Point Cloud Based Visibility Analysis: first experimental results

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Abstract

Visibility computed from a LiDAR point cloud offers several advantages compared to using a gridded digital height-model. With a higher resolution and detailed information, point cloud data can provide precise analysis as well as an opportunity to avoid the process of generating a surface representation or a solid model. Also a better inclusion of vegetation is expected. This paper describes motivations for using point cloud in visibility analysis and also makes a comparison of using two different data to perform visibility analysis.

Keywords: Visibility analysis, point cloud, surface model, 3D model.

1 Introduction

Visual properties of the built environment are generally studied in the area of public safety, traffic, advertising, etc. As people want to see more beautiful sights in their daily lives, it is necessary for authorities or urban researchers to quantify visibility of urban spaces. Based on the visibility of those beautiful landscapes and architectures, we can design a better visual environment for citizens. Therefore, one of the crucial tasks for urban designers and architects is to measure the visibility of urban spaces.

Nowadays many researchers in the field of urban design, landscape planning as well as GIS technology focus on the study of visibility analysis. The majority of them are using traditional data such as a surface elevation grid or a triangulated irregular network (TIN) to compute visual characters. However, there are some limitation of using this kind of data to gain the visual properties, such as the neglect of vegetation. With the development of LiDAR technology, there is an opportunity to use LiDAR point cloud data for visibility analysis. The emergence of point cloud data can compensate for many disadvantages of traditional modelling and analysis methods.

This paper gives a brief review of recent researches on visibility analysis, and compares visibility analysis based on surface elevation raster with point clouds based visibility analysis.

2 Motivations for using point cloud data in visibility analysis

There are benefits for researchers to use point cloud data in visibility analysis.

- Using a point cloud based model for visibility analysis can make it possible to skip the process of generating a surface model. It means that we can directly use point cloud data to perform visibility analysis, which can help in shortening the period of analysis.
- The point cloud data frequently has a much higher density than 1 point/m^2. That allows precise and accurate data usage for both visualization and analysis resulting in better quality visibility analysis.
- Moreover, point cloud data can provide much more detailed information than traditional raster data or a TIN model. Vegetation is usually neglected in traditional analysis using surface models because of the difficulty of representing trees or shrubs. But actually, we can’t neglect the impact of trees in visibility analysis, especially in the summer time when trees would partially block the line-of-sight. Thanks to the comprehensive details provided by point cloud data, it is much easier to represent as well as analysis vegetation by using this kind of data.
- Allowing a quick selection and visualization of specific classification of points. We can use the filter to see those points we are interested.
- It is also expected that point clouds can be organised very well in different LoDs (Level of details).

3 Related research

Many researchers have proposed different methods for exploring visual characters of urban spaces or natural environments for different purposes. Researchers in the area of GIS and LiDAR technology have done a lot of work for visibility analysis basing on point cloud data.

Guth (2009) calculated intervisibility of LiDAR instruments in forest for military purpose. He compared the efficiency and accuracy of grid data (DSM & DTM) with considering both situations with and without leaves. Basing on the results, he believes that using the LiDAR point cloud can greatly improve both the visualization and quantitative computations of the vegetation blockage. But he only concentrated on the natural environment rather than the built environment.

Murgoitio etc. (2013) consider tree trunks as the primary visual obstacle. After converting point cloud data to raster, they computed viewshed of a specific viewpoint in a forest by using ArcGIS 10.0. In their research, they only took trunks into account because of the missing information of leaves.

Besides, several urban designers and planners as well as landscape researches have made efforts to bridge the gap between GIS technology and urban studies.

Llobera (2003) introduced the concept of visualscape as a tentative unifying concept to describe all possible ways in which the structure of visual space may be defined, broken down and represented within GIS independently of the context in which it is applied.

Turner, e.a. (2001) show how a set of isovists can be used to generate a graph of mutual visibility between locations. The measurement of local and global characteristics of the graph, for each vertex or for the system as a whole, is of interest from an architectural perspective: to describe a configuration with reference to accessibility and visibility, to compare from location to location within a system, and to compare systems with different geometries.

