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Application of Visual Impact Size method for cityscape analysis in contexts of tall building development

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ABSTRACT

The article examines application of 3d city models to provide analysis of tall buildings impact on the cityscape. Actual remote sensing techniques, including airborne Lidar, enable collecting precise images of 3d city structures. Those images can be stored in a form of a simple DSM (Digital Surface Model) or in more advanced models such as CityGML. The application of those data opens new possibilities for new urban analyses so much significant for planning. The article introduces the Visual Impact Size (VIS), a method of computational analysis based on the 3d isovists theory. The planned height of buildings is subject of discussions, conflicts and controversies, especially in European cities which developed over centuries. This trend is growing worldwide. Most of tall buildings in Europe were built in this century. In many instances, negative consequences of an inappropriate location of a tall building result from inability to foresee its spatial impact. However, proper delimitation of all possible locations for visibility of tall buildings has key importance for urban planning. How is the impact of building changing with increasing height? How the landscape is affecting visibility of building in space? How is the impact changing dependently on urban composition and urban structure of city etc.? Important outcome of the presented subject is an interpretation of basic relationship between tall buildings and the city itself. The VIS method uses the virtual city models as basis for calculations. It allows: a) to identify all locations in the city from which the planned tall building can be seen; b) to show not only real visual impact range but also imaging of the impact power (visual impact size) of the building. The method was applied in author's professional praxis to verify locations and parameters of tall buildings. The paper presents the background of VIS method, it's idea and sample application: using the computer program developed by authors. The program is dedicated for CityGML data processing (the common standard), and use the data semantics for optimization of applied algorithms.

Keywords: tall buildings, 3d city models, 3d isovists, computational urban analysis

1. Tall buildings phenomena in Europe

In recent years tall buildings have become increasingly popular. The majority of contemporary tall buildings in the world were built this century. The phenomenon do no longer apply to the largest metropolises, but also medium-sized cities. Especially in Europe, this is an important and urban planning challenge. The European cities and their surrounding cultural landscapes have evolved gradually over centuries, if not millennia. Their built heritage, when not ravaged by war, is substantial. (Van der Hoeven and Nijhuis, 2011, p. 279). Developing of tall buildings involves major threats to landscape cohesion and integrity of those cities. Specific architectural and urban arrangement reflected in the silhouette of a city is an important part of the protected cultural heritage (Rubinowicz and Czyńska, 2015). Due to their broad visual impact range, tall buildings frequently induce unfavorable and unplanned interaction with historical buildings (fig. 1). They diminish the influence of primary architectural dominants (e.g. towers of churches and town halls) as regards their role in the overall composition. For this reason, plans to develop tall buildings trigger conflicts and controversies. In order to proceed with an objective discussion on the role of tall buildings as such, we need to develop a methodology for assessing and planning such buildings in a city landscape. We need to fully document the future, planned visual impact to formulate reliable and competent planning guidelines and strategies for landscape protection and development.

The current planning mechanisms do not fully utilize the advancement of modern technologies and analytical tools. The development of computer aided techniques, increase in computing power, as well as growing accessibility of virtual city models significantly boost and expedite verification of specific planning decisions, in particular those regarding tall buildings. However, we still miss a clearly defined methodology for diagnosing the phenomenon and dedicated analytical support. Planning of new tall buildings necessitates analyzing the urban structure of a city at various scales: from global, including the impact of a building on the space of the entire city, partial external exposition within skylines, to internal views of public space (squares and streets) (Zwoliński, 2015). Visual perception of a city is a dynamic process. Relations between buildings change together with the point of observation. These relations are analyzed against lines of buildings and visual planes. A photography of a skyline shows a part of the impression only (limited to one point in space). For planning purposes, a relevant synthesis is necessary – determining the sum of visibility fields for a planned tall building. The use of scientific theories concerning determining of isovists 3d in analyzing visual aspects of tall buildings is particularly valuable. The Visual Impact Size (VIS) method presented in the article enables determining all locations in a city from which a planned facility can be seen. This helps defining whether a new vertical dominating architectural structure may appear in areas of strong spatial values. This helps foreseeing potential changes in the skyline of a city.

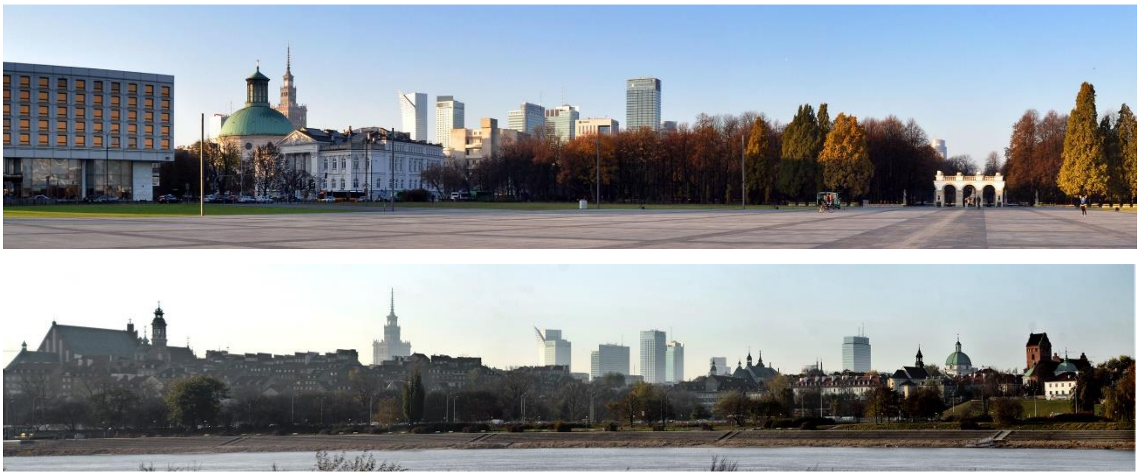

Fig. 1. Panoramic views of Warsaw – combination of historical and contemporary skyline

2. Application of isovist for urban study

2.1. Isovist theory

Visibility analysis allow us to apply mathematical certainty to the experience of urban and building environments (Turner, 2003, p. 657). Many attempts to use isovist in architectural and urban analysis followed. Since Benedikt (1979), isovists have been an active field of research. A number of authors have suggested techniques to calculate them, describe their shape, thus gaining insights into urban morphology. Isovist is usually defined as the field of view, available from a specific point of view. An isovist can also be understood as the area not in shadow cast from a point light source. In general, the isovist is a closed 2D polygon (Morello and Ratti, 2009, p. 839). In Space Syntax theory, isovist is the sum of the infinite number of lines-of-sight (or axial lines) that pass through a single point in space (usually at eye height) and occupy the same plane (usually parallel to the ground plane) (Conroy Dalton and Bafna, 2003). The development of the isovist theory has been examined by Fisher-Gewirtzman (2012) while referring to the most important publications. Turner et al. (2001) uses a set of isovist to generate a graph of mutual visibility between locations. Batty (2001) describes how a feasible computational scheme can be used for measuring isovist fields and illustrated how they can visualize their spatial and statistical properties by using maps and frequency distributions.

