Interactive visual analysis of flood scenarios using large-scale LiDAR point clouds

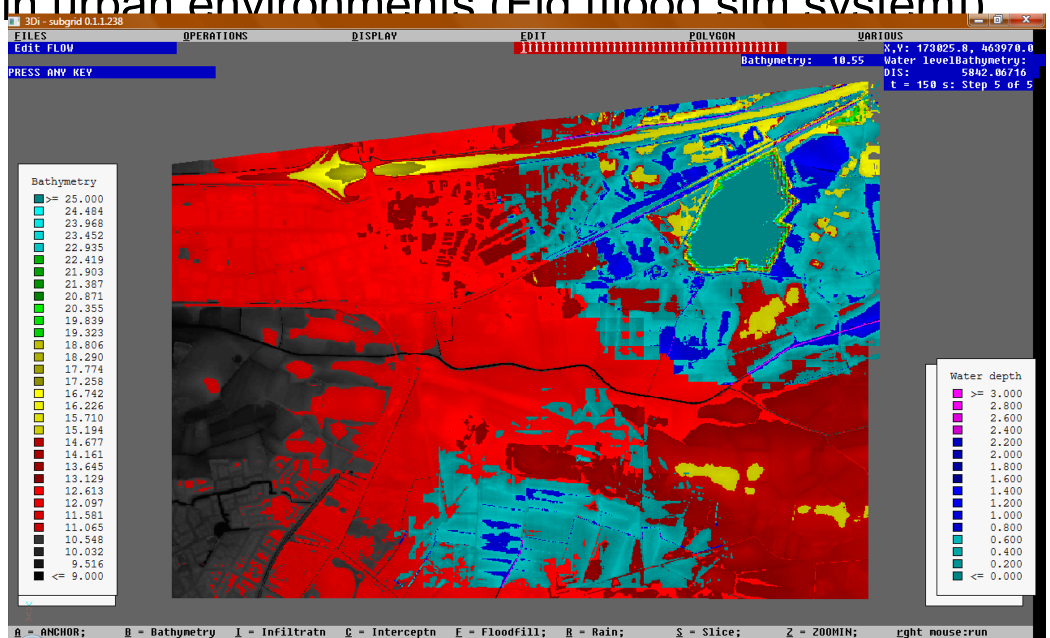
by T.Tutenel, C. Kehl and E. Eisemann

Overview

1. Visual Representation of LiDAR in Disaster Management (problem)
2. Visualisation-on-budget (method 1)
3. Geospatial data integration (method 2)
4. Historic flood in Wieringermeer 1945 (use case result 1)
5. Urban flood by precipitation in Watergraafsmeer (use case result 2)
6. Crisis management support in exercises (use case result 3)
7. Future Work

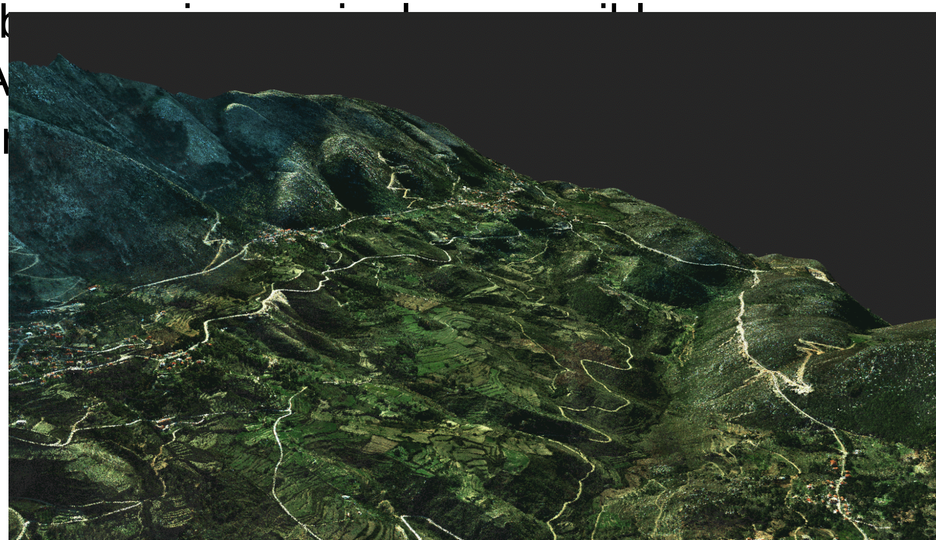
Visual Representation of LiDAR in Disaster Management

