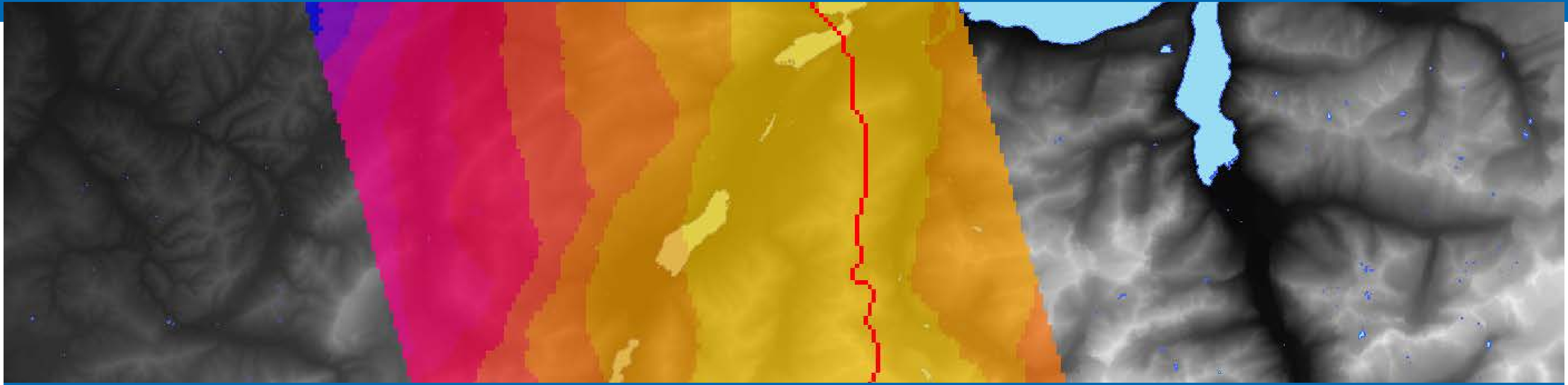


How to work with the limitations of the least cost path algorithm

09.05.2017, Muttenz

Geopython 2017

Joram Schito

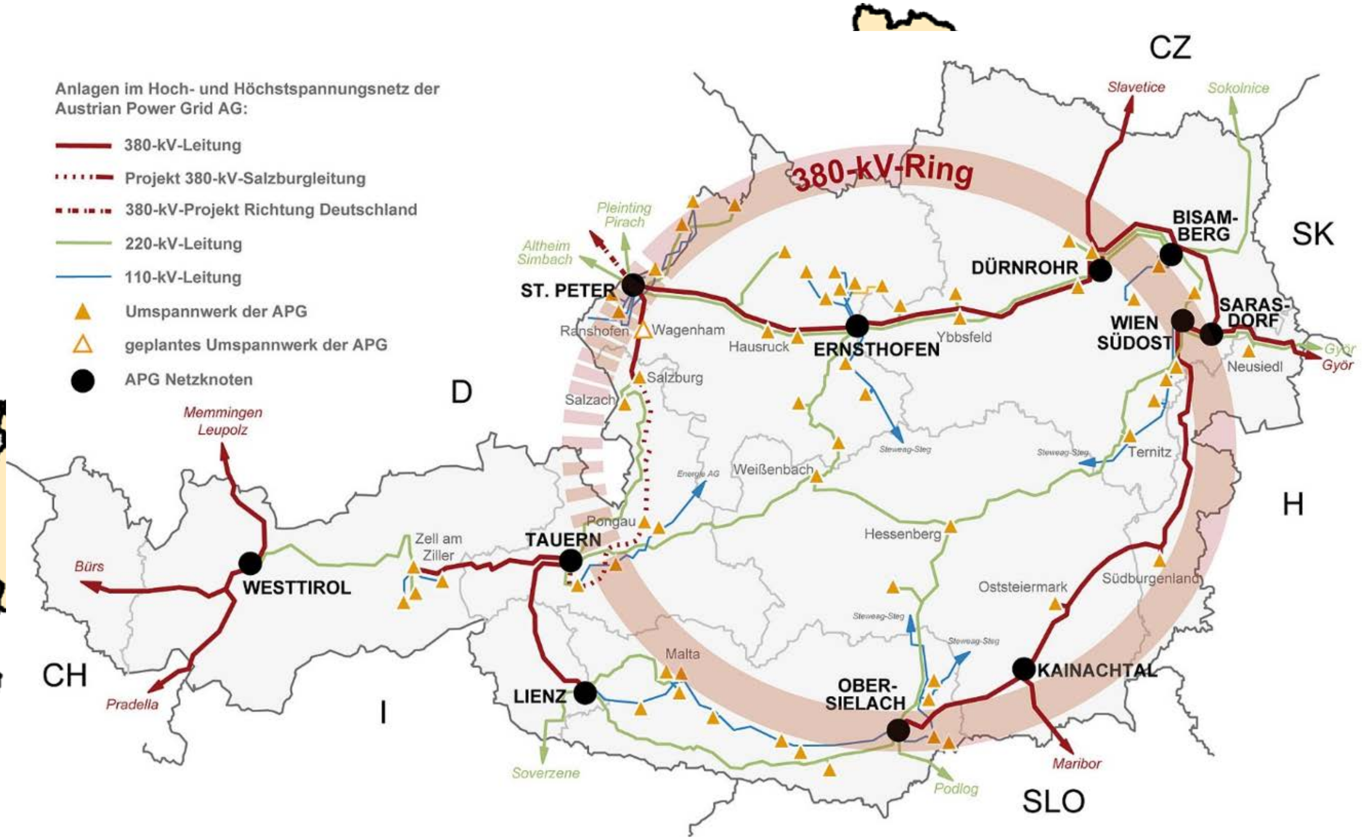
Agenda

1. Project Background
2. What is the least cost path and how is it computed?
3. Some typical problems of using least cost path and how they can be solved
4. Future Outlook
5. Discussion

Project Background

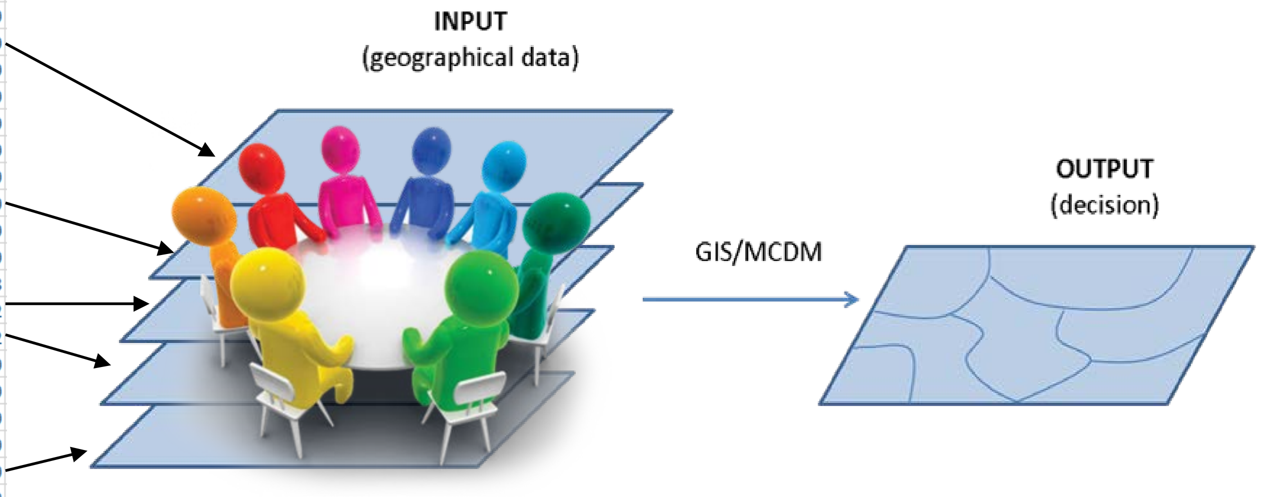
Application of 3D Geographic Information Systems for transparent and sustainable planning of electric power systems

Our study area: We focus on the 380 kV grid expansion in Switzerland and Austria



MCDA combined with GIS: Data model, decision model, and weighting define the outcome

D	E	F	G
OBJCODE	OBJNAME	Resistance_OH	Resistance_CAB
jg	Oberkreide	2	2
jh	Unterkreide	2	2
ji	Malm	0	0
jj	Bathonien - Oxfordien	0	0
jk	Trias - Dogger	0	0
jl	Dogger	0	0
jm	Lias	0	0
jn	Trias	0	0
jo	Perm (Verrucano)	0	0
jp	Oberkarbon (- Unterperm)	0	0
jq	Devon - Unterkarbon	0	0
A	Gebiete ohne ergiebige Grundwasservorkommen	0	0
B	Gletscher, Firn	7	8
C	Grundwasservorkommen in verkarstungsfaehigen Festgesteinen	2	2
D	Oberflaechengewaesser	2	2
E	Sehr ergiebige Grundwasservorkommen in den Talsohlen	0	0
F	Ergiebige Grundwasservorkommen z.T. ausserhalb von Talsohlen	0	0
G	Weniger ergiebige Grundwasservorkommen	0	0
H	Weniger ergiebige Grundwasservorkommen in gekluefteten und poroesen, nicht verkarstu	0	0
I	unbestimmt	0	0
71	Erhoehter Sulfatgehalt (Gips- und Anhydritloesung, >100 mg/l)	0	0
72	Erhoehter Chloridgehalt (Steinsalzloesung, >50 mg/l)	0	0
74	Verminderte Sauerstoffsaettigung (z.B. Torfbedeckung, <20 %)	0	0



Definition of a model to preprocess and to structure data using 4 factors and 15 subfactors

Factor	Subfactors
Environment protection	Ecosystems supporting biodiversity Protective habitats Waters protected by water act
Landscape conservation	Landscapes protected by law Conservation of agricultural land Natural monuments Visibility of power line Anti-sprawl by linear infrastructure
Urban planning	Urban areas Recreational and tourism areas Areas of high cultural value Visibility
Natural constraints	Natural hazards Slope Building ground

Factor	Subfactors
Costs	Monetary costs Impact on environment Impact on landscape

Which alternative will the stakeholders choose?

This is our product: a Decision Support System (DSS) in which a power grid can be planned in 3D and allows

Interaction

Communication

Data Integration

Realistic Impressions

LiDAR Data Integration

Exchange of Ideas

Weighting

Cost Estimation

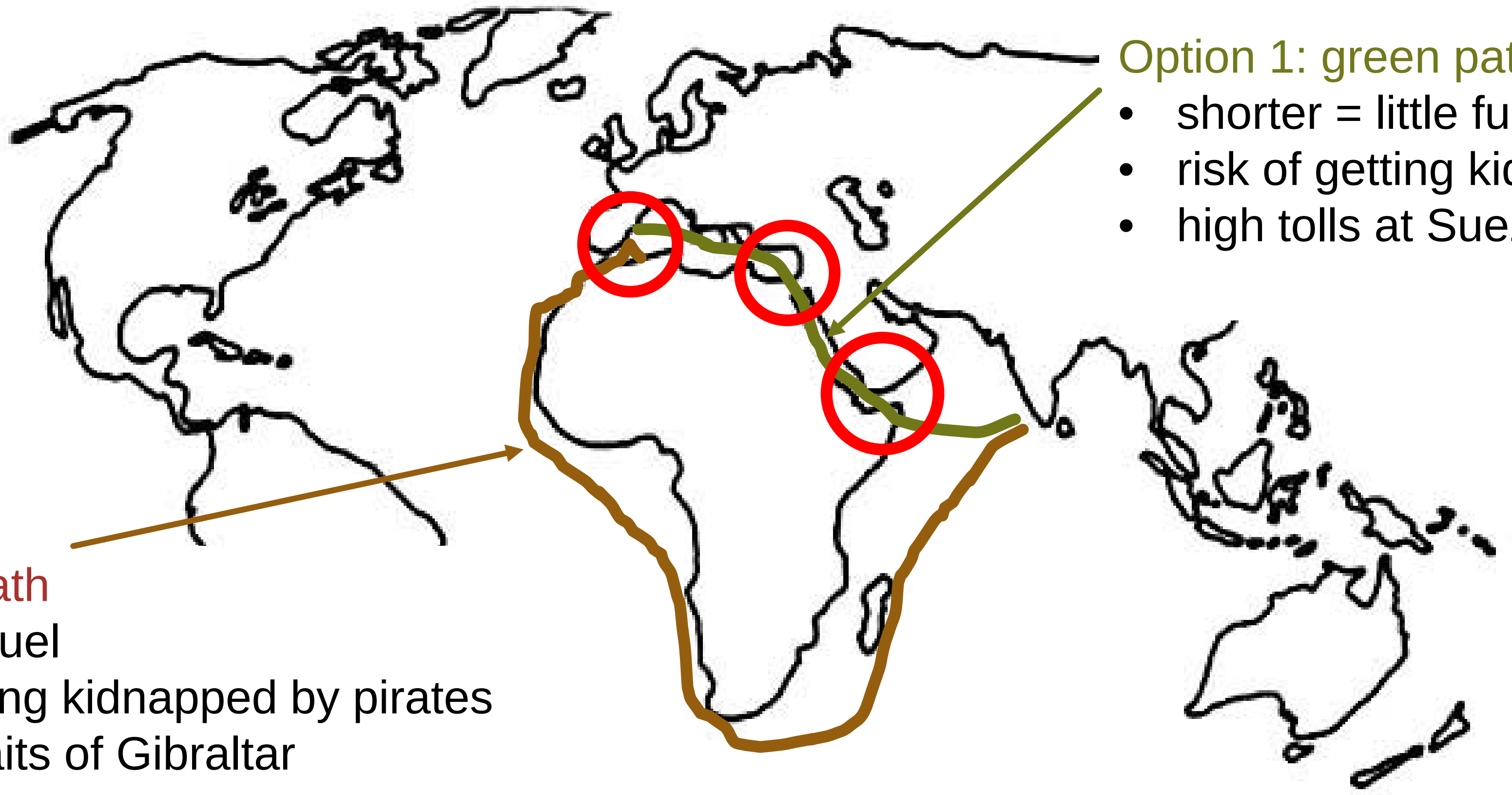
netzausbau.ethz.ch

https://www.youtube.com/watch?v=PDWy_unkKy8

What is the least cost path and how is it computed?

Introduction into the precondition, the theoretical framework and the procedure

What is the least cost path?



