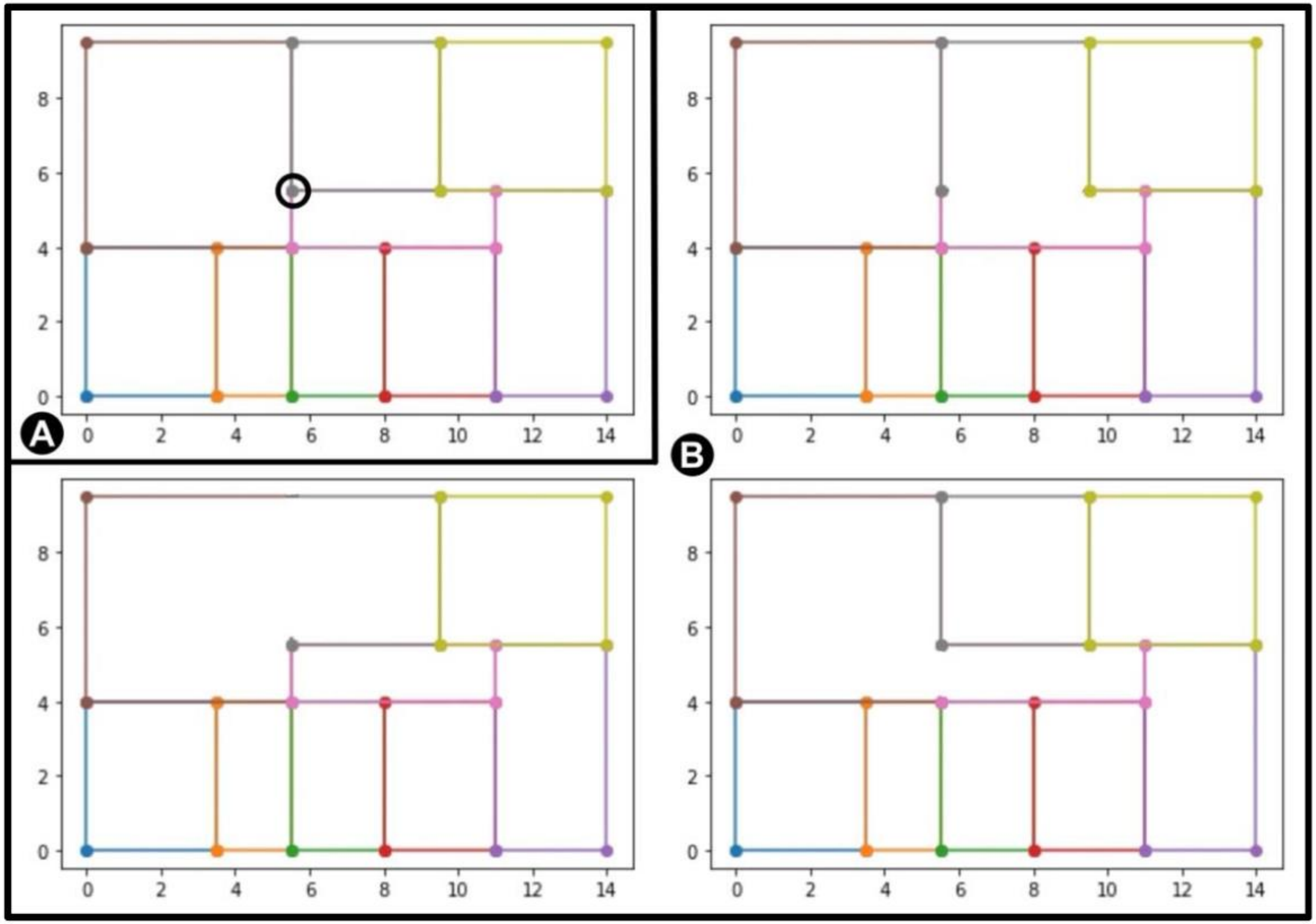

Operators (Vector)

