GEOMETRICAL ASPECTS OF CITY SKYLINE – TALL BUILDING ANALYSIS

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ABSTRACT: Virtual 3D city models and digital analytical techniques may significantly facilitate the process of studying a city structure. They enable imaging and conducting of advanced analysis of city skyline. They can be applied to tall buildings phenomenon which became one of the most important challenges for contemporary European cities. On the one hand, we attempt to maintain the unique historical values of cities and on the other, we tend to create a contemporary image of a city with tall buildings as a symbols of modernity. Therefore, in order to protect valuable urban and architectural development, location of tall buildings should be determined on the basis of prior in-depth analyses. The article presents geometrical techniques based on digital processing virtual city models: methods of visual impact range, view range and view angle analyses. Those methods have been successfully used in planning process as a basis for defining guidelines for erecting new tall buildings and protecting old city skylines.

Keywords: 3D virtual city models, 3D analysis, tall buildings, city complexity, urban planning.

1. TALL BUILDING IN EUROPE AND CULTURAL HERITAGE PROTECTION

Landscapes of European cities result from centuries of evolution taking place in urban systems. A novelty, from the point of view of historical pace of development, are new tall buildings. In the 21st c., tall buildings have become a fixed element in landscapes of many European cities. This development is increasingly popular in various countries, including Scandinavia which up until recently preferred low rising buildings, for example Malmo and Stockholm. Following footsteps of American and Asian cities, the largest metropolises of the old continent transform their historical landscapes. A skyscraper is a generally accepted attribute of modernity and grand cities, and interpreted by many people as an attribute of modernity, prestige and economic advancement. A cluster of tall buildings is a powerful symbol of a modern city, a fascinating view attracting tourists in large numbers [25].

However, developing of tall buildings involves major threats to landscape cohesion and integrity in European cities. Specific architectural and urban arrangement reflected in the silhouette of a city is an important part of the protected cultural heritage. Due to their broad visual impact range, tall buildings frequently induce unfavourable and unplanned interaction with historical buildings. 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 Europe, more than on other continents, it is believed that a tall building should have particular architectural and spatial features [18]. A tall building is considered to be an icon in terms of its nature and position in the urban structure. 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.

In many European cities, we can find effects of wrong decisions concerning the location of tall buildings. One of examples is the panorama of London as seen from the river of Thames. The panorama shows a lively expansion of various architectural forms. Several tall buildings are situated not only in the City or Canary Wharf, but they are also scattered in various parts of the city. Due to the above, in some important views, elements of historical cultural heritage, such as St. Paul's Cathedral, lose their significance (Fig. 1). Paradoxically, London has one of the most developed landscape protection systems. A comprehensive system of assessing and selecting city views was developed supported with detailed description of advantages of the existing landscape which needs to be protected [26]. This is accompanied by a system of verifying planned tall buildings by simulating their impact in selected strategic views: London Panoramas, River Prospects, Townscape Views and Linear Views [16]. However, the speed of spatial changes exceeds any controlled levels. It is not easy to counteract planning errors made several decades ago, and frequently those errors support consecutive cases of mismatch in planning locations for tall buildings. In the 20th c., when the first tall buildings were built, the tool kit of an urban planner was limited to traditional tools, such as sketches and individual cross sections. Professionals could resort to their experience and intuition only. Thus, a number of design errors were made. Is the contemporary methodology of analysing locations of tall buildings sufficient for determining relevant and comprehensive spatial policies?

The majority of cities which faced the issue of tall buildings developed modern instruments for monitoring their impact on the landscape. Such instruments for London [16, 26] are some of the most complex examples. They include detailed information concerning major views of the city, criteria for selection and significance of its cultural heritage. Each new construction project, pertaining to developing a tall building in particular, necessitates analysing the impact of a building facility on the landscape within predefined strategic views [16]. A similar procedure is applied in Koln [14] and Dusseldorf [13]. Several cities have also developed strategies for locating tall buildings [1, 4, 22, 28]. The strategies usually comprise studies of urban morphology, which examine conditions at specific sites for developing tall buildings. They define potential locations while taking into consideration factors related to the overall composition (e.g. shadow effect, accessibility, public transport, land topography, air traffic, etc.). Interesting studies have been developed in Ottawa (2007) aimed at protecting the landscape of the Parliament Hill [5] and in Vancouver (2011) to determine the potential for developing the silhouette of the city and encompassing a mountainous landscape in the background [15]. The study developed for Milan (2007-2011) focused on analysing visual experience while moving within the structure of the city. The analysis was supported by a 1:500 mock-up of the city and a special micro-camera used for simulating the reality [21]. A study developed for Warsaw (2008) is more general in its nature. It defines tendencies for developing tall buildings based on the silhouette of the city seen from the side of the river [19]. According examples of tall buildings developed recently in the city, so much limited criteria turned out to be insufficient to protect valuable urban and architectural facilities. This short overview of techniques for analysing influence of tall buildings on the landscape show how diverse approaches used can be and highlights the fact that there is no universal standard in the area. We are still searching for relevant solutions. The use of digital tools, however, is a step towards obtaining objective results and expediting analyses.

