Flexible and efficient site constraint handling for wind farm layout optimization

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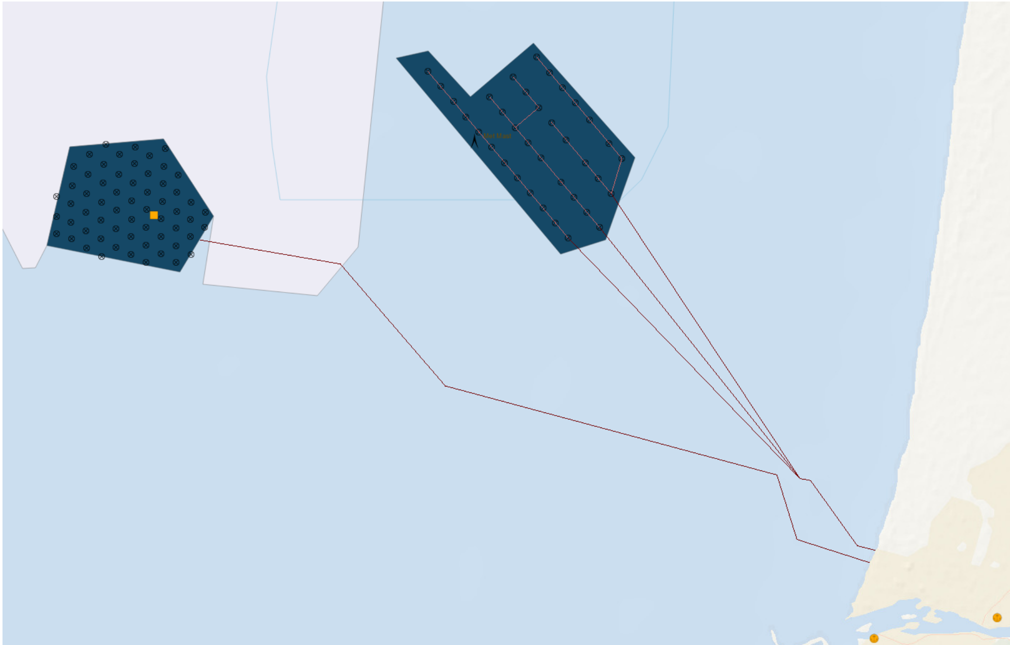
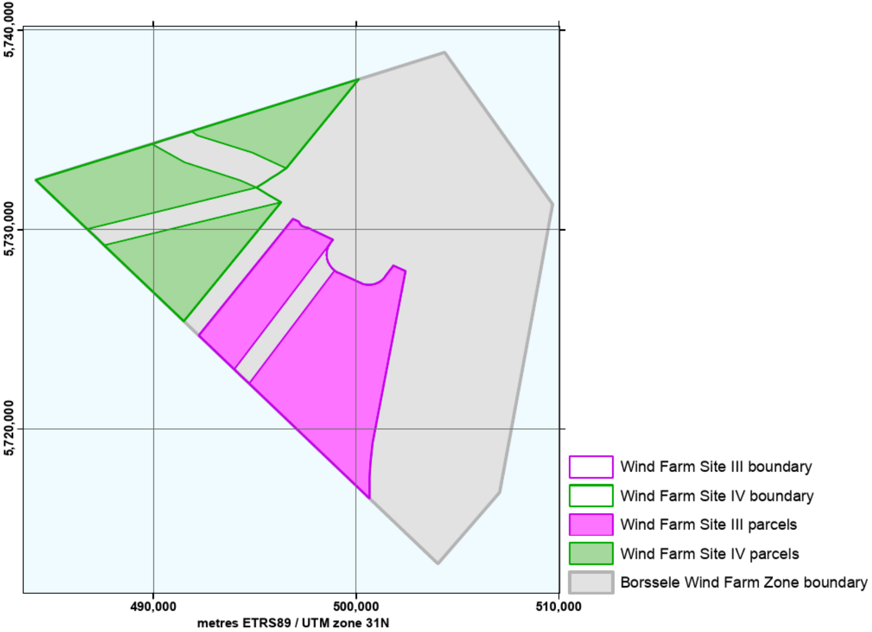
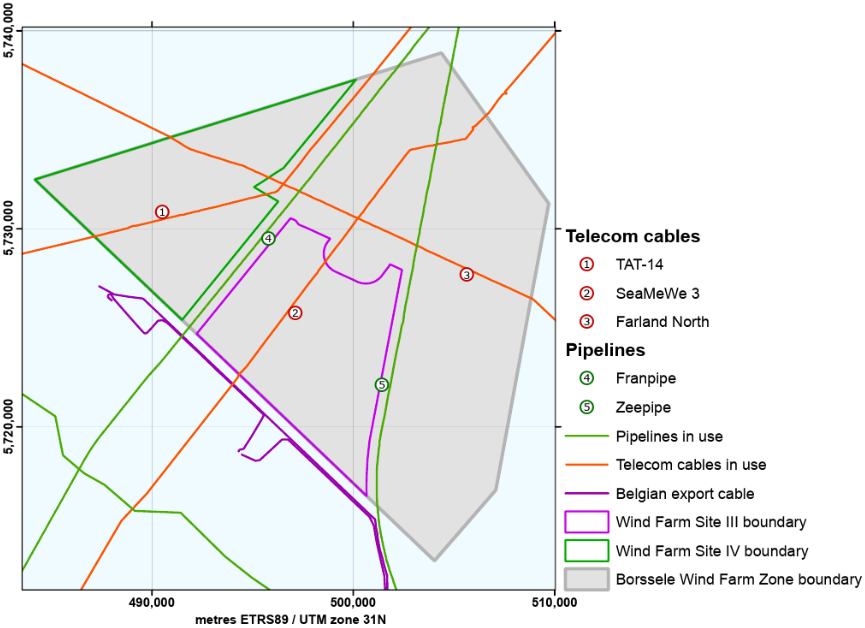
TU Delft



