COMPLEXITY OF PUBLIC SPACES SYSTEM BETWEEN KEY TALL BUILDINGS IN CITY OF SZCZECIN GEOMETRICAL ASPECT OF PUBLIC SPACES IN 3D CITY MODEL

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ABSTRACT: The paper is strongly established on compilation of urban analyses of public spaces with environment of 3D city models. It is based on the understanding, that urban space is a composition of "positive" and "negative" – physical built-up environment and non-permanent dynamic pattern of users and their activities. Presently, it is more and more proved, that public spaces are the driving force and determinants of urban quality in most cities. The most important public spaces are commonly located within city center areas, however very often overlapping with locations of tall buildings. These are either tall historical buildings of cathedrals, churches, towers, palaces etc., or modern skyscrapers. The tall buildings are not the case itself for this article, but they are used only as a pretext for choice of case study sample areas located nearby city "markers". The 400.000 inhabitants city of Szczecin in north-west part of Poland has both of the mentioned "markers" in the city center. There is a lot more European cities where key tall buildings are located nearby or within important public spaces (squares, streets, boulevards etc.). Recent period of rapid development in computer technologies affects also sphere of architecture and urban design. Technology of 3D city models is being intensively developed for different uses and also it seems to be very perspective and attractive for application in terms of advanced urban analyses. It inspires a multi-purpose approach to analysis of cityscape using 3D models, particularly a "negative" part – called 3D void between buildings. The paper uses concept of representation of public spaces in 3D city model as 3D multi-face bodies with measurable parameters. This gives an opportunity of converting typical 2D urban analyses into the world of advanced spatial geometry including more parameters describing 3D solids. The attempt of parameterization of public spaces using concept of 3D solids representing space between buildings will be a subject of this paper. The 3D city model will be used to generate 3D geometry of public spaces in the selected area. The detection will be processed using generated point cloud and cut surfaces in general 3D model. The general outcome will be multi-aspect observation of process of generating 3D voids in specific selected areas of city using 3D city models.

Keywords: 3D virtual city models, public spaces, urban analysis, tall buildings

1. CONTEXT

The main determinant of interest and specific approach to problems of space between buildings is observation of contemporary cities, where urban planning and design meets rapid technological development in sphere of computer tools and techniques. Intensive growth and transformation of cities can be observed also in urban projects focused on public spaces as important urban landmarks of cities. On the other hand, there is a growing potential of computer-based tools in present age of information, high technologies, optimization trends and growing importance of open-source data available for different applications. It is also about the growing applicability of 3D city models, not only for commercial, presentation use, but also for analytic applications. Geometrical and numeric interpretation of common phenomena, also urban areas – cities, is happening right now. The real invisible database of city life is written in system of public spaces. The crucial interest of author is how the life between buildings appears in different types of spatial forms, volumes and specific geometry of form. The approach is resultant between general analytic approach based on classic observation and understanding of life between buildings by Jan Gehl [3], and technologically advanced, analytic and computer-based approach of Space Syntax. It also refers to notion of spatial configuration and spatial cognition introduced by Kevin Lynch (1960) [10], also undertaken by Bill Hillier (1984) [4,5] and A. Penn [11] - Space Syntax. The relation between spatial configuration and spatial cognition is also widely discussed by Y. O. Kim (2001) [7]. The author's work realized within research team of CUC [15] is focused on application of 3D city models in advanced urban analyses. Author's intention of introducing analytic method in environment of 3D city models is decomposition of subconscious scheme of visual interpretation of space between buildings, towards objective listing of parameters – then reading again city database using intended algorithms. New computer tools applied in 3D city models environment allow to introduce multi-aspect urban analyses (typology, geometric complexity, capacity, quantitative data etc.). Introducing notion of complexity refers to assessing geometric parameters of space between built-up structure of city. At the present stage scientific research is focused on physical characteristics of public spaces and optimization of 3D city models as environment for advanced urban analyses.

1.1 Public spaces: relation to tall buildings

Public spaces, as a part of general cityscape are the main interest of author, but the ongoing CUC 2Tall project, focused on general impact of tall buildings on cityscape, is also oriented towards observation of public spaces surrounding of in direct relation to tall buildings. The observation is very interesting because localization and geometrical characteristics of volume between / around tall buildings is very specific and directly dependent on scale and quantity of such buildings. One of the observed typologies of tall buildings in European cities is simple division on historical tall buildings located in core historical areas of cities (these are mainly characteristic heritage sacral buildings with towers dominating over old urban structures), and modern developments of high-rise buildings in different type of localizations.

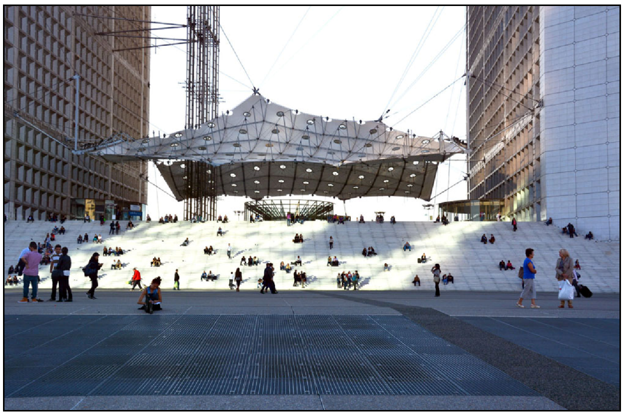

Figure 1: Public space beneath tall building. La Defense – Paris. Photo by K. Czyńska.