Figure 1: Axial view from Millennium Bridge, London, with tall buildings seen behind St. Peter's Cathedral

2. VIRTUAL CITY MODELS AS NEW TOOL FOR URBAN ANALYSIS

In recent years, the number of 3D virtual models and their precision were growing at an exponential rate. Texturing of elevations and integrating models with photographs (Google Street View) provides much higher degree of virtual imaging the reality. A pre-taste of a further advancement is a new standard of data recording, CityGML [11], developed recently. While analysing the development trends, we may assume that probably within coming years 3D models will cover entire territories of economically developed countries, fully reflecting their built-up substance and natural landscape. But, for the urban planning virtual city, models are only a new tool. Neither the degree of reality nor interactivity of visualization is important. What counts is the possibility of application for analyses and simulations, extending the conventional, manual urban planning workshop [23].

To assess the impact of tall buildings, it is necessary to visualize panoramas [6]. This is a specific form of projecting city space combining various development planes overlapping each other. Numerous experiments showed that perception of such views depends much on facilities with distinguishing building which stand out in their surroundings: contemporary and historic landmarks, existing skyscrapers of unique silhouettes, church towers, characteristic historical buildings, some elements of infrastructure and other visually accentuated elements [23]. On the one hand, it is important to differentiate model precision levels as required by specific analyses. Certain elements can be presented at a general level others need to be extremely precise. On the other hand, in the majority of planning applications, 3D city models need to be linked with a relevant database (e.g. functions of facilities) and support interpretation of structural relations (e.g. recognition of building as a whole rather than set of walls or lines).

Research on using virtual city models in urban planning has been rapidly growing. However, the potential of the tool is still very little recognised. The development of tools for developing and imaging of those models is ahead of their application. The main steam of application of virtual city models is still focused on presentation and visualization of city structure for facility services, commercial sector and marketing, promotion and learning of information on cities (like: promoting cities, tourism, visualizations for investors, etc.) [20].

2D and 3D GIS analyses are considered a more advanced way of using city models. Readymade and optimized tools dedicated to the Geographic Information System can be used for: measuring density of buildings, studding proximity, spread analysis, like dynamic air flow, acoustic analysis, simulation of disasters, traffic management etc. [17]. For instance, 3D models are used in visibility analyses. The visibility of points in a landscape from one or more locations has many applications. These include studies of scenic quality, urban design, civil and military observation needs and telecommunications planning, amongst others. Typically these operations are performed on grid files, but a similar, vector-based procedure is known as Isovist analysis [10]. The relevant theory in this field is still under development. Consequently, fields of application also increase in numbers. The development of the theory has been examined by Fisher-Gewirtzman [12] while referring to the most important publications. Among them, a particular classical role is played by Benedikt [3] who was the first to introduce the Isovist and to develop a set of analytic measurements of isovist properties. A number of researchers have developed tools for automated isovist analysis. Turner et al [29] uses a set of isovist to generate a graph of mutual visibility between locations. Batty [2] 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. Yin [30] in his doctoral thesis summaries limitations of 2D and 3D visibility calculations.

We could also witness a major progress in developing tools supporting calculations. Simple and intuitive applications for obtaining a map/visualization of the viewshed for a particular point in space were in recent years developed. Google Earth Pro provides a tool to visualize the field of visibility in the 3D models available on the platform [31]. The precision of the analysis, however, is still low and cannot be treated as a research tool. GIS tools provide seem to be more promising, for example ArcGIS by Esri. They enable determining the visibility of sight lines, identification of observer points from raster surface or construction of sight lines, among others. [32] The number of advanced GIS tools is growing. The same applies to GIS open source software. The functionality of free QGIS together with GRASS GIS package is similar to Esri. The number of possible field of application of those tools has been growing as well. One of them is diagnosis and simulation of tall buildings.