[4C Offshore: https://www.4coffshore.com/]



[Netherlands Enterprise Agency (RVO.nl) Borssele Wind Farm Zone: Project and Site Description Wind Farm Sites III and IV (2016-08)]



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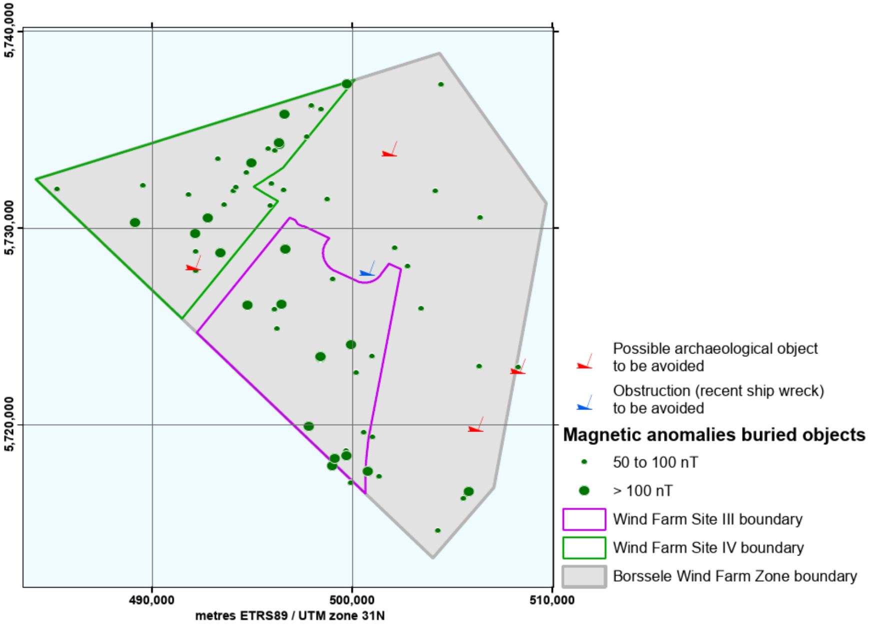

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So what do real (offshore) sites look like?

A plate of irregularly-cut pieces of Emmental cheese...

- multiple non-connected parts
- non-convex, with concavities of various sizes
- circular exclusion zones strewn around.

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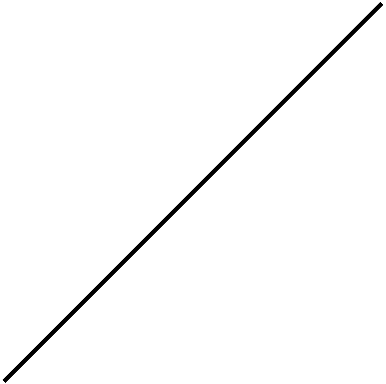
Circular constraints need to be added separately to 2, 3, 5!