New tall buildings are often prestigious and attractive architectural forms. On one side, the impact on cityscape is important factor, but on the other, public spaces beneath create the link to the city. Tall buildings are often located in key areas of city centre and their direct surrounding is very important for system of public spaces. According to Czyńska [2], there are different types of concentration and localization of tall buildings. We can observe spatial concentration (as it is in Vienna), dispersion of structure (Koln) or visual concentration (Frankfurt). The case of Szczecin is more towards dispersion of structure – but limited to basically two tall buildings in scale of the city. However the buildings are located in key areas of city centre – the Radisson / PŻM building complex site analyzed in application part of paper is located at one of important public spaces axis of Szczecin. Detailed description of the project was presented in 2013 by P. Rubinowicz [16].

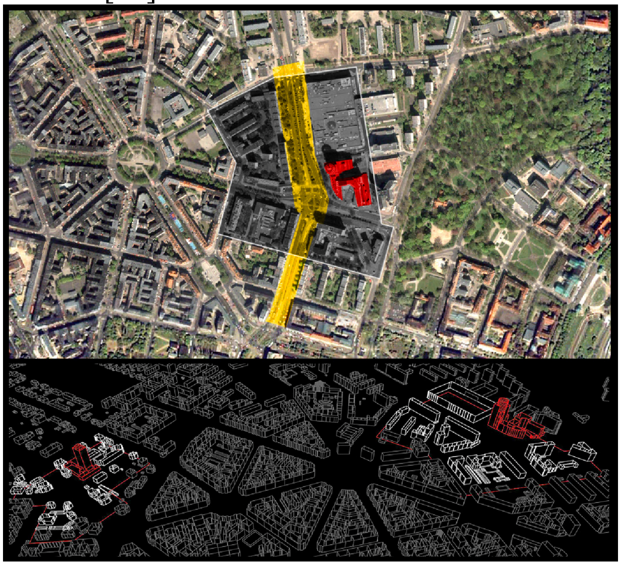

Figure 2: Localization of Radisson / PŻM building complex – Szczecin

1.2 Public spaces: significance and approach

This paper refers only to the physical and geometrical aspect of wider and very complex phenomena of public spaces in cities. The importance for sustainable development of cities is undisputed. Quality of public spaces is one determinants of general quality of cityscapes. The space between buildings is still unexplored database to be discovered using environment of 3D city models and, following rapid technological development, to describe characteristics of the space in parametric, comparable and analyzable way. Significance of space between buildings lays also in potential of anticipation of future activities and spatial organization. Moreover, advanced 3D technologies facilitate better understanding of public space as abstract geometrical volume limited by physical elements in urban space

2. PUBLIC SPACE AND 3D CITY MODEL

General understanding of public space can be easily divided into two important approaches. One is urban-oriented approach treating public space as general open space between built-up urban blocks, second is user-oriented approach understanding public spaces as specific, legible areas in city where intensive public life ocucrs. Popularity of 3D models of cities is rapidly growing in last decade. Google Earth opens possibilities to cover with 3D models practically all cities worldwide. There are also other standards, such as CityGML [8], creating powerful potential of adaptive use of 3D city models for advanced urban analyses.

Figure 3: Szczecin 3D city model with. Tall buildings in red.

The other important issue about public spaces and 3D city models is, that the models are mainly developed for built-up areas, the left part is still insufficiently explored.

2.1 3D city models and techniques

Combination of rapidly growing computer capacity and development of 3D city models can result in a powerful open-source tools for multifunctional applications. However, there are still many difficulties behind. One of the observed problems is standardization and optimization to diminish differences in available formats of data. The other technical problem is visualization and processing of big data included in 3D city models.

