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Investigation of Parameters for Sensitivity Analysis of Buildings Built with Prefabricated Technology

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---***ABSTRACT***---
The effects of climate change have a significant impact on the built environment. One method of determining climate vulnerability could be the framework recommended by the IPCC, the main elements of which are exposure, sensitivity and adaptability.
The aim of the present study is to find factors that can be derived from geometric data and simple visual inspection and are suitable for determining the sensitivity of multi-apartment residential buildings. Given that almost one-eighth of the Hungarian housing stock was built with prefabricated technology, the study focuses on these buildings. The data used for the analysis come from the National Adaptation GIS System, from OpenStreetMap database, and visual inspections. The methods of the research were literature review, calculations in MS Excel and data visualization in GIS software.
The results show that geometric features (footprint, building height, roof shape, etc.) derived from a GIS data or determined by simple visual inspection are suitable for determining the sensitivity of prefabricated residential buildings. With the help of the developed parameters, it is possible to determine the sensitivity and then the vulnerability of entire housing estates, which can be useful for local governments and regional decision-makers, among others, in sustainability planning.
KEYWORDS;-*Budapest, geometry, GIS, prefabricated building, sensitivity, vulnerability*

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I. INTRODUCTION

The composition and climate of the Earth’s atmosphere has always changed, but in the last 200-300 years, humanity has also been able to significantly influence the climate system at different territorial levels through its various activities. The civilizational achievements of modern societies (e.g.: utilities, IT networks, industrial activities, infrastructures, food supplies) are highly vulnerable to changes in the external environment, whether or not these changes are caused by human activity [1].

Regarding the situation in Hungary, in the framework of the VAHAVA project [2], it became clear for the first time in the mid-2000s that its climate vulnerability is also significant on a European scale. The analysis of the EU ESPON-CLIMATE project [3] also confirmed that the less developed regions of Hungary are also highly vulnerable on a European scale.

According to the Intergovernmental Panel on Climate Change (IPCC), it is increasingly clear that extreme weather events are due to anthropogenic climate change, highlighting the importance of exploring climate vulnerability and the importance of prevention and preparedness [1]. The man-made built environment, the buildings are also extremely vulnerable to the effects of the weather.

The aim of the present research is to develop a new - and to refine an existing Hungarian - sensitivity determination method on the basis of openly available geometric data and visually identifiable building characteristics, which is suitable for detecting the differences between multi-apartment residential buildings built with prefabricated technology with almost the same construction time and building structures. Among the climate impacts, present research focuses on refining the determination of sensitivity associated with windstorms.

II. LITERATURE BACKGROUND

Basic Hungarian study

The present research is based on a study conducted in Hungary in 2018 [4], the primary aim of which was to develop a methodology for estimating the relative climate change vulnerability of the building stock at the municipal level as a module of the National Adaptation Geographic Information System (NAGiS) [5]. The study devotes a separate chapter to determining the sensitivity of buildings, for which it introduces a building typology system and then assigns sensitivity values to specific building types. The building typology is based on the number of dwellings, the building material of the outer walls, the number of floors and the year of construction. The building typology is shown in Table 1.

<table>
<tr><th rowspan="2">Number of Apartments</th><th rowspan="2">Building Material of theOuterWalls</th><th rowspan="2">Number of Floors</th><th colspan="5">Year of Construction</th></tr>
<tr><th>before 1946</th><th>1946-1980</th><th>1981-1990</th><th>1991-2000</th><th>since 2001</th></tr>
<tr><td rowspan="2">building with 1-3 apartments (family house)</td><td>adobe, mud</td><td></td><td>1.</td><td>2.</td><td colspan="3">3.</td></tr>
<tr><td>brick, stone, handmasonry unit</td><td></td><td>4.</td><td>5.</td><td colspan="2">6.</td><td>7.</td></tr>
<tr><td>building with 4-9 apartments (smallcondominium)</td><td>brick, stone, handmasonry unit</td><td></td><td rowspan="2">8.</td><td rowspan="2">9.</td><td rowspan="3" colspan="2">10.</td><td rowspan="2">11.</td></tr>
<tr><td rowspan="8">building with 10 or more apartments (largecondominium)</td><td rowspan="2">brick, stone, handmasonry unit</td><td>-5</td></tr>
<tr><td>6-</td><td colspan="2">12.</td><td>13.</td></tr>
<tr><td rowspan="3">middleorlargeblock, cast in placeconcrete</td><td>-5</td><td></td><td colspan="3">14.</td><td></td></tr>
<tr><td>6-11</td><td></td><td colspan="3" rowspan="2">15.</td><td></td></tr>
<tr><td>12-</td><td></td><td></td></tr>
<tr><td rowspan="3">prefabricatedreinforcedconcretesandwich panel</td><td>-5</td><td></td><td colspan="3">16.</td><td></td></tr>
<tr><td>6-11</td><td></td><td colspan="3" rowspan="2">17.</td><td></td></tr>
<tr><td>12</td><td></td><td></td></tr>
</table>