Option 1: green path
- shorter = little fuel
- risk of getting kidnapped by pirates
- high tolls at Suez Canal

Option 2: brown path
- longer = much fuel
- little risk of getting kidnapped by pirates
- little tolls at Straits of Gibraltar

Total normalized costs

Multi-Criteria Decision Analysis (MCDA)

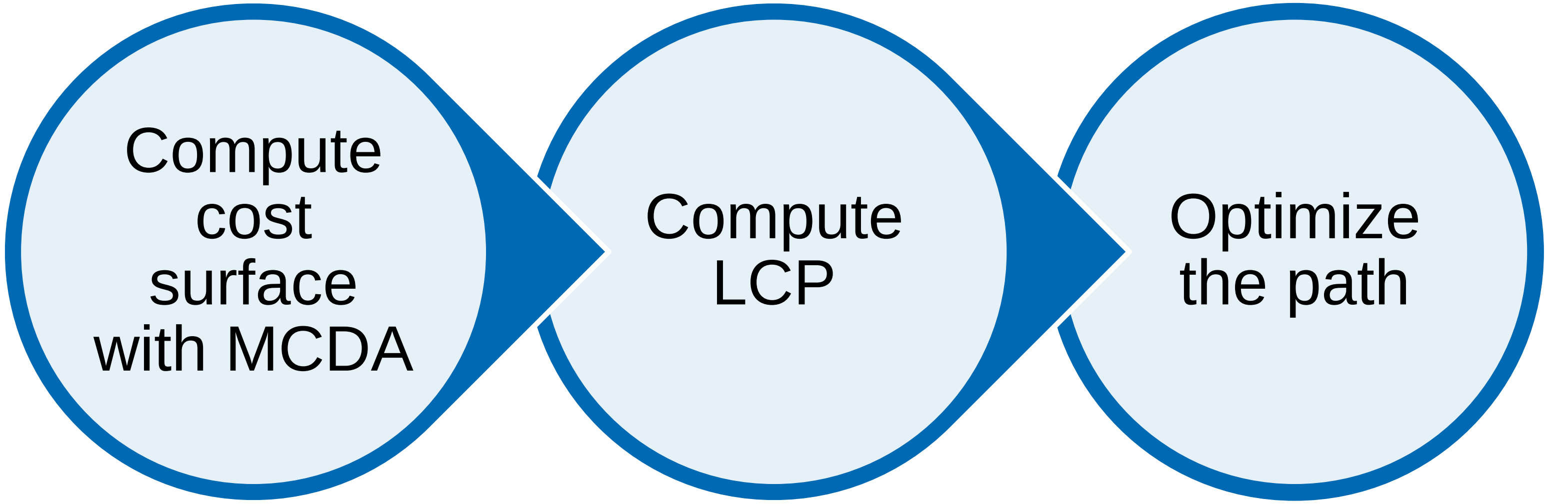
	Option 1: Through Suez Canal	Option 2: Around Africa
Costs of long distance	0.2	0.8
Costs / risks of being kidnapped	0.6	0.1
Costs of tolls	0.7	0.3
Total costs	**1.5**	**1.2**

GIS

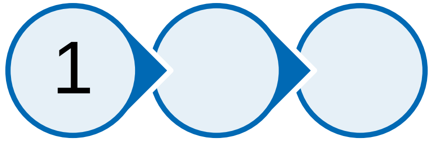
- Option 2: although being longer, the total costs are lower since risks and tolls lead to lower total costs
- Comparison is only possible due to normalized scale

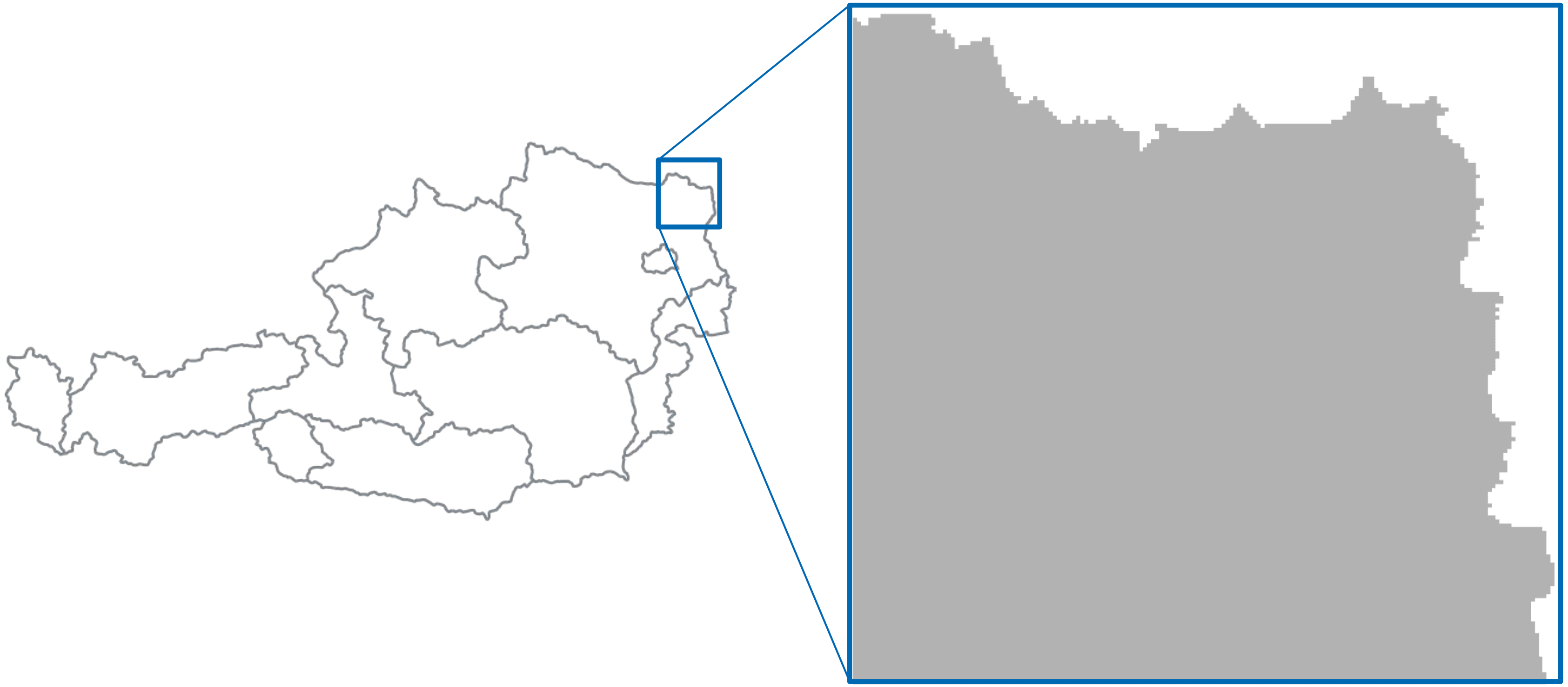
- **How do different stakeholders assess the costs of both routes?**
- **How do stakeholders define costs in general?**
- **How can this problem be solved with GIS?**

How the typical procedure of least cost path (LCP) works



How a cost surface is built





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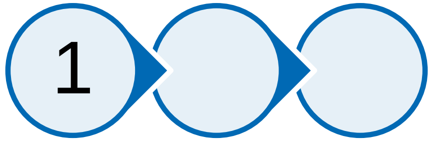
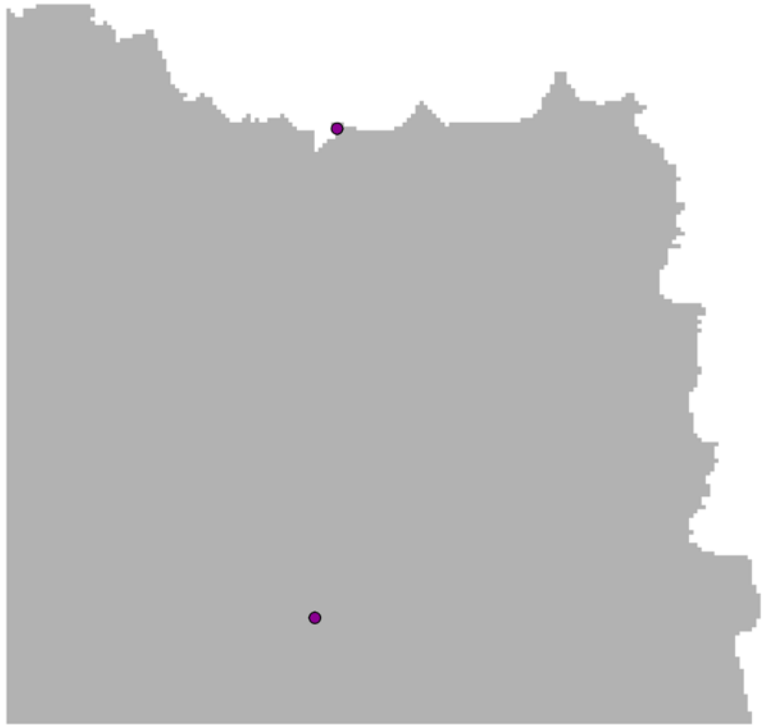
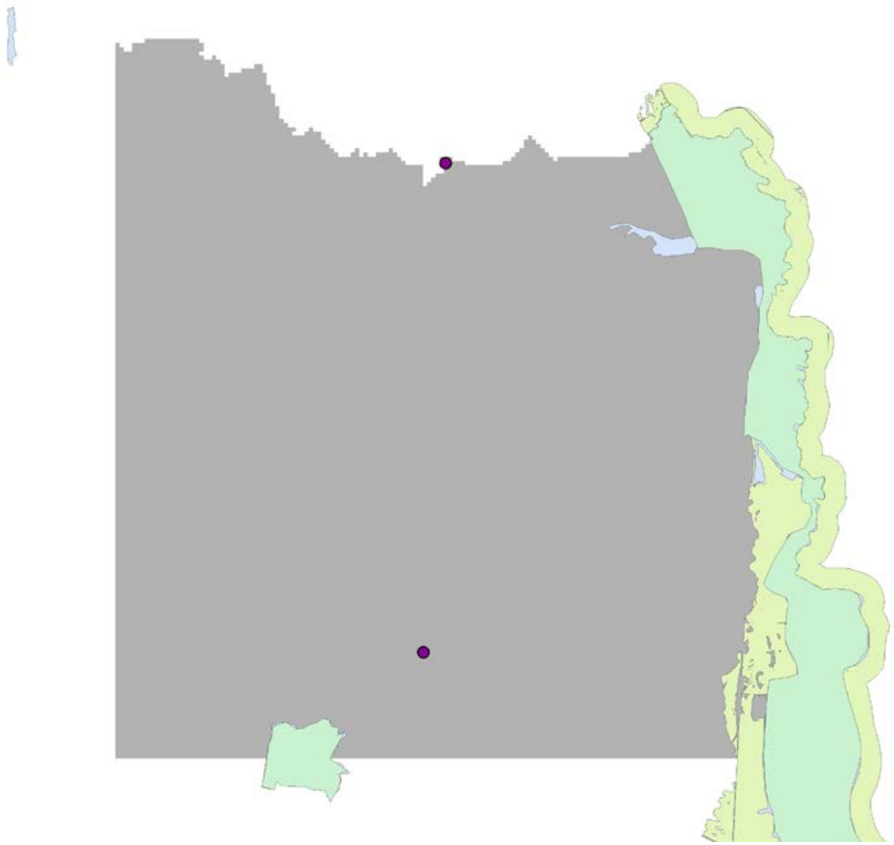




How a cost surface is built

1



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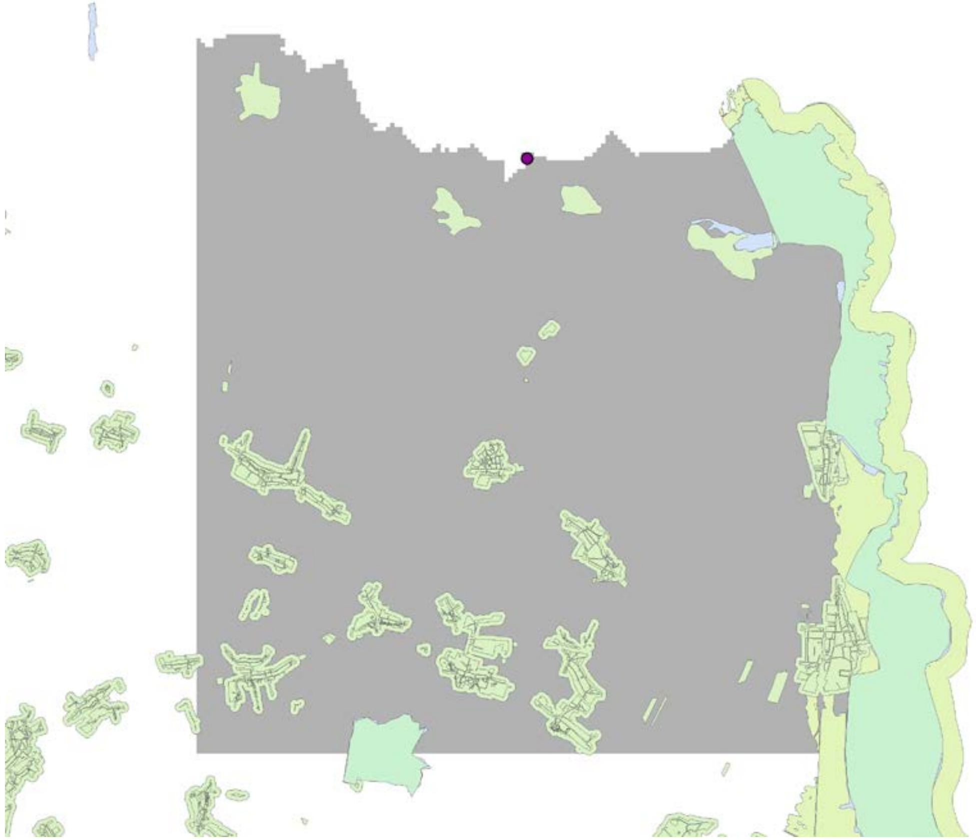
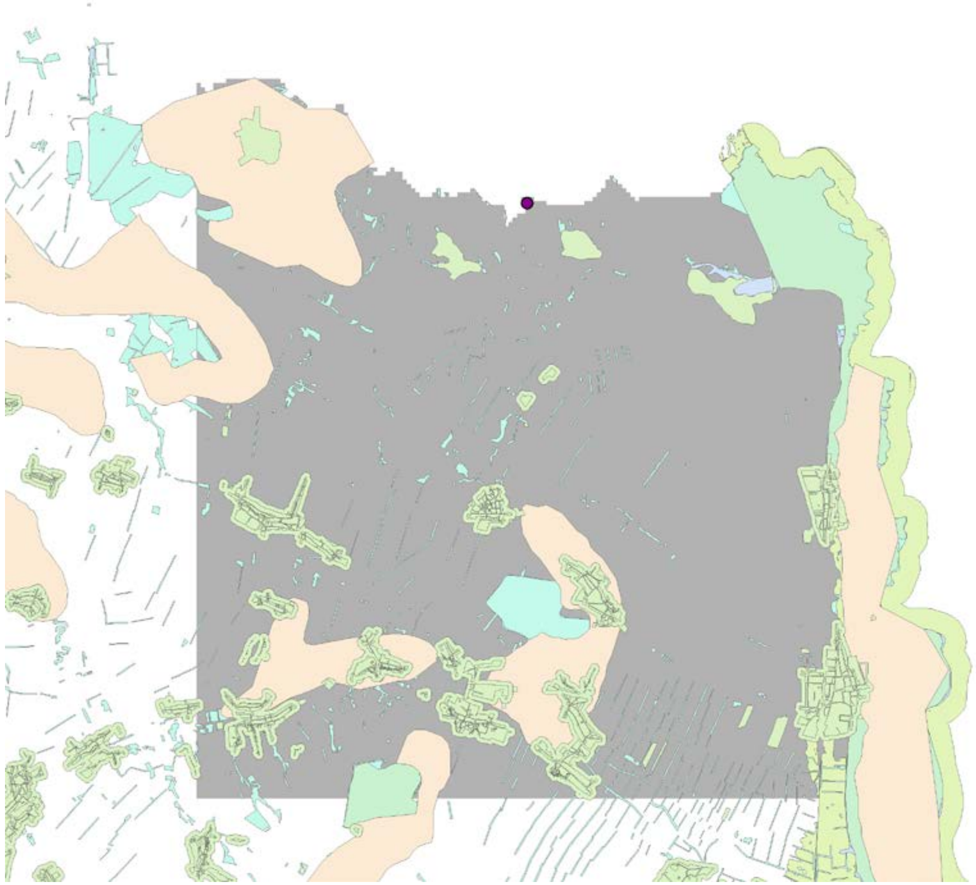


