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MODELLING THE MAXIMUM DEVELOPMENT OF URBAN HEAT ISLAND WITH THE APPLICATION OF GIS BASED SURFACE PARAMETERS IN SZEGED (PART 1): TEMPERATURE, SURVEYING AND GEOINFORMATICAL MEASUREMENTS METHODS

B. BALÁZS, T. GÁL, Z. ZBORAY and Z. SÜMEGHY

Department of Climatology and Landscape Ecology, University of Szeged, P.O.Box 653, 6701 Szeged, Hungary
E-mail: balazsb@geo.u-szeged.hu

Összefoglalás – Vizsgálatunk célja az éves átlagos hősziget kialakulását, méretét és területi szerkezetét befolyásoló speciális városi struktúra, ezen belül a geometriai szerkezet és beépítettség hatásának számszerűsítése. A kétrészes tanulmányban a korábban már alkalmazott égboltláthatósági index és beépítettségi tényezők mellett az épületkompaktság klímaalakító szerepét is vizsgáljuk. A szakirodalom szerint is teljesen új paraméter három dimenzióban egyszerre jellemzi az épületek térfogatát, valamint tagoltságukat és elsősorban termodinamikai szempontból játszik fontos szerepet. Az első részben a városklíma egyes sajátosságainak áttekintése után bemutatjuk a vizsgált területet (Szeged), valamint a hőmérsékleti, terepi és térinformatikai felmérési módszereket, amelyek – a modell megalkotásának érdekében – elengedhetetlenül szükségesek a hőmérséklet és a különböző felszínparaméterek városon belüli eloszlásának meghatározásához.

Summary – The aim of our research is to reveal quantitatively the effect of the peculiar urban structure on the development, magnitude and spatial distribution of the mean annual urban heat island. In this two-part study, besides the earlier applied sky view factor and different built-up parameters, we examine the climate modification role of the building compactness. This new parameter characterises the volume, plan area and thermodinamical role of the buildings at the same time. In the first part, after a general overview of some features of the urban climate, we will present the investigated area in Szeged, then the applied temperature, surveying and geoinformatical measurement methods. In order to establish the model, these methods are necessary to determine the intra-urban spatial distribution of the temperature and the different surface parameters.

Key words: urban heat island, urban surface parameters, geoinformatic methods, Szeged, Hungary

1. INTRODUCTION

In settlement environments the energy and water balance of the area are influenced significantly by the changed surface cover, which leads indirectly to the alteration of climate above the cities on a local scale. Among the changes the excess of urban temperatures (urban heat island – *UHI*) appears in the most identical way (*Landsberg,* 1981). This excess influences fundamentally the comfort sensation of the inhabitants. The effect has double characteristics, because in summer it is stressful with slowly cooling air at night, but in winter this same influence is advantageous, because the heating demand of buildings and the length of heating period decrease in the area of cities (*Unger and Sümeghy,* 2002). Therefore its research serves with important information, for example for urban planning (*Kuttler,* 2005). Furthermore, the composition of urban vegetation is changed and postponement of phenological phases is observable (*Lakatos and Gulyás,* 2003).

It is difficult to define the factors affecting the development and intensity of *UHI,* to determine their role quantitatively and to model this because of the complex vertical and horizontal structure of the city and because of the artificial emission of heat and pollutants. Detailed data collection is also complicated and demands significant technical investments.

The aim of our research is to calculate the effect of the special urban structure (the 3D geometric structure, and built-up ratio), on the development, magnitude and spatial distribution of the annual mean *UHI*. The question is how far it is possible to specify the description of strength and structure of urban heat island when applying these surface parameters in statistical model-equations. In this two-part study the climate modifying role of the so-called weighted volumetric compactness of buildings is examined in addition to the sky view factor (*SVF*) and built-up ratio (*B*) applied earlier (*Bottyán and Unger,* 2003; *Bottyán et al.,* 2005). It is a new parameter, which characterizes the volume and structure of buildings in 3D, and it plays a significant role from the thermodynamical point of view. In this first part we present the study area (Szeged), also the methods of temperature measurements, surveying works and geoinformatics, which are necessary to determine the distribution of the temperature and different surface parameters within the city.