The possibility of applying the isovist software can be broad and cover a number of research areas. For the majority of potential applications, reducing the simulation to two dimensions only is sufficient. However, visual analyses of tall buildings requires introducing an isovist in its full form of a 3D space.3D isovist defines the 3D field of view, which can be seen from a vantage point with a circular rotation of 360 degrees and from the ground to the sky. Adding the vertical dimension helps to better simulate the physical environment observed from the vantage point (Morello and Ratti, 2009). Yin (2013) in his doctoral thesis summaries limitations of 2D and 3D visibility calculations. Suleiman et al. (2013) explore ways of calculation 3d visibility and introduce a new algorithm based on vector GIS data.

2.2. Interpretation of 3d isovist in cityscape

The use of isovist for urban analyses generates specific results. At the 2D level, the city imaging involves simple separation of developed and undeveloped space. For various purposes, including the analysis of the urban composition, such a simplification of the city image is beneficial. A black and white plan deprived of unnecessary elements highlights proportions of urban interiors and their mutual relations. The analysis focuses solely on undeveloped space surrounded by buildings. At the 3D level, the structure of a city is more complex. Therefore, 3D isovist in a given point of a city opens a wider space for potential analyses. It includes for example visible parts of the area (depending on topography), visible sections of facades and roofs.

Each of the elements of the isovist 3D visibility field (land, facades, and roofs) can be subject of separate urban analyses, as needed. As regards the topic of the article, we can examine the visibility of a tall building from windows of other buildings. In such a case facades are the main objects of analyses (also real window surfaces for LoD3 models). A key element of the solar potential analysis (Kassner et al., 2008) is the roof on which solar panels can be established. A point for setting isovist 3Dis the center of the solar system and the analysis should take into consideration the movement of the Earth. For a long time, it has been possible to provide calculation using GIS programs necessary for the simulation of the visibility of the land grid. In mountainous areas the land configuration can be subject of separate landscape analyses important for regional planning (Ozimek, 2008).

In the scale of a city, while considering the issue of visual impact of tall buildings, land plays a key role among components that are within the isovist 3D field. Undeveloped (open) space defines a basic level of urban structure perception. Further delimitation of the space dividing it in to public and inaccessible is possible at the stage of interpreting results. The field of analysis can be limited to open space only, however it will never be equivalent to 2D analysis. A tall building can be seen not only within the direct field of vision but also above clusters of other buildings. The real range of impact grows with the height of a building.

2.3. Simulation of 2d and 3d isovists for tall buildings

Depending on its height, the analysis of visibility of a tall building according to isovist 2D and 3D is shown in the simulation below on a schematic model of a city (fig. 2). A view of the model is presented in the further part of the article (fig. 4). In both instances observation point (*O*) is located at the planned location of a new building. The 2D analysis neglects height of buildings. It results in a classical 2D visibility field that can be verified intuitively. For each point in the undeveloped part of area, the 3D analysis involves calculation of the height of a building (coordinate z of point *O*) at which the building can be seen from a given location. The simulation assumes a limit height (z_{max}) which means the maximum (rational for analysis) height of a tall building. The simulation determines three areas: a) area of full visibility (identical with 2D isovist) when the building can be seen regardless its height; b) partial visibility area when parts of the building can be seen above other buildings (height of building within $z>0$ and $z<z_{max}$); c) area of no visibility, i.e. within the range studies the building cannot be seen.

Studies discussed in the article were implemented using a computer program developed by the authors (C++). The tool enables simulating 3D isovists and using the VIS method. The program interprets models of cities in the CityGML format using semantics of the standard to optimize algorithms. In parallel, comparative research was carried out using ArcGIS with the 3D Analyst application by ESRI. Previous research and studies were developed using the AutoCAD platform by AutoDESK and dedicated authors own applications.

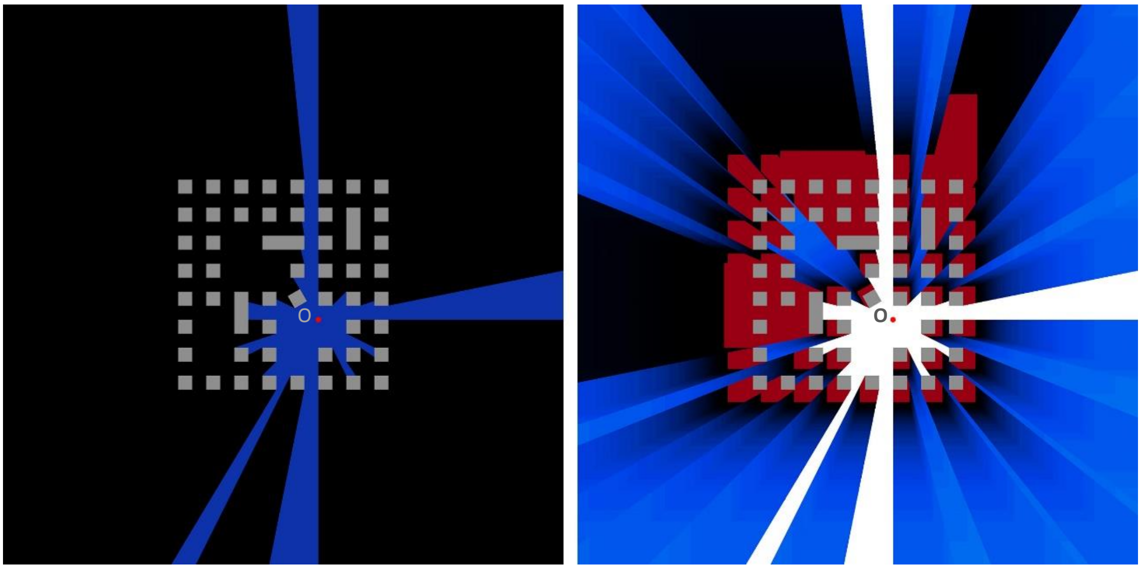

Fig. 2. Analysis of visibility of a tall building according to isovist 2D (left) and 3D (right) on a schematic model of a city. The point *O* of location of a new building is marked in red. On the left side: the isovist 2d is marked in blue. On the right side: area of full visibility is marked in white, partial visibility area is marked in blue scale, no visibility ($z > z_{\max}$) is marked in red