3. SKYLINE AND TALL BUILDINGS – SELECTED METHODS OF ANALYSIS

This chapter discusses selected methods used by the author of the article that are crucial for examining geometrical issues determining the influence of tall buildings on the skyline. The theoretical framework of those methods was initially developed between 2004–2006 and described in a doctoral thesis [7]. Later, the methods were further developed (since 2012, in Cyber Urban Centre at West Pomeranian University of Szczecin, Poland). Relevant software was developed supporting the use of new tools in urban planning.

3.1 Analysis of visual impact range

Planning of new tall buildings necessitates analysing 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) [31]. Visual perception of a city is a dynamic process. Relations between buildings change together with the point of observation. These relations are analysed 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 method aims at providing objective imaging as regards range and visual impact of a single tall building. The algorithm is based on a geometrical analysis of a virtual city model. The only requirement is to specify a precise location of a tall building. Computer simulation produces a map with all locations from which the planned building can be seen. The impact area can be presented in a projection and in two axonometric or perspective views. 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 (Fig. 2).

Objectives of the method are similar to those of isovists and methods of automated determination of visibility fields available in GIS tools. Differences apply to the interpretation and precision of simulations. 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 colour used). Complexity of results depends on the complexity of the city structure. It obviously depends on the precision of the virtual city model, including the precision of the site digital model. Taking into consideration of tall green (various ways of modelling) is important, since it may have its impact on the result of the simulation. Results of simulations using the method frequently deviate from our intuitive expectations. Geometrically defined impact of a tall building is usually much broader than we could assume and the computer analysis reveals new and not that obvious spatial relations in the city.

3.2 View angles analysis

Another direction for developing urban analysis is to examine particular viewpoints. In the case of several studies, protecting specific strategic views is an important element of the landscape development strategy. The study developed for London [16] lists 27 views which are strictly protected and are considered to be very important from the cultural heritage point of view. Traditional urban planning uses specific terms to describe a morphology of a view, including view foreground and exposition background. However, it is quite difficult to define geometrically and measure mutual relations between various planes of a view. Every change in the position of an observer changes the configuration of a view and relations between particular elements of the exposition. Research should cover all variables, including land topography, distance between buildings, building height, tall green, distance and height of an observation point. Due to the complexity of spatial relations between various buildings in the city it is necessary to find techniques for assessing the significance of particular architectural facilities for the overall composition of the city skyline.

The method of analysing view angles aims at an objective assessment of the impact of particular buildings on a given observation point. The analysis is based on calculating an angle between the observer's eye and the tallest point of each building. The largest angle is in the case of tall buildings and those situated close to the observation point (Fig. 3). By using classical designing techniques, usually involving projections and cross sections of the city, it is possible to analyse relations between selected buildings only. Virtual spatial models enable us to expedite and automate procedures, as well as significantly increase the range of buildings analysed to cover all facilities in the spatial model. Analyses take into consideration the exposition height and for each building: its height above sea level, relative height above ground level and distance to the point of exposition (Fig.4).

Thus, the simulation produces view angle maps. The algorithm used enables diverse imaging. The term of a building can be interpreted in various ways (frequently applied division into smaller elements). Contrary to traditional techniques, results are visualised in cross sections but in projections, including axonometric ones. A 10 degree scale is the most frequently used in studies (covering various angle ranges). Although, objectives of the method are relatively simple and based on elementary geometrical operations, the method itself is not popular. On the one hand, there is a shortage of readily available tools in CAD/GIS. This may result from the fact that the simulation results in a quite abstract image of a city, which does not take into consideration a fact that buildings obscure each other. On the other hand, in many instances, such a general image can be very valuable for assessing the interpretation of a view and distinguishing specific exposition planes.