Linear constraints as the basis



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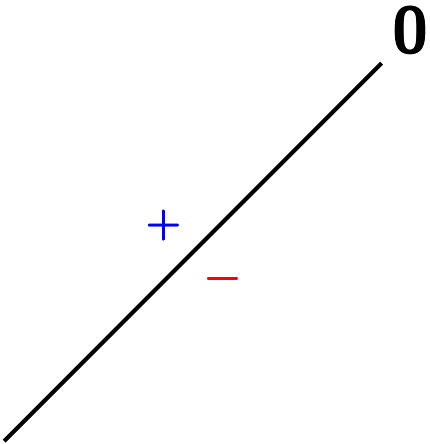

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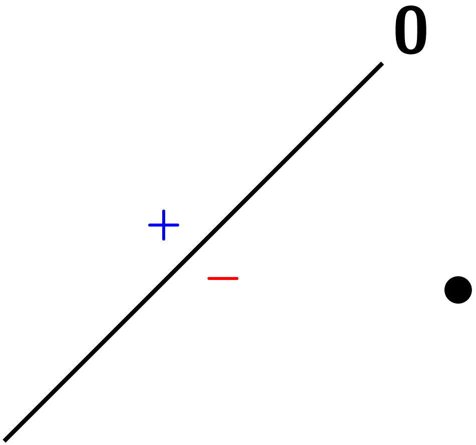

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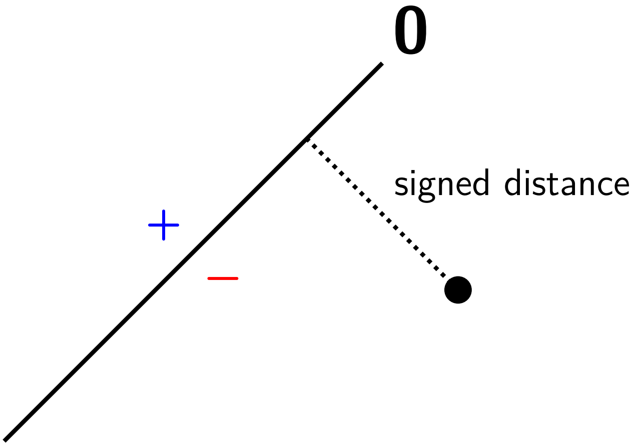

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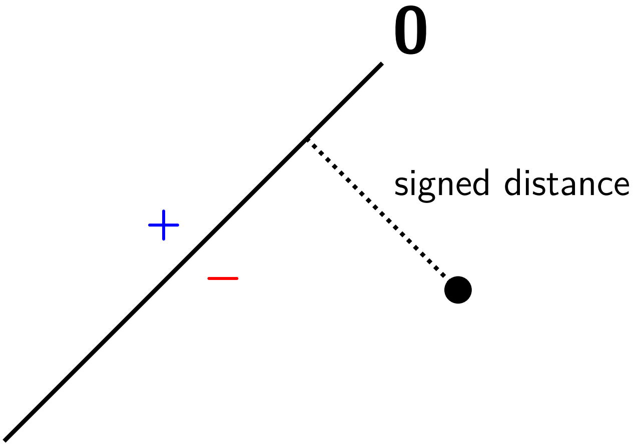

Convex polygons are sets of linear constraints

Site decomposition in terms of convex polygons and discs

- Sites are described as a tree of convex polygons and discs.
- Levels alternate between included and excluded.
- Needs to be done just once, starting from the parcels' vertex lists.

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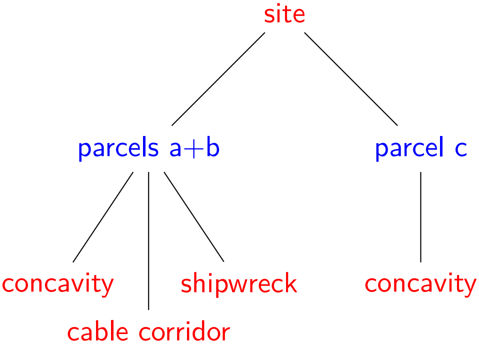

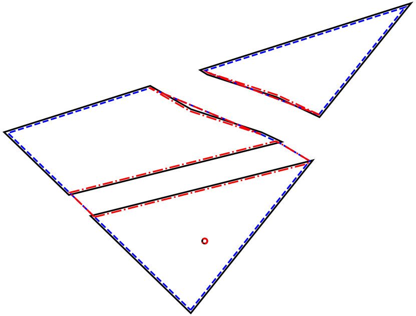

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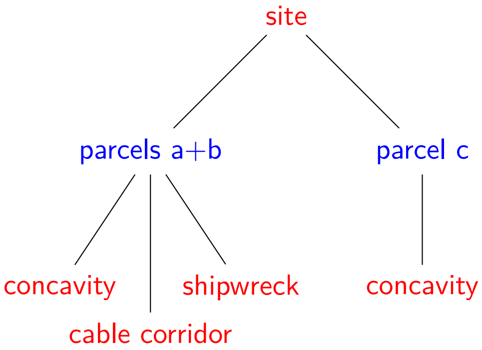