3. Visual Impact Size (VIS)

3.1. Isovist 3d and tall visual tall building impact

The literature includes a number of examples of practical isovist application (Łubczonek, 2008; Moser et al. 2010;Pal Singh et al. 2013). However, there fewer examples referring to visual aspect of high development. Van der Hoeven and Nijhuis (2012a,b; 2011) describe analysis of the visual impact of Rotterdam's and Hague's buildings on the open landscape by means of GIS. They describe two aspects of visual information: visual coverage and cumulative visibility represents the intensity, or amount of high buildings in the skyline of the city. Yamano (2005) refers to studying visibility and visual size of a tall building. Another example is the study of tall buildings performer for Helsinki (*Korkea Rakentaminen*, 2011). Isovist was used to examine the visual impact of tall buildings, with particular emphasis on the exposition above the Gulf of Finland. Professional experience of the authors confirms applicability of the isovist for analyzing tall buildings. The method was used several times for studies on city landscape. One of examples were studies of tall buildings impact on city landscape, prepared for 10 selected locations in Szczecin, in 2007-2008. Experience gathered was further developed at research level (Czyńska, 2014; 2009a,b; Rubinowicz, 2013; 2012). Major observations refer to increase of the impact area of a building with the increase in its height. The observations enabled formulating objectives of the method described in the article as the Visual Impact Size (VIS).

3.2. Increase of the visual impact field of tall building

Interesting observations concerning the nature of isovist in relations to tall buildings are linked with the structure of changing visual impact area in relation to the height. The structure of increased visual impact area is presented here, using a theoretical example, for a part of Berlin (fig. 3). The area of 9km^2 is situated in the Charlottenburg District. The point studied is placed in the center of a square (Viktoria-Luise-Platz). It represents a hypothetical tall building. The visual impact areas increases proportionally to the height of a building. Initially the area concentrates around the building, within adjacent streets and squares (fig. 3, stages 1-3). When the average height of neighboring buildings is reached (about 25-30 m) the studied facility can also be seen beyond the build-up area – at outskirts of the city (fig. 3, stages 4-6). At that stage, the impact inside the city structure increases a little. The visibility area increases at the outskirts and concentrically, from the outside, approaching the point in question (fig. 3, stages 6-8). At the height of 200 m and more the building starts dominating the landscape and becomes visible from various undeveloped areas and from large public areas in the city (streets, squares, and green areas).

The simulation shows basic features of the tall buildings visibility in the city. Figure X presents different layers of the visibility field at the planned building height of 500 m. The buildup area of this city section is 27.14% (fig. 4a), whereas the undeveloped land of 72.86% is a public space. The latter plays a crucial role in further analysis (fig. 4b). The structure of a growing visibility field of a tall building depending on the increase in its height has been presented in graphs (fig. 5). The study covers heights from 10 to 500 m. At the level of 10m the building can be seen from 1.4% of public space. Thus, it has only a local impact on the city landscape, whereas at 80m, the impact field is 5.82%, at 100 m 8.46%, and in the case of 200 m it is 24.06%. When the building is 500 m in height, it can be seen from 51.12% of public space. The increase in the visibility field is incremental, but not even. It is going to be the most significant at about 100 m to 200 m. Moreover, the geometrical structure of visibility fields and areas with no visibility at all vary. Visibility fields are more compacted (fig. 4d), and areas of no visibility are more dispersed (fig. 4c). At larger heights of the building, the geometrical complexity of the visibility field is higher, and it is virtually unpredictable intuitively.

Results of the simulation are to a large degree universal and enable explaining observations from several European cities. It explains a frequent lack of visibility of tall buildings in a city despite their clear domination over neighboring buildings. In cities such as Nurnberg, Munich and Berlin, despite mixed heights of buildings, introducing new tall buildings to the center does not involve major visual relations. What are then conditions determining the visual impact area inside a city? When does a tall building can be seen in an open landscape? A sequence of isovists shows relations between the height at a selected point and the density of urban structure. The higher the average density of buildings and higher buildings in the vicinity, the smaller the impact of a tall building in such a space. The urban composition is equally important, and the same applies to the position of a building in question. In axial arrangements, concentric in relations to an examined location, with a large number of squares and open areas the impact of tall building will increase.

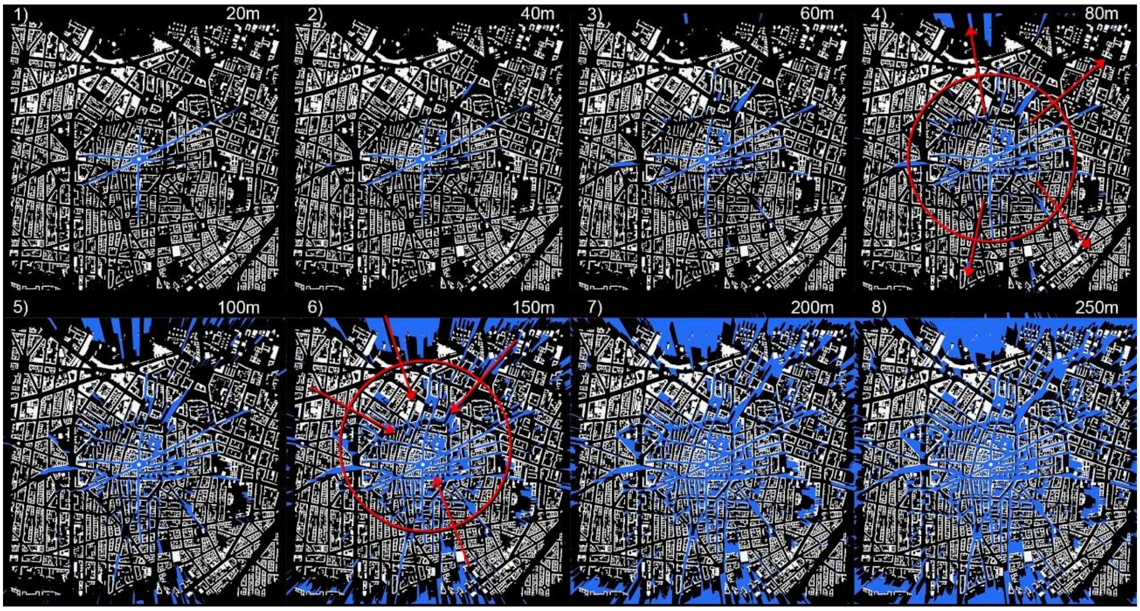

Fig. 3. Sequence of 3d isovists showing increase in visual impact area of building in urban structure depending on its height – example of Berlin. Analysis performed for buildings of: 20m, 40m, 60m, 80m, 100m, 150m, 200m, and 250m.