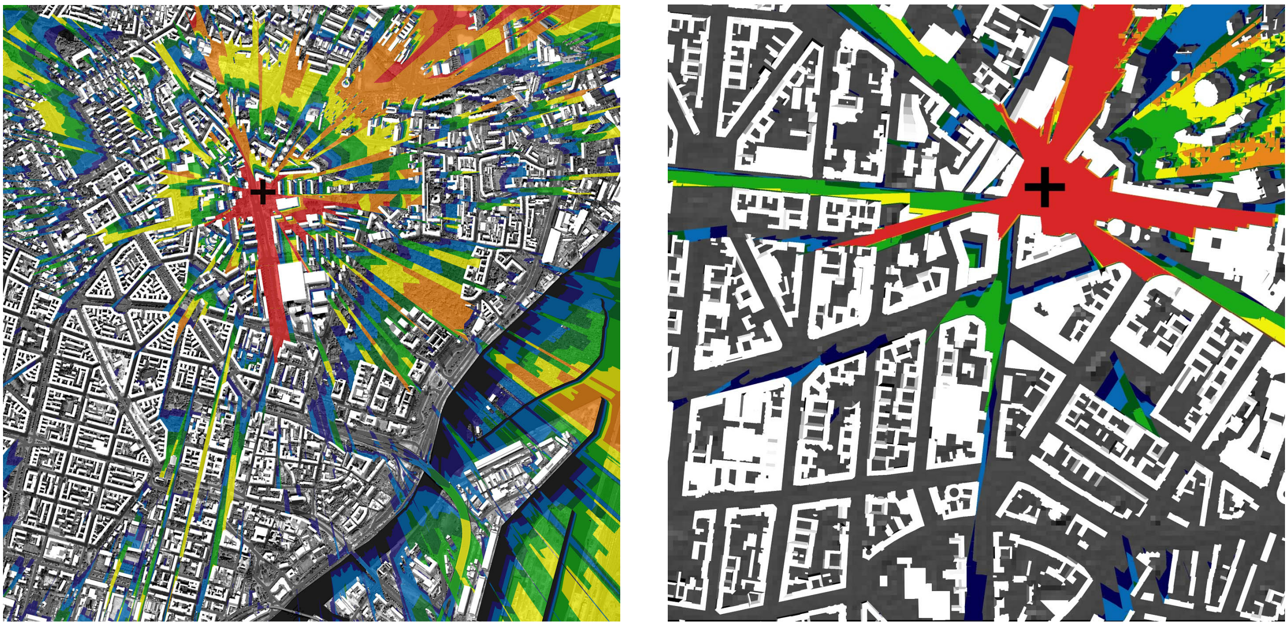

Figure 2: Analysis of visual impact range of tall building;
Hanza Tower in Szczecin, Poland (left), Zoofenster Berlin (right)

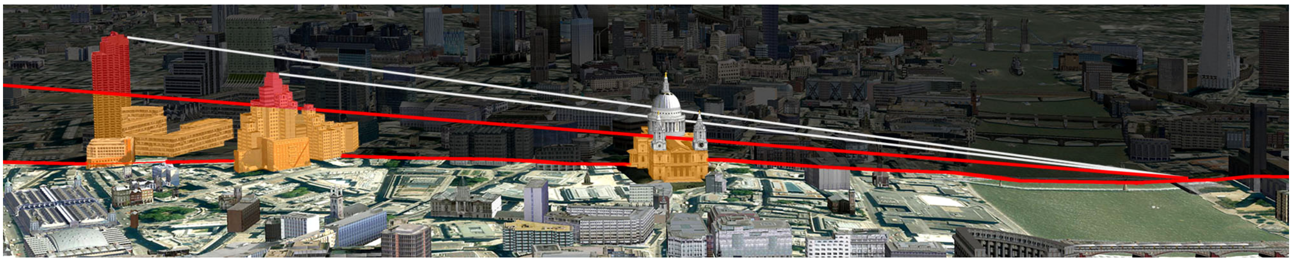

Figure 3: Illustration of the idea of view angles analysis (London)

3.3 The visibility coverage analysis of panoramic view

The method of view angle analysis provides for emulating general impact maps from a given observation point. While analysing city landscapes and studying tall buildings it is important to determine a visibility field taking into consideration mutual impact of buildings in terms of obscuring their view. Skylines expose certain set of elements of the city structure. Some buildings are more visible than others. A view comprised also trees, bridges, technical infrastructure and, first and foremost, topography (e.g. hill in background or foreground). All these elements comprise a panoramic view limited with a skyline of the city. It is possible to determine the panoramic view as a 2D image. However, all elements of the image have their third dimension and they are more of less dispersed in the real space of a city.

The method aims at determining which elements comprise a given view and imaging of those elements together with their spatial relations. While analysing tall buildings, we focus most often on panoramic views. However, any view of a square or a street can also be examined. The basis for the application of the algorithm is a virtual city model. Coordinates of an observation point are pre-set. And the result is a spatial set of elements seen from the observation point (e.g. parts of walls and sections of land, etc.). The analysis is a kind of spatial interpretation of the visible planar projection (Fig. 5). Precision depends of accuracy of the 3D city model and calculation power of a computer. Objectives of the method are similar to those of isovist described by Benedikt [3]. Isovist applications in urban planning and architecture are limited, however, to 2D studies. Determining of visibility in GIS software is frequently limited to a digital model of a given area. Yet another difference is the accuracy of results.