2. STUDY AREA

2.1. Geographical situation and climatic characteristics of the city of Szeged

Szeged is situated in the southern part of the Great Hungarian Plain, where the river Maros flows into the river Tisza. On the surface there are Holocene sediments with low relief. According to Trewartha's classification Szeged belongs to the climatic type D.1 (continental climate with longer warm season), similarly to the predominant part of the country.

The regional division of *Péczely* (1979) is applied in the more detailed climatic description. According to this the study area belongs to the warm-dry climatic region, so its aridity index is more than 1.15, the average temperature of the vegetation period is more than 15°C. The annual sum of global radiation is around the country average (4700 MJm^{-2}), while the sunshine duration is high above the average (2023 h), the percentage of clouds (57%) is under the average of the country. The prevailing winds are N and NW, but southerly wind also appears with high frequency. The mean annual rainfall is 550-600 mm, but in the last years it was less than the average so Szeged belongs to the areas of high drought sensitivity.

2.2. Structure of the city

On the basis of geographical position it is possible to divide Hungarian cities into three categories: valley, meeting point of mountainous area and plain, and plain. From the point of view of urban climate development, in the case of the first two categories it is very difficult to separate the effects of topography and human impact. Szeged belongs to the the third category, so it has favourable conditions for urban climate research. For this reason the results of systematic measurements and analysis can serve as a basis of general conclusions (*Unger et al.,* 2001).

The administrative area of Szeged is 281 km^2, but the inner city is only around 30 km^2, and the densely built-up areas are inside the flood prevention circle dike. The road structure of the city is an avenue-boulevard system on the axis of the river Tisza.

3. METHODS OF SURVEYING WORKS AND GEOINFORMATICAL MEASUREMENTS

3.1. Study area and the collection of temperature data

In the last years urban climatologic researches have been aimed at the inner parts of the city. In order to systematise the collected datasets the study area was divided into 500 m X 500 m grid-cells (*Fig. 1*). The same grid size of 0.25 km^2 was applied in some other urban climate projects (e.g. *Park,* 1986), and similar size is applied by *Long et al.* (2003) and *Lindberg et al.* (2003). The study area consists of 103+4 cells, which cover the inner and suburban part of the city. The four western cells were used just as a reference area for the comparison of temperature data. In this two-part study we used an area consisting of only 35 cells as a representative sample area (see details in *Gál et al.* (2005))