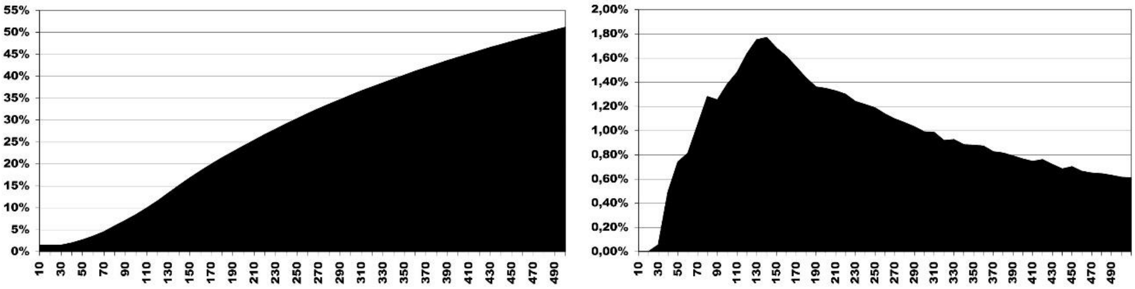

Fig. 4. Graphs showing increase in visibility field for tall building in relations to growing building height (example of Berlin). Left: visibility field expressed as percentage of total public area. Right: growth rate for visibility field at consecutive levels of building height.

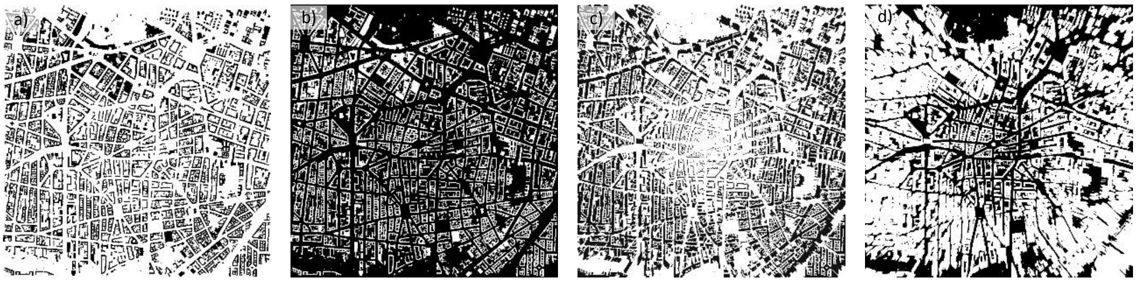

Fig. 5. Layers of visibility of individual building 500m in height (example of Berlin): a) developed areas (black) and public space (white), b) public space (black) and developed areas (white), c) public space from which building cannot be seen (black), d) public space from which facility can be seen (black).

3.3. VIS assumptions and computation rules

Conclusions regarding the increase in the visual impact area on the example of Berlin are to a large degree universal and applicable to many cities. Relations discovered inspired the authors to develop the VIS method (Czyńska, 2015; see also Yamano, 2005). Contrary to previous simulations, the method aims at showing a total impact of a tall building in a city. This leads to developing a single visual impact map (VIS) which facilitates interpretation of results and their application in planning. A novelty of the method is imaging of not only real visual impact range but also imaging of the impact power (expressed in intensity of color used).

Relevant number and height of thresholds, depending on a specific nature of a city, are crucial for the quality of results. It the number of thresholds is too big, the result is not legible. The drawing below (fig. 6) shows examples of the VIS analysis for an abstract model. Seven thresholds are assumed (20, 40, 50, 60, 80, 100, 150 and 200 m) for which the analysis was performed. Computer simulation produces a map with all locations from which the planned building can be seen. Colors used in the map reflect the strength of exposition of a planned building in space. It is the most visible from areas marked red according to the chart below (fig. 6). The impact area can be presented in a projection and in two axonometric or perspective views (fig. 7a, b, c). The VIS simulation reflects a real impact of the building in a city landscape.

The sequence below (fig. 7c) enables examining how particular 3d isovists change depending on the location of a tall building against the analyzed urban structure. Based on examples of the urban tissue we may draw general conclusions concerning the exposition of tall buildings in a city. It is possible to examine the change of the visibility area depending on different heights and locations of a building. We can also observe relations between the location and shape of the visibility area. Relations with the urban composition become clear. Terms such as street axes, shapes and size of squares, visibility foreground gain new meanings in relation to the exposition of a tall building.

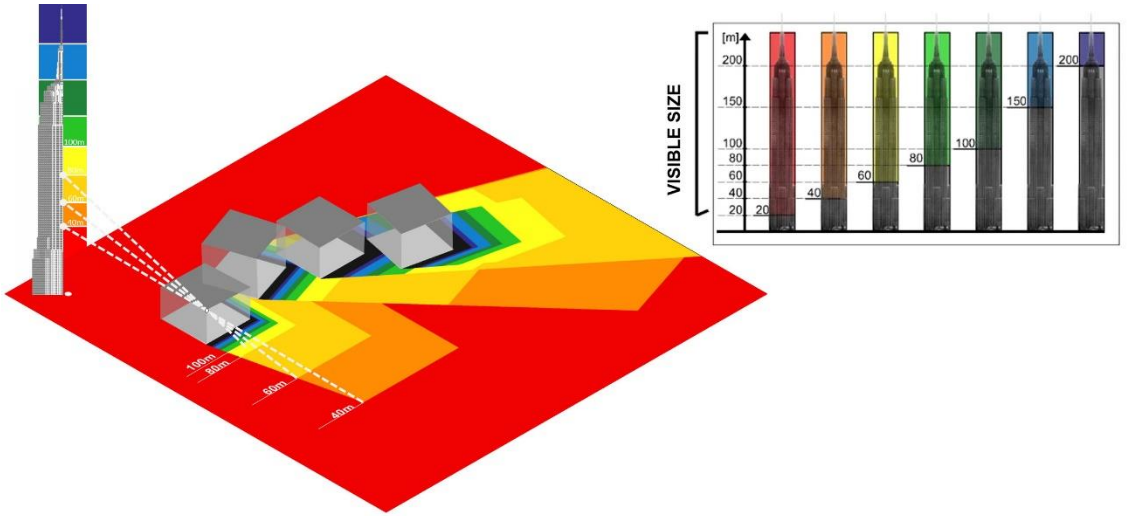

Fig. 6. Diagram explaining the principle of the VIS analysis. Colors indicates the size of building visible from area of observation

