Representing Buildings for Visibility Analyses in Urban Spaces

Jan Caha

Abstract The availability of detailed and precise digital surface models based on LiDaR data allows accurate calculation of visibility analysis even in urban areas. Lately, the viewshed analysis, which is implemented in geographical information systems, is often used to determine the visibility of buildings or other structures in both natural and urban environments. Such utilization of viewshed tool, which is originally designed to assess visibility from point to its neighbourhood, however, brings issues regarding partial visibility of the target that are usually neglected. The core of the problem here is that the target building is often represented as a single point in the viewshed analysis. This simplification can lead to an incorrect assessment of the visibility as the specific point of the building can be invisible for the observer while other parts of the building are visible. To properly analyse visibility of a building it is necessary to consider partial visibility of the target. To allow the assessment of partial visibility more than one point that represents the building needs to be defined. In this contribution, the theoretical aspects of reverse viewshed, an area from which a target point is visible, are considered with a focus on the proper representation of target building in the reverse visibility analysis. A practical study of building visibility is conducted with the building represented as single and multiple points. The results are compared and the differences are explored.

Keywords Viewshed · Reverse viewshed · Visibility · Digital surface model

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Introduction

Visibility analysis is a theme of interest for landscape and urban planning since the late 70s of the 20th century (Felleman 1979). Since the early 90s, the analysis became a topic for geographical information science (Fisher 1993). The earliest studies were calculated on digital terrain models (DTM) with relatively small precision and large spatial resolution which had significant impacts on the precision of obtained viewsheds (Maloy and Dean 2001). However, availability of more accurate datasets with better spatial resolution has improved drastically with the introduction of LiDaR (Light Detection and Ranging) based surface models. Visibility analysis calculated on surface models constructed from LiDaR data have been proven to provide better and more realistic estimates of visibility (Klouček et al. 2015) than surface models based on other sources. The main reason why LiDaR datasets provide better results of visibility analyses is the fact that these models naturally contain terrain as well as features above terrain that affect visibility such are buildings and vegetation. The models that include other features besides terrain are labeled as digital surface models (DSM). Even though it is possible to construct DSM by adding features to DTM, it is better to use DSM that were directly sensed as these are more accurate than DSM that were built from DSM and additional data (Klouček et al. 2015). Precise DSM allowed more specific applications of visibility analysis—i.e. visibility of wind turbines (Klouček et al. 2015) or buildings (Rød and van der Meer 2009; Garnero and Fabrizio 2015).

Visibility of man-made structures within urban space, be it a city or cultural landscape, requires precise DSM with raster resolution at most 2 × 2 m (Hlavatá and Oťaheľ 2010) but finer resolution—e.g. 0.5 × 0.5 m—are used as well (Rød and van der Meer 2009; Garnero and Fabrizio 2015). With these spatial resolutions of the DSM, it is possible to appropriately capture details of buildings (mainly roof shapes) as well as vegetation (separate trees in parks, etc.). However, there is one aspect arising from the implementation of viewshed analysis in GIS that is neglected and can negatively affect the result of the visibility analysis. The viewshed is implemented as a tool which determines which parts of the surface are visible from a single location. The application can be reversed; the viewshed tool can be used to determine from which area of the surface a target point can be seen. Fisher (1996) referred to this variant as reverse (inverse) viewshed to highlight the difference amongst two types of analysis. The issue that we would like to discuss in this paper is related to the representation of the target in reverse viewshed. The target building (or another structure) is often represented as a single point (see for example Rød and van der Meer (2009) or Garnero and Fabrizio (2015)). Even though that a footprint of a building can be spatially significant and a single point does not have to be a suitable representation of the target structure. Unfortunately, with detailed DSM this simplification of the target to a single point can cause omission of places from which the target is at least partially visible. For practical applications, such are urban planning or archaeology even the partial visibility of the target is important as it has consequences for the observer. The problem here is that this type of error is systemic so it will affect every visibility analysis to a specific degree and that the problem is not discussed in the literature. Since a significant number of visibility analyses is done by users that do not have formal GIS education—e.g. archaeologists, urban planners, architects or environmentalists, it is quite likely they are unaware of this issue at all. So it is important to discuss the topic and raise the awareness amongst users. The described issue affects binary (classic) viewshed as well as extended viewsheds (visibility indices) (Fisher 1996; Caha and Rášová 2015).