How a cost surface is built

1



How a cost surface is built

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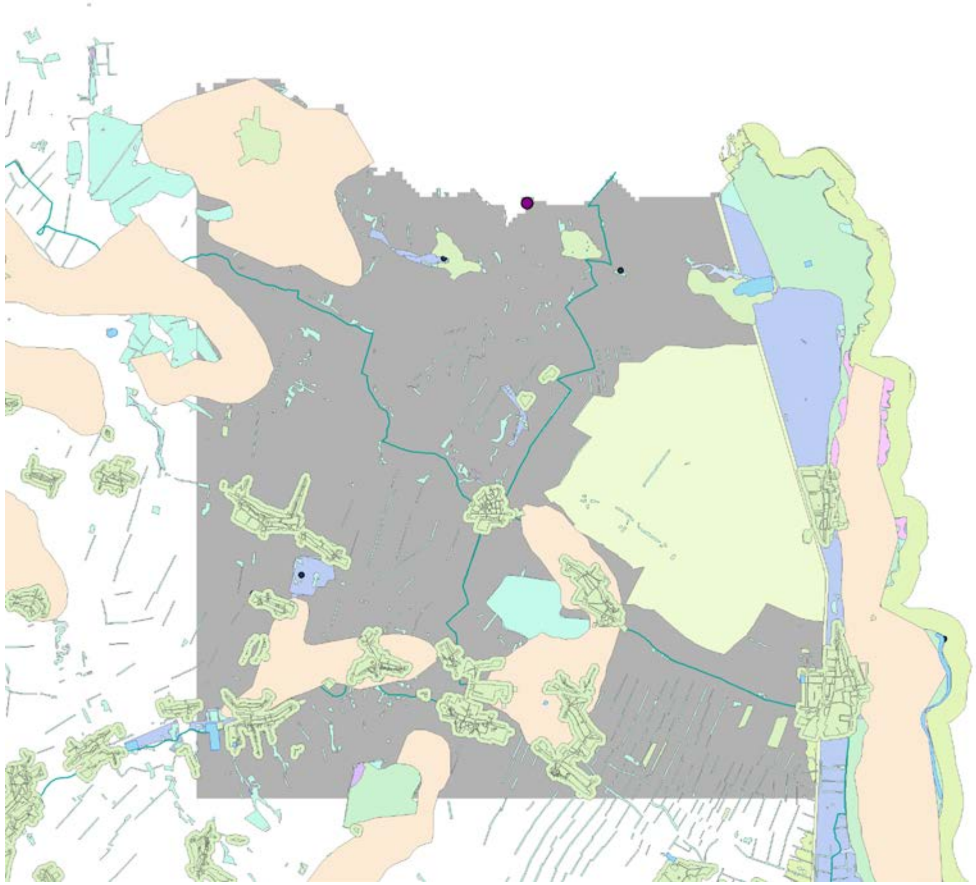
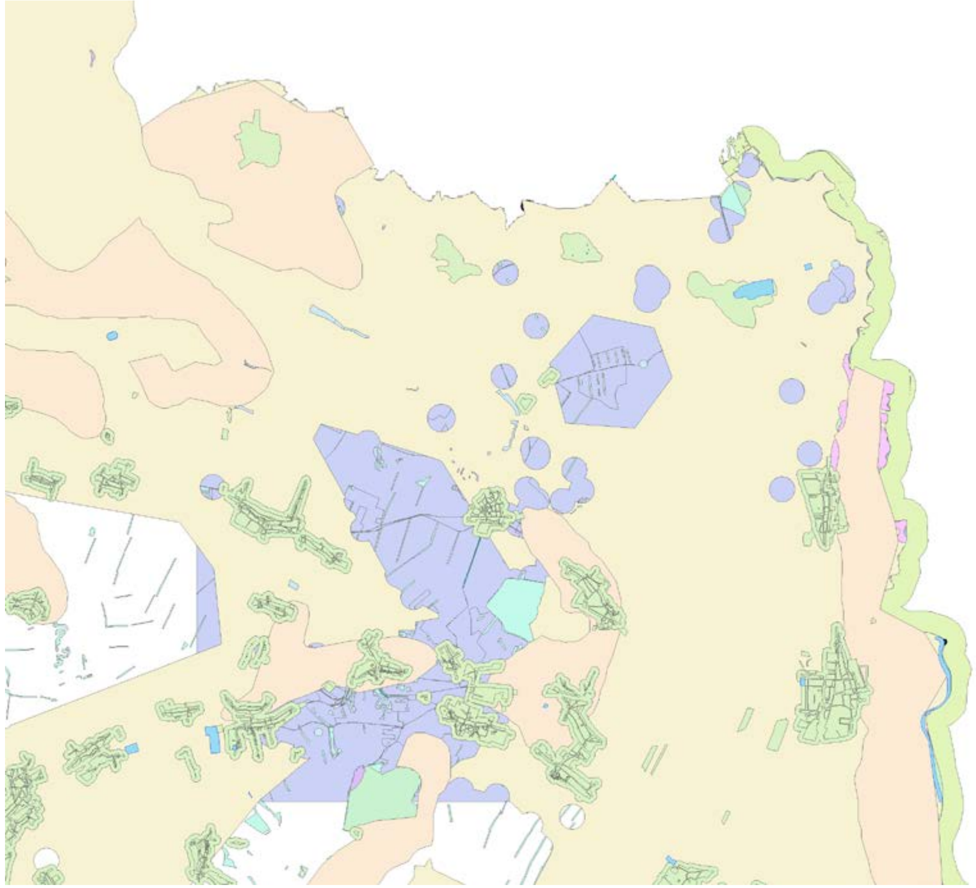


How a cost surface is built

1



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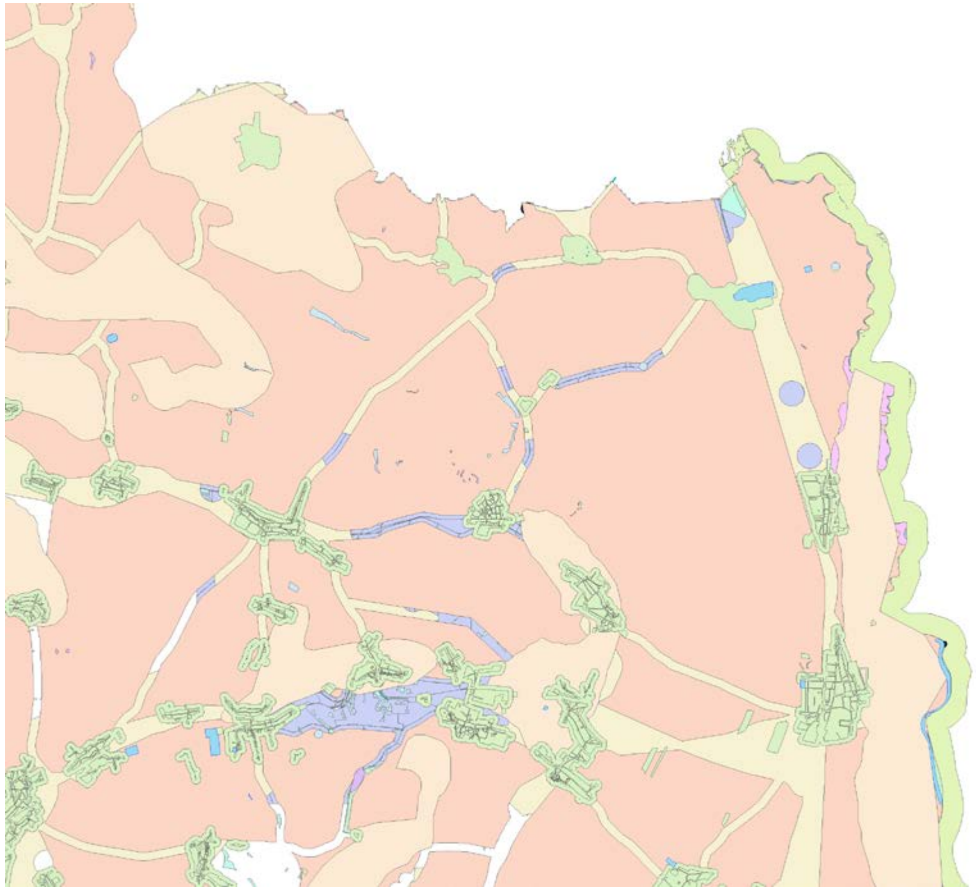

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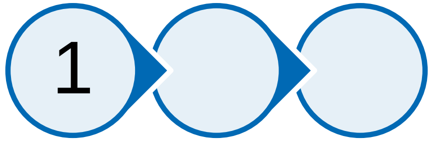
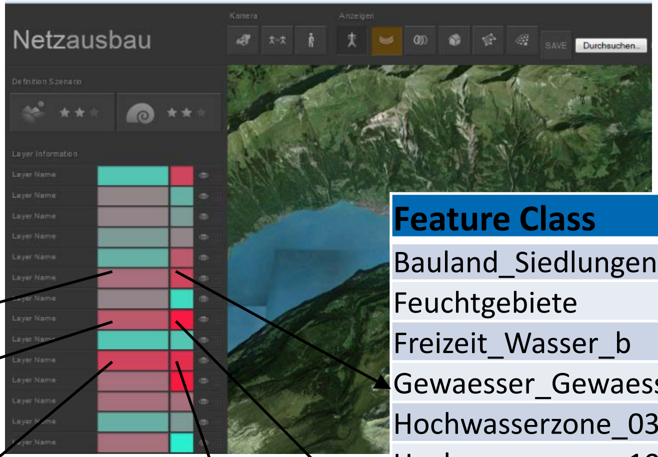
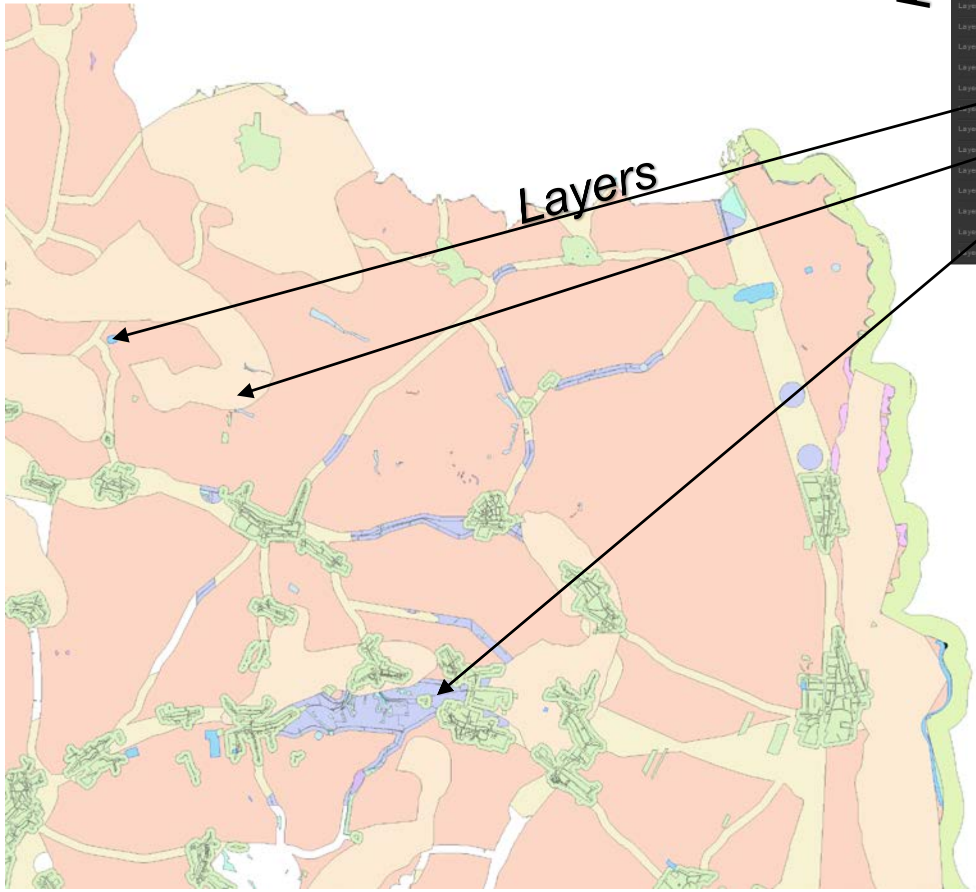