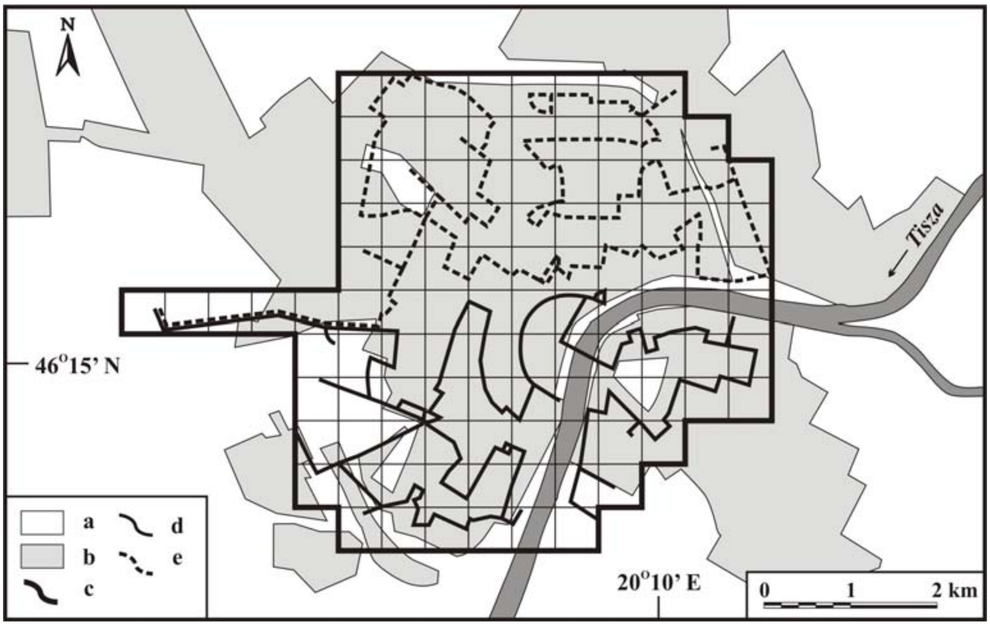

Fig. 1 The investigated area and the grid network in Szeged: (a) open area, (b) built-up area, (c) border of the investigated area, (d, e) measurement routes

Data required for the analysis of the maximum *UHI* intensity were collected in the whole (107-cell) grid network (*Fig. 1*) with measurement cars on given routes in two periods: between March 1999 and February 2000, and between April 2002 and March 2003. Such mobile measurements are wide-spread in the study of urban climate parameters (e.g. *Oke and Fuggle,* 1972; *Moreno-Garcia,* 1994; *Santos et al.,* 2003).

In the study area the representative temperature pattern was derived from measurements taken in two one-year long series every 7-10 days, so 48 and 35 times a year, respectively. The three-hour measurements were made in all weather conditions except rain. Based on experiences from previous studies data collection happened in the expected time of maximum development of the *UHI* that is at 4 hours after sunset (*Oke,* 1981; *Boruzs and Nagy,* 1999). In the hours after sunset the linear change of temperature was applied to the the calculation of the measured data, with that addition that it is only approximately valid in the suburban areas because of the the different cooling gradients (*Oke and Maxwell,* 1975).

The area was divided into two sectors because of the size of the study area and the length of measurement routes. Routes were determined to intersect all the cells at least once both there and back (*Fig. 1*). The temperature data were observed by an automatic sensor which was connected to a digital data logger. The sensor measured the values in every 10 seconds. It was placed on a bar at 0.6 m in front of the car and at 1.45 m above the ground because of the thermic disturbing effect of the car. The speed of the car was 20-30 kmh^{-1} for the sake of suitable ventilation and density of data. In compliance with this there are data from every 55-83 m along the measurement routes. At the rare stops (e.g. red light, barrier) the logged values were deleted from the database later. The measured temperature data were calculated as their average in each cell.

In our case the *UHI* intensity (ΔT) is defined as follows:

$$\Delta T = T_{cell} - T_{cell(W)}$$

where T_{cell} = temperature of the actual urban cell; $T_{cell(W)}$ = temperature of the most western rural cell (*Fig. 1*).

3.2. Determination of urban surface parameters

3.2.1. Built-up ratio, water surface and sky view factor

Determination of the built-up ratio (covered surfaces – streets, roofs, parking lots, etc.) is based on the evaluation of a SPOT XS satellite image, taken in summer 1992. The ground resolution of the pictures is 20 m, so they are suitable to determine the small-scale characteristics of the city area. The basis of the analysis was the calculation of the Normalised Difference Vegetation Index (NDVI) by raster and vector geoinformatical systems. With this index it is possible to determine the percentage of the built-up (*B*) and water surfaces (*W*) in each cell (e.g. *Unger et al.,* 2000).

Several solutions are known for the calculation of the *SVF* parameter: angular measurement by theodolite (*Szakály,* 1962), evaluation of photos taken by camera with fish-eye lens (*Oke,* 1981; *Holmer,* 1992), or the use of a software, which evaluates the 3D geometry of the surface (*Souza et al.,* 2003, 2004). In our research the approximate values of the *SVF* were determined by theodolite. Along the measurement route the elevation angles of the highest points of the buildings at both sides of streets were measured approximately every 100 m (*Unger,* 2004; *Unger et al.,* 2004).

3.2.2. Compactness parameters

The size and shape of buildings got into the focus of attention in recent urban-geometrical research and several experiments were aimed to express this by one parameter.