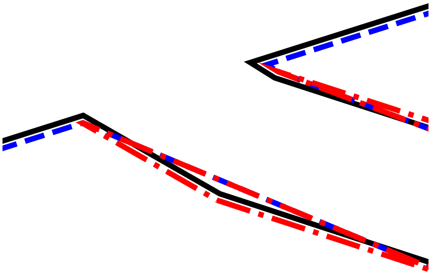

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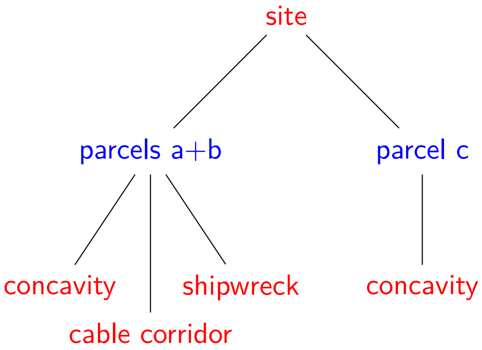

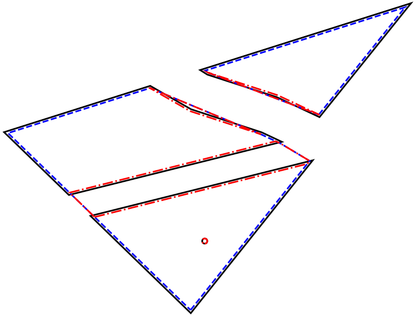

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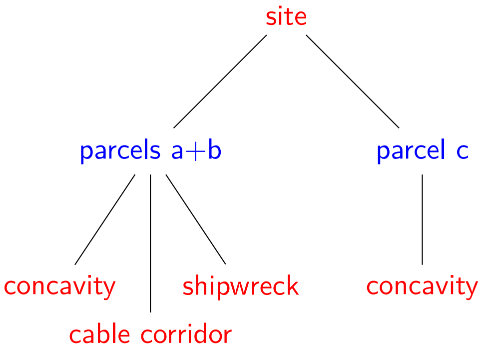

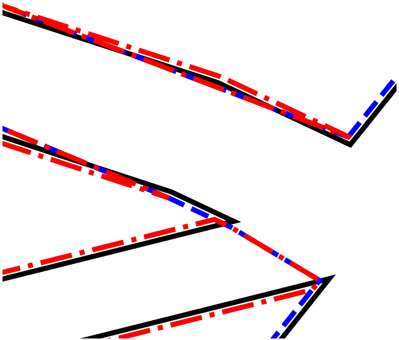

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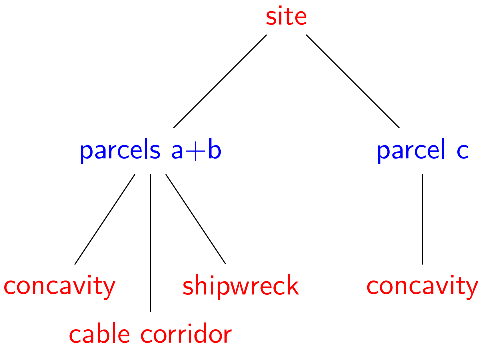

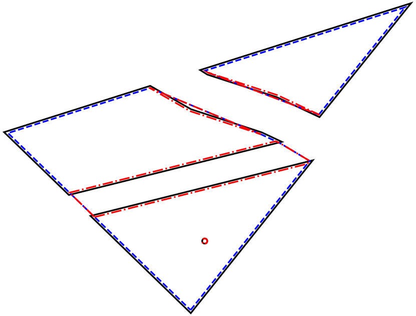

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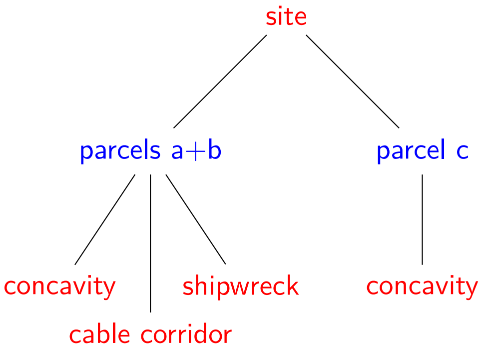

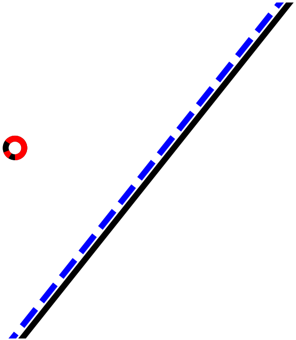

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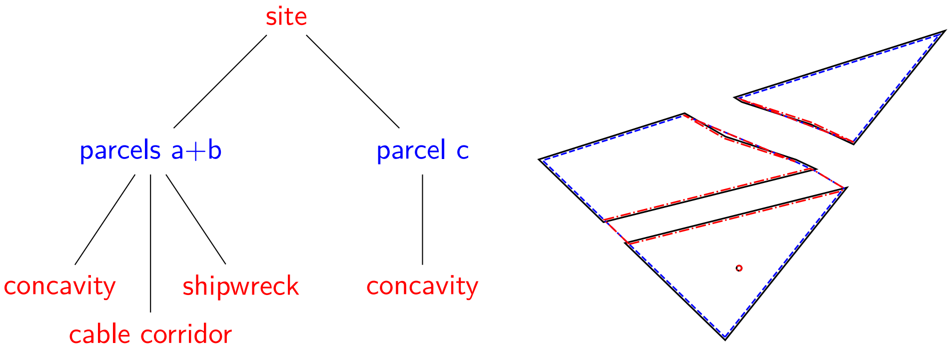