- dutch Actuel Hoogtebestand Nederland (AHN) as aerial LiDAR data set of whole Netherlands available for research
- applications in climate research and disaster management
- our work cares about visualisation of flood scenarios for flood protection management
- usually maps are used to assess and visualise flood scenarios
- 2D map information not sufficient for giving public advice in case of a flood, especially in urban environments (Fig [flood sim system]).



Visual Representation of LiDAR in Disaster Management

- recent movement towards usage of 3D geoinformation systems like GoogleEarth [Goodchild2008] and VirtualFlood3D [Busaman2010] to predict flood effects
- problem: full 3D information not globally available in every region, particularly not in smaller communities and rural areas (labour-intensive 3D modelling for Google Earth)
- Mesh-based systems deriving 2.5D information from height maps often lack necessary precision
- 2.5D LiDAR information creates new possibilities in 3D visualisation
- such data b
- aerial LiDA *nt-based rendering* (PBR) appr ka rendering])



Visual Representation of LiDAR in Disaster Management

- although commercial systems (e.g., ArcGIS) support LiDAR processing, visualisation still usually 2D map-alike
- most GIS fail processing and visualising massive, high-resolution LiDAR data; resolution compromises not acceptable in flood protection management
- we improve our visualisation system [deHaan2009, Kehl2012] by using a new approach of smooth out-of-core PBR for LiDAR data that is used for flood protection management
- enabling hydrologists and decision maker to plan new protection measures and highlight important landmarks, we use a new technique to combine KML-based geospatial metadata with the LiDAR point set

Overview

1. Visual Representation of LiDAR in Disaster Management (problem)
2. Visualisation-on-budget (method 1)
3. Geospatial data integration (method 2)
4. Historic flood in Wieringermeer 1945 (use case result 1)
5. Urban flood by precipitation in Watergraafsmeer (use case result 2)
6. Crisis management support in exercises (use case result 3)
7. Future Work

Visualisation-on-budget

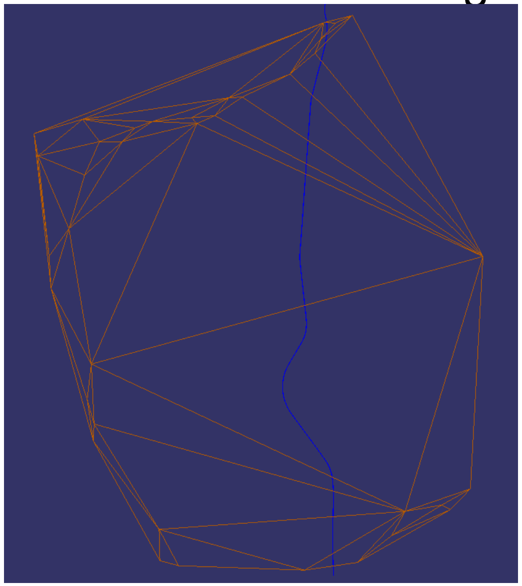
- objective is to render large-scale, high-resolution LiDAR point sets interactively and smoothly
- use tree-based Level-of-Detail (LoD) data structures to limit number of rendered points to only keep the points necessary for concise visualisation
- each LiDAR point distributed to its corresponding node in the LoD tree according to its importance (higher importance -> coarser detail level) (Fig. [Thesis p54])
- at runtime, we measure the available budget via the system's performance [Wouda2011]
- every point has a budget that is required if rendering the point
- successively more points are rendered until available budget of the system is null
- the system allows fast rendering speeds with smooth streaming of points