Platform



Layers



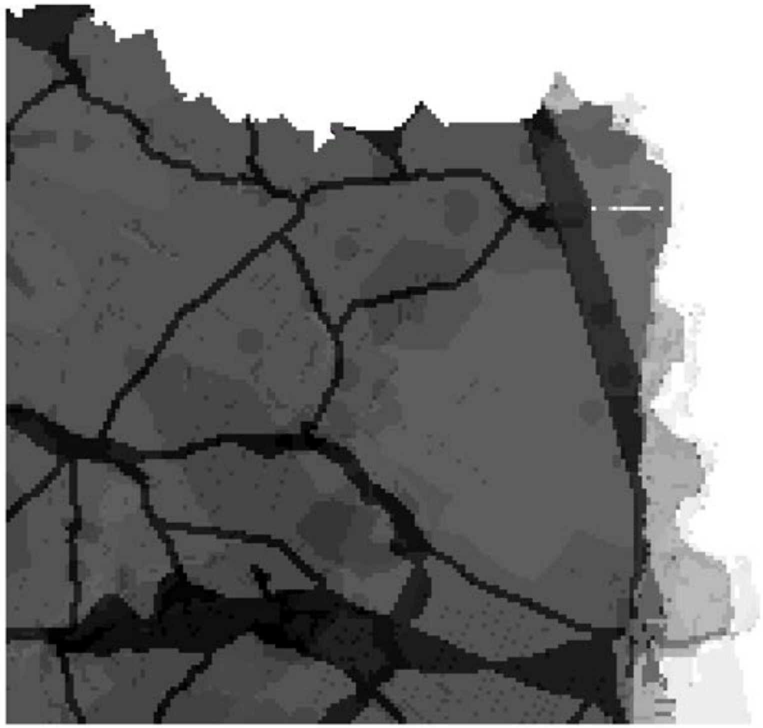
Weights

Feature Class	Resistance	Feature Weight
Bauland_Siedlungen	9	0.06
Feuchtgebiete	7	0.2
Freizeit_Wasser_b	8	0.22
Gewaesser_Gewaesserschutz	7	0.05
Hochwasserzone_030a	2	0.41
Hochwasserzone_100a	2	0.31
Hochwasserzone_300a	5	0.28
Kulturlandschaften_2	4	0.12
Landwirtschaftliche_Nutzflaechen	5	0.2
Naturdenkmaeler	2	0.25
Oekosysteme	7	0.17
Radrouten_b	5	0.72
RNA_Landschaftsschutzgebiet	5	0.05
RNA_Naturschutzgebiet	0	0.08
Sprawl_EnergieInfrastruktur	5	0.15
Sprawl_lineareInfrastruktur	9	0.35
Trockenrasen	5	0.1
Vogelschutzzonen	9	0.15
Wald	0	0.13

Weight Table

How a cost surface is built

1



Cost Surface

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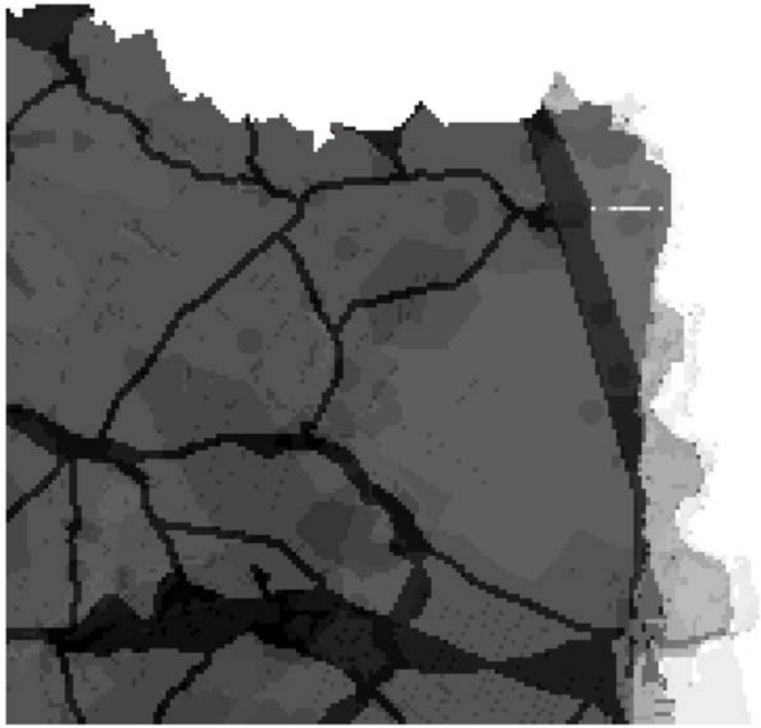
Weight Table