Site decomposition in terms of convex polygons and discs

```yaml
radius: 8.4628
location:
  - reference_system: ETRS89
  - utm_zone: 31
  - utm: [492539.33, 5733792.49]
roughness: 0.0001
parcels:
  - constraints: # IVa + IVb
      - {"x": -0.871282, "y": -0.899564, "1": -1., rotor_constraint: true} # WFZ_4, P_75
      - {"x":  1., "y": -0.798527, "1": -0.669320, rotor_constraint: true} # P_75, P_74
      - {"x":  0.598875, "y":  1., "1":  0.020557, rotor_constraint: true} # P_74, P_73
      - {"x":  0.470030, "y":  1., "1":  0.059057, rotor_constraint: true} # P_73, P_72
      - {"x":  0.416783, "y":  1., "1":  0.069992, rotor_constraint: true} # P_72, P_70
      - {"x": -0.316693, "y":  1., "1": -0.158119, rotor_constraint: true} # P_70, WFZ_4
    exclusions:
      - constraints:
          - {"x":  0.249945, "y": -1., "1": -0.395467, rotor_constraint: true}
          - {"x": -0.249356, "y":  1., "1":  0.274018, rotor_constraint: true}
      - constraints:
          - {"x": -0.573028, "y": -1., "1": -0.118584, rotor_constraint: true}
          - {"x": -0.326646, "y": -1., "1": -0.088503, rotor_constraint: true}
      - circle: # 100_m buffer around archeological shipwreck
          {center: [-0.058554, -0.658767], radius: 0.011816}
  - constraints: # IVc
      - {"x": -0.316691, "y":  1., "1": -0.158109, rotor_constraint: true} # P_82, P_78
      - {"x":  1., "y": -0.803943, "1": -0.541463, rotor_constraint: true} # P_78, P_79
      - {"x": -0.379160, "y": -1., "1":  0.094044, rotor_constraint: true} # P_79, P_81
      - {"x": -0.625480, "y": -1., "1":  0.082657, rotor_constraint: true} # P_81, P_82
    exclusions:
      - constraints:
          - {"x": 0.324121, "y": 1., "1": -0.096589, rotor_constraint: true}
          - {"x": 0.468405, "y": 1., "1": -0.136250, rotor_constraint: true}
```

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Deduced from the vertex lists for the parcel boundaries

```
boundaries:
  - polygon: # IVa
      - [-0.98795236, -0.15475832] # WFZ_4
      - [-0.68775564, -0.4455137 ] # P_77 ← not in vertices of IVa+b
      - [ 0.29881097, -0.19950719] # P_73
      - [ 0.20536654, -0.15558547] # P_72
      - [-0.12209072, -0.04862303] # P_71 ← not in vertices of IVa and IVa+b
      - [-0.31100018,  0.0596274 ] # P_70
  - polygon: # IVb
      - [-0.58775308, -0.54237308] # P_76 ← not in vertices of IVa+b
      - [-0.12313056, -0.99239048] # P_75
      - [ 0.44168357, -0.28507005] # P_74
    exclusions:
      - circle: # 100 m buffer around archeological shipwreck
          {center: [-0.058554, -0.658767], radius: 0.011816}
  - polygon: # IVc
      - [-0.08008326,  0.13274754] # P_82
      - [-0.04622915,  0.11157248] # P_81
      - [ 0.27488267,  0.00749325] # P_80 ← not in vertices of IVc
      - [ 0.47291443, -0.08526582] # P_79
      - [ 0.89693565,  0.44216109] # P_78
```

Checking site constraints efficiently

- Walk the tree from root to leaves.
- Only check the turbines inside the parent.