To be able to study the impact of tall buildings on the landscape, it is necessary to use various analytical methods. Selection of those methods depends on accuracy and recording of the model, as well as specific nature of a city landscape (topography, dispersion of urban structure, distribution of historical and contemporary dominants, etc.). For example, the combination of the view range method presented and analysis of view angles can produce interesting results. Examples of such simulations are presented in figure 6. The combination of the two methods enables determining of a build-up zone obscured by foreground buildings and obtaining information about angular values. Contrary to an open landscape, the skyline observed is distributed in space and divided into pieces. Information about angles for visible buildings may help determining height (and thus angular value) for new buildings in a given area. Results are important while determining rules for visual protection of important urban development. Planned buildings within a skyline should not have higher angular values from those in the foreground.

4. APPLICATION OF PRESENTED METHODS IN PLANNING

The methods discussed in the previous chapter supporting planning and analysing the impact of tall buildings on a city landscape and city skyline were applied in several urban studies in 2005-2011. Interaction between theory and practice, initiated in the first phase of developing those methods, was crucial while formulating their objectives. The studies were implemented by the Cyber Urban Center (West Pomeranian University of Technology of Szczecin, Poland) involving the author of the article.

4.1 Studies of several tall buildings in Szczecin, Poland

One of examples of applying analytical methods and computer aided tools were studies of tall buildings impact on landscape in selected locations in Szczecin in 2007 (Fig. 7). The studies were implemented under a contract with the local government [9]. The time for developing those studies was special. Immediately before the first wave of the global crisis (in 2008), strategic investors in Europe showed increased interest in developing tall buildings. The trend was very clear in developing European countries, such as Poland. At that time, in Szczecin, plans were developed to build several tall buildings. The studies analysed 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.

The analysis was based on a virtual model of Szczecin developed by the CUC in 2005-2007. While implementing the objective, it turned out that the visual impact range method was particularly useful (Chapter 3.1). The algorithm of the method was extended and optimized several times. Finally, a series of impact maps was produced for each location. Complexity of results exceeded any expectations. One some of them were in line with intuitive assumptions.

The group of facilities analysed included the tallest of buildings planned Hansa Tower (125 m). The analysis of its visual impact showed directions of exposition along axis of major streets and enables determining an optimized position of the facility at its plot. It also enabled setting a field of exposition from the river and assessing the relationship between the new building and the historical skyline of the city. Skyline simulations were developed for

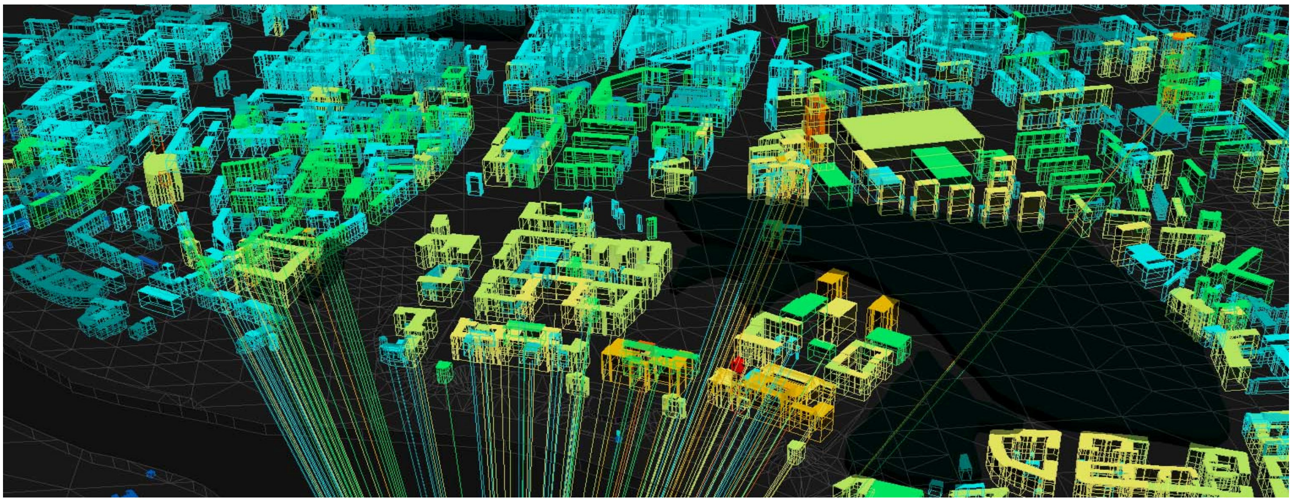

Figure 4: View angles analysis for panoramic view, Szczecin (Poland)