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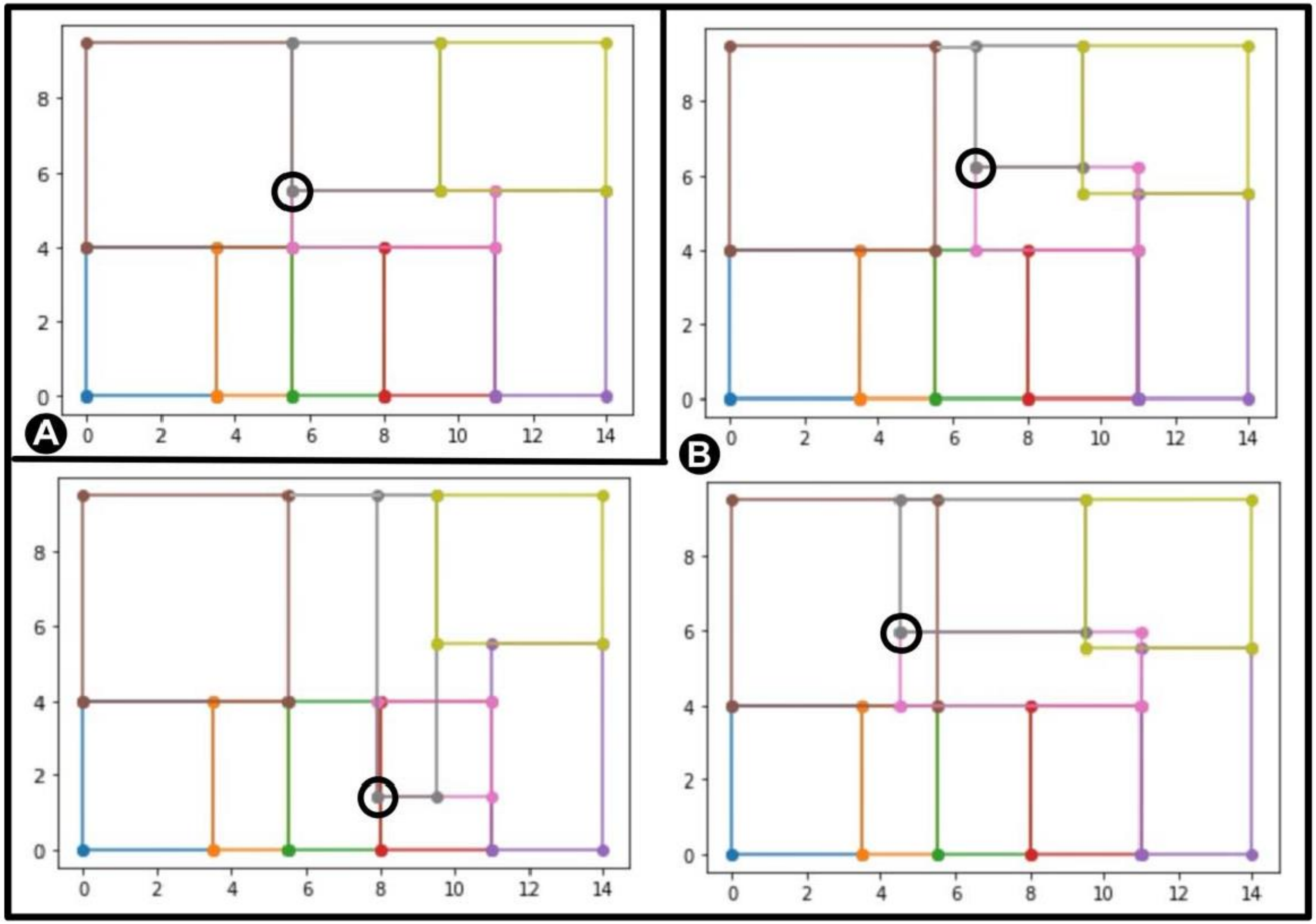

Fitness evaluation (Graph)