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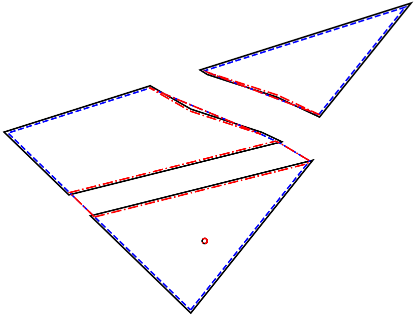
Example for Borssele IV:

- site
  - parcels a+b
    - concavity
    - cable corridor
    - shipwreck
  - parcel c
    - concavity



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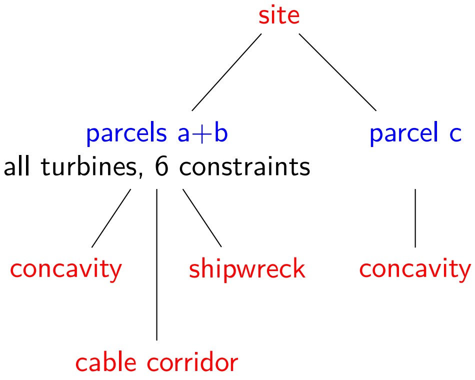

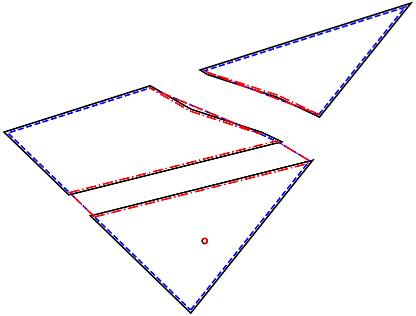

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Example for Borssele IV:

site

parcels a+b
all turbines, 6 constraints

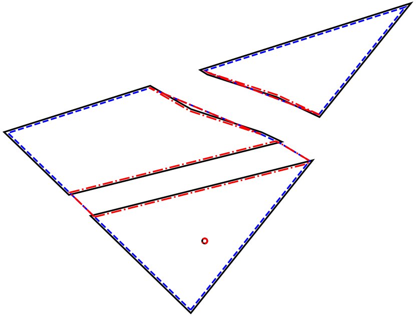
parcel c
all t's, 3 c's

concavity

cable corridor

shipwreck

concavity



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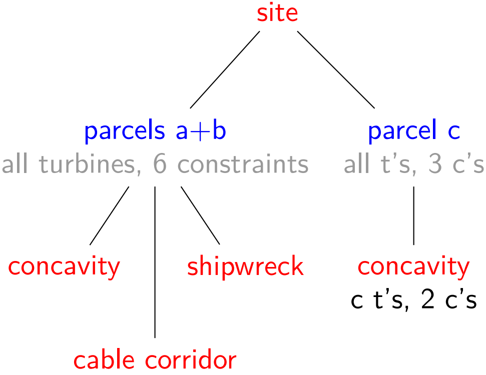

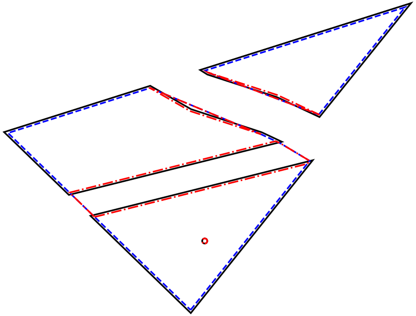

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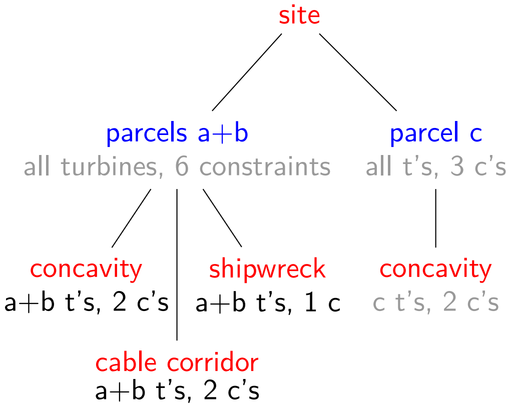
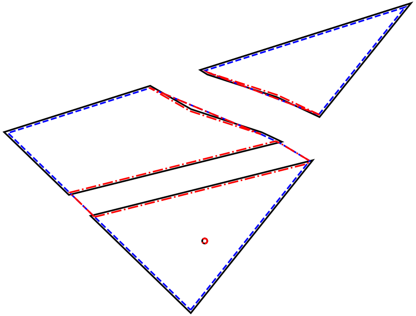
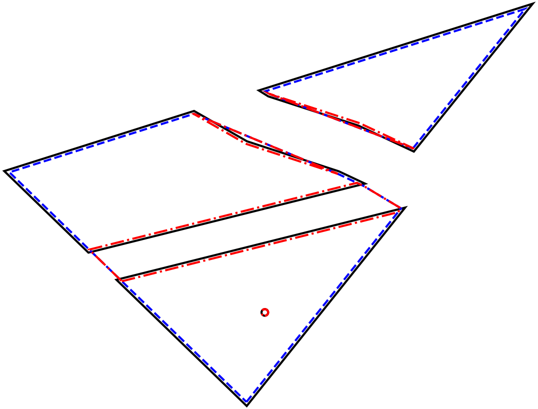




