High Precision Visibility and Dominance Analysis of Tall Building in Cityscape

On a basis of Digital Surface Model

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The article presents a methodology applied for the assessment of the tall building visual impact on the city scape, using digital tools. The method has been used by the author in the planning practice in several cities in Poland. It enables to determine not only the visibility range of a planned tall building in the city spaces, but also the extent to which it dominates. Findings are presented in a map which reflects both parameters applicable to a given facility. Computation of findings is based on the model of a city consisting of a regular cloud of points (Digital Surface Model) of high quality and dedicated C++ software (developed in cooperation with author). The Visual Impact Size (VIS) method supports the process of conservation and landscaping, in particular in historical cities. It helps predicting spatial implications tall buildings may have. It may also be used for comprehensive development of a modern skyline with tall buildings as a harmonious component of the cityscape. The method is presented using the case study of the Hanza Tower building in Szczecin (Poland).

Keywords: *digital cityscape analysis, tall buildings, visual impact, Visual Impact Size method, viewshed, Hanza Tower in Szczecin*

INTRODUCTION AND RESEARCH GOAL

The cityscape has been undergoing steady and recently increasingly rapid changes. The monitoring of the process, in particular forecasting visual consequences of new investment, has become a major challenge (Felleman 1979; Felleman 1986; Maver and Petric 1996; Danese et al. 2009). Analytical techniques are needed to enable efficient precise and speedy determination of spatial consequences of new buildings planned in specific locations. Especially tall buildings necessitate an in-depth cityscape analysis. Numerous examples of distorting historical urban development highlight the need for relevant studies and tools (Czyńska 2017; Czyńska and Rubinowicz 2017).

This article presents the study of the impact 'Hanza Tower', a new tall building, has on the centre of Szczecin, Poland. The building will be the highest object in the city with its architectural height above 125 m [1]. The study is based on the Visual Impact Size (VIS) methods which enables to determine the visibility range of a planned tall building in the city space and the degree of its domination. Findings of the analysis clearly indicate locations in the city from which the new facility can be seen. This enables to foresee whether the building is going to interact accidentally and undesirably with existing buildings. The computation of results is based on the Digital Surface Model of high resolution. It is currently, especially in Poland, the most up to date and close to reality representation of the 3D city structure. The study also used a dedicated C++ software developed, inter alia, by the author. The software enables to process data to the best quality currently possible (0.5m grid size) and obtain very precise VIS results.

METHODS AND MATERIALS

3D city model

The study presented in the article is based on Digital Surface Model (DSM) and Digital Terrain Model (DTM), which are derived from LIDAR data. Although data lack their internal semantics and structure that can facilitate their use, a simplified picture of a city provides a number of advantages. The cloud of points, which comprises digital models, contains all landscape components, such as buildings, tall green, technical infrastructure, bridges and flyovers, all reflected with the same precision (Biljecki et al. 2015). Equally important is the low cost of generating such data, their validity and accessibility. In the case of using the DSM model for studying the cityscape, the mesh size is also important since it determines the precision of the digital city picture and the quality of VIS analyses. In Poland, all major cities have high precision models developed, which is the highest of all EU member states (Rubinowicz 2017). An average height error is 10 cm. DSM model, used for the purpose of the study, has mesh density of 0.5m. This enables creating a precise picture of the city space. It was also very important to include tall green, which significantly reduces the visual impact of tall buildings (figure 1). A specialist C++ software is used to generate the VIS simulation (Rubinowicz 2017). It has been optimized for enhancing the efficiency of processing data representing a digital picture of the city space.