Graph based - low numer of produced solutions ;>

mainly human designer

graph pattern mining

Requires the process of expression (graph to design)

Fitness evaluation (Vector)

Point representation
based on the degree of fulfilment of requirements

$$F(I) = \begin{cases} -\propto, & \exists unfulfilled\ constraint \\ \sum_{i=1}^{n} w_i Req_i(I), & otherwise \end{cases}$$

Example (Vector)

Constraints

1 Six predefined rooms (3 Bedrooms, 1 bathroom, kitchen, living room)

2 No wall shorter than 0.8m

Requirements

1 There should be at least eight spaces and w1 = 0.8, Req1 from {0, 0.33, 0.5, 0.67,1}

2 The largest room should be bigger that 21 m2 and w2 = 0.7, Req2 from {0,1}.

3 There should exist a room larger than 7 m2 adjacent to the largest room and w3 = 0.6, Req3 from {0,1}.

4 The largest room should be oriented to the south and w4 = 0.5, Req4 from {0,1}.

5 There are not many spaces with areas less than 2 m2 and w5 = 0.5, Req5 from {0,0.2,0.4,0.6,0.8,1}

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Example (Vector)

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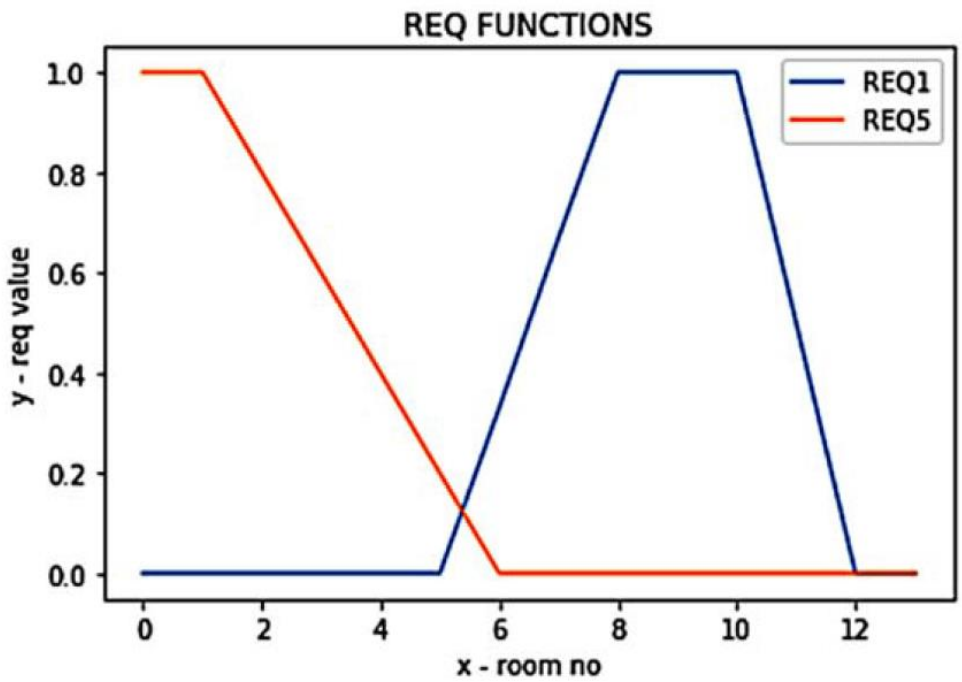
3 There should exist a room lar room and w3 = 0.6, Req3 f
4 The largest room should be c from {0,1}.
5 There are not many spaces w Req5 from {0,0.2,0.4,0.6,0.