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2393,72; -681,84; 43,69 Select objects: LWPOLYLINE  Layer: "site2"
2443,7; -681,84; 27,49                  Space: Model space
2384,37; -682,76; 27,49       Color: 1 (red)    Linetype: "BYLAYER"
2391,45; -682,63; 43,69       Thickness =    63.5000
2210,02; -682,51; 28,2        Handle = FOA
2231,47; -690,6; 28,35          Closed
2219,58; -687,06; 28,35      Thickness   63.5000
2224,84; -688,64; 28,35 Constant width    0.0000
2219,23; -683,74; 28,35           area   88.4733
2261,66; -686,59; 28,58      perimeter   52.6230
2258,92; -685,48; 28,58
2252,88; -684,24; 28,58  at point  X=1381.0954 Y=-180.3242 Z=29.8900
2258,39; -698,42; 28,58  at point  X=1379.5182 Y=-186.3243 Z=29.8900
2259,09; -695,87; 28,58  at point  X=1387.4905 Y=-199.8889 Z=29.8900
2249,49; -695,84; 28,58  at point  X=1393.5000 Y=-201.4300 Z=29.8900
```

Figure 4: Example extract from numeric image of 3D city.

Moreover, important factor related to data included in 3D models is so called LOD (Level of Detail). LOD is extremely important to get comparable data from city models developed on different platforms – different acucracy is demanded for different analytic applications. Representation of public spaces is specific problem in 3D models, because of complexity of small scale detail – very resource-consuming for processing in computers.

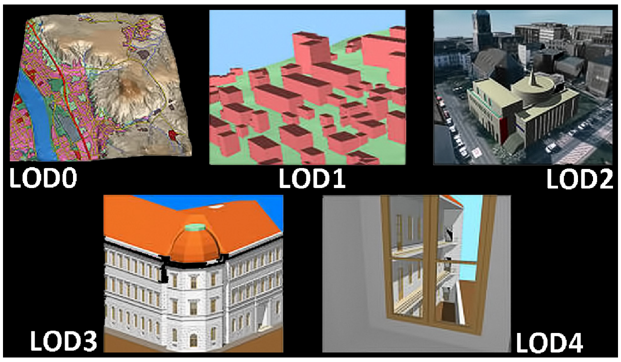

Figure 5: Five levels of detail defined in CityGML standard. Figure by T. H. Kolbe, G. Groeger, L. Pluemer [9]

All the existing formats of city models (Google, CityGML, game engines, ESRI etc.) contain database of parameters useful for analytic interpretation. There is also potential of GIS predefined tools (such as Quantum GIS with Grass etc.) to be applied on standardized data content. Finally there is also a bit other branch of tools for simulation purposes, particularly interesting in sense of Agent-Based Modelling for analysis public space use. The presented work developed within CUC is realized in combination of platforms: AutoCAD with individually programmed AutoLISP scripts (P. Rubinowicz) and Quantum GIS with Grass extension. The key and most important issue for all the presented data analysis is concept of writing 3D city and public spaces as a list of numbers and configuration of XYZ points in space (Figure 4). The odd, at the first glance, understanding the cityscape as a basic code or list of numbers, is a very important to get objective parametric data for processing with individually set up algorithms.

2.2 3D city model: public space samples

Selection of sample public spaces within city of Szczecin was driven by spatial characteristics of sites and assumptions of the ongoing 2TaLL project: "Application of 3D Virtual City Models in Urban Analyses of Tall Buildings" – realized by CUC research team at WPUT Szczecin. Both selected sites are located in the very city centre area of the city. Both are located directly at the only two modern tall buildings scattered in Szczecin. The entire 3D virtual city model of Szczecin used for sample application in this article was developed by CUC. The samples of Berlin 3D city model are used by courtesy of VCS Berlin – specialist firm for CityGML standard.

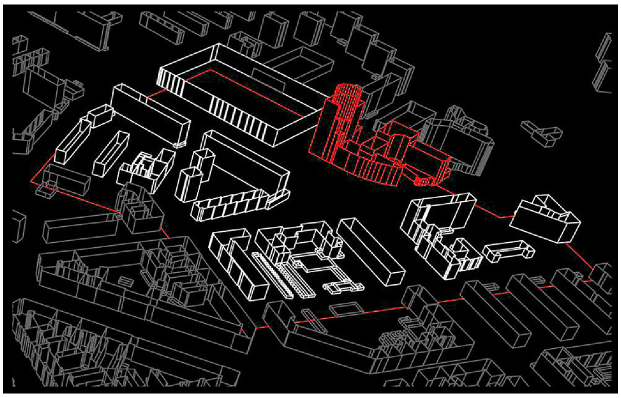

Figure 6: Selected site 01: Area at Radisson / PŻM building complex.

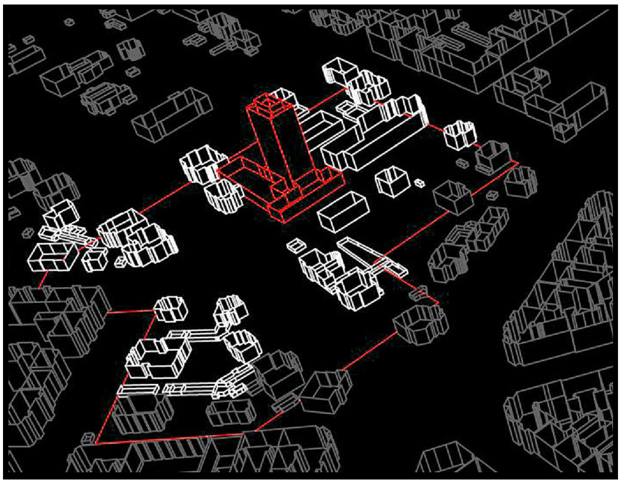

Figure 7: Selected site 02: area at local TV tower.

According to 3D geometry of selected areas, both represent type or varied urban built-up area around single tall building adjacent to main city street grid. Both sites contain variety of building heights and sizes. Site 01 – mostly used for analytic sample application in this paper – has more irregular spatial shape and higher complexity in sense of variety of architectural forms surrounding the area.

