COMPUTATIONAL METHODS FOR EXAMINING RECIPROCAL RELATIONS BETWEEN THE VIEWSHED OF PLANNED FACILITIES AND HISTORICAL DOMINANTS

Their integration within the cultural landscape

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Abstract. The article presents a methodology for the assessment of the impact of new buildings on the cultural landscape, in particular the exposure of historical landmarks. While using digital analysis and a 3D city model, the methodology examines reciprocal visual relations between historical and planned buildings. The following methods have been used: a) Visual Impact Size (VIS) which enables to determine a visual impact area and the degree of architectural facility domination in space; b) comparative analysis (cumulative viewshed) which enables to determine areas where viewsheds of new investment and historical buildings overlap; c) simulation of selected views from the level of human eyesight. The proposed landscape examination methodology has been presented using the case study of Katowice, Poland. The goal was to determine reciprocal relations between historical landmarks of the Silesia Museum and tall buildings planned in the vicinity. The study used a Digital Surface Model (DSM), a 3D city model. All simulations have been performed using software developed by the author (C++).

Keywords. Cumulative viewshed; digital cityscape analysis; historical dominants; visual impact; VIS method.

1. Introduction

The conservation of a historical urban landscape usually involves the designation of protected areas where so called Assets of Cultural Interest are the most important components of the cityscape and new investment should be subordinated regarding its form and materials used (O'Connor 2011). However, in the planning practice, such methods are frequently insufficient, especially in the context of a visual protection against the impact of tall buildings. Tall buildings have very large visual impact range and can be seen from kilometres away (Van der Hoeven, Nijhuis 2011). The use of 3D and computation methods enables to produce more advanced simulation and the protection of facilities that are important for the cultural heritage in cities.

The goal of the research presented in this article is to discuss the method that can support identification and planning of investment in terms of their impact on

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the exposition of historical dominants. The method defines viewsheds (Danese et al. 2009) for historical facilities, which are components of a cultural heritage, and then the same for planned buildings. The study uses the Visual Impact Size (VIS) method (Czyńska 2015). The comparison of VIS analyses for a group of protected historical buildings and new ones enables us to identify exposure locations that can be loosely examined at the next stage through simulations using, e.g. height lines (Czyńska 2010). This enables to show the actual impact of planned buildings on the cityscape and their relationship to historical dominants.

2. Methods and materials

2.1. 3D CITY MODEL

The Digital Surface Model (DSM), or a 3D city model, of high resolution (grid size of 50 cm), is a basis for the study presented in the article. It consists of a regular cloud of points which contains all cityscape components, such as buildings, trees, bridges and overpasses, reflected with identical accuracy (for each element). Therefore, the DSM is a very good environment for visual analyses (Rubinowicz 2018). Nevertheless, the proposed method can also be applied using other city model formats, e.g. CityGML (Kolbe 2009). Its drawback, however, when compared with the DSM, is that it usually does not take into account trees despite of its major impact on the visibility of architectural facilities in space.

The study uses specialist C++ software which was developed with the involvement of the author and it is dedicated to complex computational tasks (e.g. visual analysis) for large urban areas. It is particularly important when examining tall buildings that may have their impact within the range of several kilometres. The algorithm has been optimized for enhancing the efficiency of processing data representing a digital picture of the city space. Although the study uses proprietary software, it is possible to conduct a similar process based on a standard specialist GIS software as well. In this case, the complexity of calculations due to the size of input data and computation time can be a limitation. Software applied in the study enables the emulation of the visibility field for an individual control point within 1.0 sq km and a mesh size of 0.5 m during approx. 48 s (4 core processor and 32GB RAM). The study always includes the full resolution DSM model. The precision of the model has relatively minor impact on the simulation time.

2.2. METHODS

The examination of visual interactions between existing historical dominants and planned tall buildings necessitated a new suitable methodology. The methodology was based on the following: a) preparation of VIS maps for historical dominants; b) development of similar VIS maps for planned buildings; c) comparison of visual impact - cumulative viewshed; d) development of photographic documentation for selected vistas; e) preparation of simulations regarding the impact of tall buildings as seen from the human eye sight level using height lines.