Bilsen and Stolk (2007) have established an open framework for Isovist-Based Visibility Analysis (IBAV) for urban design and planning. They performed the visibility analysis on several study cases, ranging from modern to traditional, rural to urban, and private to public to address and exemplify IBVA and the framework. They have gained rich results and also proposed a relatively complete framework for analysing visibility on urban streets. But unfortunately, they didn't take vegetation into account.

Similarly, Weitkamp (2010) has proposed a five-step method for landscape visual openness by using Isovist Analyst, an ArcView extension proposed by Rana (2006). And Weitkamp also performed the method on study cases for verification.

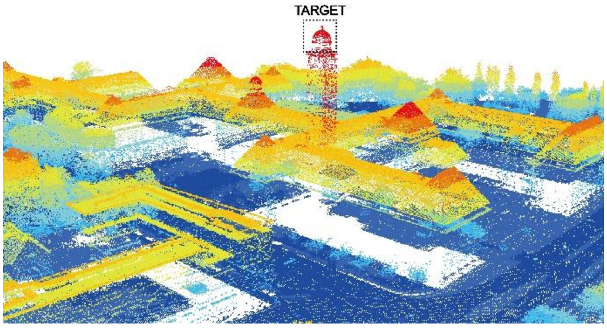
Further, Peters etc. (2015) use medial axis transform (MAT) for visibility analysis in a built environment including trees and buildings. The medial balls are interior, i.e. inside buildings. The computation of a point's normal is the most important part of this research, and in their paper, they also admitted that it is hard to define the normal of vegetation points.

Building on recent studies, we find that vegetation remains a problem for visibility analysis.

4 Current case study

In this paper, a small area in Delft, the Netherlands is considered as a study case to perform visibility analysis for both the surface representation and the point cloud model. We only compare results based on different types of input data to see the performance of point cloud data by similar visibility analysis in mainstream GIS commercial software. In the domain of architecture, landscape and urbanism, ArcGIS is the most popular software for using GIS technology. For this reason, we choose ArcGIS 10.3 as the analysis platform for our analysis.

Figure 1: Study area in Delft, the Netherlands and the target tower for visibility analysis (pointclouds.nl)



The tower of the Faculty of Architecture and the built environment in TU Delft was selected as a landmark, and we chose the top of the tower as view target for visibility analysis, see Figure 1.

4.1 Data preparation

4.1.1 Digital Surface Model

Results generated from a 3D model would be considered as an analysis demo to point cloud. After downloading vector models from 3D kaart Nederland, we converted a small area surrounding the building of the Faculty of Architecture and the built environment for viewshed analysis. This raster, i.e. the Digital Surface Model (DSM) of study area, includes only the heights of buildings and the elevation of ground. This DSM has a cell size of 1x1(m) and an area of 1.1 km^2. And the whole size of the raster is 1028x1079.

4.1.2 Point cloud Model

Streets were meshed into grids with a size of 5mx5m and a height derived from ground surface. All the viewpoints, i.e. observer points, are extracted from the centroid point of each street grid with an offset of 1.6m.

Due to the limitation of memory, we have to reduce the size of point cloud by narrowing the computation area and reducing the density of point cloud. Areas involved in visibility analysis are shown in Figure 3, and the density of point cloud is reduced to about 10 point/m^2. The amount of points is 1,068,338 in total.

Because points have no extend, we have made some conversion for points to make it possible to block the sight lines. In this paper, we use cubes to represent sight obstructions. We considered each point as the centroid point of each blocking cube, as seen in Figure 4.

According to the density of points mentioned above (10 points occupy 1 m2), a point covers 0.1 m2. As a result, we consider a cube with an edge length of 0.35m for each point. Since trees, high shrubs and buildings are the only things can block our view, we extracted these elements for generating the blocking cube with 6 polygons of each point.