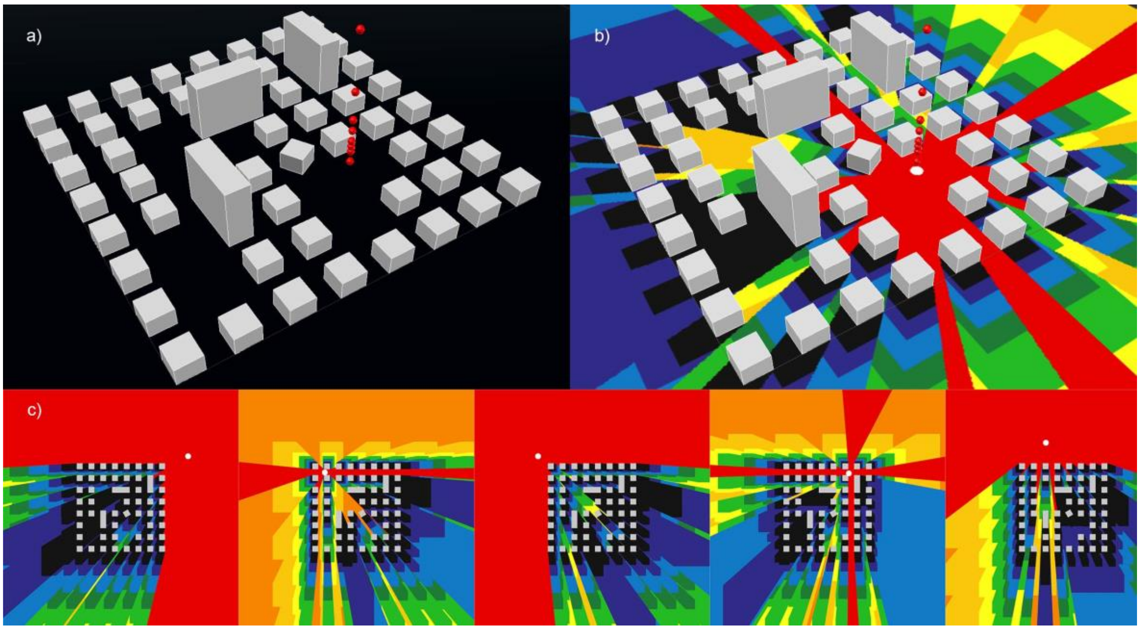

Fig. 7. VIS analysis for a schematic build-up development model. Analysis performed for 8 heights of hypothetic tall building (a). Colors reflect strength of exposition of building in space (b). Below (c): simulation for several locations of building.

4. Application of the VIS method in planning

The application of the VIS method can be observed using the example of a real city space – e.g. part of Frankfurt center. The city has its individual landscape where tall buildings prevail (fig. 8a). The study examines a location situated at one of squares in the middle of dense structure of streets based on a historical grid in the immediate neighborhood of a tall buildings cluster. The analysis indicates location of strong exposition (fig. 8c). Usually, the result is limited to examining of public space, understood as all undeveloped sites in a city. Simulation, however, may include examining of tall building visibility from other buildings and all predefined geometrical elements of the 3D city model. In this particular case of the Frankfurt old town, these include adjacent axes of streets leading towards the building. Along the river of Main, visibility of the building is excellent, since the building is exposed from 40 m in height. Provided there are limitations to the development of the city skyline from the side of the river, the above analysis could help determining the maximum permitted height of buildings at the square. The major advantage of the method is that it determines all locations of visual exposition of a building in a city, which is crucial for determining planning guidelines.

The analysis of Frankfurt was developed using the computer program developed by the authors (C++). Input material included a CityGML model of a city with precision of LoD2 imaging (with geometry of roofs – fig. 8b). VIS simulations can be performer using a conventional GIS software and available tools. Differences apply to the precision of simulations. The algorithm used in the program developed by the authors emulated VIS maps using a vector model of a city as a basis. GIS tools such as ArcGIS (with 3D Analyst application) by ESRI use the Digital Surface Model which reflects the geometry of a city in a simplified manner. The precision of imaging of the model is important in the case of analyzing a complex geometry of buildings comprising historical skylines of European cities. They contain a number of tower like elements. Neglecting them may distort results of the analyses and impede their interpretation in urban planning. However, analyses based on DSM models are frequently the only solution possible (in case CityGML model is not available). In such a case, results of the VIS analyses are less precise and depend on the precision of the model. Their advantage is, however, it the possibility of examining large sections of a city and reduced cost of data acquisition. This has been described more extensively in other publications (Czyńska, 2015).