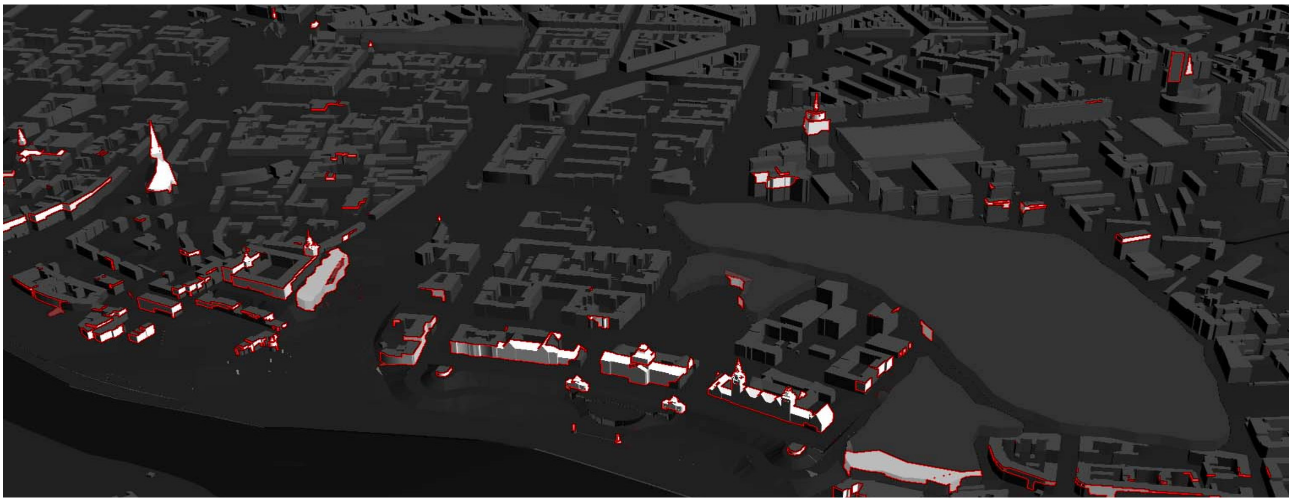

Figure 5: Visibility range analysis of panoramic view, Szczecin (Poland)

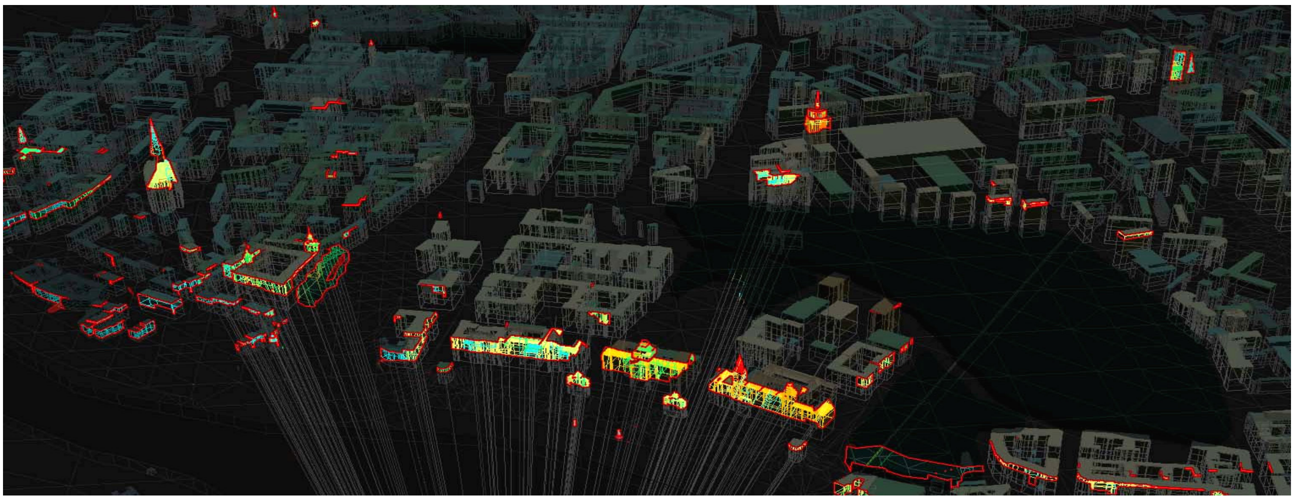

Figure 6: Combination of the view range method and analysis of view angles, Szczecin (Poland)