3. 3D NEGATIVE OF CITY SPACE

Using environment of 3D city models for parameterization of space between buildings, in sense of its geometrical parameters and complexity, bases on general concept that urban space is a composition of "positive" and "negative". The positive part is all the built-up area (buildings, structures etc.), the negative is the entire in-between space – introduced in this paper as the 3D VOID. Both of them, together with dynamic patterns and flow of users, contribute to the cityscape as a whole. It is extremely important to observe, that apart from the subconscious perception of physical elements in city as geometrical forms of particular dimension and volume, the space between physical objects has in fact exactly the same physical features – unseen, but possible to describe in parametric way. The exception in the presented approach is greenery – which is, in this particular case, not considered as a part of positive or negative in 3D city model.

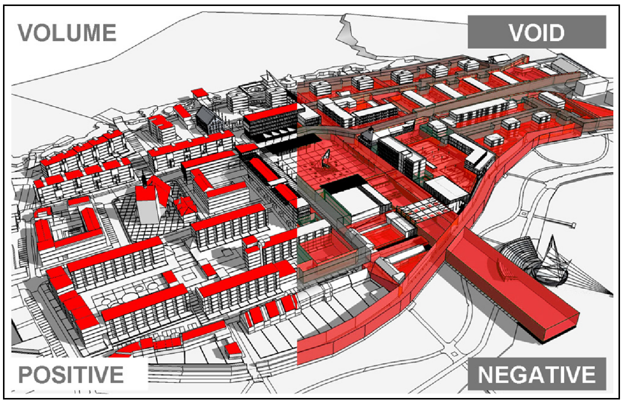

Figure 8: 3D city model: positive/negative concept of cityscape.

Understanding the "negative" part of cityscape as a hidden geometry is a key to introduce 3D geometrical interpretation of the volume limited by physical elements of a cityscape. The environment of 3D city models has a potential to discover and explore this area in parametric way.

3.1 Introducing 3D VOID

The observed need of professional and advanced computer-based tools supporting analysis, planning and simulation of key urban processes ocucrring in cities as well as following tendencies numeric interpretation of common phenomena resulted in using geometry of 3D city model to create and process the invisible space between buildings. The volume of open space limited by built-up structures has been interpreted as a geometrical spatial form and individually called 3D VOID. This three-dimensional void is possible for geometrical tracing based on limitations of surrounding objects in 3D city model. This objects are: buildings surrounding open space (side limitation) – mainly modeled as 3D solids, terrain (bottom limitation) – modeled as 3D mesh and tops of built structures surrounding public space (top limitation) – represented in 3D model as top points of facades, roofs etc. The 3D VOID is in this context only static interpretation of physical environment of the city but in advanced way could be used for combination with data from user-oriented analyses of pedestrian behaviors and flows. The sample application of 3D VOID presents process of individual process and tool for automation of creating such object in 3D.

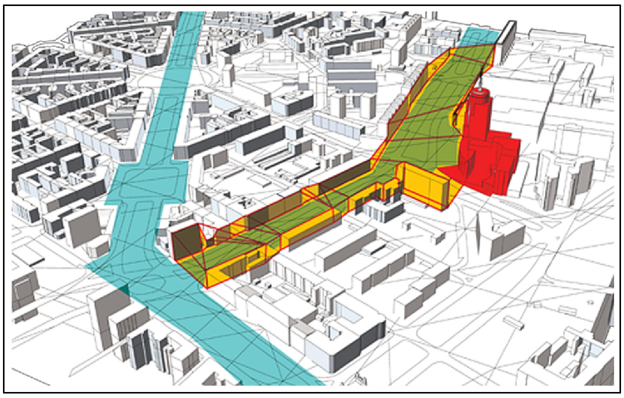

Figure 9: Conceptual visualization of 3D VOID idea in 3D city model.

The process of 3D VOID generation bases on simple geometrical rules and elements applied in AutoCAD / GIS platforms. The sample of automation was tested on three different city models (Szczecin, Berlin, Lublin) and proved reasonability of getting objective data for analysis with automated and optimized city models.

3.2 Generating 3D VOID

The very first step in process of generation of 3D VOID in 3d city model is marking analysis area and decomposition of the model into primitive geometrical shapes - lines and points. The 3D objects representing built-up structures (buildings) in city models are constructed in different ways (extruded polylines, meshes, solids etc.). For the purpose of optimization, AutoLISP procedure exploding model into horizontal / vertical lines and points was developed and tested.

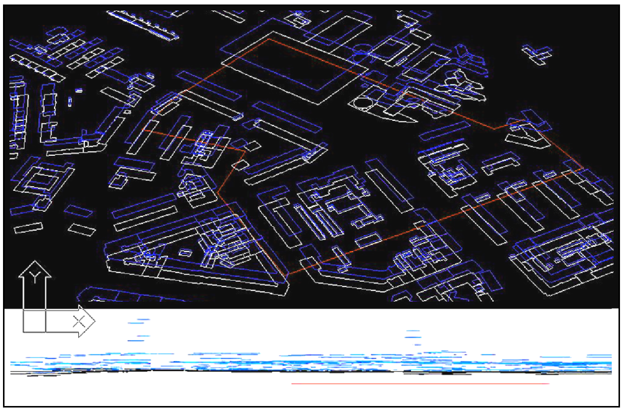

Figure 10: Fragmentation of 3D geometry into simple shapes.