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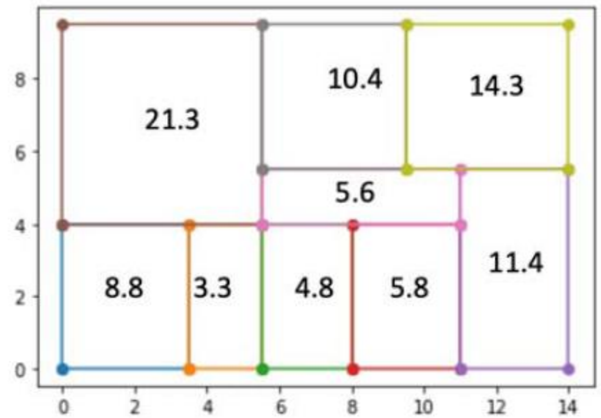
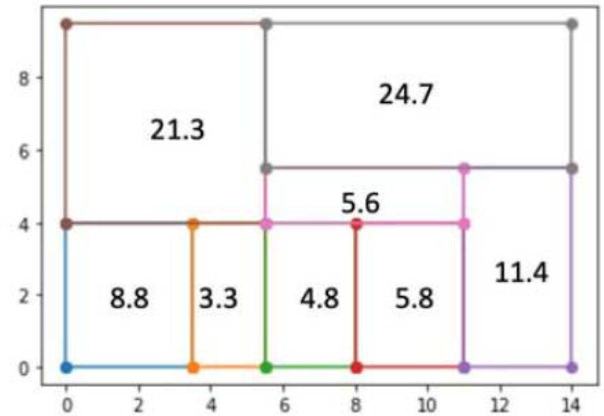
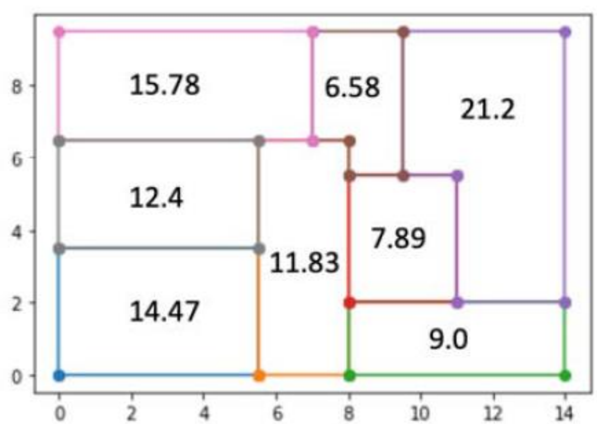


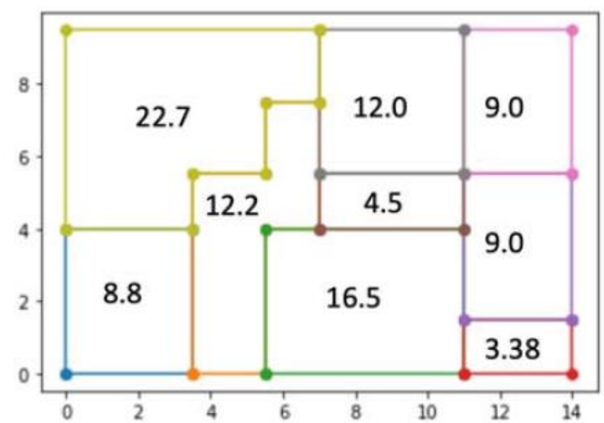
$F(I_1)$=1x0.8+1x0.7+1x0.6+1x0.5+1x0.5=3.1 **MAX**



$F(I_2)$=1x0.8+1x0.7+1x0.6+1x0.5+1x0.5=3.1 **MAX**



F (I_3)=1x0.8+1x0.7+1x0.6+1x0.5+1x0.5=3.1 **MAX**



F (I_4)=1x0.8+1x0.7+1x0.6+1x0.5+1x0.5=3.1 **MAX**

Example (Vector)

Constraints
1 Six predefined rooms (3 Bedrooms, 1 bathroom, kitchen, living room)
2 No wall shorter than 0.8m