In the study concerned, a key role was played by the VIS method which enables to simulate the viewshed of a building. The basics of the method stem from so called “reversed viewshed”, that is an area from which a target point is visible (Caha 2017). Together with the visibility range, the method calculates the degree of domination of a facility in space, namely its domination or only partial visibility of a building. 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) (Caha 2017). 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 10÷20 m. It depends, however, on the specific nature of the facility in question and the required precision of calculation.

As regards the research concerned, a major context in the theory of digital picture analysis comprise multiple viewshed (Kim, Rana & Wise 2004) and cumulative viewshed (Wheatley 1995). Multiple viewshed combines the total visibility for a number of points in space, while cumulative viewshed enables to obtain information about locations where visibility areas overlap for specific observation points. In this particular case, these are areas in which new investment influences the visibility of historical dominants. Cumulative viewshed maps are developed individually for each height examined in the VIS.

Locations where viewsheds of historical dominants and new buildings overlap are the exposure areas for which visualisations are developed simulating the level of a human eye sight. They show the actual impact of new buildings in the cityscape and their interaction with facilities that need to be protected. To extend the use of such simulations in the planning practice, instead of simulating the shape of an architectural facility, the methods uses three-dimensional height lines (Czyńska 2010). They provide information concerning impact depending on various heights of a planned building combined with its exposure, and help determine the view and maximum heights for the new building.

The VIS analysis does not take into account the distance from the facility in question. It results from major differences in the perception of high-rising buildings depending on the specific nature of the cityscape. Based on a number of examples worldwide, tall buildings can have their visual impact over a distance of several kilometres. A good example of the above, is a tall building in London, which disturbed one of strategic vistas of St Paul's Cathedral ("Skyscraper that 'destroys' view of St Paul's", 2016). The VIS method calculates the total possible range of visual impact. The result is then interpreted by an expert. Nevertheless, taking into account the distance is a question of the future development of the VIS method.

3. Katowice case study

3.1. RESEARCH PROBLEM

The above methodology was used to analyse the impact of new tall buildings on a historical cityscape of Katowice, Poland, in particular facilities of a former mine in Katowice which comprise the Silesia Museum. Katowice is a city located in the largest industrial region in Poland. The history of the city has been associated with the mining industry. Traces of the cultural heritage can still be seen in the landscape and as such should be protected. The Silesia Museum completed in 2012 (designed by Riegler Riewe Architekten) involved rehabilitation of buildings of a former coal mine (small red brick buildings). New museum facilities are hidden underground to highlight historical industrial facilities, including a winding tower and water tower. These are local dominants made of red brick and steel lettuce structure and subtle details. The architectural design of the Silesia Museum has won the recognition at the European level and it is now a major landmark of the city (see Figure 1a).

North of the museum planned is a new residential estate with tall buildings (investor: TDJ Estate, design: Medusa Group - see Figure 1b). In total, the plan includes 8 buildings exceeding the average height of other buildings in the immediate vicinity (from 38 m to 54 m above ground level). Considering cityscape conditions, configuration of land and exposition of valuable industrial heritage facilities, new tall buildings may significantly threaten the integrity of Silesia Museum dominants.

Therefore, the study aims to verify whether planned tall buildings impact the exposure of the dominants, and if yes, then in what way? What will be the character of the new neighbourhood? Will it dominate the cityscape? How many iconic vistas of the Museum will be changed by the new investment?

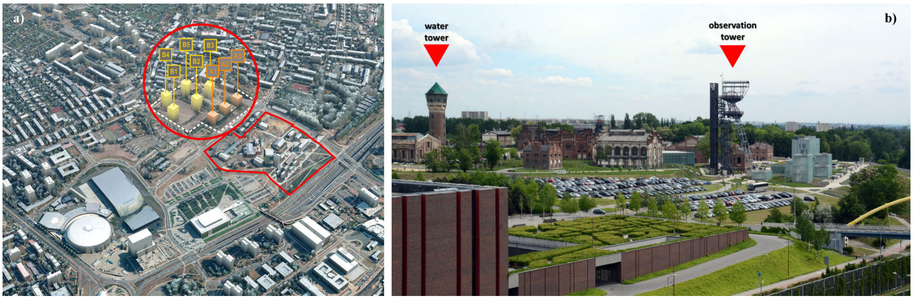

Figure 1. Historical dominants of Silesia Museum in Katowice and planned investment: a)visualisation of city including Museum and planned residential estate by TDJ-Estate (A1÷B5), b)historical dominants: observation tower and water tower.