Next stage refers to coordinates hidden behind all the primitive geometric shapes. The key for generation of 3D VOID is optimization of primitive geometrical content and automated generation of point cloud. The automatically generated XYZ points in 3D model for all nodes of exploded lines are the purest numeric code representing elements in 3D model. Figure 10 shows part of 3D model exploded in simple geometrical forms of lines / polylines. The numeric data is simple to export in text format, which is readable for major part of computer platforms and software (CAD, GIS). In the following stage the city will turn into points – only XYZ points.

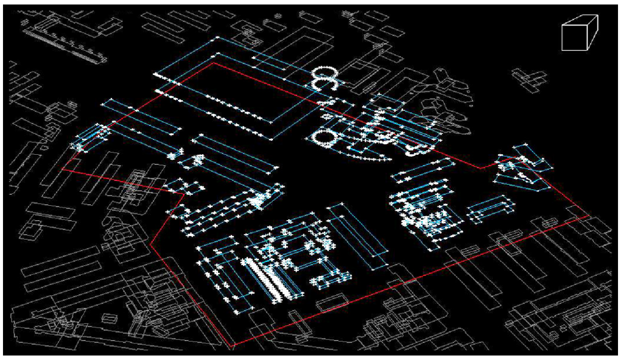

Figure 11: Fragmentation of 3D geometry into simple shapes.

The structure of generated point cloud is that there are nodes representing bottom plan of buildings and structures, but also those representing top points. They differ in coordinates on Z axis, but in plan XY view the nodes have the same coordinates (Figure 11). Together with automated generation of a point cloud (they can be represented as any graphic symbol), the programming procedure makes identification of point cloud layers analyzing and dividing nodes into bottom – ground layer and top – roof layer.

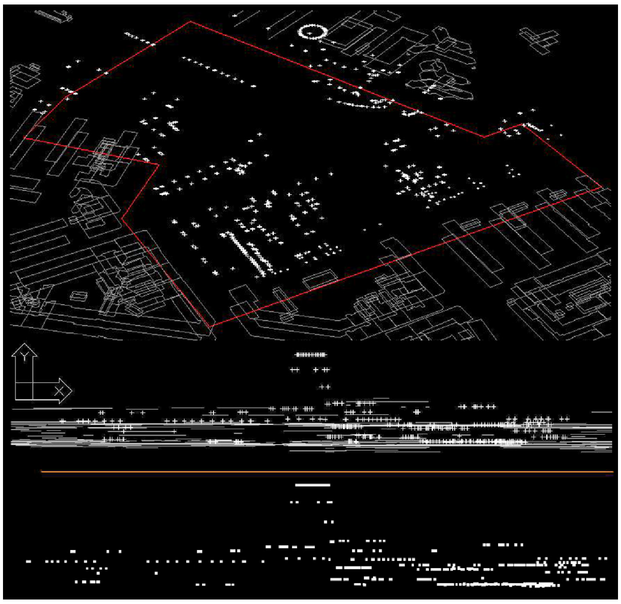

Figure 12: Automated generation of 3D point cloud with spectral view.

Figure 12 shows generated point cloud within the limited area (red line) in perspective and spectral view. The distribution of points on Z axis is clearly visible in spectral view. Using simple operations like hiding, deleting or specific selection it is possible to export numeric .TXT data on decomposed 3D city model. It is also possible to use other algorithms to select specific points and identify other elements of city. The resultant data from point cloud generation is a clear and objective interpretation of the city in 3D environment. The notions of buildings, streets and other common elements disappear and are replaced by pure XYZ code, or extended code with more parameters (Figure 4). In the next stage of data processing there is a transfer of numeric data to other environment. The selected sample site of Szczecin was exported as a numeric point cloud to GIS platform – to Quantum GIS software. It is a powerful GIS computer tool having possibilities to use predefined tools of such data processing. The data processing can take place in core platform of QGIS, but also in its free analytic extension – Grass. It offers number of predefined analyses – as well as geometrical. One of them is very important to implement next stage of generation of 3D VOID.

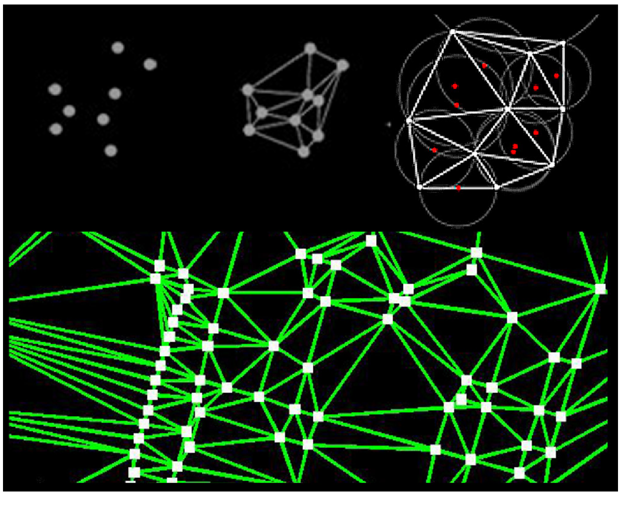

Figure 13: Delaunay triangulation of point cloud in GIS environment.

The point cloud representing top points of elements in 3D models (points of top elements of buildings) is converted into triangular surface using Delaunay triangulation [15]. Figures [13,14] show general principles of Delaunay triangulation and process of triangulation executed on point cloud generated for area around key Radisson / PŻM tall building in Szczecin.

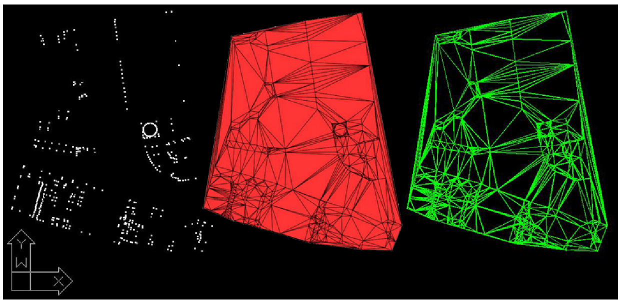

Figure 14: Flat surface resultant by Delaunay triangulation of point cloud.

The important feature of generated on GIS platform triangular surface is possibility of easy export to common and standardized .DXF format. It facilitates re-import of geometry to AutoCAD environment. The other specific feature of generated triangular surface is that the triangulation ocucrs in two dimensions, so the surface ready for re-import to CAD is basically flat (Figure 14). The following phase of generation of 3D VOID uses combination of GIS output with core 3D model CAD data.

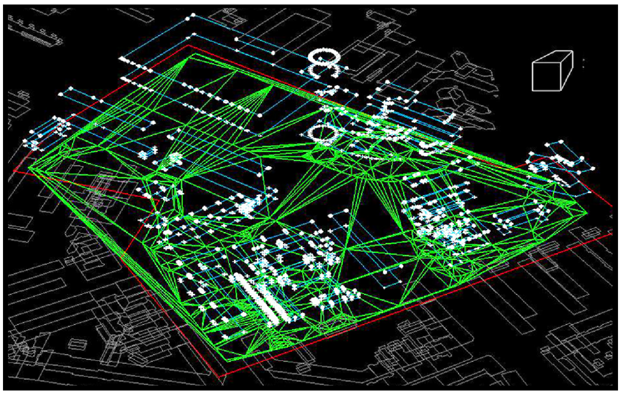

Figure 15: Combination of GIS / CAD data in 3D city model.