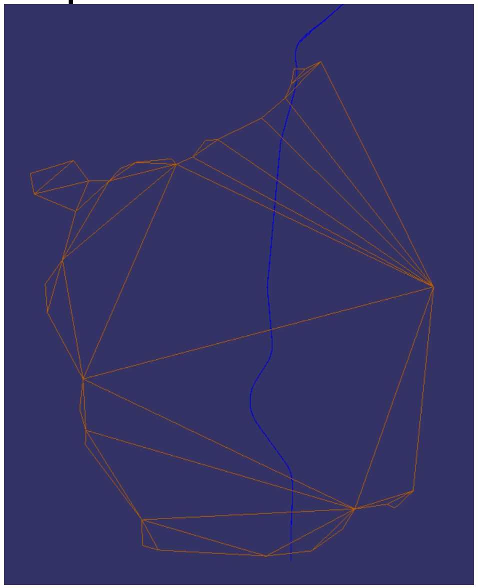
Geospatial data integration

- goal is to visually annotate the point set via geospatial metadata
- common interchange format: Google's KML
- accept 2D polygonal data, created by, for example, Google Maps
- polygonal format: vector list
- our approach: colour the LiDAR points according to stored styles of KML-described areas
- therefore necessary: valid polygon description and established point-polygon relation (which point is in which polygon)
- trivial point-to-point OpenGL polygon setup leads to artefacts -> Triangulation necessary
- for extracting a triangulation that includes original polygon: Constrained Delaunay Triangulation with polygon boundary as constraint

Geospatial data integration

- therefore point-in-triangle check executed for every LiDAR point on every triangle and coloured respectively
- GPU-based implementation even in high-performance graphics adapters relatively slow
- therefore: improvement by storing triangles in a quadtree
- due to spatial subdivision, point-in-triangle check for each point is only performed on adjacent triangles
- this allows interactive blending of geospatial metadata with the LiDAR point cloud





Crisis management support in exercises

- exercise use case in Delfland - Schieveen, a small test polder in a rural environment
- goal: assess how the local water board can give advices to the safety region institution (i.e. the fire departments, police stations, hospitals and the municipality) in case of a dyke breach-caused flood
- combined flood simulation after critical dyke breach, including water height as well as velocities, with wave animation and the coloured LiDAR point set
- assessment done via video of flood simulation and its mitigation, displayed in our system

Crisis management support in exercises

Crisis management support in exercises

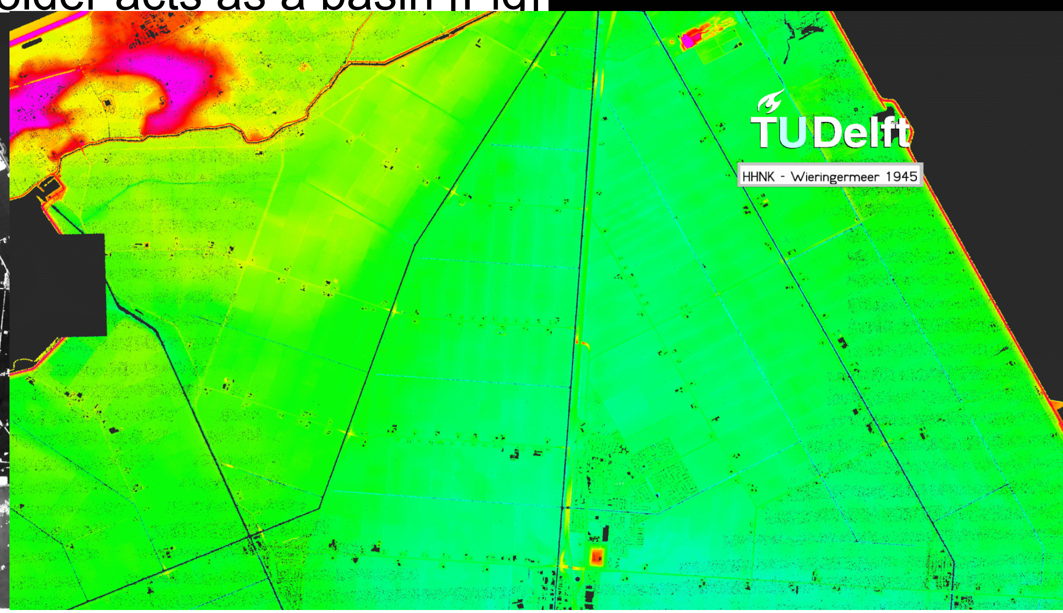
- important information perceived by safety region institution are:
  - evolution / mitigation direction of the flood based on the animation
  - most threatened residential areas, affecting evacuation priority
- implementation of new flood protection policies as a precaution based on this exercise assessment possible