In this paper, we would like to discuss how simplification of target building to a single point can affect the outcomes of reverse viewshed analysis and compare the results with reverse viewshed calculated for target represented by several points. Firstly, some theoretical background regarding the visibility determination will be given, and then a case study of building visibility will be presented. The case study will focus on assessment of building visibility in urban space. The last section of the paper will provide conclusion and recommendations for visibility analyses of buildings.

Reversed Viewshed Analysis

As mentioned previously, it is necessary to differentiate between viewshed, an area visible from a point, and reverse viewshed, an area from which a point is visible, to properly describe visibility analysis that should be performed. In studies where visibility of a building is assessed the reverse viewshed is always calculated, as the question in these studies is: "From which locations the target point can be seen?" Unfortunately, since both viewshed and reverse viewshed are determined using the same tool (viewshed—ArcGIS, r.viewshed—GRASS GIS) with different settings (interchanged values of observer's and target's offset) the authors commonly make no distinction between these types of visibility analysis. Examples of such studies are Rød and van der Meer (2009), Hlavatá and Oťaheľ (2010) and Garnero and Fabrizio (2015). This lack of distinction is unfortunate as the interchangeability only applies for binary viewshed. If extended viewshed (visibility indices), such is for example difference of viewing angle between the target point and local horizon (Caha and Rášová 2015), are determined then it is no longer possible to use the same tool to calculate extended viewshed and reversed extended viewshed as these characteristics of visibility are not reciprocal.

The extended viewsheds provide supplementary information about visibility beyond the boolean information visible/invisible (Fisher 1996) and provide answers to questions such as: "How well is the target visible?" The unfortunate fact is that the extended viewshed are not implemented in widely available software, and the same applies for extended reverse viewsheds (Fisher 1996). The situation has not changed during the 20 years that passed since Fisher's article, neither the extended viewshed or the reverse extended viewsheds are still implemented in common GIS.

Representation of Target in Visibility Analysis

Originally, the viewshed is an analysis designed to assess which parts of a surface are visible from a specific observing location on the surface. The analysis as it was proposed was never focused on the visibility of specific target location. The visibility of the target (e.g. building) can be evaluated based on viewshed values in the site of the target. In such case, the outcomes of the analysis are still valid as the visibility is calculated from single point to several points forming the target. The number of points that are used to evaluate target's visibility depends, of course, on the size of the target and cell size of a surface model. However, if viewshed tool is used to determine the reverse viewshed, the logic behind the analysis shifts significantly. The analysis assesses visibility of single point for observers located in individual cells of a raster. The questing arising here is whether a single point is a faithful representation of the target and when a target should be considered visible. While the single point can be a proper representation of small building on DTM with cell size 30 × 30 m, the same will not be true for a large building on DSM with cell size 1 × 1 m. The DSM surface will contain significantly more features that will affect the visibility and partial visibility of the target structure is more likely in such situation. For most urban and landscape planning situations, even partial visibility of target is interesting because the target affects the observer and its perception of the environment.

The problematics of partial visibility was firstly mentioned by Fisher (1993) who proposed variants of viewshed algorithm for assessment of partial visibility of a target cell. The proposed algorithm used five points as a representation of a cell (cell's centre point plus its four corners) and was able to identify the situation when only part of a cell was visible to the observer. However, because visibility analysis is relatively computationally demanding and that the determination of partial visibility is even more demanding the algorithms were never more significantly tested except the original study (Fisher 1993). Nevertheless, the results obtained by Fisher (1993) showed that the utilization of more than one point as a representation of the target leads to increase of visible area. Obviously, if the representation of target cell in the visibility analysis can affect the outcomes of the analysis, it is necessary to consider effects of target representation in reversed viewshed, where the target is usually significantly larger than one cell.