3.2. APPLICATION OF COMPUTATIONAL METHODS

Cityscape analyses have been implemented based on digital height data covering an area of 25 sq km in Katowice. The DSM model was fitted onto a mesh of 50 x 50 cm. The model was revised and updated to eliminate technical errors and supplement changes in build-up environment of the city, i.e. demolition, new facilities etc. All visualisations and analyses have been developed using C++ dedicated software created partially by the author.

The first stage involved the development of VIS maps in various options: a) for observation tower; b) for water tower; c) for both historical dominants of Silesia Museum; d) for group of 3 planned residential buildings of smaller height; e) for group of 5 planned residential buildings; and f) for 8 new buildings. Each map provides important and accurate information about the impact of particular buildings on the city space and their domination. The VIS analysis includes 7 identical levels for all facilities in question, i.e. 10, 20, 30, 40, 50, 60, 70 m. Each level is marked with a different colour which represents the domination of a given facility in space (red - major impact, blue - minor impact). A collective VIS map for historical dominants and collective VIS map for 8 new buildings are presented in figure below (see Figure 2).

Another stage involved the juxtaposing of impact areas for both historical dominants and the impact of eight tall buildings - a cumulative viewshed. A number of maps have been developed to show overlapping exposure areas, each for a different height between 10÷70 m above ground level (see Figure 3). The maps show three values: yellow - cumulative visibility of historical dominants; blue - aggregated visibility of new tall buildings; red - visibility of both historical dominants and planned buildings.

VIS maps (Figure 2) enable to examine all locations within a city from which specific facilities can be seen. The cumulative viewshed (Figure 3) presents interaction of viewsheds of protected historical facilities and new buildings. This helps to identify visibility points at which planned buildings can be a threat to the cityscape. At the same time, it is a starting point for field studies and the documentation of vistas. For the most important vistas, the study developed simulations of views from the human eye sight level showing the transformation of the cityscape after new buildings are completed, as well as their actual relationship with historical dominants. Particular simulations provide information important for planning of revisions to the height of planned buildings - enables to determine maximum height at which a given facility extends above the line of buildings in specific vistas. The study used multiple colour blocks placed in the cityscape of Katowice to mark the location and height of new buildings (see Figure 4). Colours used are identical as those in VIS analysis.

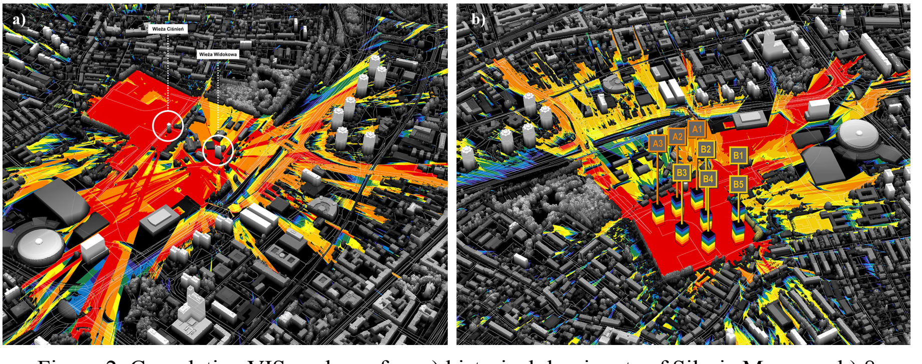

Figure 2. Cumulative VIS analyses for: a) historical dominants of Silesia Museum, b) 8 buildings planned by TDJ-Estate. Colours denote the power of building facility domination in space (red - major, bue - minor).