Table 1. Building typology for determining sensitivity [4]

The sensitivities of each building type have been defined for three exposure indicators:

1. Change in the annual average number of days affected by precipitation in excess of 30 mm
2. Change in the annual average number of days affected by hurricanes, strong winds, hurricanes (gusts above 85 km / h)
3. Change in the annual average number of days affected by a sudden drop in temperature (10 ° C in 3 hours)

In determining the sensitivity, the boundary structures of the buildings and their possible damages were generally taken into account, and then sample buildings representing the building stock of Hungary were assembled on the basis of these structures. A so-called age factor has been applied, based on which the older the building is, the more sensitive it is, and a height factor, based on which the taller a building is, the more sensitive it is to the effects of the wind. As a result, the sensitivity of the 17 building types to the three exposure indicators was determined [4].

Prefabricated residential buildings in the Hungarian typology

Between 1967 and 1990, an average of 30-35,000 flats were built in Hungary with prefabricated technology each year, with a total of about 520,000 flats [6, 7], which is approx. 13% of the Hungarian dwelling-stock [8]. It can be seen that in the above typology (Table 1) there are two types of multi-apartment residential buildings built with prefabricated technology (Type 16 and Type 17), the difference in their sensitivity is practically given by the different number of levels. Although prefabricated residential buildings can be considered structurally uniform, their cubature, geometric properties (eg shape of the floor plan, shape of the roof , etc.) can be very different, which also affects their sensitivity. Figure 1 shows two buildings with different geometric design, but belonging to the same type (Type 17), so with the same sensitivity according to the above-mentioned Hungarian study.

Figure 1. Prefabricated residential buildings with different geometric properties [9]

III. POSSIBLE STRUCTURAL DAMAGE CAUSED BY WIND

In Hungary, the average annual number of days affected by wind gusts, strong wind gusts and hurricanes (gusts exceeding 85 km/h) will increase on average for both 2021-2050 and 2071-2100 based on projections taking into account the RCA4, CNRM-CM5 climate model RCP 4.5 scenario [10]. It should be noted, however, that there is a great deal of uncertainty about future changes in wind speed and direction, but the UK, among others, is expected to become windier once and the number of storms will increase [11].

An increase in the compressive and suction effects of the wind can also lead to structural and building structural problems. Surfaces most exposed to wind are most at risk, especially roofs and façades of buildings and tall buildings and their connected structures (eg shutters, blinds, etc.). Stronger winds can easily dismantle loose roofing elements, causing damage to ceramic or concrete tile roof as well as to waterproofing layer of flat roofs [12-14]. From a structural point of view, the building corners are especially dangerous - the so-called edge areas - because the wind can damage structures more easily in these places. In these edge areas, for example, more dowels are used to secure the façade insulation or more loads are applied at the corners of the flat roof. In Hungary, as a rule of thumb, the load on a flat roof is 45 kg/m2 in the general inner field, 130 kg/m2 in the outer band and 225 kg/m2 in the 'corner fields'.

The wind can knock down trees near the building, breaking down the branches of the trees, which can also cause damage to building structures [14].

The extent of the wind effect naturally depends on some other properties of the building: location, protection, orientation, height, shape of the roof, roof angle [12].

IV. PARAMETERS CONSIDERED IN OTHER STUDIES

The study of vulnerability of buildings to windstorms is addressed in a number of international studies that consider different properties of buildings to be important in defining the basic elements of vulnerability. The results of some research are summarized in Table 2.