One of such parameters is the so-called compactness, and according to the interpretation of *Long et al.* (2003) this is the ratio between the perimeter of the building and the perimeter of a circle of the same area. This parameter is mainly emphasised because of its aerodinamical importance. This value describes a 2-dimension (2D) slice of urban geometry, but the vertical structure of the city also affects the physical conditions of the air significantly. Applying statistical methods, it was possible to indicate the connection between the *UHI* and the new 3D parameters (e.g. the building mass – *BM*), supported by geoinformatic evaluation (*Santos et al.,* 2003). Regardless of their surface the *BM* describes the buildings' volume, and the mass is calculated from the volume which can be connected to the heat-storing capacity of the given building.

Accordingly, if the connection of the surface geometry and the *UHI* is examined, it is necessary to look for a parameter more expressive then the previous one. This has to satisfy the following requirements:

- It has to describe the surface of buildings from the viewpoint of their heat emission and absorption capacity towards the ambient air.
- It has to include the volume (or mass) and thus, it should also give a value for the heat storage capacity of buildings.

Using geoinformatical evaluation methods it is possible to determine the heigths of walls (H), the area (A) and the perimeter (P), and from these the surface (S) of buildings. However, the plan area of buildings cannot be considered an active surface from the point of view of the ambient air, therefore calculating the active surface of a building (S_b) it is necessary to disregard this area:

$$S_b = P \cdot H + A$$

A given body cools slower if its surface belonging to a given volume is smaller. Similarly, a given body can store more heat if the volume belonging to a given surface is larger. Therefore, it seems more practical to take the volume/surface ratio of body into account for the creation of the new parameter. The most compact building form (cube) of settlements has to be considered a reference, because it is house-like; also among the prism-form buildings the cube has the smallest surface with a given volume (*Fig. 2*).

In the interests of comparison an approximate value was calculated for the volume of a given building, and the smaller parts of buildings and the roofs were disregarded. This geometrical simplification is possible because many flat-roofed buildings exist in the area (e.g. block-houses as well as industrial buildings, etc.) moreover the determination of the volume of more complicated forms would be practically impossible in case of thousands of buildings. The simplified volume (V_b) is calculated in the following way:

$$V_b = A \cdot H$$

Consequently, the volume (V_b) and surface (S_b) in case of a given building are available. Based on the following equation it is possible to calculate the side length (a) and thus the active surface (S_c) of a cube of the same volume (V_c):

$$V_b = V_c = a^3, \qquad S_c = 5 \cdot a^2$$

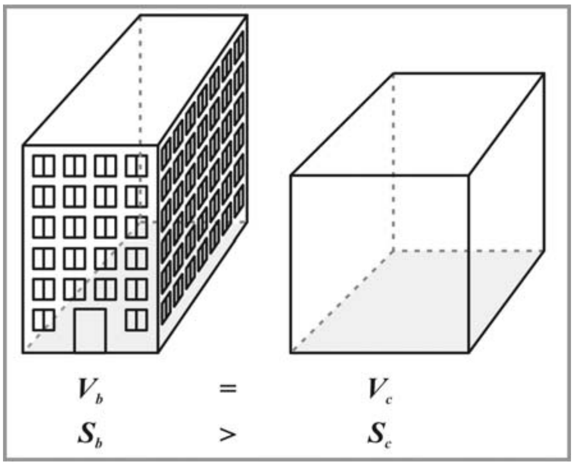

Fig. 2 Comparison of the characteristics of a building in the city and a cube; V_b, V_c, S_b and S_c mark the volume of the building, volume of the cube, surface of the building and surface of the cube, respectively

Dividing the building surface (S_b) by the cube surface (S_c), the result is a dimensionless ratio value larger than 1, which means in geometrical sense the deviation of a given body from the cube. Since the above-mentioned parameters (ΔT, B, W, SVF) were determined to cells, it is worth to apply this method in case of new parameters as well. This ratio is called *compactness* (C), and its mean by cell is called *average compactness* (C_m):

$$C = \frac{S_b}{S_c}, \qquad C_m = \frac{1}{n}\sum_{i=1}^{n} C_i$$

In each cell the number and size of the buldings are very varied and C_m is not suitable to express this. As a solution the compactness values (C) of houses are multiplied by the volume (V_b) of the house. Thus, compactness is weighted by the value of the volume, and then summarized values are calculated to all the buildings of the cell. The new parameter (C_v) is the *weighted volumetric compactness* (in m^3):

$$C_v = \sum_{i=1}^{n} \left(C_i \cdot V_{bi} \right) = \sum_{i=1}^{n} \left(\frac{S_{bi}}{S_{ci}} \cdot V_{bi} \right)$$