Correcting constraint violations: *move to the closest border point*



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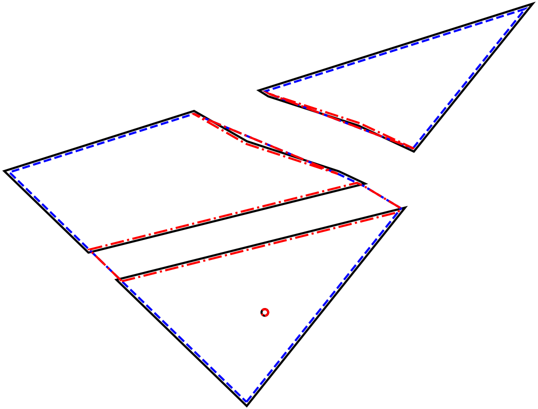

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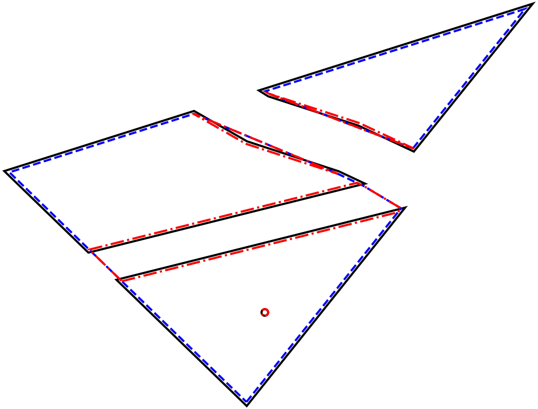

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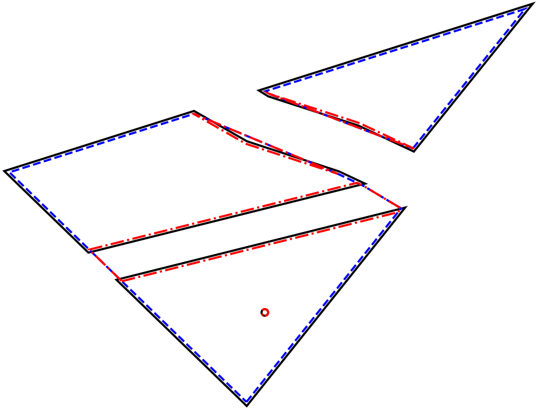

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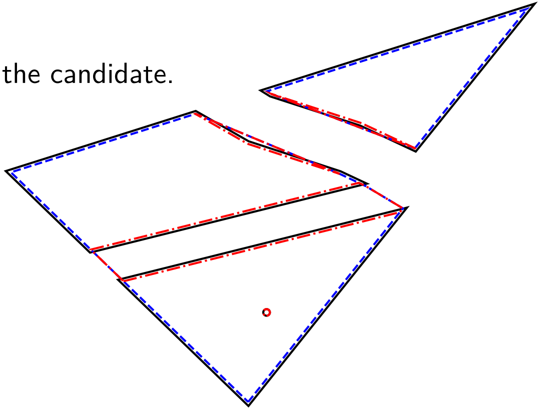