Requirements
1 There should be at least eight spaces and w1 = 0.8, Req1 from {0, 0.33, 0.5, 0.67,1}
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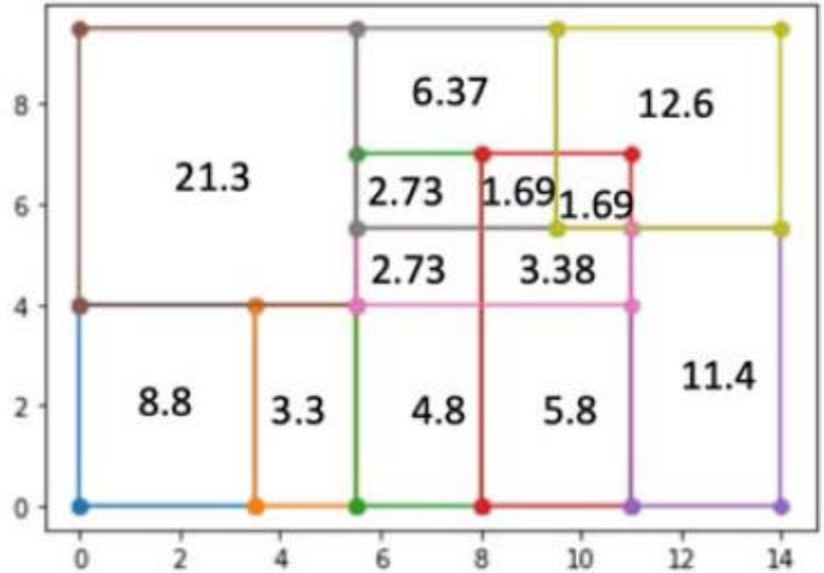
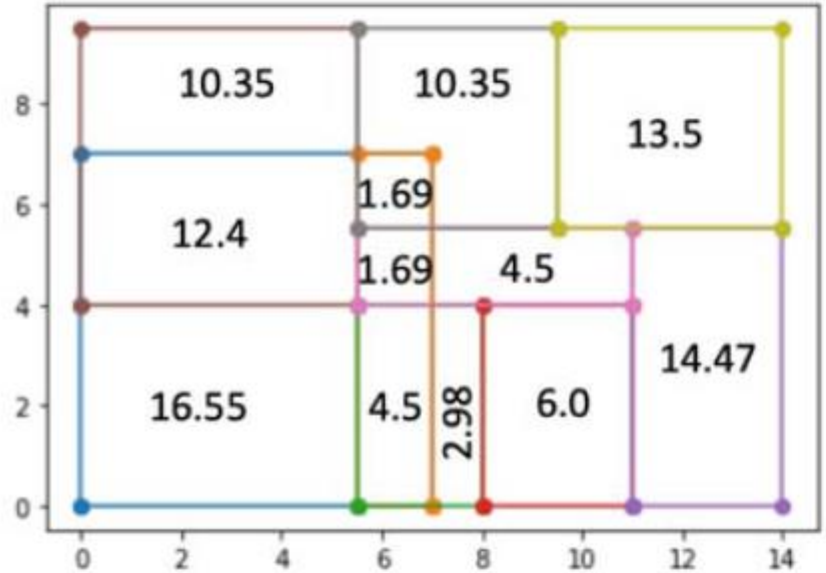
5 There are not many spaces with areas less than 2 m2 and w5 = 0.5, Req5 from {0,0.2,0.4,0.6,0.8,1}



$F(I_5)=0x0.8+1x0.7+1x0.6+1x0.5+0.8x0.5=2.2$



$F(I_6)=0x0.8+0x0.7+1x0.6+1x0.5+0.8x0.5=1.5$

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Conclusions

Graph based representation

+ better at prserving structural information
- complex operators
- smaller population

Vector based representation

+ faster computations
+ more flexible
- harder to add semantics

Other possibilities

Multi-storey buildings

Katarzyna Grzesiak-Kopeć,Barbara Strug , Grazyna Slusarczyk, Specification-Driven Evolution of Floor Plan Design. PPSN (2) 2022 368-381

Graph learning ?

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Thank you for your attention