How a cost surface is built

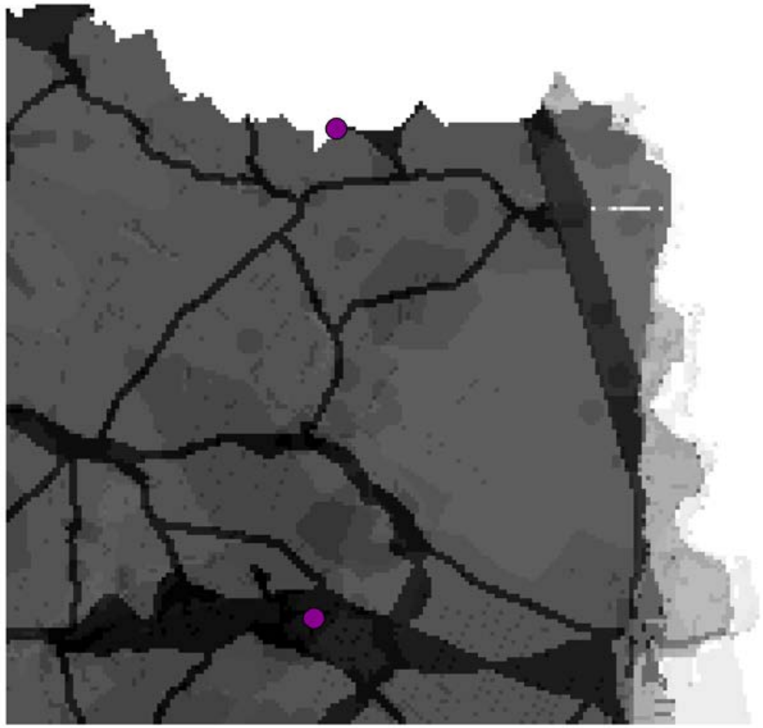
1



Cost Surface

How a cost surface is built

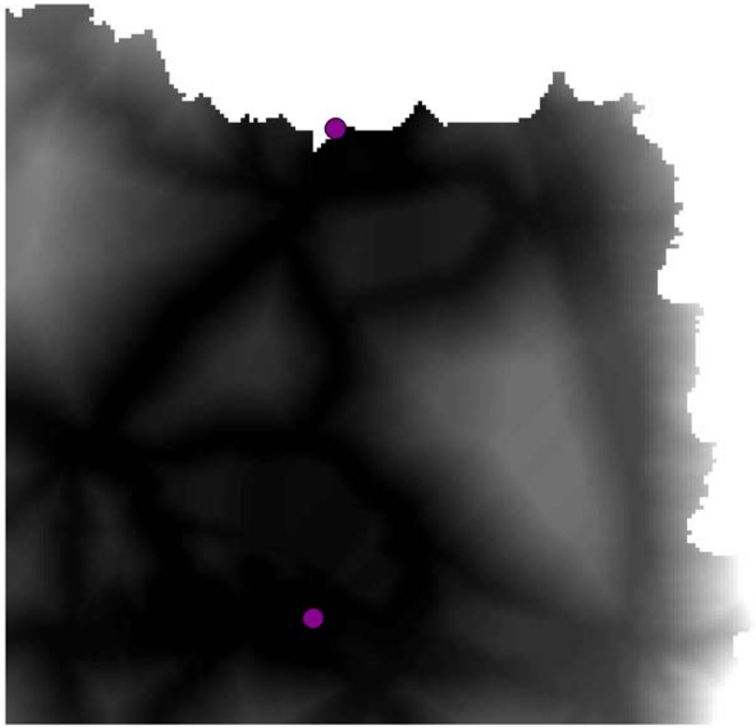
1



Cost Surface

How a cost surface is built

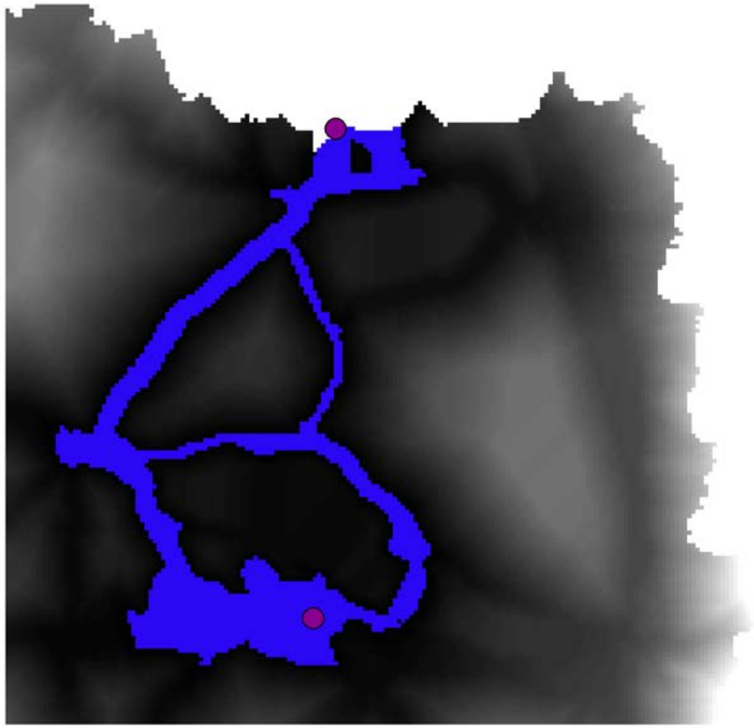
2



Global Cost Surface

How a cost surface is built

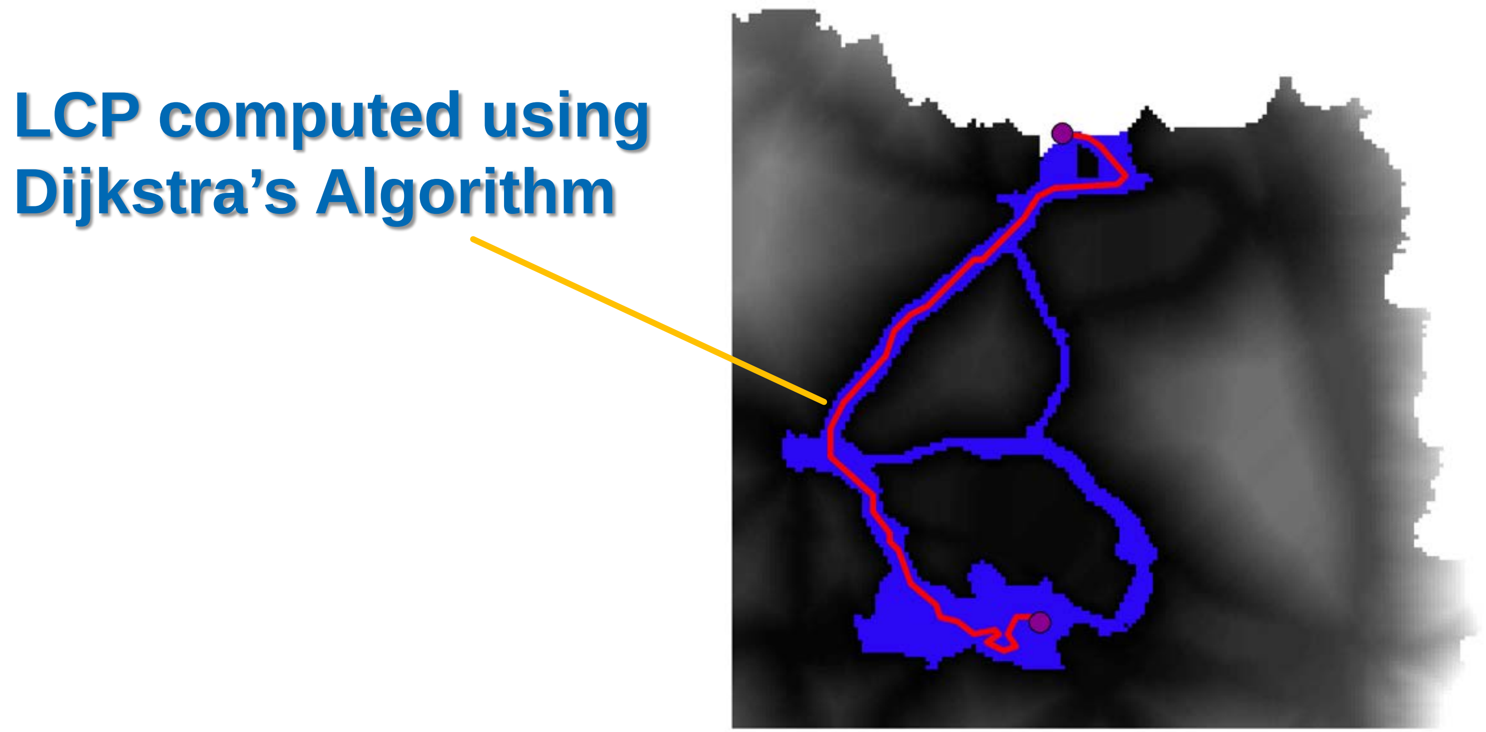
2



Global Cost Surface + Corridor

How a cost surface is built

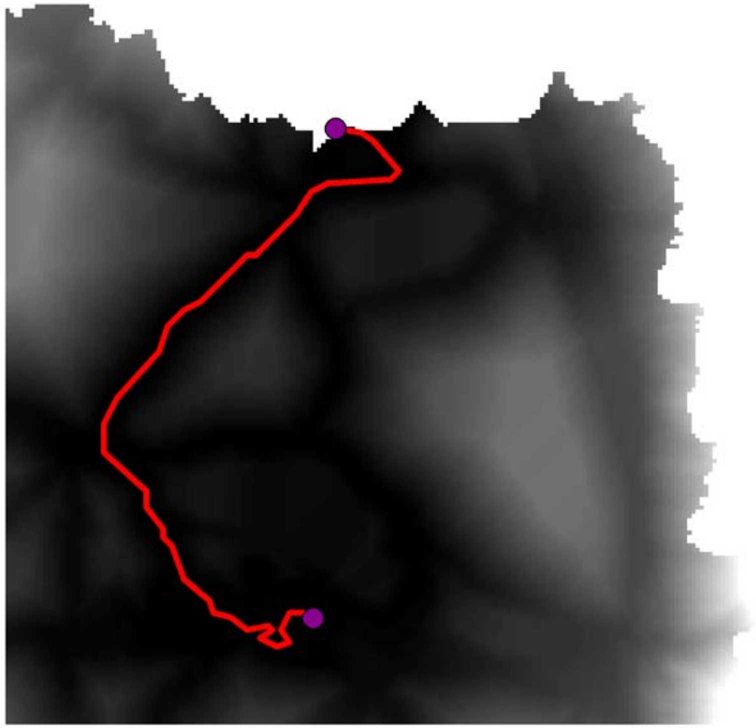
2



Global Cost Surface + Corridor + Path

How a cost surface is built

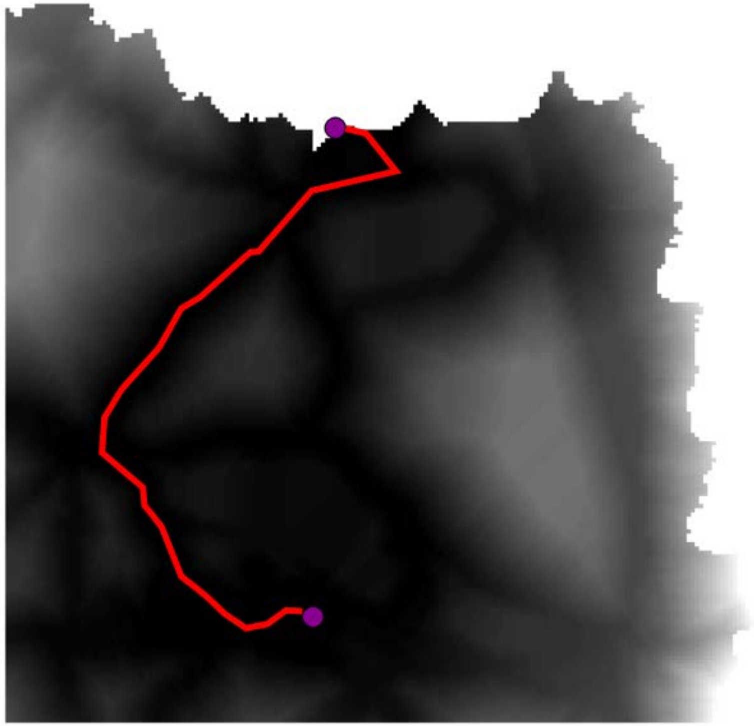
2



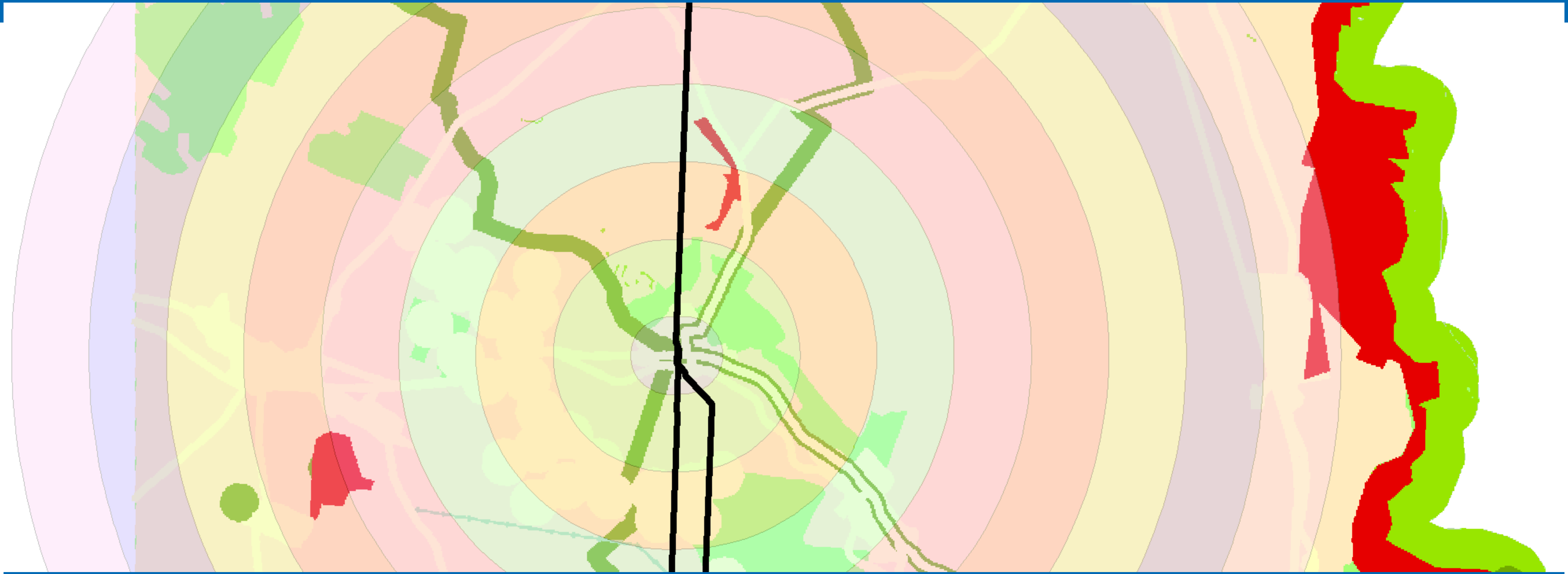
Global Cost Surface + Path

How a cost surface is built

3



Global Cost Surface + Straightened Path



Some typical problems of using least cost path and how they can be solved

12 limitations of using MCDA + LCP

Advantages and Limitations of the Least Cost Path Algorithm for Planning Transmission Lines

Keywords

Shortest Path, Least Cost Path, Least Cost Corridor, Multi-Criteria Decision Analysis, GIS, GIScience.

Abstract

As for linear infrastructure in general, the planning of transmission lines makes use of Geographic Information Systems, including algorithms capable to determine an ideal path between two points. Therefore, two methods are commonly combined with each other in order to find a solution suitable for all involved stakeholders: the Least Cost Path algorithm, which determines a path of lowest friction, and Multi-Criteria Decision Analysis, which structures decision-making in order to avoid subjectivity. Although both methods are well-established in the transmission line planning process, their use still leads to some inconsistencies. In this paper, we refer to previous transmission line planning projects that made use of both methods. Twelve inconsistencies are identified based on the raster representation, Djikstra's algorithm, and concerning practical limitations. We then provide solutions for these inconsistencies found in the literature and through our own work in this field.

Schito, Piveteau, Buffat, Grassi, and Raubal (in progress)

- Constraints based on the raster representation
- Constraints based on Dijkstra's algorithm
- Practical limitations

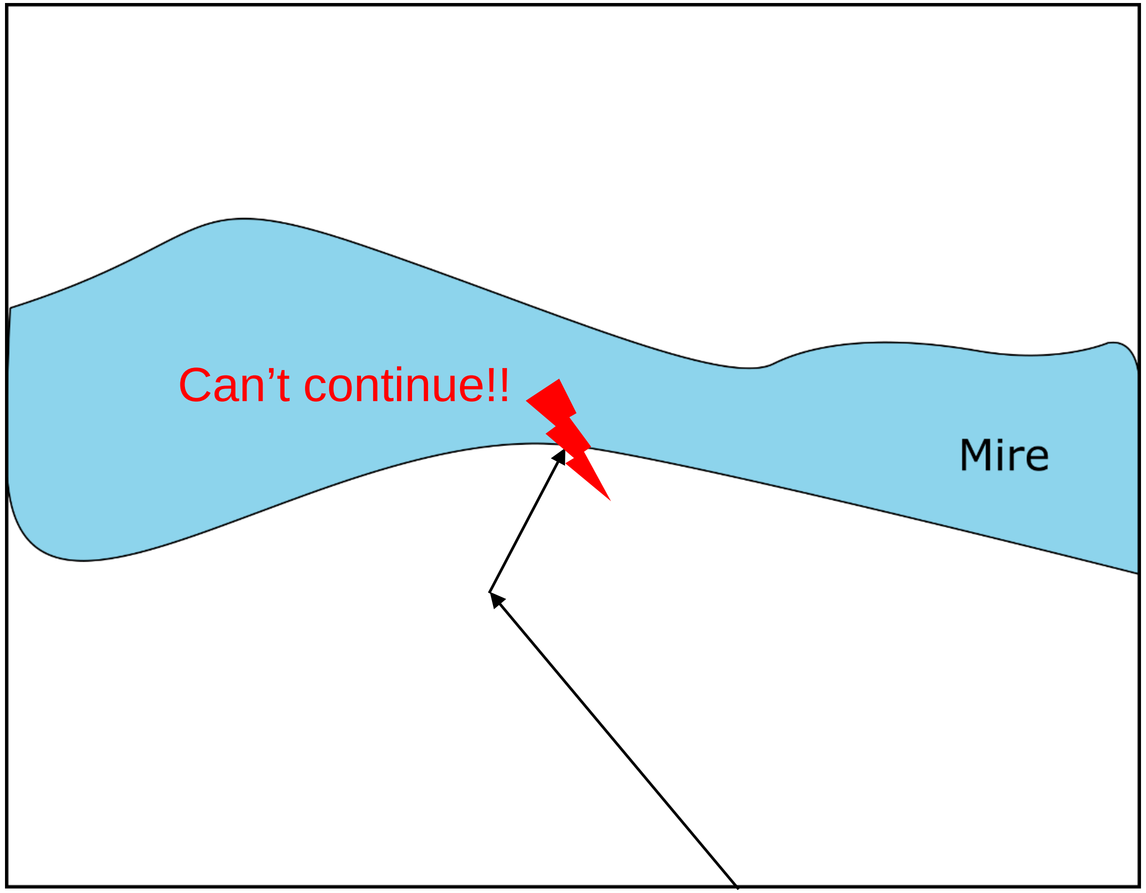
Raster

Some constraints based on the raster representation

Imagine, you want to span this mire…
(OK, assume there were no legal restrictions)

http://naturepreserves.ohiodnr.gov (2017)

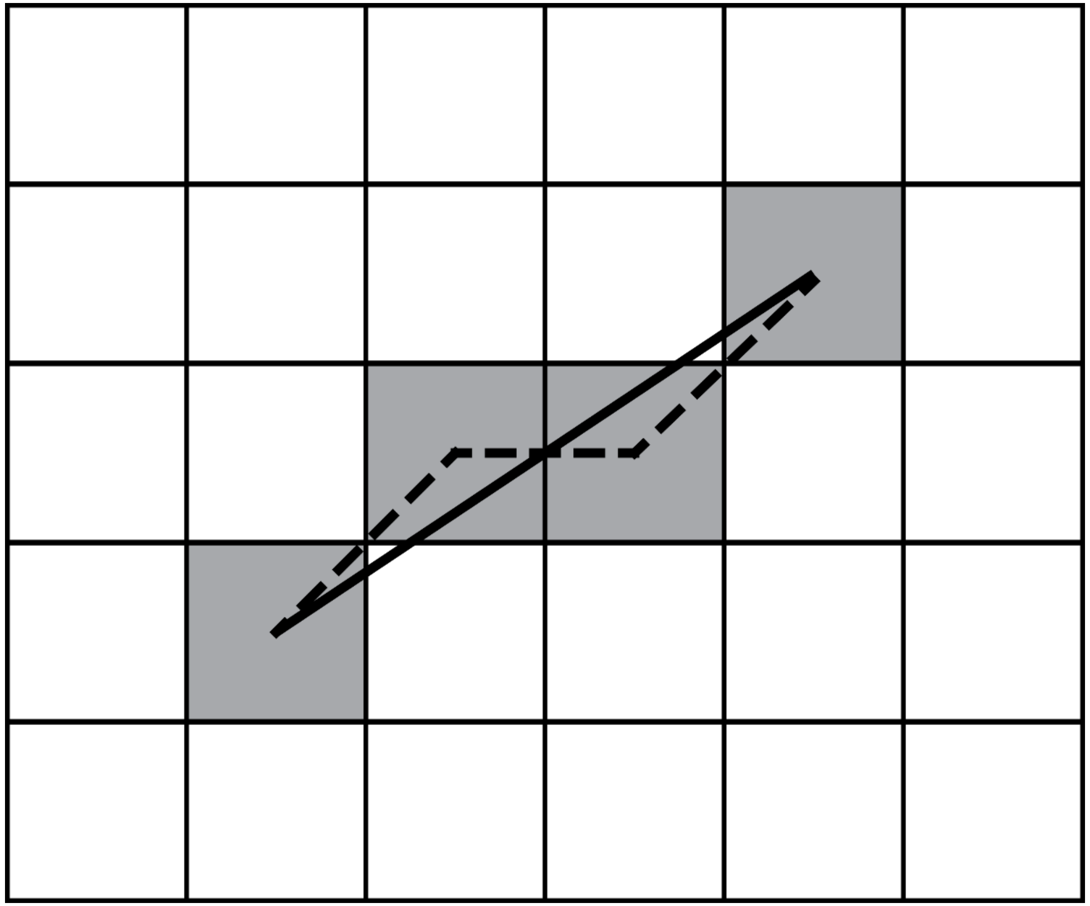
Since LCP computes continuous paths, spanning is not possible



Schito (2017)

- Even though it was technically and legally possible, the mire left cannot be spanned because no continuous path can be computed.
- Furthermore, LCP is computed based on one cost surface. → However, different costs for transmission towers and for cables cannot be considered at once.