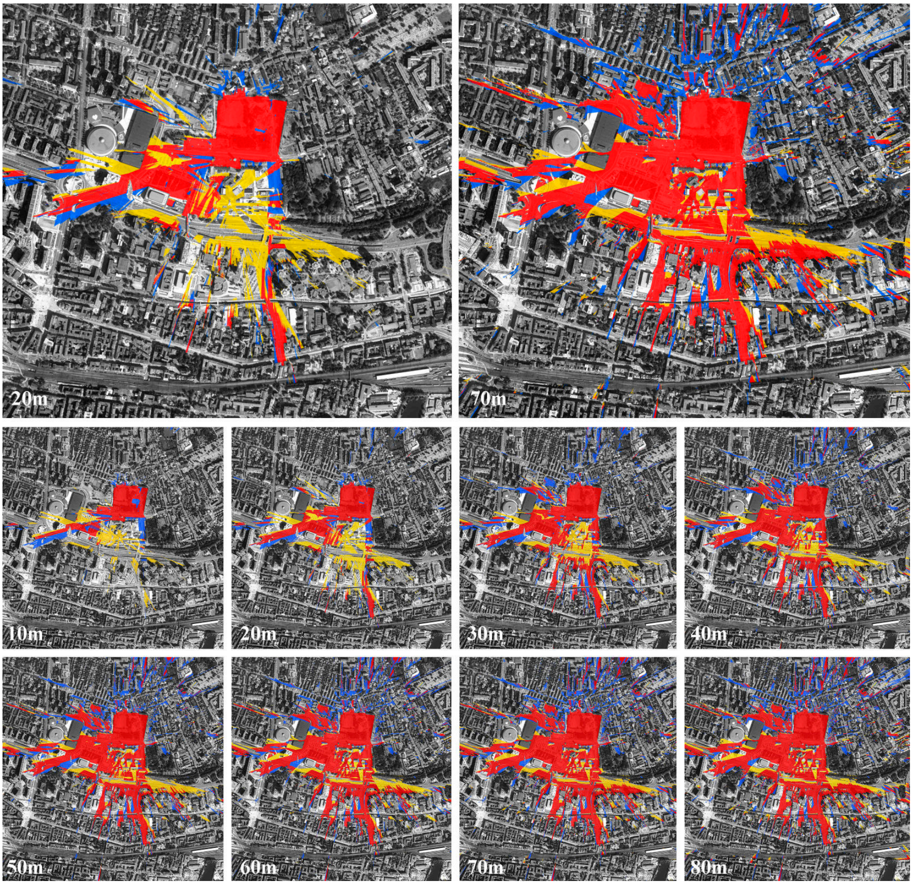

Figure 3. Cumulative viewshed - comparison of viewsheds of historical facilities (2 dominants) and planned buildings (8 facilities), at different levels. Red is used to mark areas of simultaneous visibility.

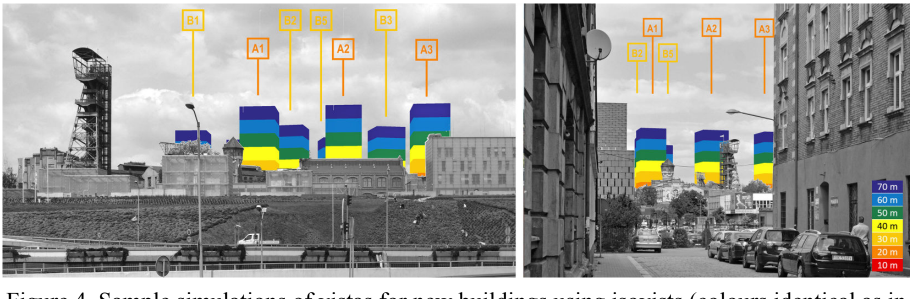

Figure 4. Sample simulations of vistas for new buildings using isovists (colours identical as in VIS analysis - height ranges every 10 m).