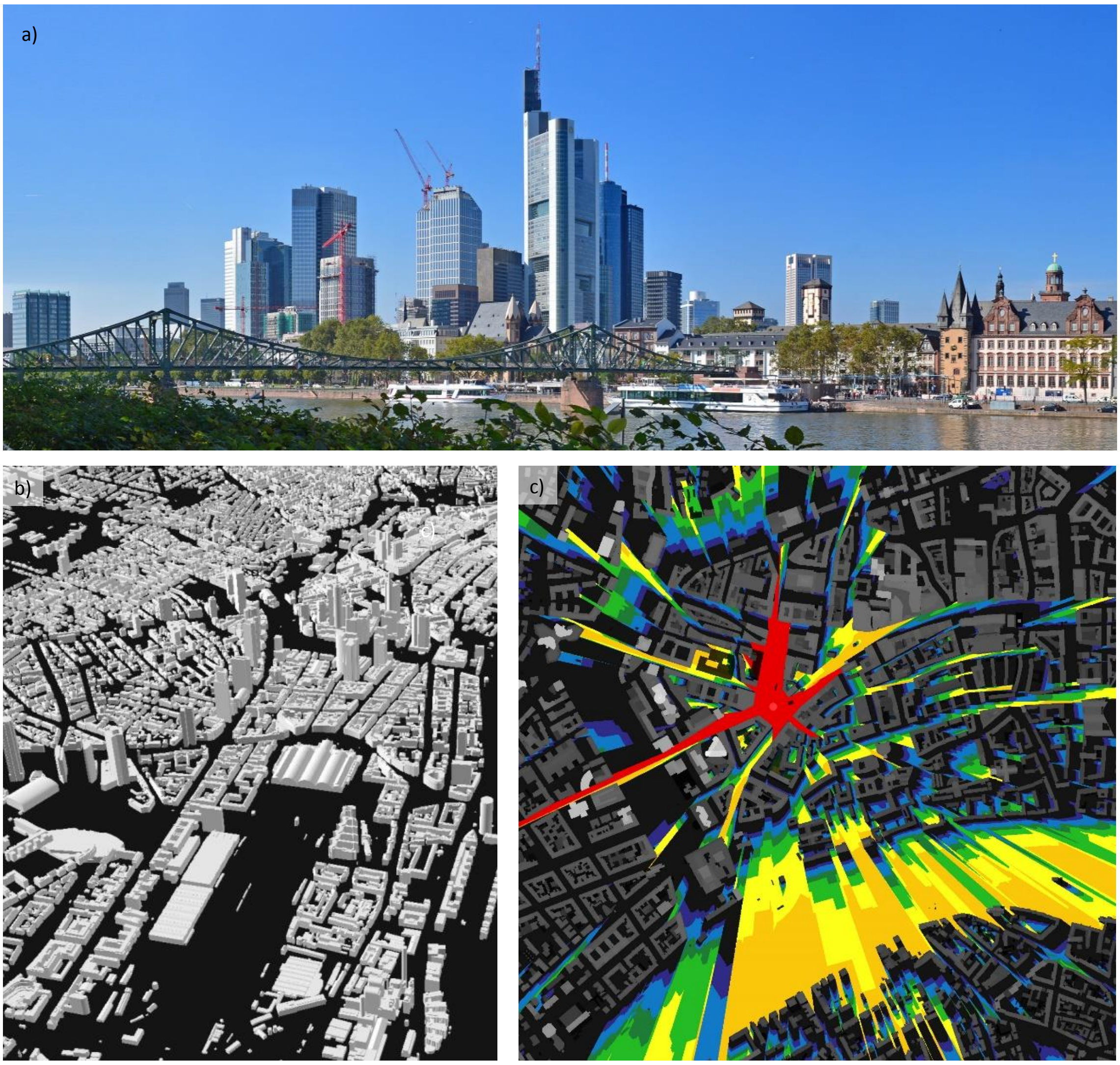

Fig. 8. Analyses of VIS for Frankfurt: a) panoramic view of the city from the river side; b) CityGML model of city and c) VIS analyse for location of tall building in old town area

In the professional practice of the authors, the VIS method proved to be particularly useful (Czyńska, 2009a). It was used in 2007 to verify potential locations of tall buildings in Szczecin, Poland. The studies were implemented under a contract with the local government (Czyńska et al., 2007). The studies analyzed in total 10 potential investment projects. The aim was to determine the impact of planned facilities on the city landscape while taking into consideration cultural values and define detailed guidelines concerning their height and form (fig. 9). Yet another example of the application of methods is the 'Study of visual values of the city of Lublin' developed under a contract with the local government in 2011 (Czyńska et al., 2011). It aimed at determining rules for protecting historical skylines and silhouettes.

In the case of analysis for Szczecin, results differed significantly from what authorities expected. VIS simulations revealed the real complexity of visual phenomena. The range of impact of individual buildings covered sometimes distant and dispersed sections of public space in the city. Simulation provided a starting point for further analyses. In order to organize, interpret and describe results it was necessary to divide VIS into visibility zones (fig. 10). An important example, discussed in other publications (Rubinowicz, 2013), is the analysis of two tall buildings near a square in the vicinity of an inbound road (Szyrockiego Square). Analyses showed that the buildings could be seen inside the landscape of the Main Cemetery. The interaction revealed using computer techniques was hardly foreseeable and appeared as a major surprise. Similarly, in case of other building facilities interesting 'spatial discoveries' were made. Results of the simulation significantly influenced final planning guidelines for tall buildings. In some locations tall buildings was excluded or to a large degree limited their height (fig. 9). The guidelines were included in master plans.

5. Conclusions

Developing tall buildings in European cities is controversial and generates strong emotions. There are probably as many supporters as well as those who are skeptical to such a development. To bring the discussion to the level of objective and measureable arguments it is necessary to develop tools that enable analyzing the phenomenon at its geometrical level. In other words, analyzing it in an objective manner to the extent possible so the result achieved is not debatable. In many instances the negative impact of tall buildings on the city landscape is the result of mistakes in the planning process, disregarding of important views in analyses, etc. Although a realistic visualization of a new investment project has become a standard element of the architectural design process, a reverse action which involves determining all locations in a city from which a building can be seen is a larger challenge. The use of the isovist theory enables examining such relations.

The VIS method, outlined in the article, is a proposal for imaging of the tall building impact on the landscape of a city. On the one hand, objectives of the method result from research by the authors, and on the other, they are effects of their professional experience from developing guidelines for potential tall buildings (where method was applied). In important part of VIS is to visualize the impact of a tall building. With the increase in accessibility and precision of digital 3D city models, possibilities for using the method in real urban planning increase as well. The simulations presented in the article were developed using a special computer program developed by the authors, dedicated to analyzing CityGML models. However, it is possible to generate approximate VIS using DSM models and LiDAR data (LAS). It is also possible to simulate approximate VIS results by using different GIS programs. The main limitation and challenge is the size of data to be processed, which is applicable mainly to large cities. The VIS analysis should cover the entire space of a city and sometimes also its wider landscape context.