VIS method

The VIS method enables measuring the total visibility of a building depending on its height (Czyńska 2015). It helps to answer the question: from which location can the building be seen, and also: how well is it visible? The basics of the method stem from so called "reversed viewshed", that is an area from which a target point is visible (Caha 2017). The method is related to the 'extended viewshed', a method which calculates additional visibility depending on the distance between the observer and the height of the target point, i.e. angle values (Fisher 1996). The VIS method presented calculates a maximum height for each point in the city, above which a given facility can be seen. The analysis covers a specific section of the city with the mesh size of, usually, 0.5m). Each facility is represented by a single point (set in its centre) or a collection of control points (which enables to reflect facility in more comprehensive manner). Although the result has a continuous nature, i.e. the calculation leads to precise limit height values, the interpretation of findings is better once we limit the number of thresholds (depending on height of individual building). Usually, it is 8 to 10 different heights every 20 m. It depends, however, on the specific nature of the facility in question and the required precision of calculation. This produces an aggregated representation of the visual impact of a building that can be seen from specific thresholds. Results can be displayed in various ways - projections, axonometric views and perspectives. In practical terms, a map with colours marking the exposure of a given building in the city is the best for the interpretation of the results.

SIMULATION PROCESS

The VIS method is going to be presented based on the case study of a tall building in the centre of Szczecin, Poland. The construction of the 'Hanza Tower' Building is in progress. The building has an unusual shape - elongated twisted rectangular cuboid with slanted top surfaces on both sides (figure 2a).

Figure 1
Visualisation of DSM model, including tall green which is an important type of development that has its impact on visibility of buildings

The silhouette of the tall building is supposed to be twice as wide when seen from north and south than from east and west. This has several visual consequences that cannot be determined when testing a single point situated in the middle of the building envelope. Once we know the geometry of the building we are able to adjust parameters of the analysis and produce precise results reflecting the actual impact of the tall building on the cityscape. Considering its unusual shape, a set of control points was used (A1÷A5), and the VIS analysis was performed for those points (figure 2b).

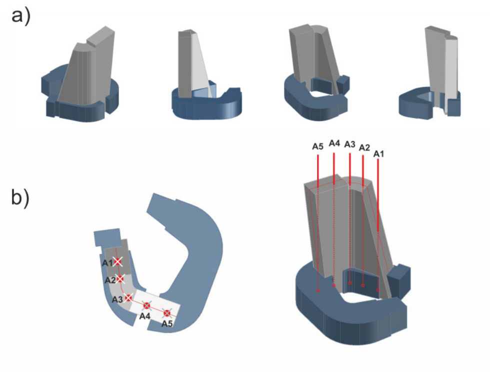


Figure 2
Presentation of Hanza Tower shape (Szczecin, Poland) (a) and VIS analysis control points (b)

The possibility of including tall green is very important for the VIS analysis, since it has a significant impact on the visibility (Czyńska 2017). In DSM models, trees are reflected with high precision, both in terms of their height and the volume of the crown (figure 1). This cannot be done in full and with precision in CAD or CityGML vector-based models (Kolbe 2009; Biljecki et al. 2015). The VIS analysis for Hanza Tower included two visual impact options of the tall building: with and without tall green. Both options enable better insight into the impact of the building during and after the peak vegetation (figure 3).

VIS simulations for Hanza Tower also covered both options due to the number of control points (figure 2b). Each point has a slightly different impact range. Therefore, the study developed a) individual simulation for 5 control points within 36km2; b) collective simulation for all control points within 36km2; c) including and excluding tall green for all 5 control points collectively. Computation results are presented in figures below (figure 3, 4).

RESULTS

Observations presented in the article are general and do not intend to contribute to a detailed assessment of the Hanza Tower impact on the Szczecin's cityscape. The goal is to present the methodology