Figure 15 presents combination of re-imported data from QGIS platform and core CAD content of 3D city model to prepared for last steps of generation of 3D VOID between buildings. The original point cloud is in XY coordinates exactly in the same position as imported triangular flat surface from GIS. The next step is to get 3D triangular surface representing top surface of elements in city model (nodes with highest Z coordinate). Such prepared combination of data can be used for automated (by another AutoLISP script) extrusion of flat triangular surface to height (Z coordinates) of original point cloud. Figure 16 shows automated generation of 3D triangular mesh adjusting flat Delaunay triangulation to 3D point cloud executed in AutoCAD. This step is extremely important in sense of automation of the process o generation 3D VOIDS. It bases on individually programmed script for such 3D adjustments.

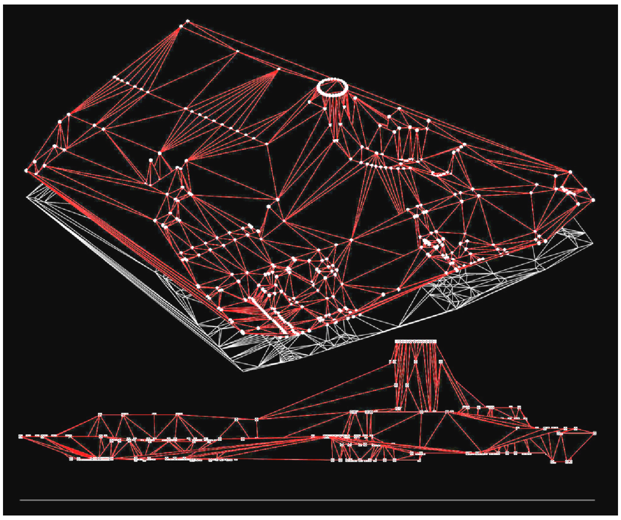

Figure 16: Adjusting 2D triangulation to 3D point cloud.

After having generated thin triangular 3D surface, it has to be extruded down to the ground level of model to get 3D solid in the 3D city model. The apparent 3D form is a new, alternative representation of city in 3D model. Top of the surface bases on connection between points on the edges of built-up structures. Additionally it is worth mentioning that also for exploring issue of complexity in 3D models, a special procedure was programmed for automated generation of links between points peer-to peer each other, and will be tested soon. It gives possibility to analyze complexity of space between buildings in sense of number of possible connections. Getting back to the core city model, the following step assumes generating 2D plan from 3D city model (also automated by AutoLISP procedure). The 2D plan is used to extrude solids representing built-up volume. The extrusion can be executed to any height ≥ than top points of structures in the 3D city model.

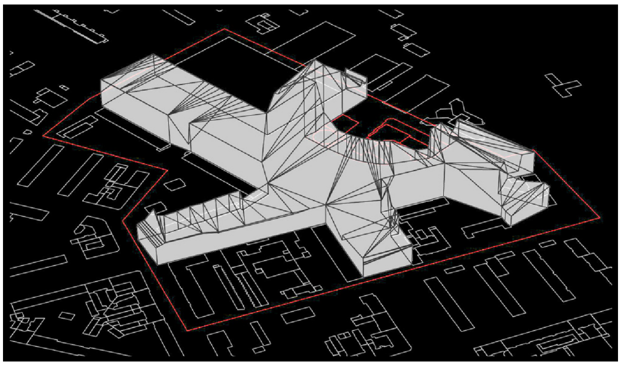

Figure 17: Pure 3D VOID after Boolean operations in 3D city model.

Finally the 3D VOID generation process needs application of another geometrical operations predefined in CAD software – popular Boolean operations. 3D Boolean operations are executed to subtract existing 3D structures from general triangular solid and finally to generate the entire 3D VOID. The last stage of ends up with automated generation of 3D general footprint of system of public spaces (space between buildings). The 3D VOID contains all the open spaces within selected area (Figure 18)

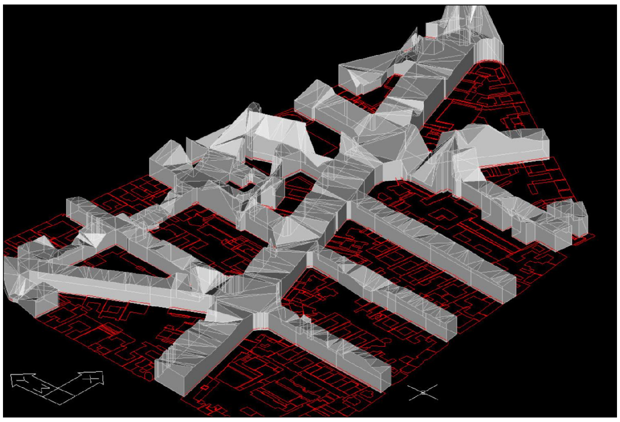

Figure 18: Sample 3D void of larger area in Berlin. Model by courtesy of VCS Berlin.

Final decomposition of 3D city model into particular, specific voids opens a possibility of multi-aspect analysis of the space between buildings. It is also available to use generated 3D VOIDS as separate elements of independent urban analyses. The last important factor to understand is that each 3D VOID as geometric solid is also constructed and described by faces/vertexes and solids (Figure 19). All of them can be analyzed separately using different specific algorithms.

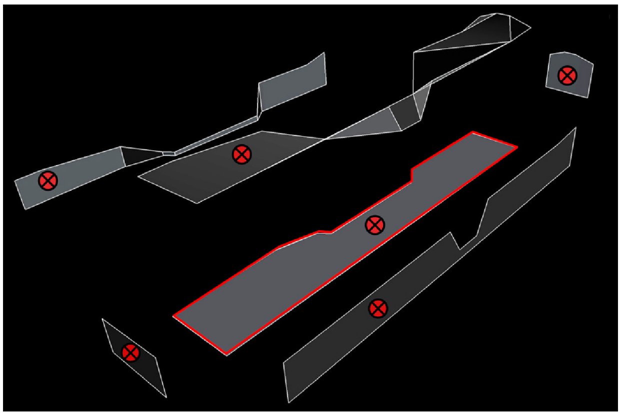

Figure 19: Theoretical construction of generated 3D VOID.

4. INTERPRETATION

All the presented stages of generating so called 3D VOIDS in city model result in intermediate data which can be read in parametric way. All of them: 3D linear structures, 3D point clouds, 3D triangular surfaces or solid 3D VOID itself. This part of the paper includes a brief introduction to selected possible 3 levels of interpretation of data in sense of geometric complexity of public spaces measured by 3D VOID method and tool used in environment of 3D city models. The interpretation will be presented for general point cloud, cut surface image of public space and 3D solid. The strength of the presented method is concept of