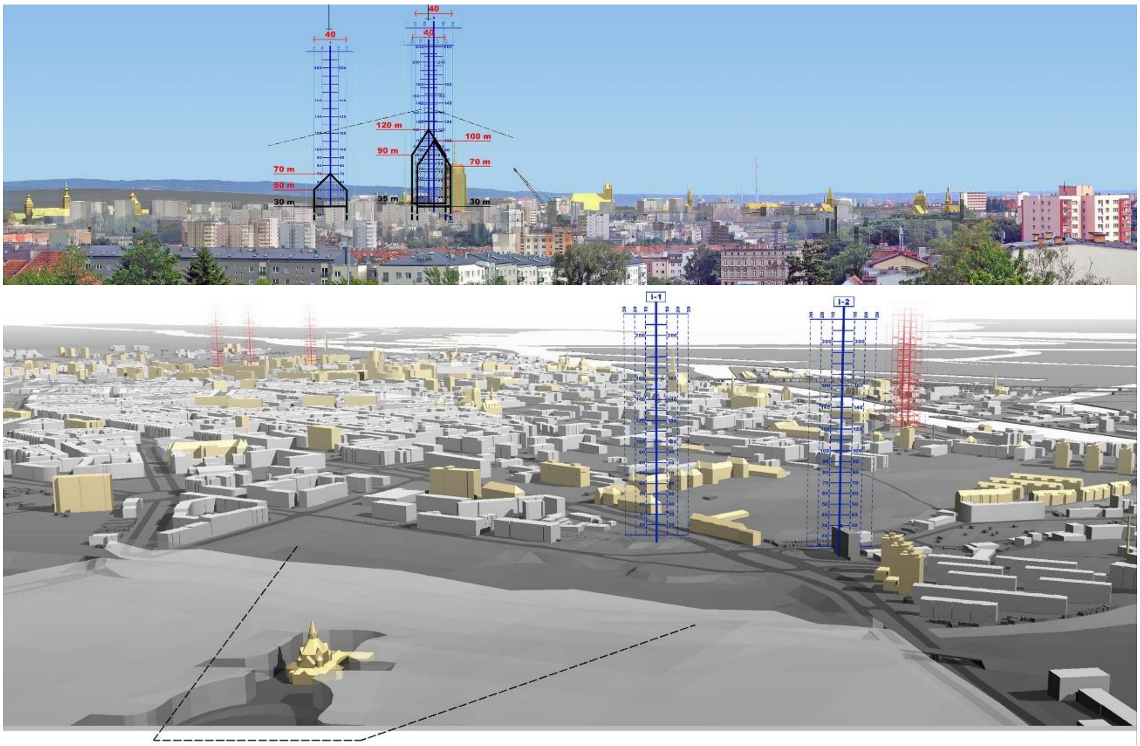

Fig. 9. Analysis of impact of planed tall buildings on cityscape in Szczecin (Poland) with detailed guidelines concerning their height and form (above). The analysis covered large area of city (below)

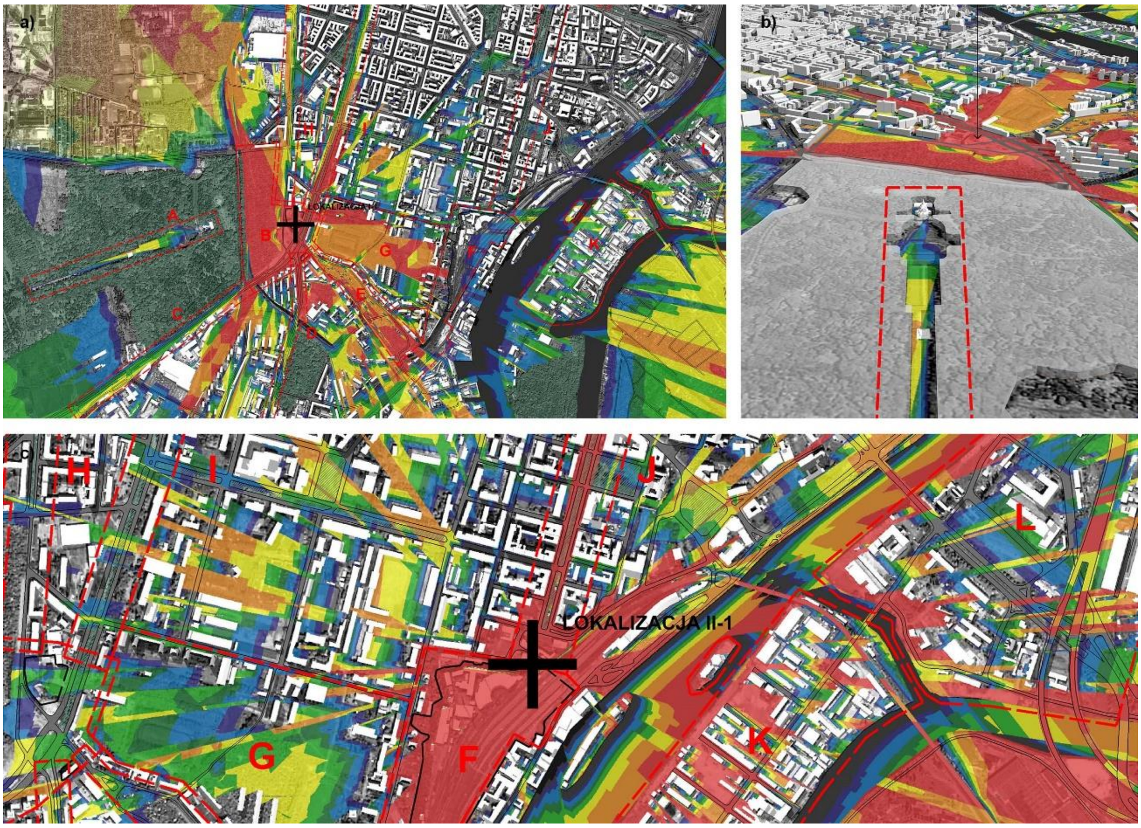

Fig. 10. Analyses of VIS for Szczecin (Poland) form 2007: a) VIS for tall building at Szyrockiego Square, b) visual impact of building inside the landscape of the Main Cemetery, c) VIS divided into visibility zones

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REFERENCES

Batty, M. (2001), 'Exploring isovist fields: space and shape in architectural and urban morphology'. In *Environment and Planning B: Planning and Design*, Vol. 28, p.123-150.

Benedikt, M. L. (1979), 'To take hold of space: isovist fields', In *Environment and Planning B: Planning and Design*, Vol. 6, p. 47-65.