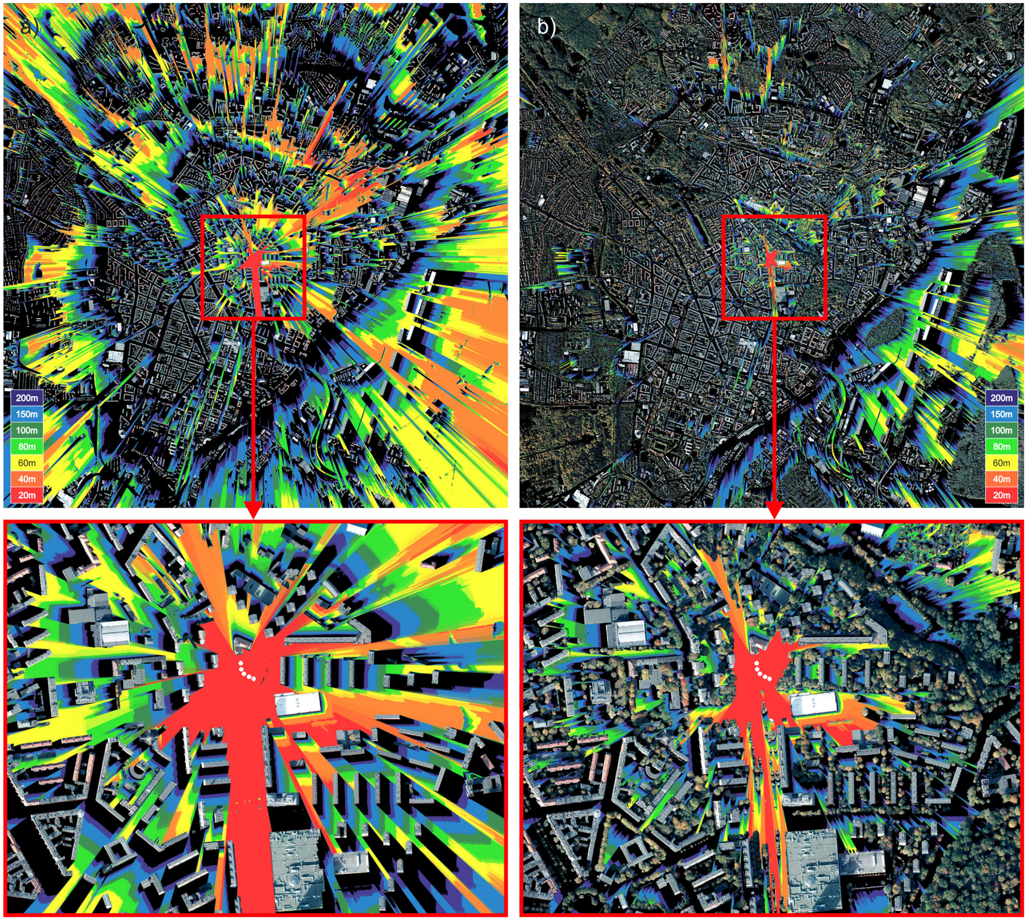
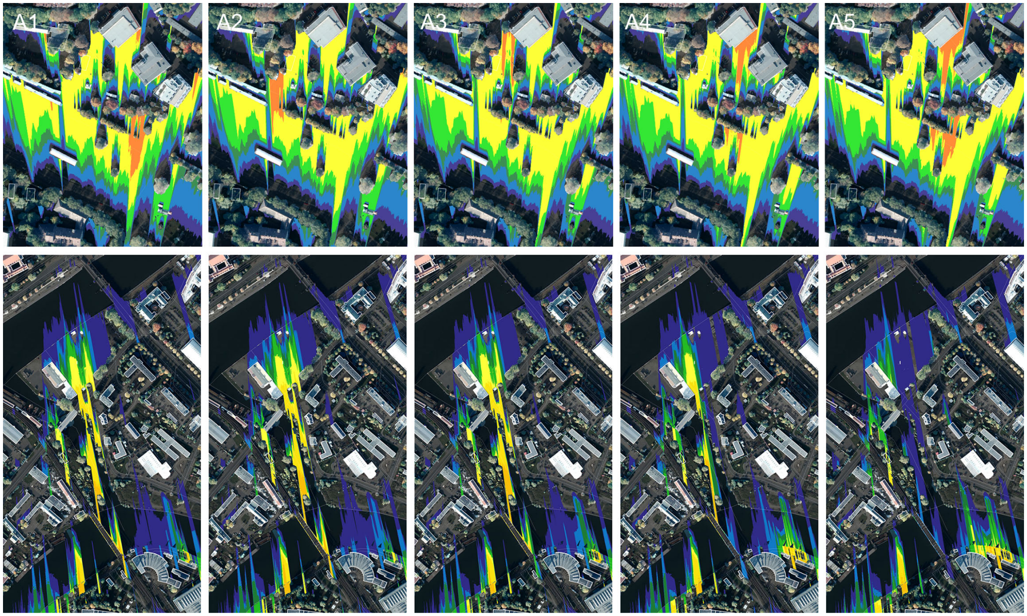