incorporating potential of multi-environment universal data to be applied for advanced urban analyses. The components and intermediate products of 3D VOID method are applicable for analyses in both CAD and GIS environments. Particularly, presented QGIS platform has a great number of predefined tools to be used on the data. The interpretation of complexity of public space in the sample sites was also about finding geometric regularities and typology of public spaces in cities. The 3D VOID method can deliver objective and comparable data for studies on specific public spaces in geometrical sense. There is a lot of parameters in the space between buildings represented in form of 3D object. They can be explored in different type of interpretations. The following part introduces some of them.

4.1 Point cloud

The 3D point cloud generated at the early stage of presented analytic process is a powerful set of data on general cityscape, as well as space between buildings. Figure 20 presents perspective view which contains potential of visual intuitive interpretation spaces in-between built-up areas. Firstly the concentration of points in space clearly indicates open structures of the city, then using proper algorithm to analyze and group particular distances between points we can refer to density of buildings. Also programming points with data on functions of particular parts of buildings it is possible to generate functional and user accessibility point cloud for public spaces. The point cloud has potential of comparable analysis of cityscapes in aspect of system of public spaces in entire city extent. Geometrical regularities of distribution of points is also readable parameter for typologies of public spaces around the city.

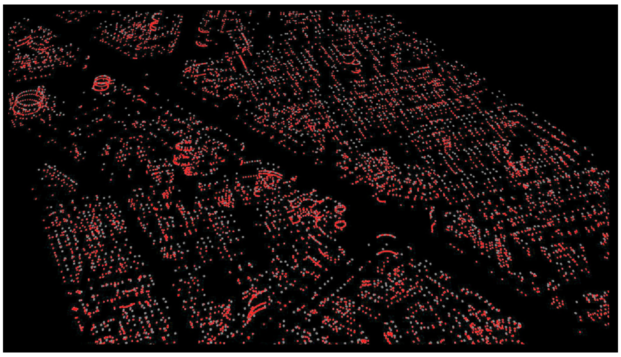

Figure 20: Sample 3D point cloud of area in Berlin. Model by courtesy of VCS Berlin.

The second extremely interesting mean of interpretation of point cloud is its effect of spectrum - using point cloud as a spectral view on system of public spaces. The elevation view of point cloud creates a spectrum of concentration of points showing geometrical regularity of city profile in both X/Y and Z directions. It also refers to concept of X-RAY observation of the city introduced in earlier research by CUC (K. Czyńska / W. Marzęcki / P. Rubinowicz). The presented on Figure 21 spectrum of point cloud also gives potential of observation and interpretation of flow of points at ground layer (Z=0 points) and top layer (building height Z points).

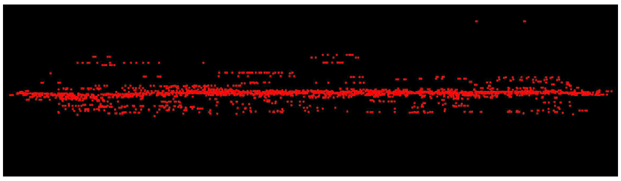

Figure 21: Spectrum of generated 3D city point cloud in elevation view.

The point cloud interpretation level is mostly intended for city-wide scale observations and analyses of space between buildings.

4.2 Cut surface image

The more detailed level of interpretation for both point cloud and entire 3D VOID is using sequences of repeatable offset sections to generate different patterns of public spaces in sense of geometrical characteristics of plan view from each cut surface. Figure 22 presents 3D concept of cut surfaces in 3D model.

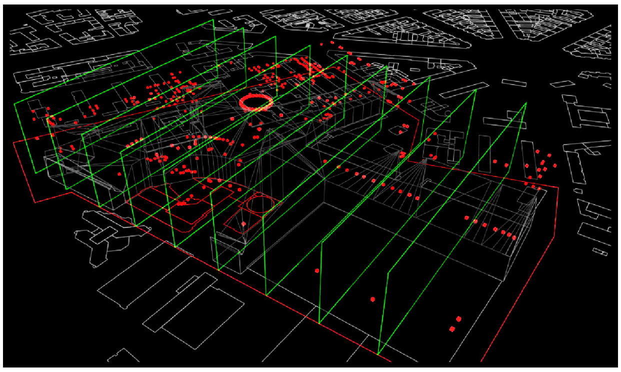

Figure 22: 3D cut surface interpretation concept.

Once, this level of interpretation focuses on identification of public spaces using point cloud for reading typology created by cut surface analysis. The interpretation can be recorded as a common shape of polyline linking properly selected points in point cloud. The set of linear images has further potential of image data content analysis comparing the shapes and searching for regularities and typologies. The cut surface images can be also analyzed in sense of general proportion of open space to built-up areas in cities. (Figure 23).

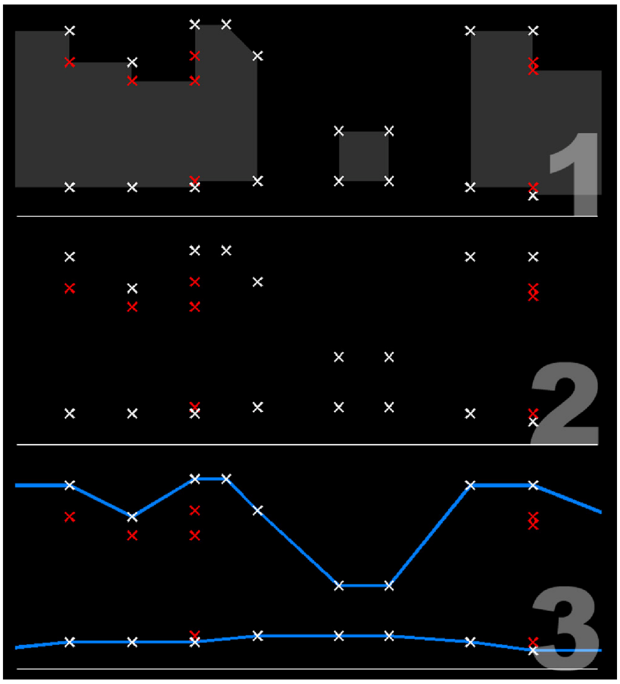

Figure 23: 3D cut surface complexity analysis of public space.