Historic flood in Wieringermeer 1945

- case study assess historic flood in holland's "Noorderkwartier"
- flooded Wieringermeer is 4th largest dutch polder
- was flooded during the 2nd world war by the german army on their retreat to germany; whole polder inundated
- manuscripts of water height measurements in regular timesteps available
- in our case: use the measurements as reference to compare and calibrate modern flood simulations

Historic flood in Wieringermeer 1945

- by visually analysing the result of the calibrated flood simulation, following facts are to note:
  - water distributes quickly along channels, so that adjacent areas are quickly inundated [small video]
  - in the low plain rescuing higher grounds are scarce [Fig]
  - the polder acts as a basin [Fig]

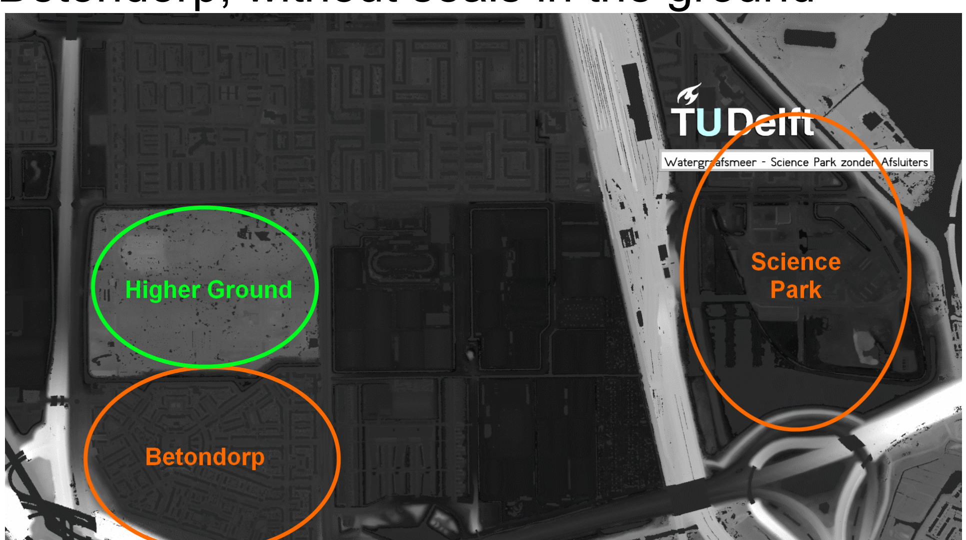


Historic flood in Wieringermeer 1945

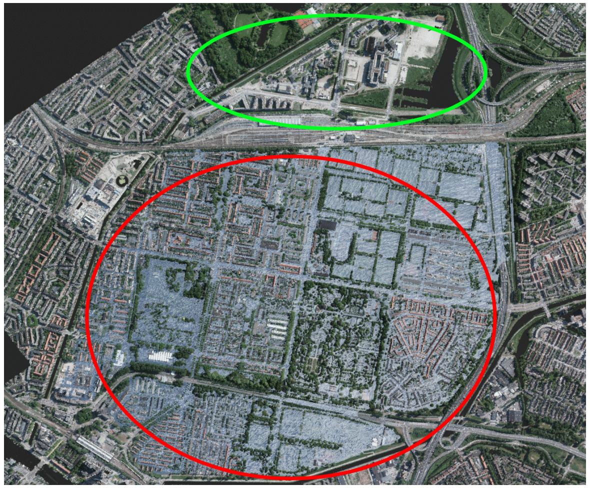
- Conclusions to be drawn:
    - large polders are vulnerable, even for small boundary incidents, and contain a large water volume if inundated
    - therefore creation of medium-sized or small polders($<100km^2$), as in the Schie- and Rhine-area, preferable because they limit flood damage
    - if building large polders is inevitable, artificial hills or higher grounds can act as security zones in case of an accident