3.3. Geoinformatical methods and their applications

Geoinformatics is extremely suitable for the collective handling of large datasets and maps. By its application it is possible to realise measuring, processing, and demonstration of data. Digital photogrammetry is a special branch of geoinformatics. According to the definition, it is a science of image creation from an object without touching it, and the handling and processing of these images (*Barsi,* 2000). Pictures are either taken by digital cameras, or the information is stored on traditional film that is the analogue information holder and has to be digitised by scanning. During photogrammetrical processing the images are restored to the spatial position and direction valid at the time of exposure (exterior orientation). After the orientation it is possible to measure and map spatial extensions with the application of pictures taken from two different directions, similarly to human perception.

3.3.1. Applied databases, software and maps

Raster basis:

30 pieces of overlapping (60%) aerial photographs cover the city of Szeged (*Fig. 3*). The negatives were digitised by a scanner (14 micron resolution), thus the size of one photograph in TIFF format is nearly 900 Mbytes.

Important information needed for the use of aerial photographs:

- date of flight: 13th November 1992, am 11:45- pm 12:15 (highest Sun altitude),
- photograph scale: 1:11.000,
- flying altitude: 1760 m.

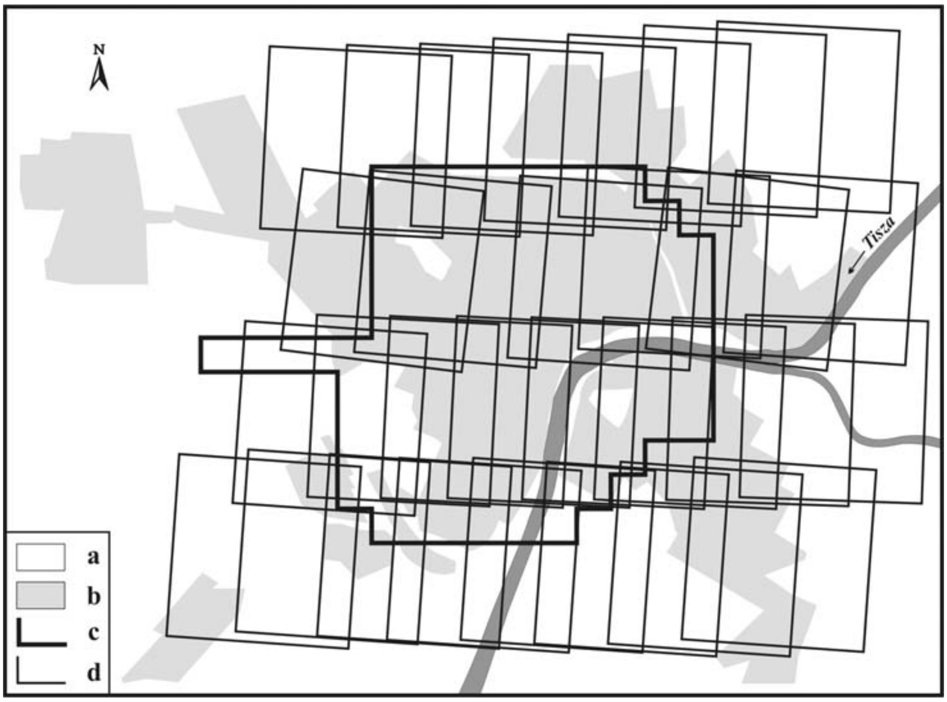

Fig. 3 The study area and the overlapping of aerial photographs on Szeged: (a) open area, (b) built-up area, (c) border of the investigated area and (d) frame of aerial photo

Accurate measuring is only possible if the digitised negatives used are of excellent quality. There is a very essential qualitative difference between the scanning of negative applied by us and the often used method of scanning of paper copies.