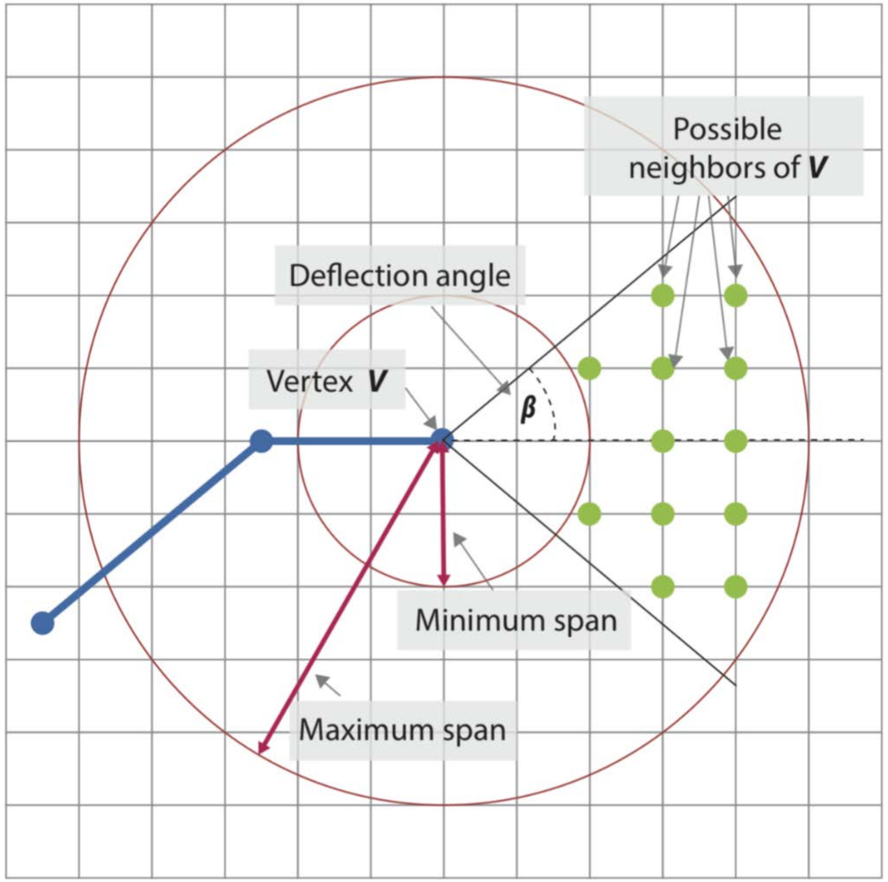
Raster discretization



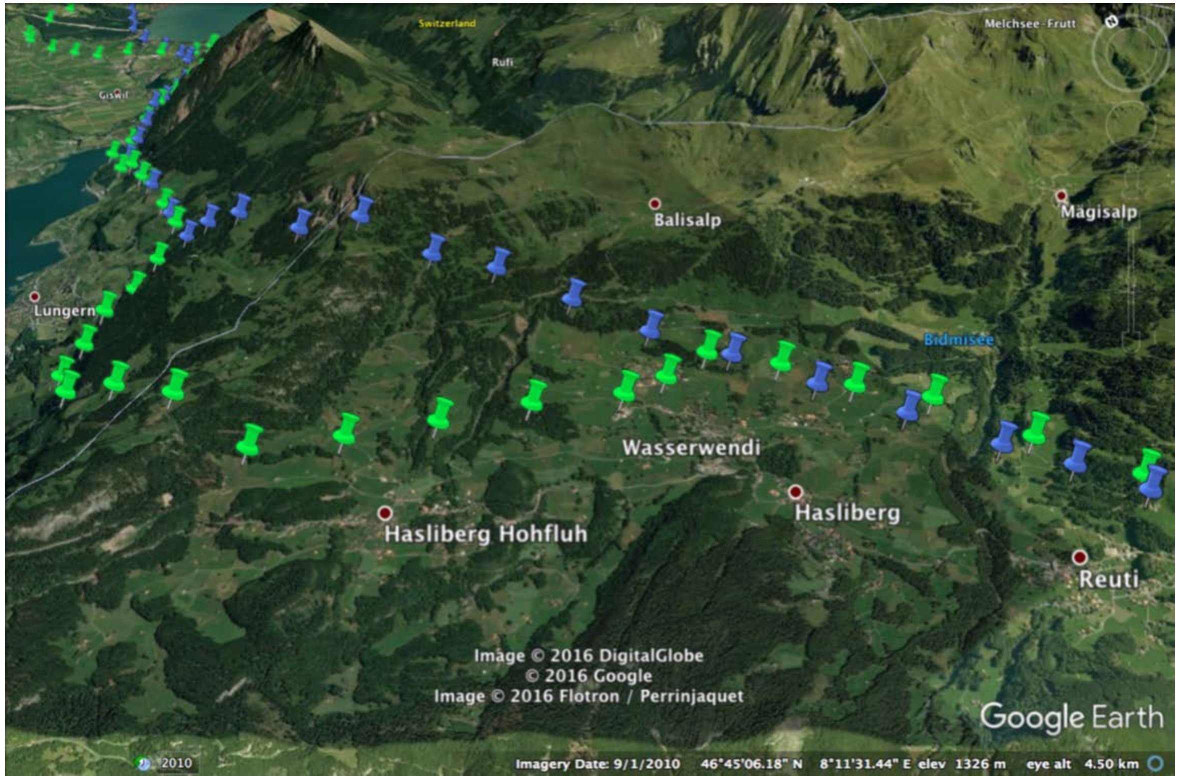
Schito, Grassi, and Raubal (2015, in progress)

- Due to the lattice, the most direct way from A to B is discretized and thus, extended.
- Thus, the modeled costs do not correspond to the true costs.
- In reality, zig-zag paths are avoided as much as possible.

Raster discretization: A solution proposed by Rheinert (1999) and newly implemented and improved by Piveteau (2017)

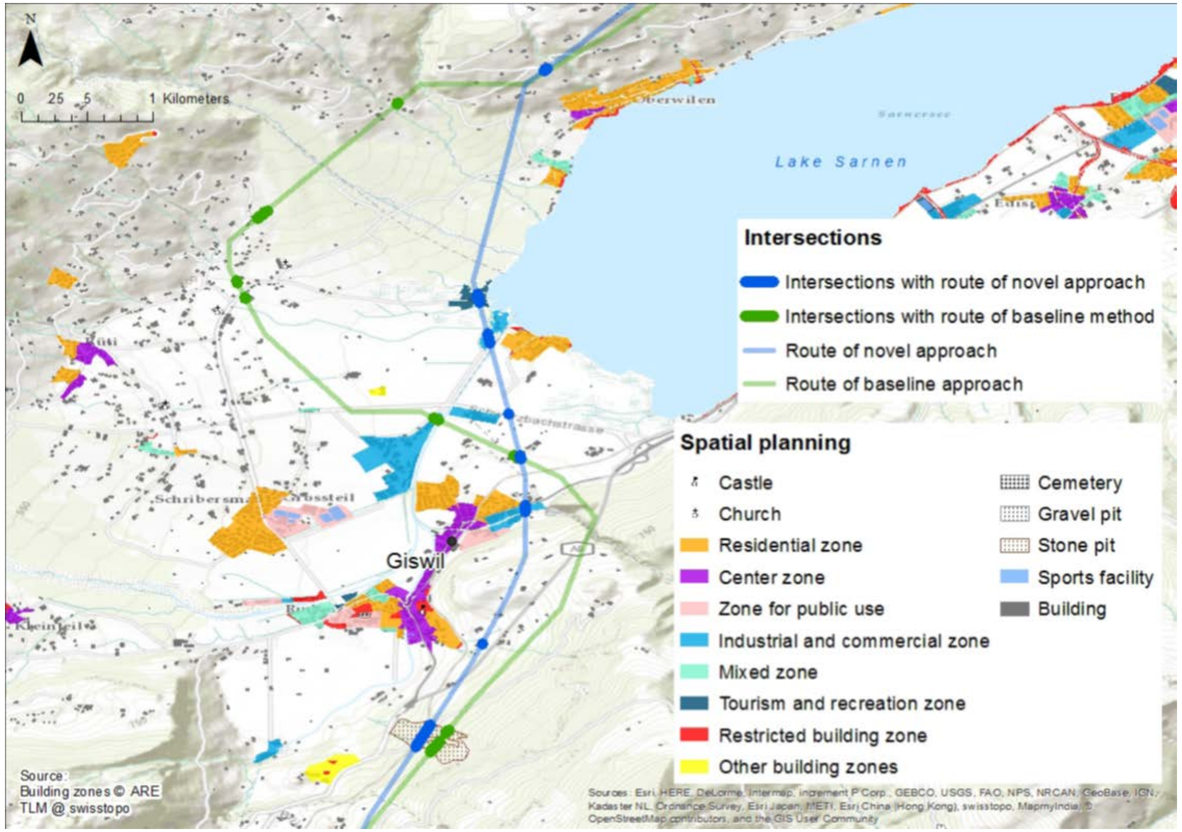


Piveteau (2017)



Piveteau (2017)

Piveteau (2017) compared the classical raster-based LCP method with her approach that also considers the relief and optimizes the path



Piveteau (2017)

- The novel approach affects less vulnerable land. It sets a transmission tower only where it is needed.
- Experts significantly prefer the solutions of the novel approach over the classical LCP method because the resulting path avoids settlements and future expansion areas more systematically.

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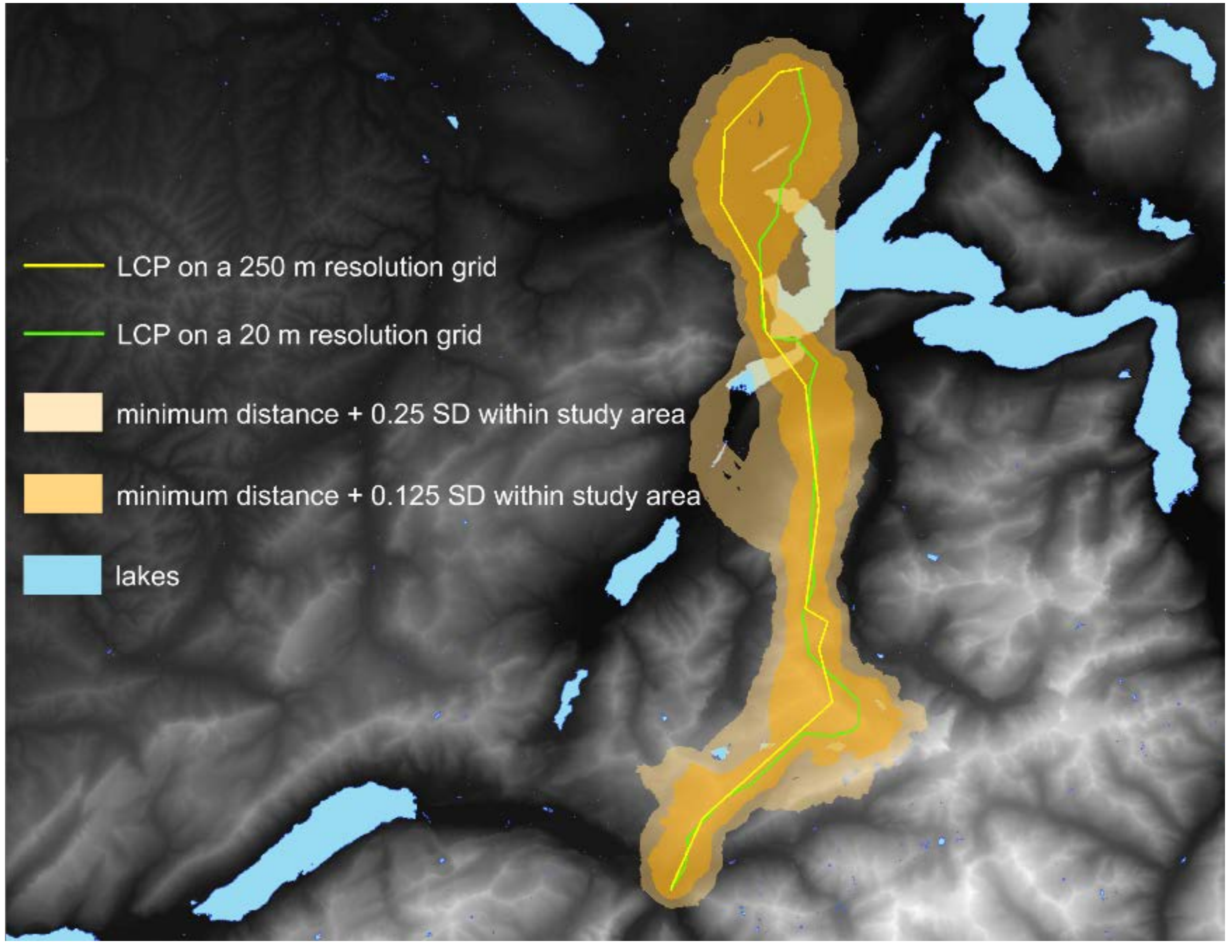
PLUS

Cell size affects the LCP



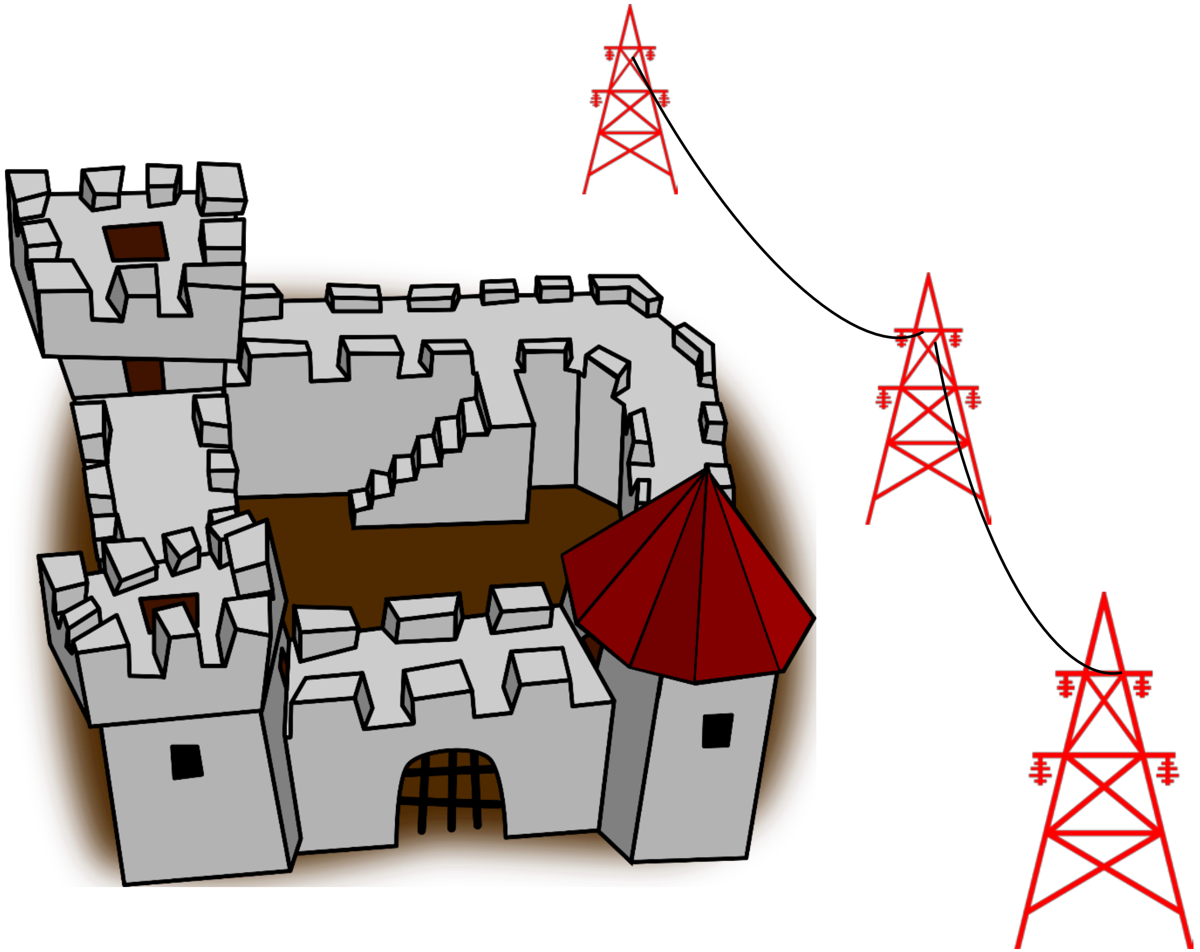
Schito (2015)

- Here, both lines lie within the corridor of 0.125 SD tolerance, albeit using a different resolution.
- Is this method suitable for path straightening?
- Is this method suitable for providing different alternatives?