Figure 2: Point cloud model of analysis area:
Top – LOD1 solid model;
Bottom – point cloud model

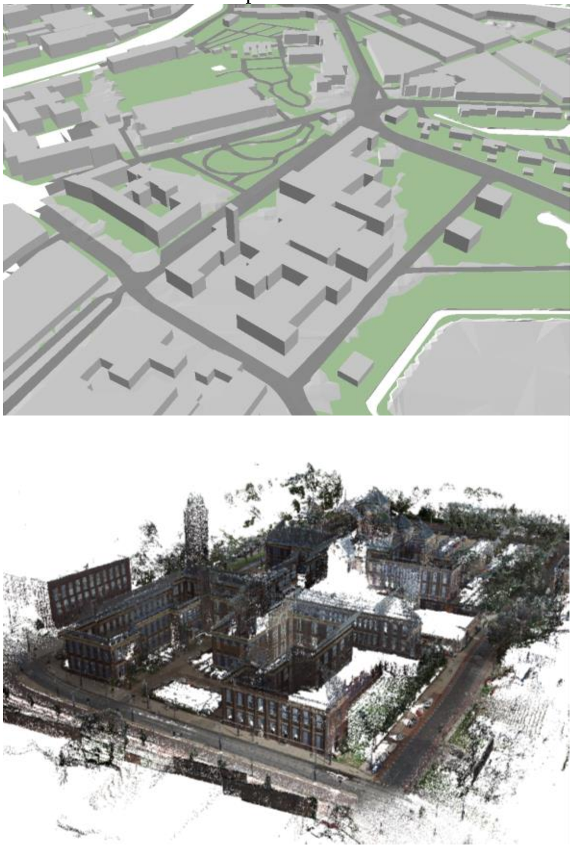


Figure 3: the analysis area for point cloud

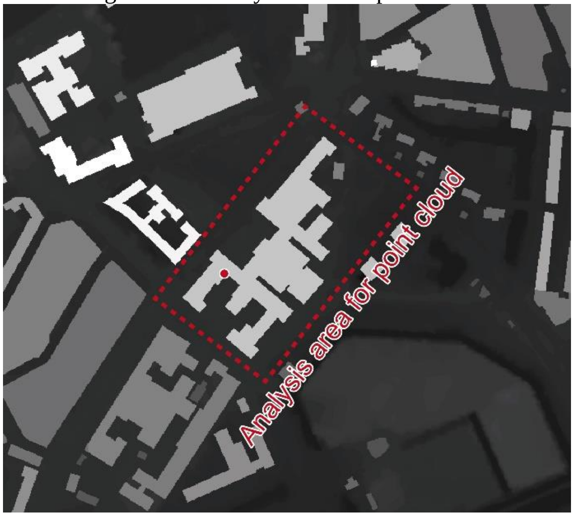


Figure 4: Generating cubes of each point to block the sight lines.

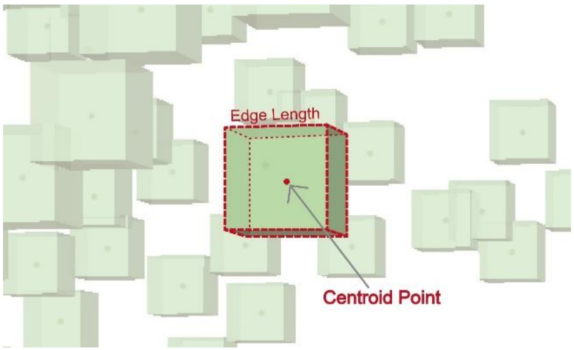
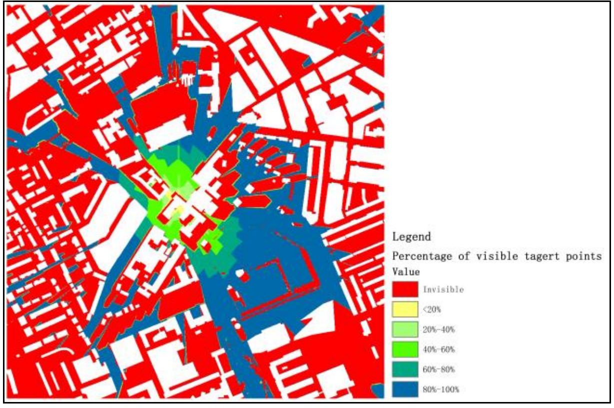