Figure 1 shows a simple demonstration of the issues related to an assessment of building visibility. Visibility of target building (represented as a very light grey rectangle) is evaluated from two viewpoints (vp1, vp2). If the target building is represented by single point (tp1), which is located in a centre of the target polygon, then it is invisible from both viewpoints due to obstacles (grey rectangle and circle). However, if two more points (tp2, tp3) are used to evaluate visibility, the target becomes partially visible for both observers. From viewpoint vp1 the observer can see both target points located on sides of the target but can not see the middle point. From viewpoint vp2 the user can see one side of the building but not the other side nor the middle point. The target, however, is still visible for the observer, even

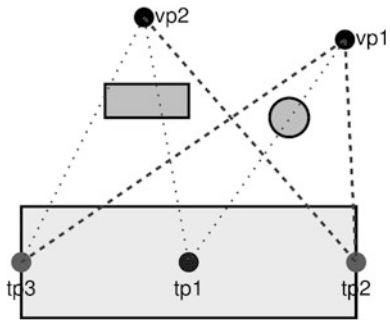


Fig. 1 Visibility of target object (*very light grey rectangle*) from two points (*vp1*, *vp2*) in situation when the target object is represented by three points (*tp1*, *tp2*, *tp3*). LoS where target point is visible are shown as *dashed lines*, LoS where the target is not visible are displayed as *dotted lines*

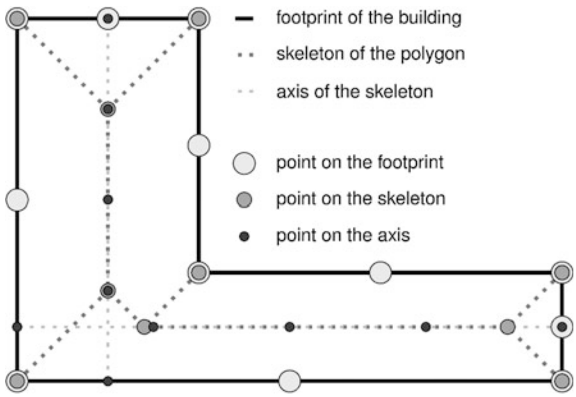
though, it is relatively small part of the target. This example illustrates the issue which should be considered for reversed viewshed analyses as the situation similar to Fig. 1 will occur quite often especially on precise DSM in urban spaces. The reason why reversed visibility of target in urban spaces are affected more likely by this phenomenon than reversed visibility in natural landscape is that urban space form a significant number of vistas, street canyons and often contain isolated trees or vertical structures that will lead to a partial visibility of target. Another factor that is likely to cause partial visibility is a size of the target. If the visibility of radio tower or lookout tower should be assessed then the horizontal dimension of the target is unlikely to be significant. However, buildings can have significant horizontal dimensions, ranging from tens to hundreds of meters, which makes them more likely to be partially visible especially in urban spaces.

The situations of partial visibility that were discussed previously were focused on boolean visibility, but extended viewsheds (visibility indices) are affected as well. Let us consider the difference of viewing angle between the target point and local horizon (Caha and Rášová 2015) as an example of extended viewshed. It is rather obvious that there will be a different value of extended viewshed for every point that represents the target. There is no universal approach how to evaluate the resulting extended viewsheds; the solution depends on the exact question that the analysis should answer.

Selection of Points Representing the Target

The selection of points that will be used as an approximation of the target for reverse viewshed analysis is a crucial step. There is need to balance the number of points, as the number of points will affect the computational loads and time necessary to obtain the results, and adequacy of representation. Hlavatá and Oťahel' (2010) mention representing specific buildings by more than one point for their study, but unfortunately provide no details regarding this matter.

Fig. 2 Different sampling strategies for selection of points representing the target



There are several possible strategies for selection of the points (Fig. 2):

- important points or equal distance sampling of building's footprint,
- important points or equal distance sampling of building's main and/or minor axis,
- important points or equal distance sampling of a straight skeleton (Aichholzer et al. 1995) from building's footprint,
- important points selected by the user based on his expert opinion.