Figure 3
VIS analysis for Hanza Tower collectively for all control points in various options: a) excluding tall green; b) including tall green

of urban analysis that can be used in planning practice. VIS analysis findings show high complexity of the visual impact area of the building, an area which, de facto, can be the measure of the city space complexity. A similar phenomenon has already been observed while examining other tall buildings, including Sky Tower in Wrocław (Czyńska and Rubinowicz 2017). The Hanza Tower impact area extends all over the 6x6 km area examined and shows a very dispersed structure (in particular while taking into consideration tall green). In general the propagation of the visual impact area for Hanza Tower is the direct result of natural and anthropogenic cityscape factors.

In the south, within a group of buildings in the city centre, the new building can be seen along main street axes determined by facades. It is the terminating vista of several such axes (figure 5). In the north, the visual impact is more dispersed (figure 3b). It re-

Figure 4
Different visual impact of control points



sults from a lower density and compactness of buildings and a larger share of tall green. In the east, from the side of the Oder River, the visual impact area is larger. Along the river bank, the new building can be seen from boulevards, bridges and undeveloped areas (figure 3b). Those are the areas of the most attractive due to landscape values in the city. In this location, a group of buildings on top of the Wały Chrobrego embankment is the major landmark. The new tall building can also be seen in the background of the Castle Route, the main in and outbound road leading to the city centre (figure 5).

The VIS analysis for 5 control points highlight an important factor influencing Hanza Tower visual impact on the cityscape. The observed width of the building will vary depending on the direction. From the south, the building will appear much wider than from the east, since control points are in line providing a similar result of the VIS analysis. It is very important for the overall image of the city. Usually, wide bodies of tall buildings are excessively overwhelming in relation to historical landmarks in the city, since the latter are usually slender and symmetrical. Therefore, in wide panoramas from the side of the river (east), Hanza Tower will better resonate with historical buildings.

Results of the VIS analysis have major accuracy and precision (figure 4). It was possible due to the following: a) precise and updated DSM model (mesh size 0.5 m); b) dedicated software generating precision of up to 15 cm; c) covering more than one control point representing the building; d) optional integration of tall trees which may to a large extent influence the visibility of a tall building in a city.

At a very early stage of Hanza Tower planning, over 10 years ago, the author of the article together with her team analysed its impact on the cityscape (Czyńska et al. 2007). Findings of the visual study were presented to the City and included in the Masterplan. The actual building will be in line with guide-