4. Results and discussion

4.1. INTERPRETATION OF RESULTS

The VIS analysis showed a broad visual impact of buildings planned in the vicinity of the Silesia Museum. A preliminary comparative VIS analysis for the investment planned and historical dominants indicates that those areas overlap to a considerable extent. It means that the vistas of historical Silesia Museum dominants will be irreversibly changed.

This has been confirmed by the cumulative viewshed analysis for specific heights (Figure 3). While examining a sequence of maps we could observe that the cumulative viewshed increased with the height of buildings planned. This enlarges the area marked red and reduces the visibility of dominants (yellow). It means that buildings planned will have a major impact on the exposure of historical facilities.

Cumulative viewshed results are presented in table below (see Table 1). Columns 2 and 3 show cumulative viewsheds: group A - for historical dominants; group B - for 8 new buildings. Column 4 refers to the common part with overlapping viewsheds of group A and group B. Columns 5 and 6, however, are the most important for the interpretation of results, since they show the degree of interference of new buildings with the facilities of the Silesia Museum.

The result corresponds with the initial intuitive perception. The majority of vistas (60 to 80%) with dominants of the Silesia Museum will be changed by the visual presence of new tall buildings (Table 1 - column no. 5). As many as 56 to 67% of vistas with planned buildings will include historical dominants as well (Table 1 - column no. 6). Although in the second instance there is no question of a reduced visual value of buildings planned, the question of how new buildings can fit into the cityscape, the Silesia Museum in particular, is debatable.

Table 1. Viewsheds of historical dominants and new tall buildings.

1	2	3	4	5	6
Height examined	Viewshed of hist. dominants	Viewshed of new buildings	Overlapping area	Interference of new building into vistas with hist. dominants	Presence of hist. dominants in vistas with new buildings
	A	**B**	**A∩B**	**(A∩B) / A**	**(A∩B) / B**
[m]	[thou. m2]	[thou. m2]	[thou. m2]	%	%
10	205.64	183.91	123.14	**59.9%**	**67.0%**
20	357.89	314.92	215.79	**60.3%**	**68.5%**
30	463.24	538.87	328.65	**70.9%**	**61.0%**
40	595.34	737.19	434.94	**73.1%**	**59.0%**
50	761.91	998.63	567.54	**74.5%**	**56.8%**
60	945.89	1295.71	727.73	**76.9%**	**56.2%**
70	1152.25	1620.18	915.79	**79.5%**	**56.5%**

Further conclusions can be drawn based on the simulation of selected views seen from the human eye sight level. In total, the study examined more than ten iconic vistas of the Silesia Museum from different directions (sample visualisation - see Figure 4). In the majority of viewsheds examined, new buildings can be seen with historical facilities in the background. This means that their previous role in the cityscape as primary dominants is going to change. Those facilities will lose their initial integrity. They will no longer be observed against the background of the sky, and their delicate, partially transparent structure will be dominated by new buildings.

Partial results provide a lot of valuable information related to the cityscape of Katowice. They, however, need to be interpreted by an expert familiar with the specific nature of the cityscape, its morphology and history. Then it is possible to examine and interpret the meaning of particular visual impact.

A good example of the above is the viewshed of the Silesia Museum from Damrota Street. A narrow viewshed, shown in figure below (see Figure 5a), although in relation to the entire map poor, is de facto one of key and very iconic perspectives of Silesia Museum dominants. The axial composition of space ends with historical towers (see Figure 5b). The simulation shows the way new tall buildings interfere with the cityscape. Buildings can be seen once they reach the height of 30 m. Therefore, to reduce the visual impact of new buildings, it is necessary to reduce their height up to that level.