Urban flood by precipitation in Watergraafsmeer

- case study series to assess impact of seals on flood mitigation
- flood caused by extreme precipitation
- two locations in that area are assumed to receive the heavy precipitation (Science Park and Betondorp) [Fig]
- outcome of different scenarios is visually compared:
  - flood in Science Park, with seals in the ground
  - flood in Science Park, without seals in the ground
  - flood in Betondorp, with seals in the ground
  - flood in Betondorp, without seals in the ground



Urban flood by precipitation in Watergraafsmeer



Betondorp with seals

Science Park with seals

Betondorp without seals

Science Park without seals

Urban flood by precipitation in Watergraafsmeer

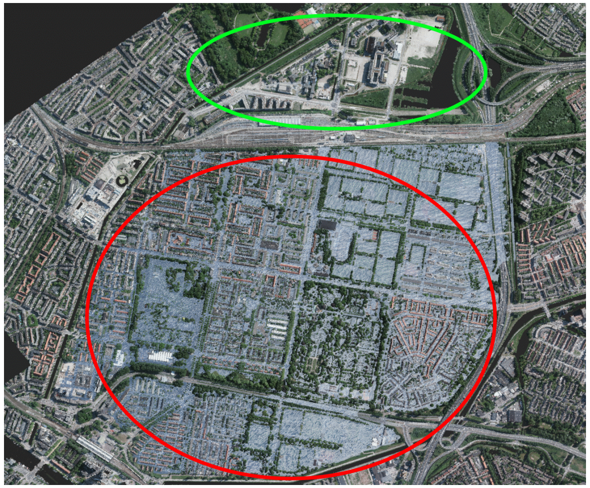
Impact of Seals in Science Park:

- without seals, the flood mitigation along the channels in the adjacent resident blocks; later mitigation occurs along streets
- with seals, the flood is majorly self-contained in the Science Park area; flood only slightly mitigates to one adjacent residence block via underground railway tunnel

Impact of Seals in Betondorp:

- also in this case full water cover of all residential blocks and the Science Park without active seals
- with seals being active, Science Park is kept dry while the residential area gets flooded; flood mitigation pattern stays the same with active seals