Figure 5: Visibility graph from raster DSM



4.2 Visibility analysis

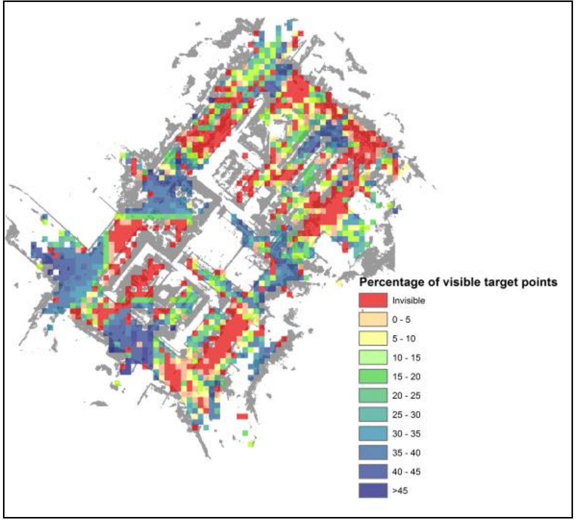
4.2.1 Analysis demo

Based on the DSM of study area, we use the function viewshed analysis to obtain the analysis demo of this research. Figure 5 is the visibility graph from the surface model. Red areas represent places where we can‘t see the tower at all, i.e. the tower is invisible from these area. The output will only record the number of times that each cell location in the input surface raster can be seen by the input observation points. We divide the number of seeing times by the number of total target points to illustrate the possibility of seeing the tower. We could find that 80%-100% of the dome of the tower can be seen from the blue area.

4.2.2 Intervisibility from point cloud

In this section, we use functions embedded in ArcGIS to compute the inter-visibility between observer points and target tower points by directly using point cloud without constructing a surface model for every building and vegetation.

Figure 6: Visibility graph from point cloud based visibility analysis



After several processes for generating cubes for points, we gained the intervisibility between target points and viewpoints based on cubes (Figure 6). In next section, we will compare the visibility graphs of gridded model and point cloud.

4.3 Results

Basing on the results, we make a comparison of two data in visibility analysis using ArcGIS.

4.3.1 Efficiency

Table 2 compares the computation environment and execution time for the gridded model and the point cloud. For the surface model, it only took few seconds to obtain visibility graph in the study of this paper. In the chosen Analysis Platform, ArcGIS 10.3, a point cloud based visibility analysis will take much longer than a surface model based viewshed analysis because 3D polygons for visibility analysis could spend more memory than a surface based model.

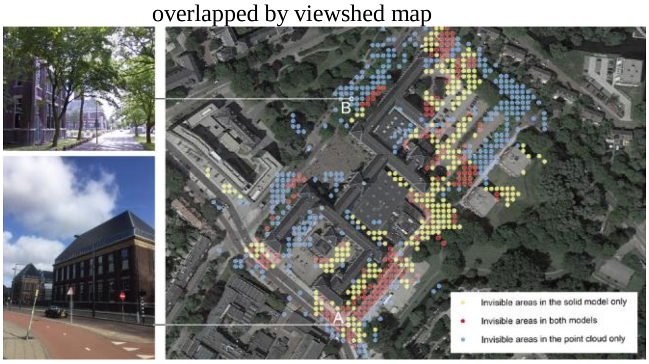
4.3.2 Accuracy

We add the visibility information (percentage of visible targets) from viewshed map to 1412 viewpoints involved in pointcloud based visibility analysis. Therefore two visibility results from different input data can be compared in the same environment to see if it is possible to use directly point cloud for visibility analysis.