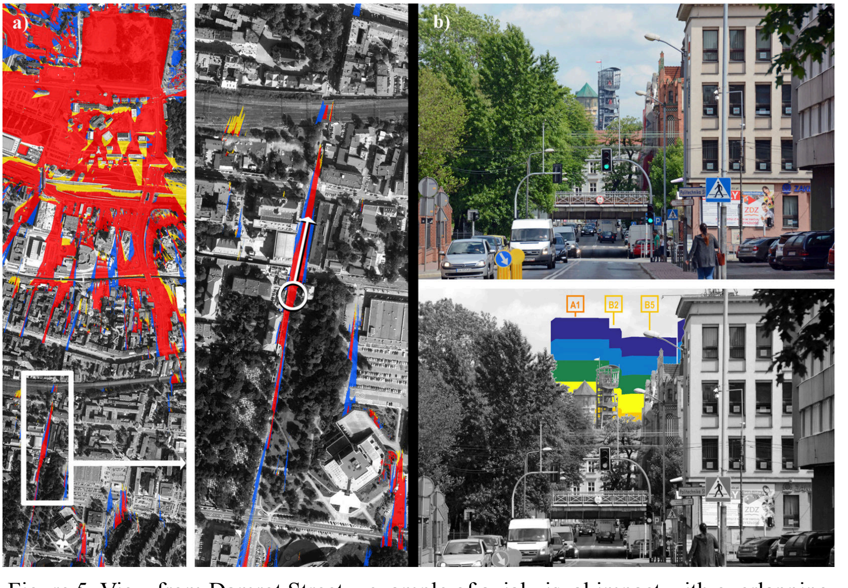

Figure 5. View from Damrot Street – example of axial visual impact with overlapping viewsheds of historical dominants and planned tall buildings: a) Cumulative viewshed, b) simulation from the human eye sight level.

4.2. THE METHOD AND OTHER RESEARCH

The methodology comprises several techniques that can be useful while developing expert opinions on the impact of investment on the environment (Environmental Impact Assessment, or EIA) as regards the protection of cultural heritage (Bond et. al. 2004). Such studies are usually based on viewshed analyses (Ozimek & Ozimek 2017). The theory related to measuring the viewshed has been developed for decades. With the development of computation capacity and accessibility of spatial data it is increasingly often used to analyse e.g. tall buildings. Van der Hoeven & Nijhuis (2011) have analysed a multiple viewshed for tall buildings in Rotterdam. The analysis, however, produced poor accuracy due to too small resolution of the 3D city model applied.

Apart from information whether a facility can be seen from a given location, an important aspect of the analysis is how powerful its exposure is. While examining a tall building in Trondheim, Rød and van der Meer (2009) determined angular values and the degree of domination of the facility in specific urban space. The VIS method, discussed in the article, determines domination by dividing a control point into height thresholds for which viewsheds are calculated. Results obtained are very accurate (up to 15 cm) in comparison to other studies published (Tabik 2012). It is possible due to the use of VIS dedicated software. The software enables to process DSM models at high precision level. It provides a full control over the viewshed calculation process.

Studies presented also involve the problem of a 3D visualisation of planned architectural facilities in the existing urban space. Falconer et.al. (2015) aims at making the designing process more interactive to produce a sustainable urban environment. The method of examining blocks of buildings (using height lines) is an attempt to expand the use of architectural concept visualisation (Pullar, Tidey 2001). It can be used in planning to determine the desired height of new buildings based on the analysis of their spatial context (Saedi et.al. 2019).

5. Conclusion

The study uses digital techniques in cityscape analysis to assess reciprocal visual relationship between historical facilities (protected) and new buildings planned. The proposed methodology is based on the visual impact analysis (VIS). VIS analyses are carried out separately for the group of historical dominants and the group of buildings planned, and then results of those analyses are compared in a measurable manner (cumulative viewshed). It enables to distinguish areas of exposure in which new facilities can interfere with the cityscape.

The application of the method is presented using the example of a case study of Katowice. Analyses covered 25 sq km of the city using a full precision DSM model (mesh of 0.5 m). Results of the VIS analyses and the culmulative viewshed analysis showed major impact of new buildings planned, since their viewsheds overlapped those of historical towers of the Silesia Museum (60-80%). Simulations developed for selected vistas confirmed that planned buildings could be seen with the museum in the background. The VIS method has enabled to identify a number of visual correlations also in distant locations and those that can hardly be determined intuitively. Selected vistas have been examined using height lines.

On the one hand, the cumulative viewshed analysis of historical and planned facilities enables to identify locations that need to be further examined in greater detail. On the other hand, the overlap of viewsheds of historical and planned buildings is a measurable parameter which provides information about a possible risk of interference with the cityscape. The methodology can be used in planning practice in various cities including the use of other GIS software.