Each of these approaches has its advantages and disadvantages and is suitable for different types of targets. For example, the selection of points from building's footprint is only suitable for buildings that have a relatively flat roof because the inner part of the structure is not considered. However, the strategy works fine for modern buildings, especially high-rise buildings, as they tend to have flat roofs (Yu et al. 2016). For most applications, the combination of one of the first three methods with the fourth method will most likely be the optimal solution.

In Fig. 2 different sampling strategies are used for every approach. The points on the footprint of the building are placed in every corner and in the middle of every edge. The points on the skeleton of the polygon are placed on every vertex of the straight skeleton. The points on the axis are located at the start, end of the axis and every 25% of the length of the axis, which means that five points are used for every axis.

Case Study

The case study if focused on the visibility of National Monument in Vitov, Prague, Czech Republic. The structure was chosen due to its vertical dominancy with respect to surrounding areas and the diversity of neighbourhood which consists of densely built-up areas as well as parks and other recreation grounds. The National

Monument consist of an equestrian statue and a building. The size of the complex is roughly 140 × 50 m. The dimensions of the complex are considerable primarily due to its longitudinal nature.

The viewshed analysis is done in an area of size 1 km around the target building. The area of interest is shown in Fig. 3. The datasets used for this study are provided by "© IPR Praha" (www.geoportalpraha.cz) as open source data with licence CC BY-SA 4.0. The necessary datasets for the case study are DSM and DTM, both datasets have the spatial resolution of 1 × 1 m and are based on LiDaR data. All the visibility analyses calculated for this case study are done with observer's offset 1.5 m and target's offset 0 m.

Figure 4 shows DSM of the building with the representative point highlighted, a single point that could be used for reversed visibility analysis, and additional points that will be used for visibility analyses to represent the building adequately. The single representative point is selected as centre of the polygon delimiting the building (without considering the statue). The 8 points representing the National Monument are located on the main axis of the structure and are selected with respect to significant features of the building as well as the distance amongst them. One point is located on the statue in front of the main building, five points are located on the main section of the building (highest part), and two are located in the rear part of the building which is lower than the main section. The distance amongst points on the main section of the building is on average 15 m, the points on rear section are on average 20 m apart, and the point on the statue is 32 m from the first point on the building. The width of the building is not considered as important as its length for the purpose of this study and with respect to the geomorphological location of the building. However, different shapes of buildings would require different spatial layout of the points.