Dijkstra

Constraints based on Dijkstra’s algorithm

Would you be bothered if a power line was built beside your beautiful castle?



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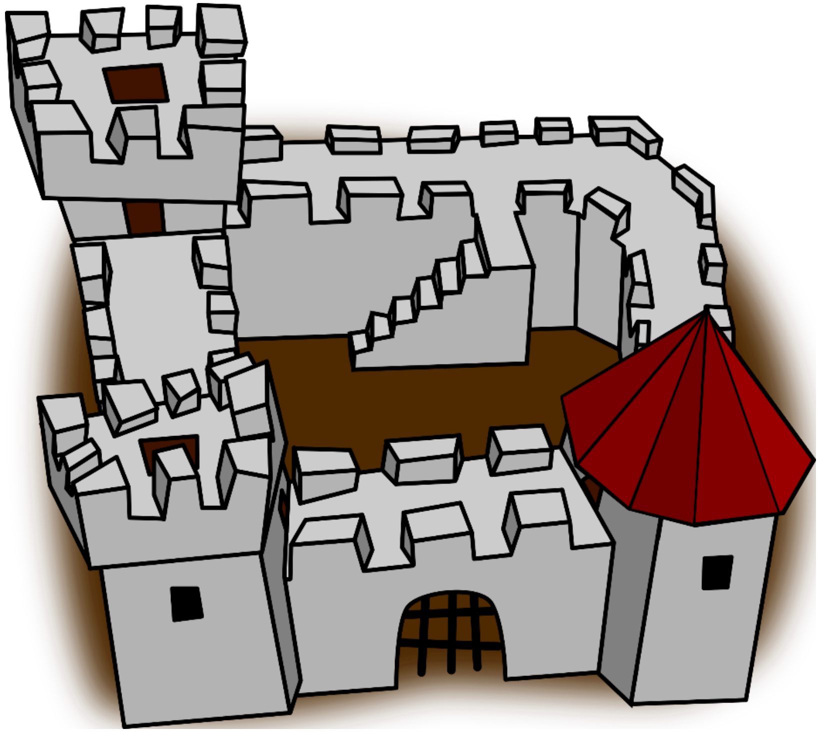

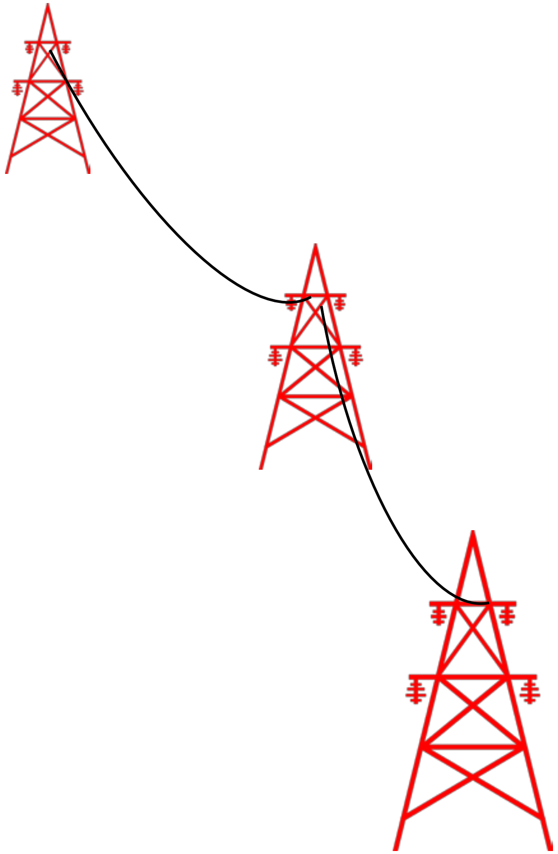

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PLUS

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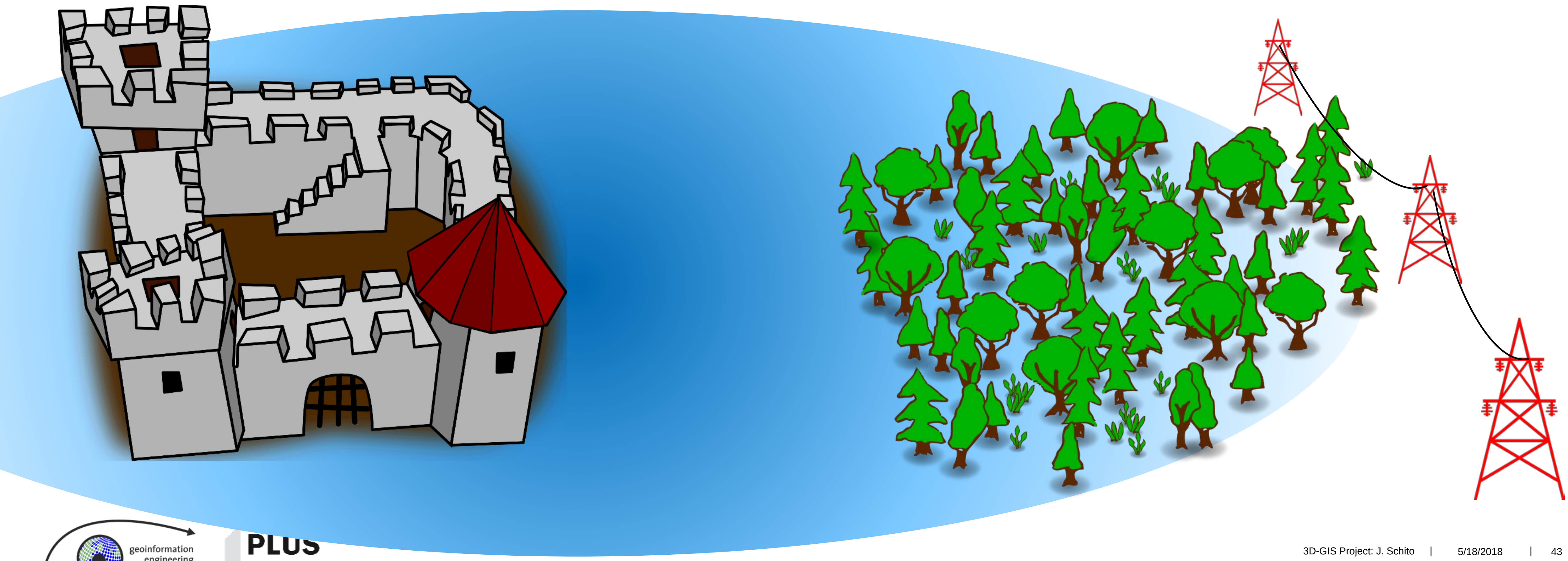
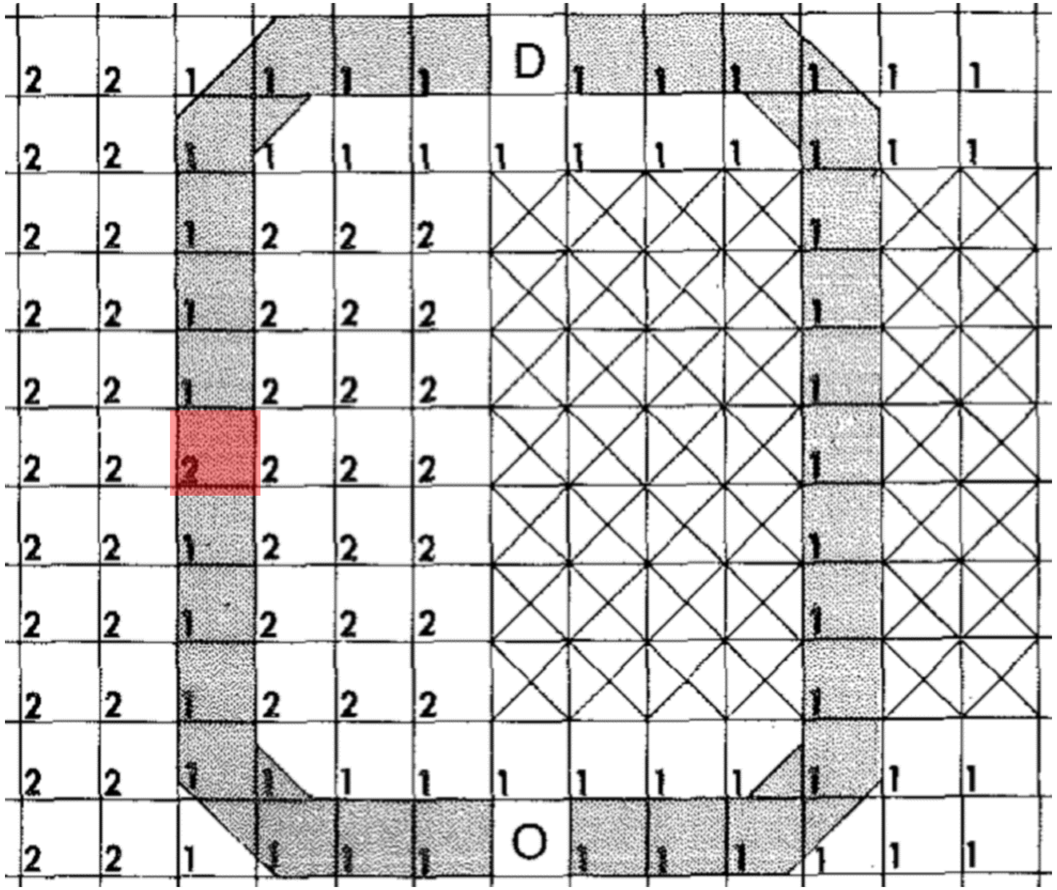


Proximity, as described by Huber & Church (1985), means that the LCP tends to follow given borders and that it does not consider surrounding resistances



Huber & Church (1985)

Schito (2015)

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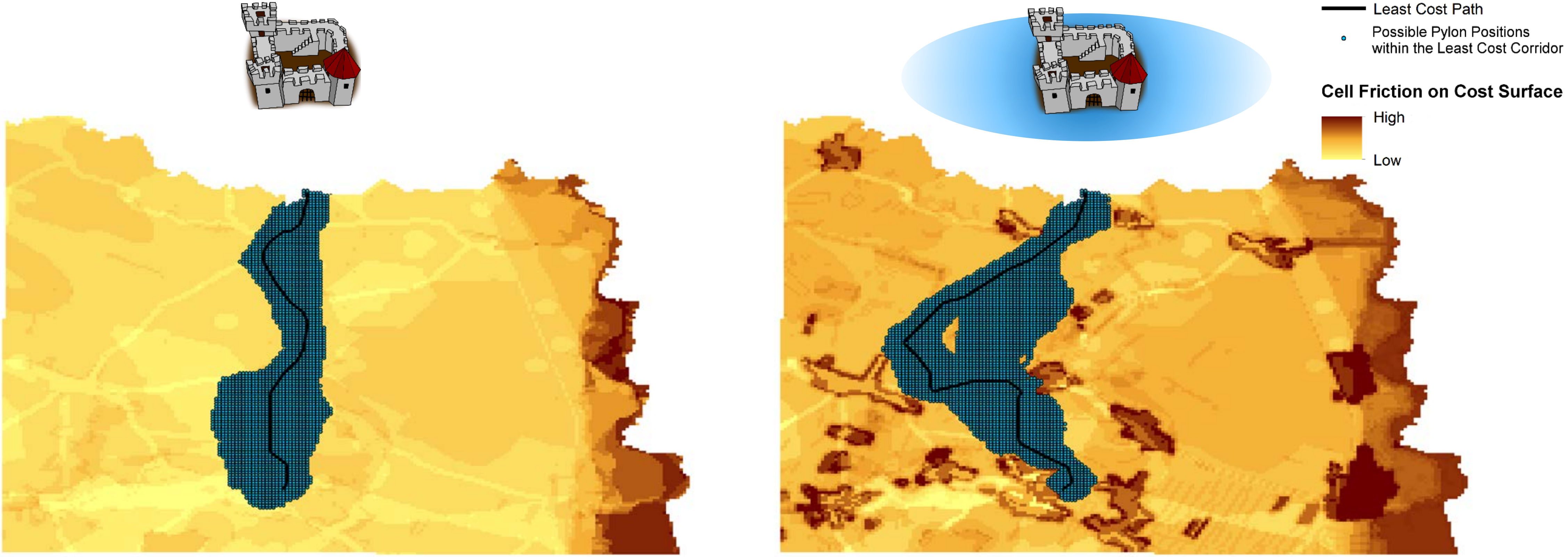
PLUS

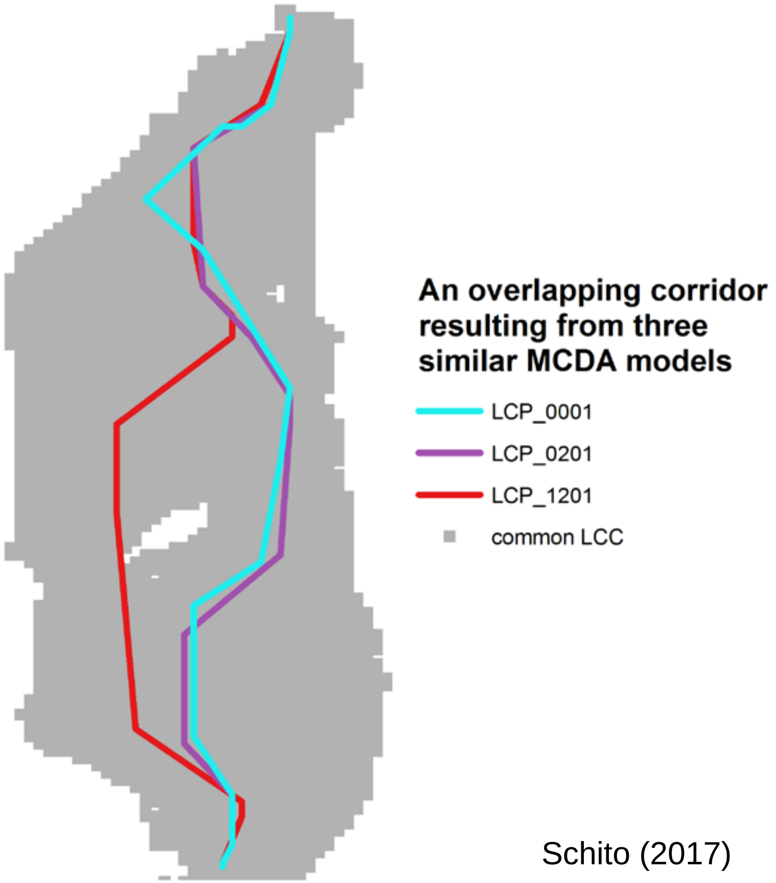
Buffering leads to more realistic models since Tobler's First Law of Geography is considered