areas of the strongest impact (Fig. 2). The studies helped excluding some locations for developing tall buildings, and in other locations such facilities were allowed provided minimum height was preserved. Guidelines became a part of master plans which comprise local law. Until 2013, about 30% of plots were developed according to those guidelines.

4.2 Protection of historical panorama of Lublin, Poland

Yet another example of the application of methods (presented in Chapter 3) is the 'Study of visual values of the city of Lublin' developed under a contract with the local government in 2011 [8]. It aimed at determining rules for protecting historical skylines and silhouettes. Basic questions for the project team included: What should be the direction for the development of the city to preserve panoramas of the invaluable in Europe old town of Lublin? How can their exposition be strengthened? Is it possible to erect tall buildings in Lublin?

The tasks mentioned above and specific city landscape were decisive as regards selecting tools for their implementation. A limiting factor was input material important for further digital analyses. The city did not have its 3D model ready and there was shortage of time and finance for developing it. Therefore, it was not possible to use computer methods. The only input available was a digital model of the area. Based on 2D land register maps, the team developed analytical models of buildings [24]. While determining zones for protecting views of the old town, two methods described in Chapter 3: analysis of view angles and analysis of visibility range turned out to be particularly useful (Fig. 8).

Determining of the exposition background zone was an important task under the study. It was very difficult to define it geometrically. Boundaries of the zone were determined by combining the two methods. Synthesis of findings from the two methods enabled establishing areas particularly sensitive to new investment. The team observed major relations between angular values and topography, and thus visibility of buildings in space. Findings of the study were included in the current strategy for spatial development of Lublin.

5. CONCLUSIONS

Tall buildings in European cities are usually give rise to various controversies, discussions and disputes. One the one hand, we have trends to preserve cultural values of a historically developed landscape and skylines, whereas on the other arguments are raised that a modern image of a city should be created with tall buildings considered as a reflection of advancement, modernity and prestige. Wrong decisions are sometimes based on insufficient knowledge about spatial consequences of buildings planned. For this reason, objective findings of geometrical methods used for landscape analysis is crucial. Another reason for promoting scientific research on city landscape is a rapid development of geo-information techniques, which results in growing availability and precision of virtual city models. It is a new tool in urban planning and the potential for application is not fully explored.

Analytical methods presented in the article provide for a broader assessment of the impact tall buildings have on a city landscape if compared with more traditional techniques used in urban planning. Geometrical analysis is a basis for algorithms used. By its nature, results are objective and cannot be debatable. Doubts may apply to accuracy of simulations and relevance of the methods as regards the implementation of specific planning goals. According to previous experience in applying the methods, two conclusions can be drawn. Firstly, visual impact of tall buildings on the city landscape is a complex issue. Even in medium sized cities, such as Szczecin and Lublin, majority of spatial interaction can hardly be foreseen intuitively. Secondly, the interpretation of findings is an equally complex and tedious process. Imaging of results is frequently quite abstract. Similarly to the interpretation of a magnetic resonance image in medicine, the analysis of results derived from methods concerned require considerable competence in using the tool and urban knowledge.

The research methods have their limitations. Quality of results depends on the accuracy of a 3D city model used and its format. Not all models can be used for analytical analysis. An important obstacle is the power of computers and effectiveness of algorithms used in applications. Further research focus on optimizing and developing new methods of urban simulations using the most recent computer techniques, such as simulating impacts or tall buildings on complex spatial structure of cities, delimitating areas of protection of city panoramas and historically originated urban interiors and introducing multi-aspect systems of urban analyses (3D-UAS) to combine spheres of geo-information with urban planning, which is the main focus of the 2TALL Project (Application of 3D Virtual City Models in Urban Analyses of Tall Buildings) currently under implementation by the author and the CUC team.