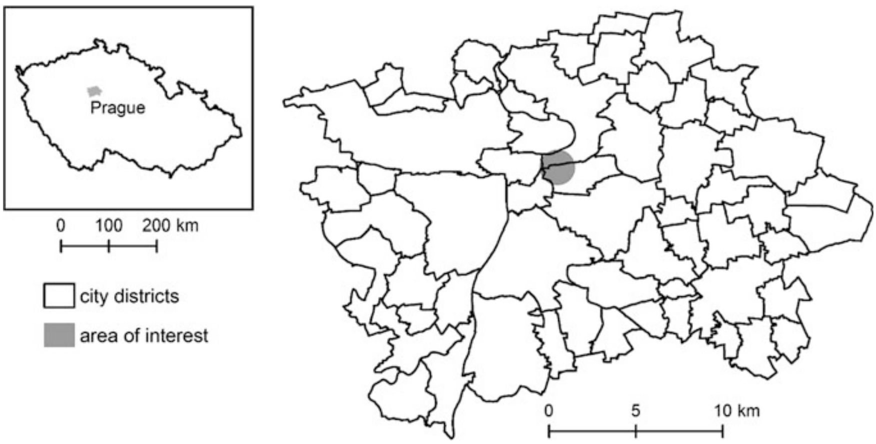


Fig. 3 Location of area of interest in Prague

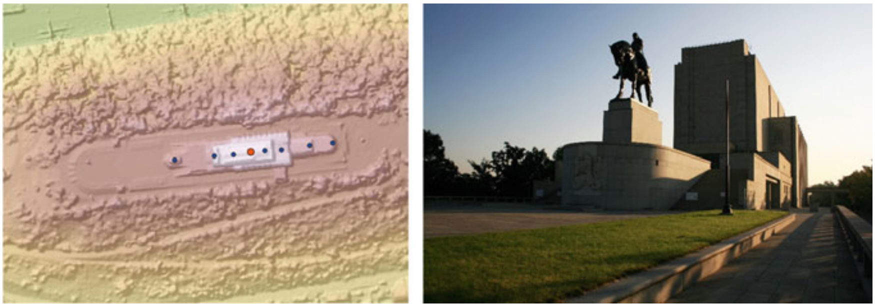


Fig. 4 National Monument in Vitkov. *Left* shaded digital surface model with representative point (*orange*) and additional points (*blue*). *Right* photography of the monument (*Source* Ondřej Kořínek [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons)

The number of points representing the target structure is selected as a compromise between a proper representation of the target and computational time necessary to obtain the result. The computational time rises linearly with increasing number of points. Since it is not usually necessary to calculate this type of analysis in real time, the time demands are not a significant issue for this type of analysis.

Prior to visibility analysis of the building, three preprocessing steps need to be performed. Firstly, the points representing the building need to obtain the elevation information from DSM. The second phase is to remove the building itself from DSM and replace the area with values from DTM (Hlavatá and Oťaheľ 2010). This step is necessary otherwise parts of the building can overshadow the target points which would result in an incorrect assessment of building visibility. Since reverse viewshed will be determined it is reasonable to remove areas that are inaccessible for the observer from the area of interest. Such areas are roofs of buildings and places with notable vegetation (Bartie et al. 2011), both types can be identified from the difference of DSM and DTM. In our case, if the absolute value of difference between DSM and DTM is higher than 2 m the area is marked as inaccessible for the observer. The threshold (2 m) is selected as borderline that separates smaller trees and shrub from regular sized trees.

The reverse visibility analyses of the national monument are calculated for the representative point, which serves as an example of simple visibility analysis, and for eight points that properly represent the whole building. The representation of structure by a single point is used in several studies (Rød and van der Meer 2009; Garnero and Fabrizio 2015) but the representation by several points was also mentioned previously (Hlavatá and Oťaheľ 2010). For both variants, boolean viewshed and one extended viewshed (viewing angle between the target point and local horizon) were calculated. To generate a single outcome for the multipoint variant of the analysis the resulting grids were merged using the maximal value of visibility for every cell. This answers questions “From which locations is at least one target point visible?” and “How well is visible the most notable part of the building?" It would be possible to answer different questions as well but for the purpose of this study these question we considered as sufficient.

An initial comparison of visibility of representative point and visibility of at least one point is in Fig. 5. The representative point is visible from 201,986 cells of the raster. At least one of the points representing the target building is visible from 264,917 cells, which is 31.16% increase from the visibility of the representative point. As visible from the Fig. 5, the additional areas, from which other points than the representative point are visible, are located mainly in long straight streets, behind vertically significant structures and near edges of buildings. Figure 6 shows a 3D representation of views from viewpoints (location of viewpoints is in Fig. 5). For each of these viewpoints, the representative point is hidden either by a structure (A) or by vegetation (B and C), but significant part of the building is still visible for the observer. These 3D visualizations perhaps most appropriately explain the essence of the issue of proper representation of the target in reverse viewshed analyses.