The cut surface level of analysis gives also more detailed scope on geometric shape and proportions of each public spaces itself as it is presented on Figure 24. by combination of linear scheme and solid objects in 3D model.

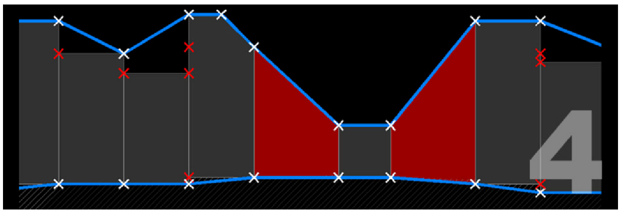

Figure 24: 3D cut surface complexity analysis – geometrical typology of public spaces.

The cut surface image level of interpretation of 3D VOID is extremely important for exploring phenomena of typologies in both scales – between different cities and within different public spaces in the specific city.

4.3 3D solid

The last but not least level of interpretation is analysis of quantitative parameters of 3D solid created as a 3D model of space between buildings. The 3D VOID is also resultant from geometry of forms being limitation of the shape, so geometric complexity level of triangular solid is possible to explore using the count of polygons in specific areas. The other aspect of the 3D geometry to be put under investigation is comparative analysis of volumes in certain areas of city. This responds also to parameters of capacity of particular public spaces. The 3D VOID brings also possibility of generating functional patterns of public spaces and patterns of accessibility for users getting data on functions and entrances directly from adjacent buildings. The other, more advanced scheme of interpretation, taking into consideration heights of polygons (Z coordinates) and its angle against sun direction, is identification of mostly shaded areas of public space in city. Figure 25 presents multi-polygonal structure of 3D VOID used for the introduced level of interpretation.

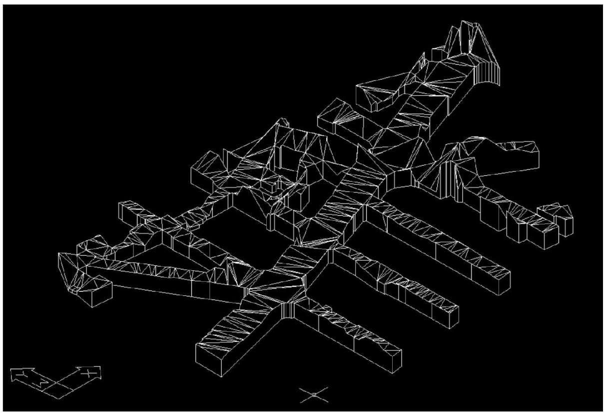

Figure 25: 3D VOID level of interpretation of complexity and spatial parameters of space between buildings.

Finally the 3D VOID can be applied as a geometric boundary for application in simulative environment of Agent-Based Modelling of pedestrian flow etc.

Table 1: 3D VOID interpretation matrix for geometry and complexity of space between buildings.

Level of interpretation	Parametric data
Point cloud	- concentration of points: open space to built-up area ratio; - functional pattern of points: functional attractiveness / accessibility for users; - spectrum of points: geometrical regularities of public spaces in city-wide extent; - X-Ray observation: geometrical flow of points at bottom / top layers of point cloud
Cut surface image	- linear connections/graphs: regularity and typology of public spaces in comparison to other cities; - combination of linear schemes and solid objects: proportions and geometric shape of public spaces;
3D solid / 3D VOID	-polygon count: complexity level; -adjacent faces data: functional patterns of public spaces in city; -Z coord. and angle of polygons: shading parameters of public spaces

5. CONCLUSIONS

The presented analytic approach for physical parameters of space between buildings, called 3D VOID, brought into environment of 3D virtual city models, contributes to issues of importance of public spaces in urban areas, general trend of parametric computations, rapid development of computer technologies and general analysis of cityscape. The research initiates deeper exploration of unexplored city database hidden in geometry of its in-between spaces. The concept aims to introduce multi-aspect computer-based analytic tool into the environment of standardized and optimized 3D virtual city models, particularly to its still insufficiently explored part of space between buildings. Geometric interpretation of this space for purpose of advanced parametric urban analyses is directed towards anticipation of extended use of virtual models technology for sustainable development of cities.

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