References

"Skyscraper that 'destroys' view of St Paul's" : 2016. Available from <https://www.architectsjournal.co.uk/news/outrageover-somskyscraper-that-destroys-view-of-st-pauls/10015058.article> (accessed 3rd February 2020).

Bond, A., Langstaff, L., Baxter, R., Wallentinus, H.-G., Kofoed, J., Lisitzin, K. and Lundström, S.: 2004, Dealing with the cultural heritage aspect of environmental impact assessment in Europe, *Impact Assessment and Project Appraisal*, **22**, 37-45.

Caha, J. 2017, Representing buildings for visibility analyses in urban spaces, *in* I. Ivan et al. (ed.), *Dynamics in GIscience, Lecture Notes in Geoinformation and Cartography*, Springer International Publishing, 17-29.

Czyńska, K.: 2010, Tall buildings and harmonious city landscape, *Space & Form*, **13**, 276-280.

Czyńska, K.: 2015, Application of Lidar Data and 3d-City Models in Visual Impact Simulations of Tall Buildings, *International Archives of the Photogrammetry Remote Sensing and Spatial Information Science*, **XL-7/W3**, 1359–1366.

Danese, M., Nole, G. and Murgante, B. 2009, Visual impact assessment in urban planning, *in* B. Murgante, G. Borruso and A. Lapucci (eds.), *Geocomputation and Urban Planning*, Springer-Verlag, Berlin Heidelberg, 133–146.

Falconer, R. E., Isaacs, J. P., Gilmour, D. and Blackwood, D. J. 2015, Indicator Modelling and Interactive Visualisation for Urban Sustainability Assessment, *in* C. Silva (ed.), *Challenges, and Opportunities in Urban E-Planning*, PA: IGI Global, Hershey, 188-209.

Van der Hoeven, F. and Nijhuis, S.: 2011, Hi Rise, I can see you! Planning and visibility assessment of high building development in Rotterdam, *Research in Urbanism Series*, **2**, 277–301.

Kim, Y., Rana, S. and Wise, S.: 2004, Exploring multiple viewshed analysis using terrain features and optimisation techniques., *Computers and Geosciences*, **30**, 1019-1032.

Kolbe, T. H. 2009, Representing and Exchanging 3D City Models with CityGML, *in* J. Lee and S. Zlatanova (eds.), *3D Geo-Information Sciences. Lecture Notes in Geoinformation and Cartography*, Springer International Publishing, Berlin Heidelberg, 15-31.

Ozimek, A. and Ozimek, P.: 2017, Viewshed Analyses as Support for Objective Landscape Assessment, *Journal of Digital Landscape Architecture*, **2**, 190-197.

Pullar, D. V. and Tidey, M. E.: 2001, Coupling 3D visualisation to qualitative assessment of built environment designs, *Landscape and Urban Planning*, **55**, 29-40.

Rubinowicz, P.: 2018, Application of Available Digital Resources for City Visualisation and Urban Analysis, *Proceedings of the 36th eCAADe Conference 2018: Computing for a better tomorrow*, Łódź, Poland, 595-602.

Rød, J. and van der Meer, D.: 2009, Visibility and dominance analysis: assessing a high-rise building, *Environment and Planning B: Planning and Design*, **36**, 698-710.

Saeidi, S., Mirkarimi, S. H., Mohammadzadeh, M., Salmanmahiny, A. and Arrowsmith, C.: 2019, Assessing the visual impacts of new urban features: coupling visibility analysis with 3D city modelling, *Geocarto International*, **34**(12), 1315-1331.

Tabik, S., Zapata, E. and Romero, L.: 2012, Simultaneous computation of total viewshed on large high resolution grids, *International Journal of Geographical Information Science*, **27**(4), 1-11.

Wheatley, D. 1995, Cumulative viewshed analysis: a GIS-based method for investigating, *in* G. Lock and Z. Stancic (eds.), *Archaeology and Geographic*, Taylor and Francis, London, 171–186.