The extended reverse viewshed calculated for the national monument is viewing angle between the target point and local horizon which describes how high above the horizon the target points raises. The comparison is then made as the difference between extended reversed viewshed calculated for 8 target points and the representative point. Figure 7 shows the difference between values of extended reverse viewsheds in degrees. The highest differences are close to the target building

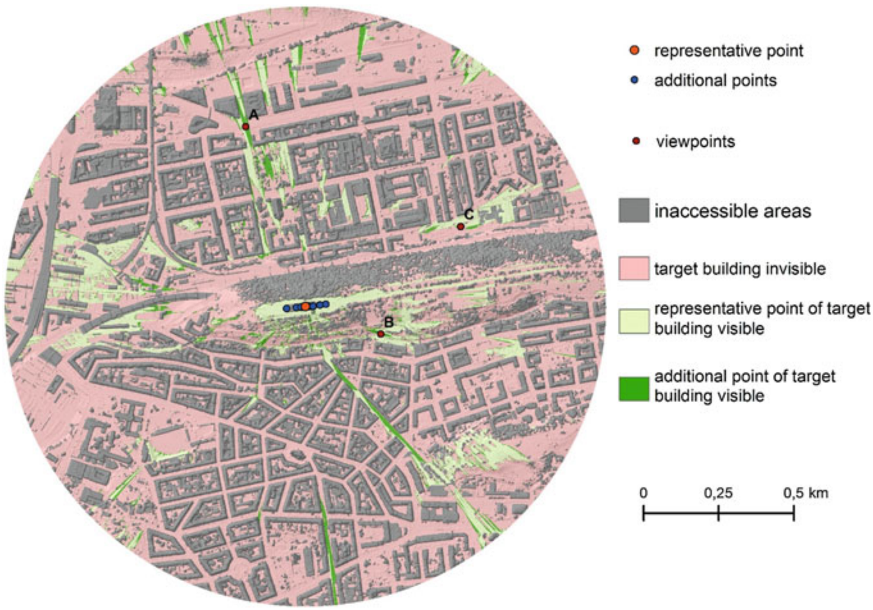


Fig. 5 The difference between reversed viewshed determined for representative point and all the points

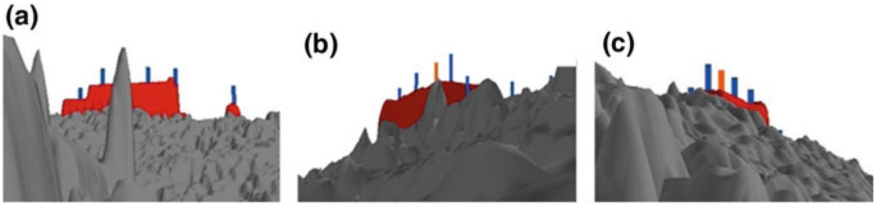


Fig. 6 3D visualization of DSM with the target building highlighted and the *points* representing the building exaggerated. The three examples represent viewpoints from the previous figure. In all three cases the representative point is invisible but the building as a whole is visible

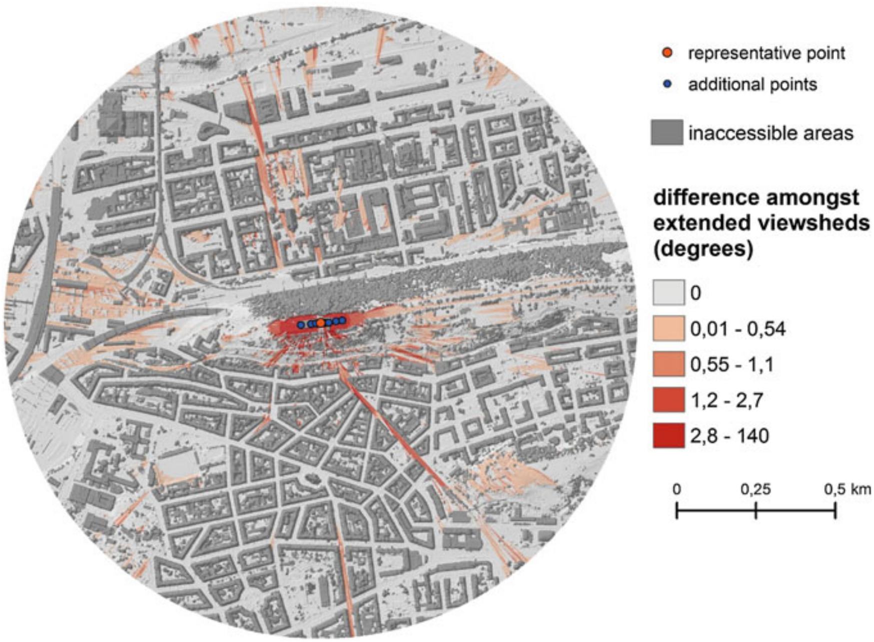


Fig. 7 The difference between extended reverse viewshed—the difference of viewing angle between the target point and local horizon—determined for representative point and all the points