Vector basis:

The plan areas of buildings were available in DXF format. The mean error of the vector file is 10 cm, therefore its accuracy can be considered as geodesic.

ERDAS IMAGINE:

This software has been developed for resources research therefore with its pyramid-based data-storage and handling system it makes possible the opening, conversion and processing of large raster files (*ERDAS,* 2000). This extendable and developable software environment consists of modules and has a graphic user interface. The following modules were used in this study: OrthoBASE, Stereo Analyst and VirtualGIS.

ESRI ArcView:

The program is based on the concept of integrated georelational unified topologic data model and was made for database creating, modelling and analysis. It is a complex GIS data base environment. The main concepts of development were the open system structure (portability), the object-orientated approach (data model, user surface and applications), and the support of client-server network connections.

Xtools extension: it is developed for vector-based spatial analysis, the conversion of shape files and tabular data management.

1:10,000 scale maps:

Geodesic-topographic maps of Unified National Mapping System (in Hungarian EOTR): No. 27-323, 27-332, 27-341, 27-342, 27-343.

3.3.2. Processing

Digital Elevation Model:

The Digital Elevation Model (DEM) is a general spatial model, which means it represents a bare surface without landmarks. For the creation of the DEM it is possible to use digitised contour lines, points measured by GPS or geodesical methods, and other available elevation databases, or points can be measured by photogrammetrical means. Following data acquisition the DEM is created by the assignment of a regular grid by means of linear and non-linear algorithms.

In the case of Szeged the variation of the elevation is small (75.5–83 m a.s.l.), so using a DEM enabled us to increase accuracy (as the DEM determines the accuracy of the orthophoto). After digitising the 1:10,000 scale maps the contour lines were vectorised in ERDAS IMAGINE (Arc/Info format), then DEM of this area created by use of the Create Surface application. Later we used this DEM for the preparing of orthophotos and for the visual representation of the model in VirtualGIS.

Aerial photos (import and orthocorrection):

The ERDAS IMAGINE is able to handle lots of various data formats, like for example TIFF, BMP, PCX, LAN. In the case of TIFF files, ERDAS IMAGINE can read the GeoTIFF and the TIFF World formats as well. For further use it is necessary to transform the TIFF format into IMG format, which is the own format of ERDAS IMAGINE. During the import of files additional RRD files (containing information on the pyramid structure) are produced for each picture. With the help of this pyramid-like data storage system, the program can handle large amount of data (the size of all the aerial photos together is more than 30 GBytes).

The basis of orthocorrection is the DEM. The process involves creation of the Block File, input of the digitised aerial photos in IMG format into the Block File, calculation of Pyramid Layers, measurement of the adjusting points, aerial triangulation, the creation and quality-control of orthophotos.

Plan areas of buildings:

ArcView is able to open the plan area in DXF format, but it is also necessary to transform it into shape format. A grid of the complete study area is fitted to this basis. Buildings with an area of more than 15 m^2 were measured, since in the case of smaller (room-like) buildings the heat absorption and emission are negligible, moreover these are difficult to determine on the aerial photos.

To check this presumption, a suburban and a central cell were analysed. Results show that in the suburban area the number of buildings with an area of less than 15 m^2 is about half (51.2%) of the number of all the buildings in the cell, but it means only 4.5% of the building plan area of the complete cell. In the central cell about one-third of the buildings (37.1%) are smaller than the limit, but it means only 1.7% of the plan area of the complete cell. If the volume of these tiny buildings were calculated they would play an even more insignificant role in the cells, because of their small heights.

All buildings got an eight-digit identifier, whose first four digits show the number of the cell, and the following four digits show their serial number within the cell. To ensure easier orientation the IMG format orthophotos were laid under the plan areas of buildings. Both vector and raster data are in the Unified National Projection (EOV in Hungarian) so they exactly overlap each other (layer structure).