Urban flood by precipitation in Watergraafsmeer



Betondorp with seals

Science Park with seals

Betondorp without seals

Science Park without seals

Urban flood by precipitation in Watergraafsmeer

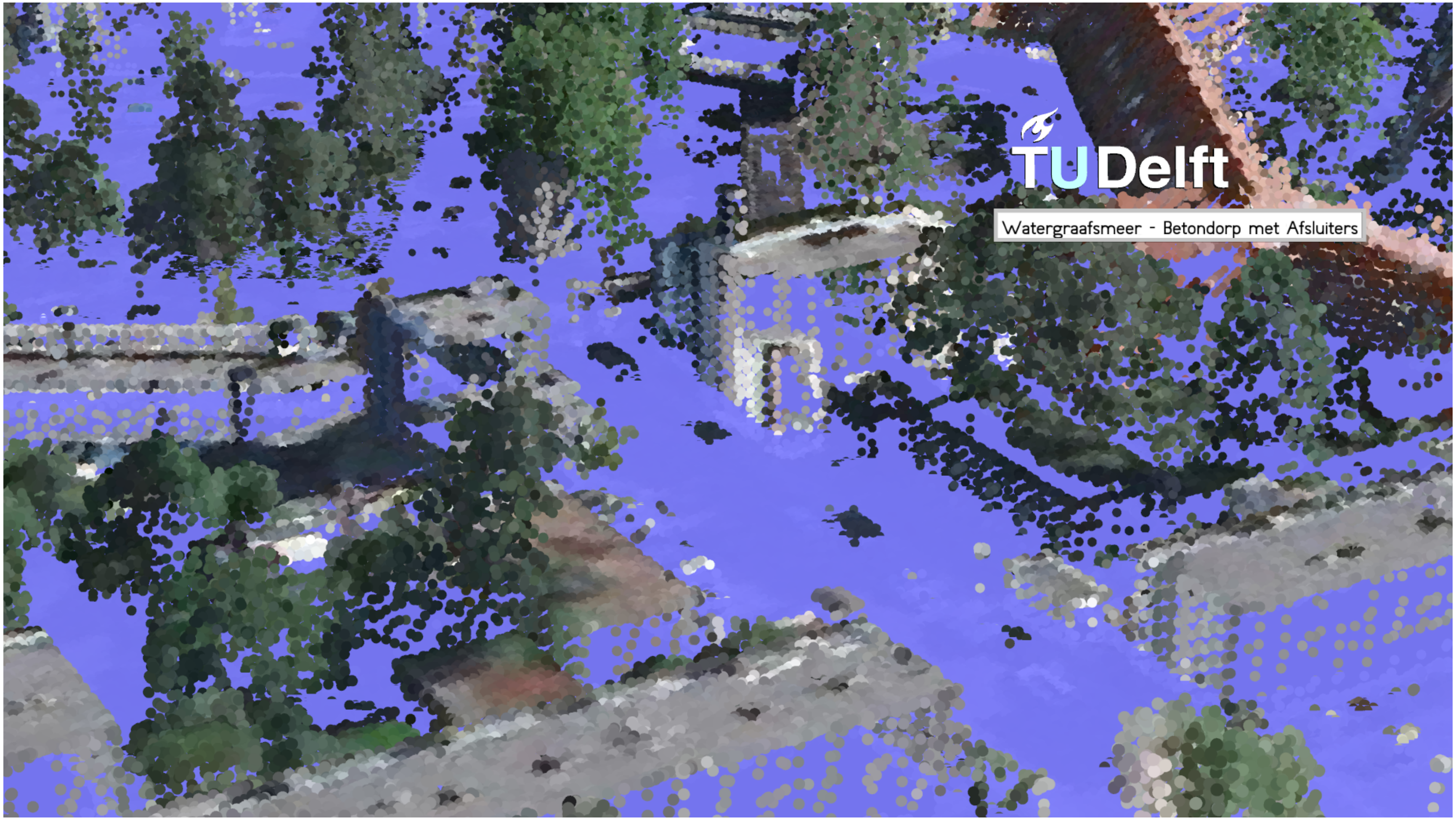
Impact of flood source location:

- park area west of Betondorp is higher ground, which is not affected by flood events from the Science Park
- Betondorp not separated via channels from adjacent residential blocks, therefore extreme precipitation in this area affects larger population

Conclusions:

- fast advancing flood event gives population little time for evacuation, therefore search for higher ground or higher buildings advisable
- 3D view helps in advising minimal ground height for save stay [Fig]
- channel systems transports the water and separates residential units in flood events
- seals are beneficial to contain an urban flood hazard and limit the damage caused in the area

Urban flood by precipitation in Watergraafsmeer



Future Work

- integration of our system into regional standard procedures for flood protection policy
- further use case for Groningen urban area
- visual integration of cloud- and rainfall measurements [Fig]
- using distributed rendering to compose visualisation of very large 3D displays/projectors
- support of larger, higher-resolution flood simulations (e.g. 2m² resolution for municipal level) via quadtree-based data structure
- use of AHN-3 terrestrial LiDAR to improve evacuation prediction because of better urban details

References

[deHaan2009] G. de Haan. Scalable visualization of massive point clouds. *Nederlandse Commissie voor Geodesie KNAW*, 49:59, 2009

[Kehl2010] Christian Kehl and Gerwin de Haan. Interactive simulation and visualisation of realistic flooding scenarios. In *Intelligent Systems for Crisis Management*, 2012.

[Wouda2011] Berend Wouda. Visualization on a budget for massive lidar point clouds. Master's thesis, Delft University of Technology, 2011.

[Busaman2010] Anurak Busaman, Somporn Chuai-Aree, Wattana Kanubua. VirtualFlood3D: Software for Simulation and and Visualization of Water Flooding. In *14th Intern. Annual Symposium on Computational Science and Engineering*, 2010

[Goodchild2008] M.F. Goodchild. The use cases of digital earth. In *International Journal of Digital Eart*h, 2008