because in these cases the value of extended reverse viewshed is affected by the distance from the target point. However, even points located further from the target point show some amount of difference caused by the fact that the representative point does not have to be the most prominent point representing target building. The differences for the cells located more than 150 m from the representative point are summarized as a histogram in Fig. 8. The minimum distance is chosen to filter out high values of differences which are caused by other reasons than the different visibility of points representing the target building. The results show that even

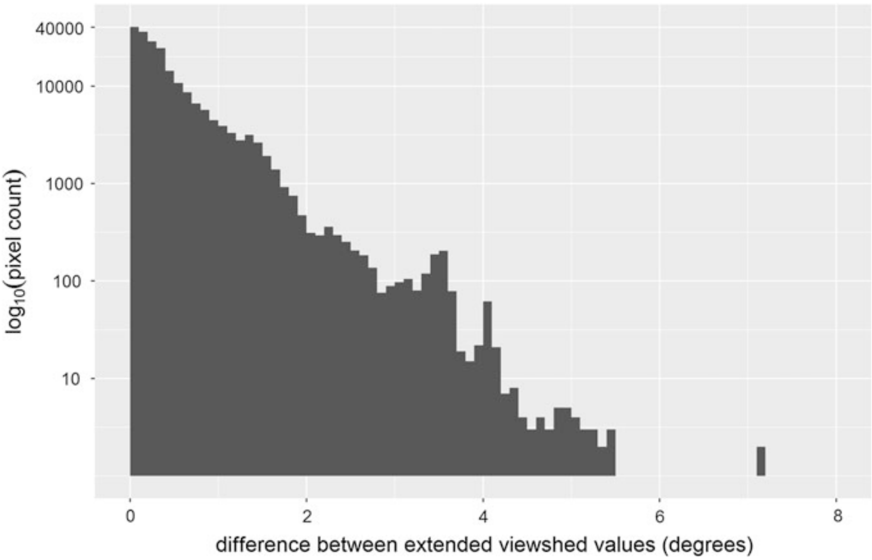


Fig. 8 Histogram of the extended reverse viewshed differences for cells located more than 150 m from the representative point

though, the number of cells with zero or minimal difference is the highest (Fig. 8), 97% of cells have difference higher than 0.016 degree, which could be considered as significant difference based on Ogburn's (2006) research which identifies the value of 1' as a threshold for resolution acuity. With difference higher than the threshold of resolution acuity the observer should be able to distinguish that specific part of the target is more distinctive that other part. In this particular case, it means that some sections of the building are higher above the local horizon than the representative point.

Conclusions

The presented research focus on the importance of target representation for reverse viewshed analysis. With the growing number of studies that assess visibility of buildings, it is necessary to point out and study factors that can affect the credibility of obtained results. This paper describes that the common approach of representing the target building (or other man-made structure) by a single point for visibility analysis can cause the results of the analysis to be incomplete. The incompleteness is a product of the determination of visibility of specific point representing the target building while neglecting possible partial visibility of the building or in other words visibility of other points that can represent the target. The issue of results omission will more likely affect visibility analysis on detailed and precise surface models especially in urban spaces where visibility obstacles have significantly higher variability (in terms of both height and dimensions). The reasons for these omissions are theoretically described and practically demonstrated on a case study of the National monument in Vitkov, Prague.