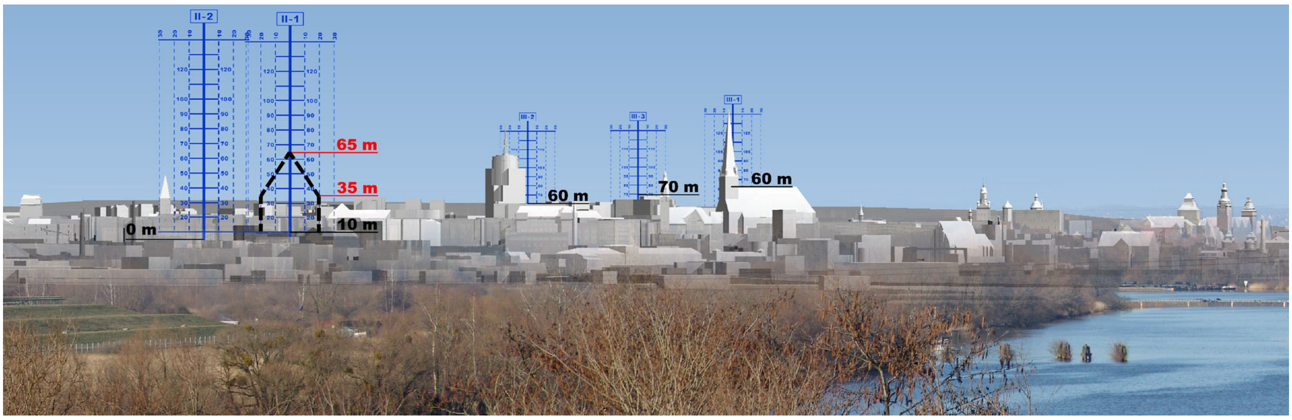

Figure 7: Simulation of planned tall buildings in city skyline (Szczecin, Poland 2007)

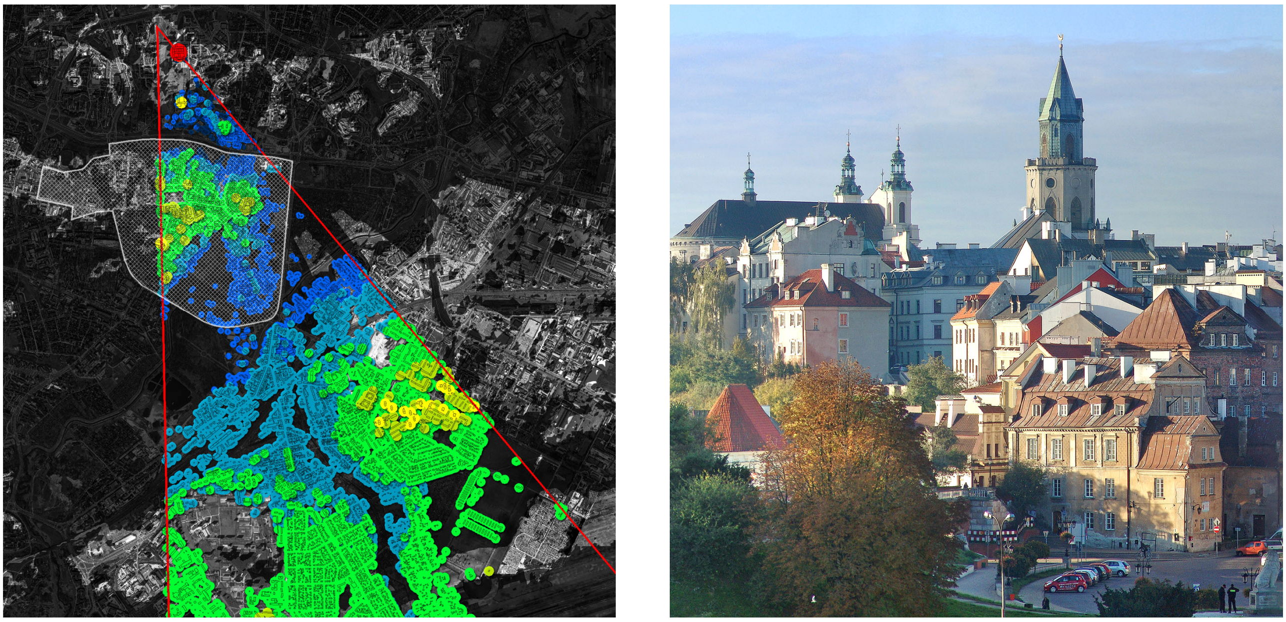

Figure 8: A fragment of historical panorama of Lublin (Poland) and computer analysis with view angle method

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