Conroy Dalton, R., Bafna, S. (2003), 'The syntactical image of the city: a reciprocal definition of spatial syntaxes', In: Hanson, J. (ed.), *Proceedings of the Fourth International Space Syntax Symposium*, London: University College London, p. 59.1-59.22.

Czyńska, K. (2015), 'Application of Lidar Data and 3D-City Models in Visual Impact Simulations of Tall Buildings', 36th International Symposium on Remote Sensing of Environment, 11–15 May 2015, Berlin, Germany. In: *Int. Arch. Photogramm. Remote Sens.* Spatial Inf. Sci., XL-7/W3, doi:10.5194/isprsarchives-XL-7-W3-1359-2015, p. 1359-1366.

Czyńska, K. (2014), 'Geometrical Aspects of City Skyline – Tall Building Analysis'. In: Schröcker, H.-P. and Husty, M. (eds.), *Proceedings of the 16th International Conference on Geometry and Graphics*, Innsbruck: Faculty of Engineering Science, p. 519–530.

Czyńska, K., Marzęcki, W., Rubinowicz, P. (2011), *View values of Lublin*, Urban Study commissioned by Department of Spatial Planning, City of Lublin.

Czyńska, K. (2009a), 'Can tall buildings enrich the beauty of the city?' In: *Proceedings of international conference Urban Landscape Renewal*, Gliwice , p. 401-409.

Czyńska, K. (2009b), 'Using a model of virtual city for research on visibility range of panoramas of the city'. In *Space and Form* no 12, p. 111-114.

Czyńska, K., Marzęcki, W., Rubinowicz, P. (2007), *Analyses of visual impact and definition of spatial guidelines for high buildings in Szczecin*, Urban Study commissioned by Department of Spatial Planning, City of Szczecin.

Fisher-Gewirtzman, D. (2012), '3D models as a platform for urban analysis and studies on human perception of space'.In *Usage, Usability, and Utility of 3D City Models*. p. 01001.1–01001.16. Available at: http://dx.doi.org/10.1051/3u3d/201201001.

Kassner, R., Koppe, W., Schüttenberg, T., Bareth, G. (2008), Analysis of the solar potential of roofs by using official lidar data. In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B4. Beijing, p. 399-404.

Korkea Rakentaminen Helsingissä, Kaupunkimittausosasto, Helsinki 2011, ISSN 1235-4104

Łubczonek, J. (2008), 'Application of GIS Techniques in VTS Radar Stations Planning'. In: *Proceedings of International Radar Symposium*. Wrocław: Telecommunications Research Inst, p. 277-280.

Morello, E, Ratti, C. (2009), 'A digital image of the city: 3D isovists in Lynch's urban analysis'. In: *Environment and Planning B: Planning and Design* 36(5), p. 837-853.

Moser, J., Albrecht, F., Kosar, B. (2010), 'Beyond visualisation – 3D GIS analyses for virtual city models'. In: *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVIII-4, *ISPRS International Conference on 3D Geoinformation*, Berlin 3-4 November 2010, p. 143-147.

Ozimek, P., Ozimek, A., (2008), Computer Aided Method of Visual Absorption Capacity Estimation. In: Buhmann, Pietsch, Heins (Eds.), *Digital Design in Landscape Architecture, Proceedings at Anhalt University of Applied Sciences* 2007/08, Wichmann Verlag, Heidelberg, p. 105-114.

Pal Singh S., Jain K., Mandla V. R. (2013), 'Virtual 3D city modeling: techniques and applications'. In: Isikdag, U. (ed.), *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. XL-2/W2, *ISPRS 8th 3DGeoInfo Conference*. Istanbul 27–29 November 2013, p. 73-91.

Rubinowicz, P., Czyńska, K. (2015), 'Study of City Landscape Heritage Using Lidar Data and 3d-City Models', 36th International Symposium on Remote Sensing of Environment, 11–15 May 2015, Berlin, Germany. In: *Int. Arch. Photogramm. Remote Sens*. Spatial Inf. Sci., XL-7/W3, doi:10.5194/isprsarchives-XL-7-W3-1395-2015, p. 1395-1402.

Rubinowicz, P. (2013), 'Cyber Urban Center: The Visual Impact Simulations for Tall Buildings Analyzes in Szczecin'. In: *Proceedings of International Conference Creative Urbanism*. Lviv: National University Lviv Polytechnic, in press.

Rubinowicz, P. (2012), 'Various Aspect of Urban Structure Analysis while Assessing the Friendliness of a Place – Example of Lublin', In: *Proceedings of international conference Urban Landscape Renewal*, no 6, vol. 2, Gliwice, p. 345-350.

Suleiman, W., Joliveau, T., Favier, E. (2013), 'A New Algorithm for 3D Isovist'. In: *Proceedings of 15th International Symposium on Spatial Data Handling Geospatial dynamics, geosimulation and exploratory visualization*, Bonn 22-24 August 2012, p 157-173.

Turner, A., Doxa, M., O'Sullivan, D., Pen, A. (2001), 'From isovist to visibility graphs: a methodology for the analysis of architectural space'. In *Environment and Planning B: Planning and Design*. Vol. 28, p. 103-122.

Van der Hoeven, F., Nijhuis, S. (2012a), 'Devloping Rotterdam's Skyline'. In: *CTBUH Journal* Issue II, p. 32-36.

Van der Hoeven, F., Nijhuis, S. (2012b), 'Planning and Visibility Assessment of High Building Development in The Hague'. In: Meyer, H., and Zandbelt D. (eds.), *High-Rise and the Sustainable City*, Techne Press, p. 102-119.

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

Yamano, T., Yoshikawa, S. (2005), 'Cityscape analysis and simulation with three-dimensional urban model'. In: *Proceedings of the 9th International Conference on Computers in Urban Planning and Urban Management* (CUPUM2005). London: University College of London, p. 1-14.

Yin, J. (2013), *Mobile 2D and 3D Spatial Query Techniques for the Geospatial Web*, Doctoral Thesis, Dublin Institute of Technology.

Zwolinski, A., Jarzemski, M. (2015), 'Computing and monitoring potential of public spaces by shading analysis using 3d lidar data and advanced image analysis', 36th International Symposium on Remote Sensing of Environment, 11–15 May 2015, Berlin, Germany. In: *Int. Arch. Photogramm. Remote Sens.* Spatial Inf. Sci., XL-7/W3, doi:10.5194/isprsarchives-XL-7-W3-743-2015, p. 743-750.