The case study revealed that if eight points are used to represent the National monument, the reverse viewshed area will be bigger by 31% than if the building is represented by a single point. These results confirm the findings presented by Fisher (1993), who reported up to 50% rise in the area for viewshed analysis if the partial visibility of raster cells was considered. The exact value of the disparity is, however, always case specifics and depends on many factors (e.g. geomorphology of the terrain, structure of DSM) so no general conclusions about the causes can be done. The most influential factors that will affect the difference between results obtained for single and multiple point representations are dimensions and shape of the object, type of neighbourhood around the target and spatial configuration of visibility obstacles. In the case study, we identified few situations that caused the biggest area differences between the results for different target representations. Amongst them three were the most prominent—straight long streets that offer view only on the part of the target, locations were vertically significant structures with relatively small footprint (towers) hide the representative point while the rest of the target is visible and vegetation causing the same issue.

The issue described in this contribution is significant as a building visibility is one of the factors for urban and environmental planners to consider when authorizing new construction. The results of our research show that single point reverse visibility is likely to provide a smaller area from which the target is visible. For proper assessment of the visibility, the entire spatial extent of the building has to be considered to provide an exact result. The result of visibility analysis should cover even the situations in which the target is only partially visible as even the partial visibility of the target affects the observer. This is especially true in the case of assessment of building visibility in urban space.

The further research should focus on identification of the optimal number of points that should represent a target based on its size and shape. For the purpose of this research the number of points was estimated based on expert knowledge, but some general guidelines are necessary for practical implementations. The influence of partial target visibility on extended reverse viewshed is another topic that deserves attention as it helps with an assessment of how well the target is visible.

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References

Aichholzer, O., Aurenhammer, F., Alberts, D., & Gärtner, B. (1995). A novel type of skeleton for polygons. *Journal of Universal Computer Science, 1*(12), 752–761.

Bartie, P., Reitsma, F., Kingham, S., & Mills, S. (2011). Incorporating vegetation into visual exposure modelling in urban environments. *International Journal of Geographical Information Science, 25*(5), 851–868.

Caha, J., & Rášová, A. (2015). Line-of-sight derived indices: Viewing angle difference to a local horizon and the difference of viewing angle and the slope of line of sight. In K. Růžičková & T. Inspektor (Eds.), *Surface models for geosciences SE—6* (pp. 61–72). Ostrava: Springer International Publishing.

Felleman, J. P. (1979). *Landscape visibility mapping: Theory and practice*. New York: Syracuse.

Fisher, P. F. (1993). Algorithm and implementation uncertainty in viewshed analysis. *International Journal of Geographical Information Systems, 7*(4), 331–347.

Fisher, P. F. (1996). Extending the applicability of viewsheds in landscape planning. *Photogrammetric Engineering and Remote Sensing, 62*(11), 1297–1302.

Garnero, G., & Fabrizio, E. (2015). Visibility analysis in urban spaces: A raster-based approach and case studies. *Environment and Planning B: Planning and Design, 42,* 688–707.

Hlavatá, Z., & Oťaheľ, J. (2010). Vizuálna analýza vybraných historických dominánt Bratislavy. *Geografický Časopis, 62*(4), 293–311.

Klouček, T., Lagner, O., & Šímová, P. (2015). How does data accuracy influence the reliability of digital viewshed models? A case study with wind turbines. *Applied Geography, 64,* 46–54.

Maloy, M. A., & Dean, D. J. (2001). An accuracy assessment of various GIS-based viewshed delineation techniques. *Photogrammetric Engineering & Remote Sensing, 67*(11), 1293–1298.

Ogburn, D. E. (2006). Assessing the level of visibility of cultural objects in past landscapes. *Journal of Archaeological Science, 33*(3), 405–413.

Rød, J. K., & van der Meer, D. (2009). Visibility and dominance analysis: Assessing a high-rise building project in Trondheim. *Environment and Planning B: Planning and Design, 36*(4), 698–710.

Yu, S., Yu, B., Song, W., Wu, B., Zhou, J., & Huang, Y. (2016). Landscape and urban planning view-based greenery: A three-dimensional assessment of city buildings' green visibility using floor green view index. *Landscape and Urban Planning, 152,* 13–26.

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