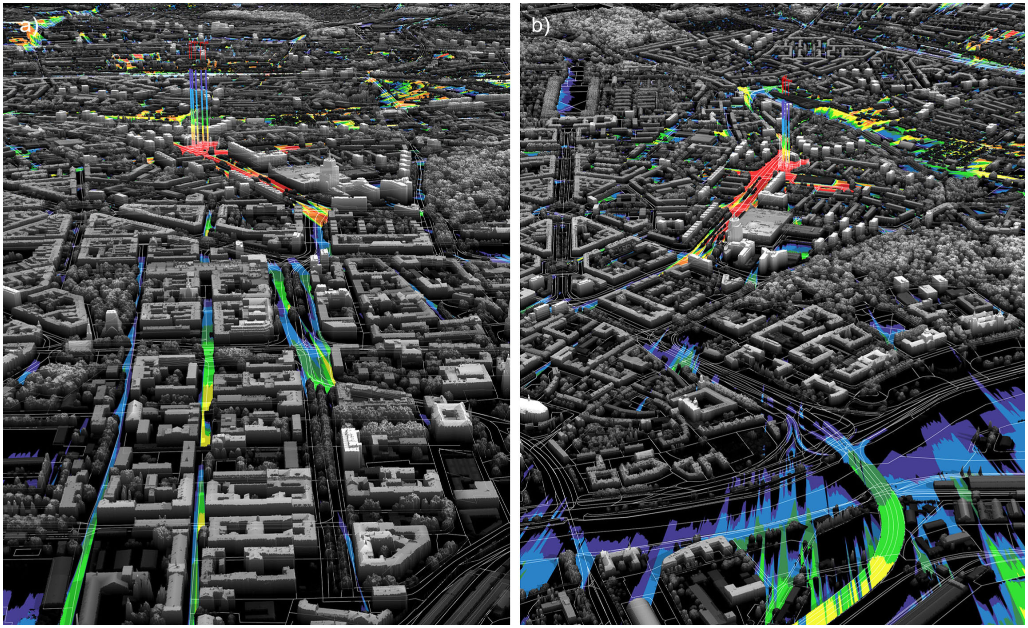


Figure 5
Impact of Hanza Tower: a) along street axes; b) along river bank, e.g. Castle Route

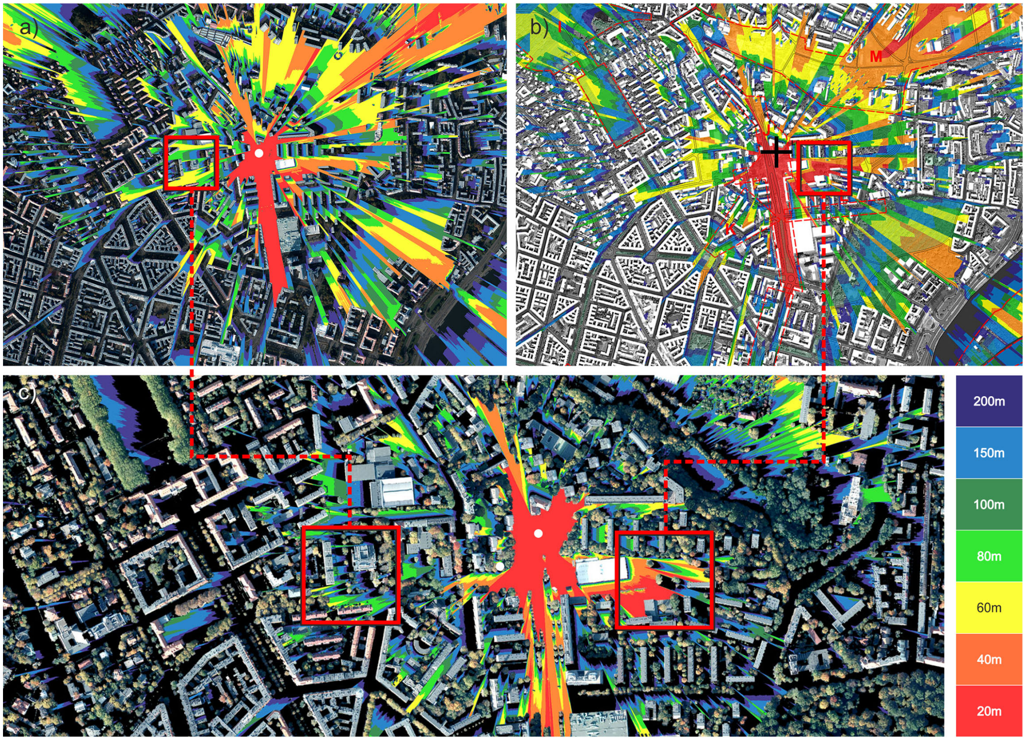
lines presented to a large extent, e.g. maximum height of the building. The study presented was designed to verify and compare findings of the 2007 analysis based on the vector CAD model. The contemporary calculation capability enables to obtain more precise results of the VIS. Comparison of VIS analysis findings of 2007 and 2018 is presented in a figure below (figure 6).