Simple additive weighting, by reducing weighting the more frequently a cell overlaps

Schito (2016)

LCP stops after the start has been connected with the end



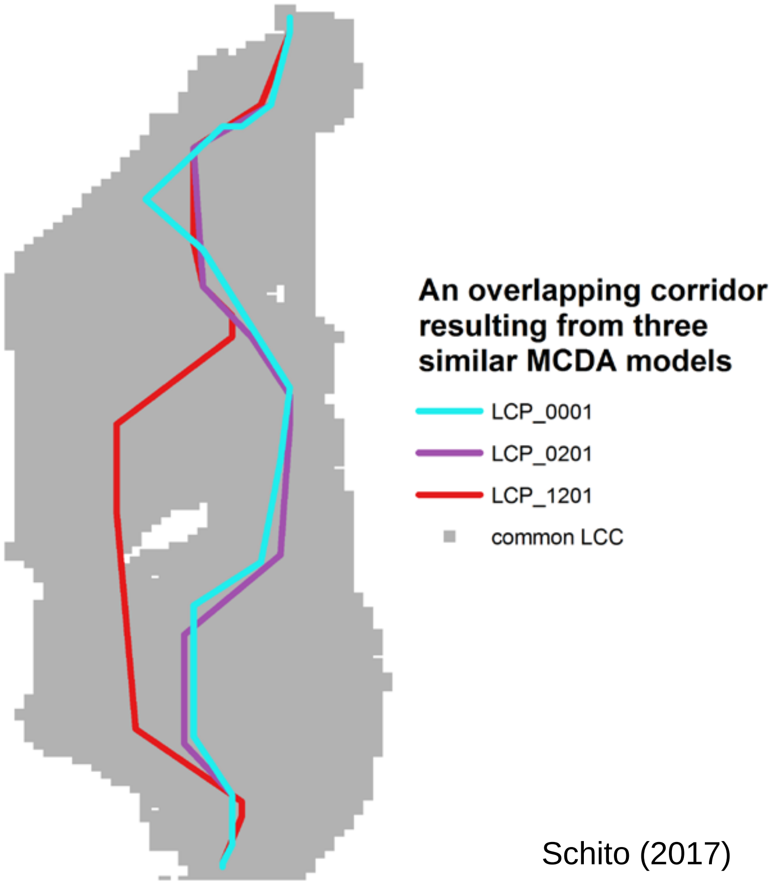
Schito (2017)

- Every line represents an ideal solution for a given cost surface.
- Means: The circumstances cannot be changed during the same LCP run.
- Means: LCP is not suitable to find a solution when different transmission technologies (overhead line and earth cables) must be combined.

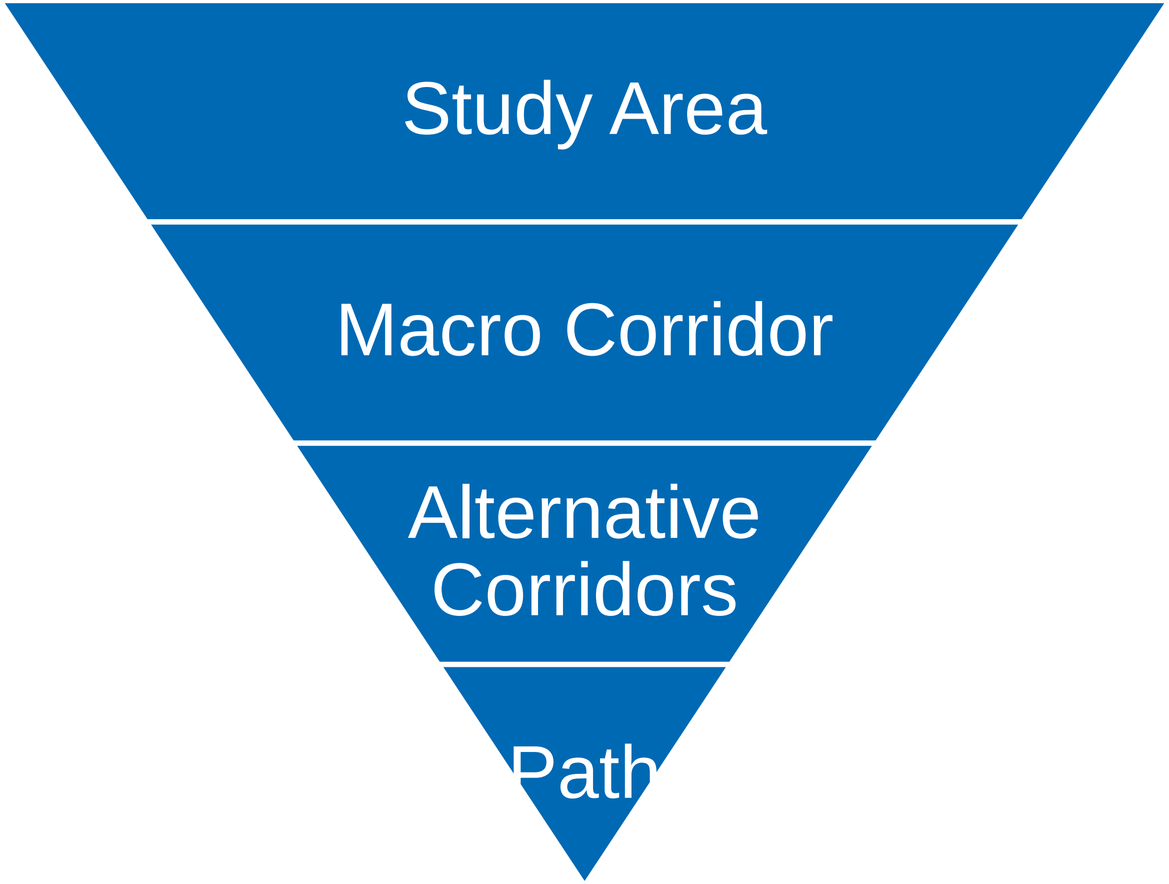
Practice

Practical limitations

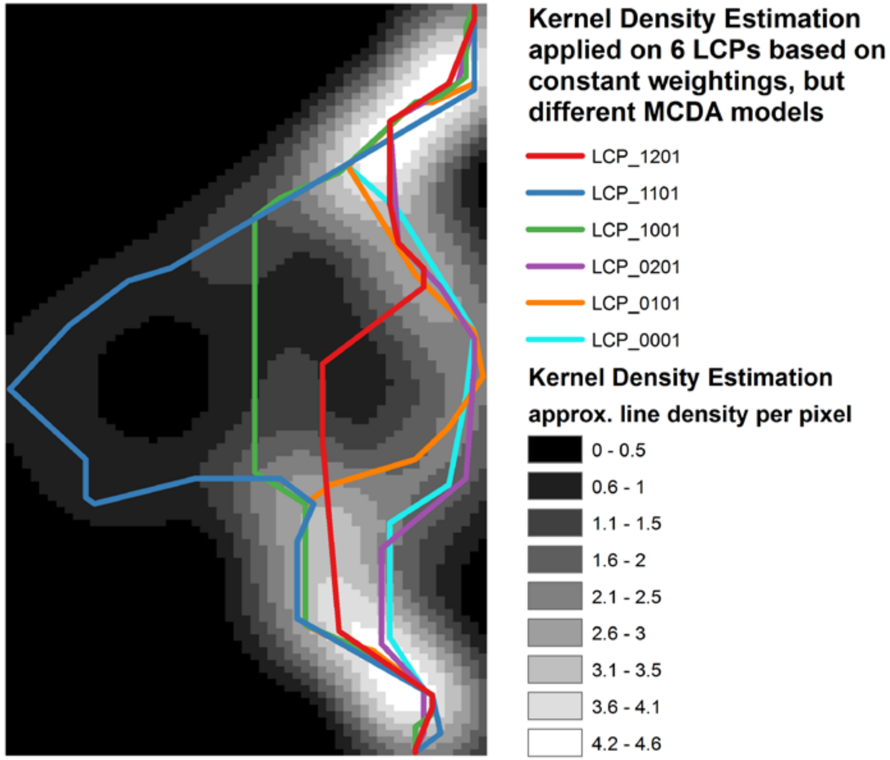
LCP reduces solutions to one pixel, neglecting other solutions



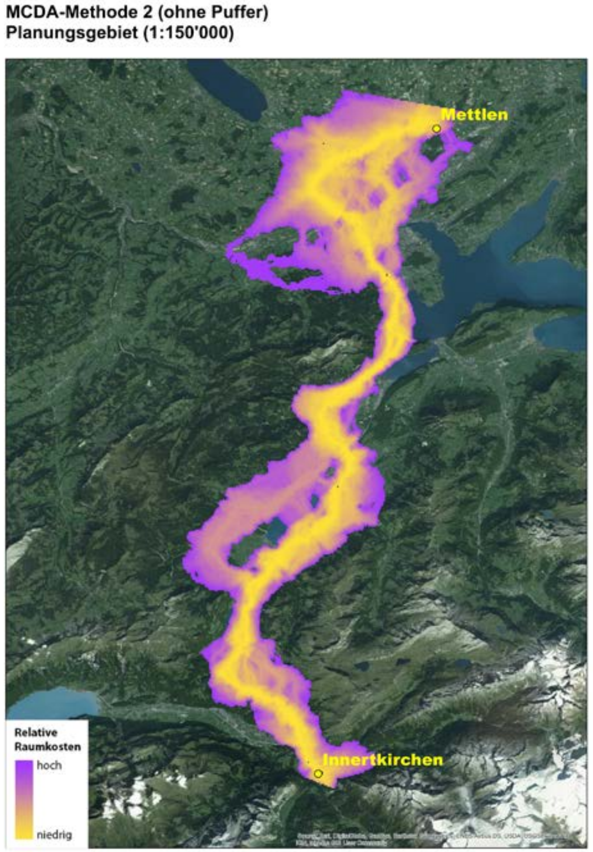
Schito (2017)



However, LCP can be used to determine a feasible corridor



Schito (2017)



Schito (2017)

Future Outlook

On WP3 & WP4

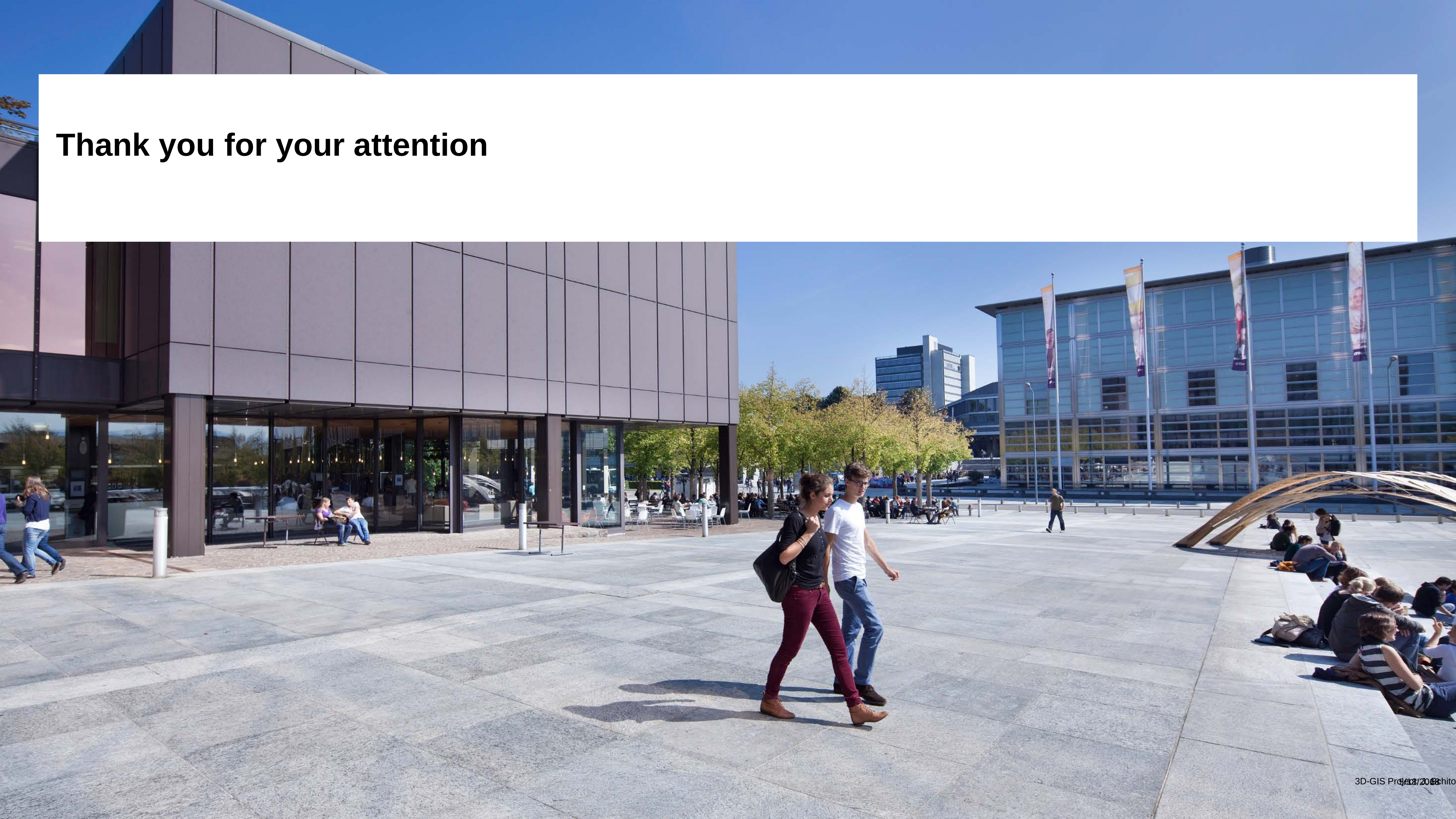
Next steps

- www.netzausbau.ethz.ch
- www.ikg.ethz.ch: 3D GIS for planning electric power systems
- Youtube: 3D Decision Support System zur Unterstützung der Leitungsplanung

- Evaluate the effects of the different MCDA methods through a sensitivity analysis.
- Integrate LiDAR data into the 3D DSS in order to get a more realistic impression of the virtual reality.

Discussion

Open Questions? Don't hesitate to ask.



Thank you for your attention