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5. Take the closest candidate
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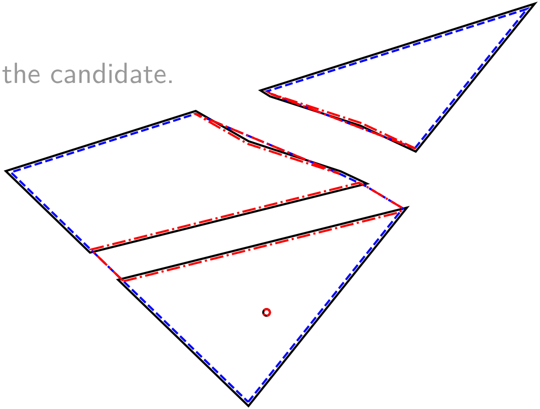
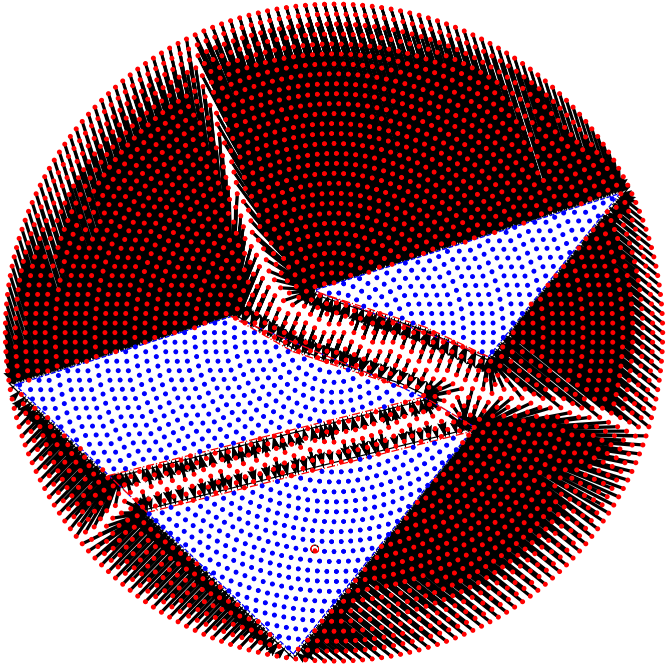
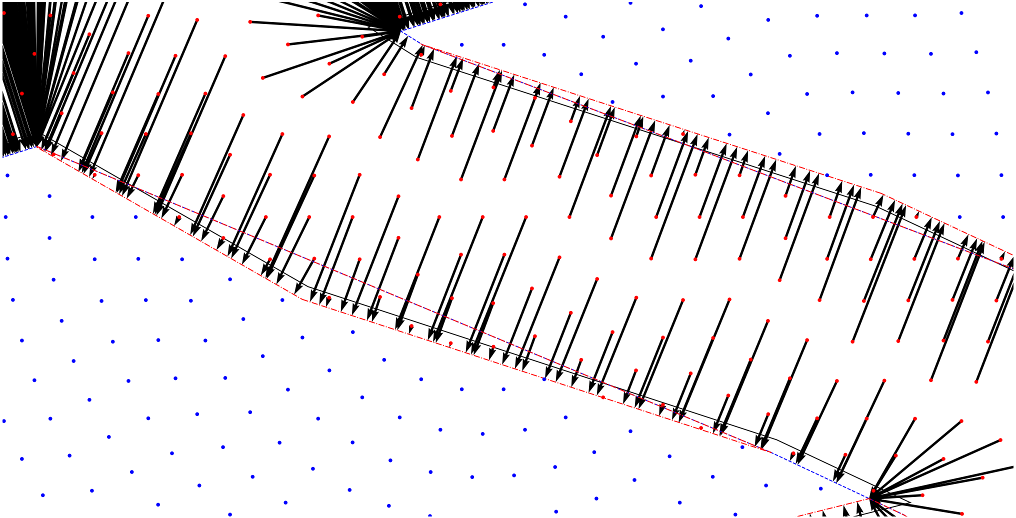
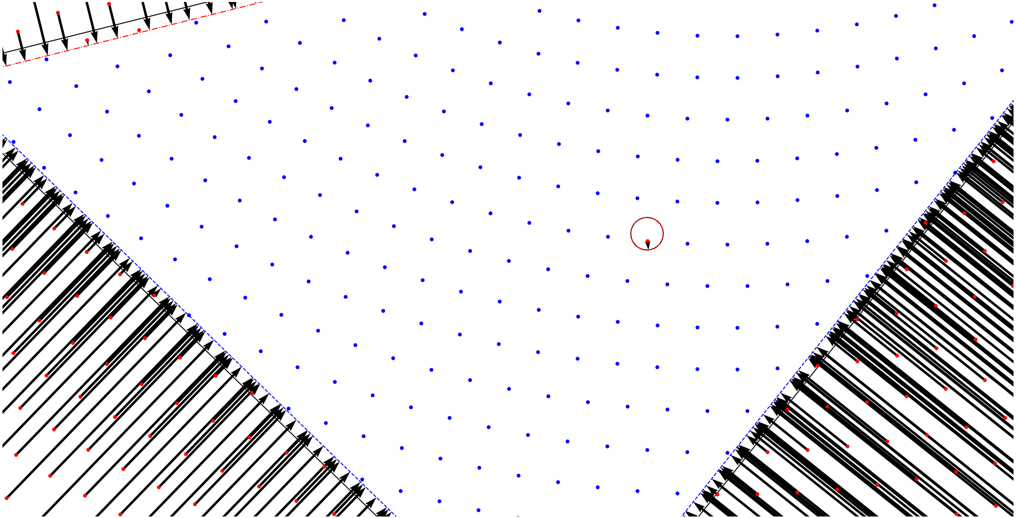






(My current implementation differs from the algorithm sketched.)



Conclusions

- Site constraint handling deserves more attention.

- Efficient approaches are possible.

To do

- Decent overview of constraint handling approaches. (*Your input is appreciated!*)
- Efficiency relative to other approaches.
- Actual characterization of computational complexity.
- Better implementation of correction algorithm.
- Restriction to ‘simple’ decompositions?

Thanks! Questions?