On a wider scale the comparative analysis of VIS findings shows a number of similarities, especially in large undeveloped areas. Major differences can be observed, however, at the level of individual squares and streets where the visual impact was significant. This is partially the result of spatial changes which have taken place in the past decade. The higher precision of the model applied (DSM) is also very important, since it reflects the actual situation in the city. The model applied in 2007 was a mere approximation of the actual city space. It included simplified models and failed to examine tall green. The calculation of the real impact of a building on the city space should include the influence of trees. The difference in impact has been presented in the figure below (figure 6c).

DISCUSSION

The literature provides examples of a similar reversed viewshed application for calculating the visual impact of tall building. Worth mentioning are Rød and van der Meer (2009) who analysed a tall building in Trondheim. While examining its impact area they determined also the degree of domination in a specific city space, i.e. whether the building is going to be seen in its large part or a small part only. The VIS method presented in this article enables to obtain a similar result without any need for additional calculations that can be done by a limited number of applications (GIS type). Caha (2017) presented research which enhanced precision of viewshed results by a

Figure 6
VIS simulation for Hanza Tower: a) in 2018 based on DSM model; b) in 2007 based CAD model; c) differences including tall green



better shape projection of a given facility. In the case of elongated architectural forms (e.g. Hanza Tower), a number of control points have been used, for which a cumulative viewshed has been calculated. A similar solution was used by the author in her research and planning practice to examine the landscape impact of the seminary library in Warsaw (2015).

As Fisher rightly noticed in 1991, viewshed results depend very much on the quality of input data. In the case of cityscape studies, input data, or 3D models, are crucial for a desired precision of the result. Too little precision of the DSM model (mesh in excess of 0.5 m) influences the quality of the result (Bishop 2003). A simplified structure or geometry of CAD and CityGML models also reduces the accuracy of the result. In the case of tall buildings, the area scope of the analysis is particularly important and it should be as wide as possible. Tall buildings have a wide visual impact area, extending much beyond its immediate surrounding, and sometimes also administrative boundaries of a city (e.g. Sky Tower in Wrocław, Poland). A large analysis area in combination with high resolution of the DSM model can be a challenge for a computer. Therefore, it is necessary to optimise the algorithm applied for VIS calculations. Software applied in the study enables the emulation of the visibility field for an individual control point within 1.0 km2 and a mesh size of 0.5 m during approx. 48 s (4 core processor and 32GB RAM).

CONCLUSIONS

The analyses of Hanza Tower in Szczecin using the VIS method based on the DSM model and mesh size of 0.5 m enable to obtain precise results for the visual impact area. A comparative study furnished with a similar calculation of 2007 and based on CAD model show several major differences. The differences result from the following: a) spatial transformation of the city in the past 10 years; b) no possibility to include the impact of trees if included in the CAD model of 2007; c) higher projection precision than in the DSM model as regards height, since in CAD height was estimated only. The use of DSM significantly improved the accuracy of VIS results. The mesh size of 0.5 m enables to reach significant accuracy in reflecting the 3D city space as a basis for further calculation. Despite some vertical deviations regarding external walls of a building and slightly simplified roof geometry due to the interpolation of LiDAR measurement points, the data are sufficient to reach precise and reliable results of the analysis. Moreover, the use of a number of control points, covered by the study, better reflects the actual visual impact of the building of an unusual shape.

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