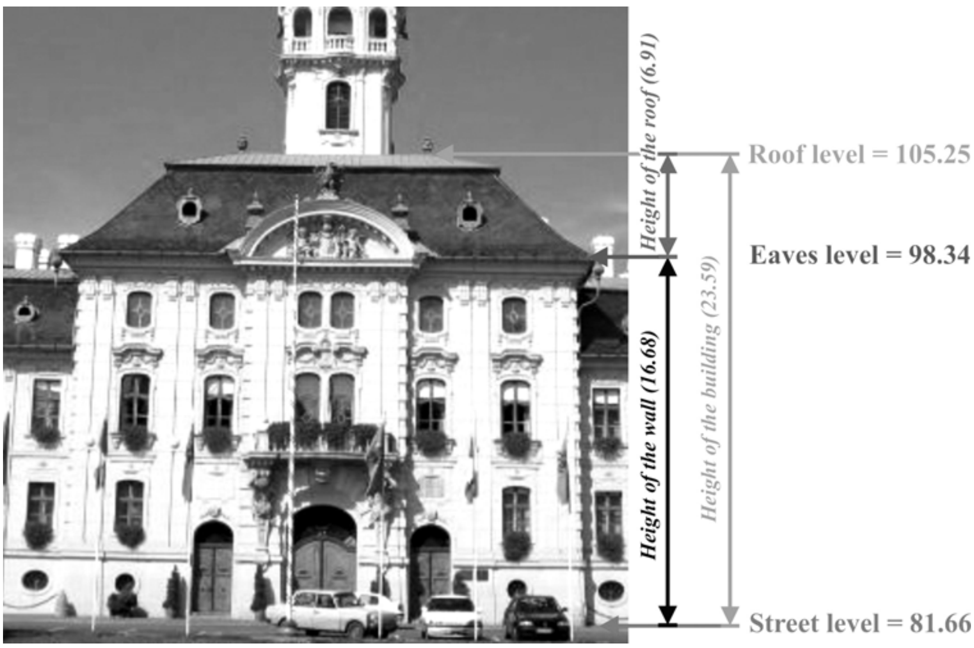

Fig. 4 Measured building data during the evaluation

3.3.3. Measurement and presentation

The 3D measurements were taken in the ERDAS IMAGINE Stereo Analyst module. There are several ways of stereo visualisation; in our case the well-known anaglif method was applied. Floating cursor was used in the measurement, which can be moved in Z direction in addition to X and Y direction. Three data were measured on all buildings: the street level, the eaves level and the roof level, and roof-types also were described with a code (*Fig. 4*).

The ERDAS IMAGINE offers many tools in the 3D visualisation. One of these is the Image Drape and with this the image can be fit perfectly on the suitable DEM in the presentation. The point of view and other parameters can be freely modified. This is a possibility to get a simplified 3D image of the building by choosing suitable elevation data (*Fig. 5*). The figure demonstrates very well the structural-morphological differences in the city. The view of picture is from the NW part of the inner city towards the NE part of the city. The higher buildings of the city centre are visible on the right side, followed by smaller ones, and finally high block houses extend in the distance.

Fig. 5 Bird's-eye view generated by VirtualGIS on a part of the city

3.3.4. Update and accuracy

The newly-built large shopping centres have not existed in the aerial photos of 1992, although they have already been presented in the plan area database. Since these giant buildings with their large parking lots can significantly influence the thermal conditions of their environments, data update was important. This was done with the help of aerial photos taken on 5 August 2003 so now the surface parameters dataset is connected strongly in time to the periods of temperature measurements.

Heights data of buildings measured by ERDAS were checked by theodolite measurement in the cells at the edge of the study area. Here the error of the aerial-triangulation could be expected to be the highest but the ratio of difference of the values was 5% on average compared to the entire height of the building, and based on almost 100 element, the average deviation was not more than 58 cm.

4. FURTHER STEPS

In this article we reviewed the study area, the measured urban surface parameters and the applied methods (remote sensing, field measurements). In the next part of this article we shall describe the applied mathematical methods defining representative sampling and the structure of the statistical model (*Gál et al.,* 2005). Then we present the model created by the above-mentioned methods and its verification including possibilities of implementation and further development.

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