From the results comparison Table 3 and two visibility graphs we can see that:

- The structures of two visibility graphs are quite similar and the number of visible points is quite close in two models. It means that the result of point cloud based analysis can be considered as a reliable result.
- The number of overlapping invisible points is 198 which is less than either the number of invisible points in gridded models or the number in point clouds. For testing the results, we also have taken photos. From two visibility graphs we can see that some invisible areas in gridded models are defined as visible in point clouds. For example, point A in Figure 7 is invisible in the gridded model whereas visible in point clouds. This is because vehicle point clouds would miss surfaces of pitched roofs which could block sight lines (see Figure 2). Besides, targets are invisible in some areas in point clouds where the targets are visible in the gridded model. These areas are actually blocked by trees. As mentioned in motivations, vegetation is absent in gridded models, but can be well presented in point clouds. As a result, areas covered by trees are invisible in point clouds. For instance, from point B we can't see the top of the tower in reality (see Figure 7), but B is visible in the gridded model.

Figure 7: Ground truth testing, the Google map to the right is overlapped by viewshed map



- The maximum percentage of visible target points in viewshed is 100%, this means that we can see the whole shape of the dome in gridded model. But actually, we can only see half of the dome. The result from point clouds is far closer to the reality. This error of viewshed comes from the shortage of LOD1 models which doesn't contain the real shape of buildings. Consequently, missing details and low resolution of models lead to inaccurate results. Conversely, thanks to the detailed information, we can extract hundreds of points easily from point clouds to present the real shape of the dome of the tower. And an approximate real shape of dome would help in acquiring result of high quality.

Through the comparison, we find that gridded models can provide a relatively reliable result that shows visible areas and invisible areas, but fail to reveal how much we can see from a visible viewpoint. On the contrary, vehicle-borne point clouds fail to provide accurate visible areas due to the missing sloping roofs. However, point clouds can provide not only a precise shape of the dome in our case, but also the abundant information of vegetation. This can enable us to obtain detailed levels of visibility.

Table 1: Data information

Data Type	Data Source	Original Data	Containing Subjects	Data resolution/ points density
Raster	3D kaart Nederland	Vector models in the format of multipatch	Terrain, water, buildings in LOD1	1x1m
Point-cloud	AHN3	.laz	Ground, vegetation, buildings, water, other constructions like lights and cars	10+ points/m^2

Table 2: Comparison of two types of data in visibility analysis

Input Data	Number of target points	Number of viewpoints	Number of grids	Number of polygons	Execution time
Raster	37	Every grid of the raster	1028x1079	/	27.02s
Point cloud	110	1412	/	2,533,008 (There are 422,168 cubes in total, each has 6 polygons)	459s

Table 3: Comparison of the results from two kinds of different data

Input Data	Number of invisible viewpoints	Number of overlapping invisible viewpoints	Number of visible viewpoints	Max percentage of visible targets	Mean percentage of visible targets
Raster	472	198	940	100%	60.51%
Point cloud	434		978	49.09%	23.42%

5 Conclusion and future research

In this paper, we only used traditional visibility algorithm to deal with the computation of point cloud. Basing on the comparison, we found that it is possible to perform a point cloud based visibility analysis to obtain detailed visual properties. Although a point cloud based visibility analysis could result in better quality, it also requires a significantly larger data set to compute analysis. However, using the LiDAR point cloud can greatly improve both the visualization and quantitative computations of the vegetation blockage, which is always neglected in traditional models.

Besides, improved analysis will require better classification of LiDAR datasets, especially to pick out constructions and vegetation, the most obstacles to sight lines. But in our case, there are some drawbacks with the original point cloud, such as some missing areas outside the building. Since the results depend on the obstacles, we truly believe that consistent input data with a proper density will make it more valuable to improve analysis.

In future research, we plan to propose a visibility analysis method suitable for point cloud data by reducing elements, or to say polygons, involved in the computation. The idea of Level of Details (LoD) can help in reducing the redundancy of data. Also, it is beneficial to use GPU for parallel computation. And a mixed model combined with polygon-based buildings and point-based vegetation could be used in visibility analysis.

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