Author	Ref.	Importantfactorsbasedontheresearch
Alwetaishi&Sonetti, 2017	[15]	building form
		orientation
Bhandariet. al., 2005	[16]	floorplan of the building
		roofshape, height, angle of inclination
Ginger et. al., 2010	[17]	constructiontime
		building size
		roofshape, angle of inclination
Horváth & Pálvölgyi, 2011	[18]	building age
		building value
		roofsize, rooftype, roofshell
Peiris, Hill, 2012	[19]	constructiontime
Roafet. al., 2009	[11]	building age
		building height
		roofsize, roofshell
Ruck, Heneka, 2008	[20]	building age

Table 2. Important factors in determining wind sensitivity according to other studies

V. SUMMARY OF THE LITERATURE SEARCH, PARAMETERS EXAMINED IN THE PRESENT RESEARCH

In conclusion, in the case of wind sensitivity researches, the important characteristics of buildings are the shape of the building, the shape of the roof, the roof cladding, and the height of the building.

In the above-mentioned Hungarian basic research on the vulnerability of buildings [4], the height of the building was taken into account when determining the sensitivity to wind (buildings were classified into three categories and higher and higher buildings received higher scores), but this was classified into building types. In the present research, building height is examined as a unique building parameter. In addition, the study examines other possible parameters such as roof shape, roof cladding, and building form: it uses map visualization to find the answer to whether these parameters can be used to differentiate between residential buildings and housing estates.

The examination of the cladding is not relevant in Hungarian conditions, because the flat-roofed prefabricated buildings are all equipped with bituminous or PVC membrane, and the pitched-roofed buildings all have ceramic or concrete tiles.

Regarding the shape of buildings, the study introduces the 'number of corners' as a geometric feature, thus trying to approximate the geometric complexity and thus the sensitivity to wind. Figure 2 shows two examples of geometrically simpler and more complex buildings (with fewer or more corners) from the Füredi and Káposztásmegyer housing estates.

Figure 2. Geometrically simpler and more complex buildings [9]

VI. MATERIAL AND METHOD

Sample areas of the study

More than a third of the Hungarian prefabricated residential buildings are located in Budapest [6, 7], therefore the capital was selected for the sample area study. The selection of housing estates was based on the combined consideration of several factors: different location within the settlement, different construction times, different number of dwellings (<5000, 5000-10000, >10000). Based on this, six housing estates were selected, the main data and schematic layout of which are listed in the Table 3. The location of the housing estates within the capital is shown in Figure 3.

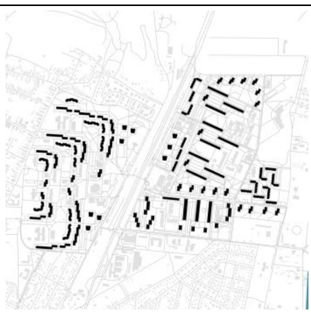
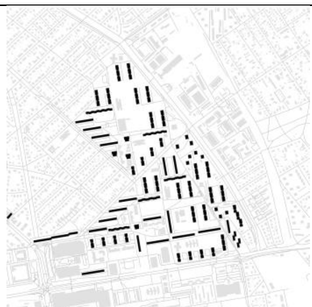
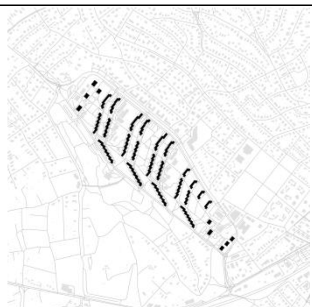
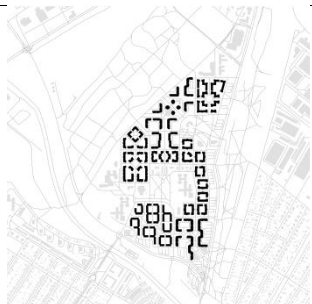
housingestate	Békásmegyer	Füredi	Gazdagrét
constructiontime	1972-1986	1964-1982	1981-1986
number of dwellings	13400	12200	4200
schematiclayout			
housingestate	Havanna	Káposztásmegyer	Budafok-Rózsakert
constructiontime	1976-1981	1984-1992	1976-1982
number of dwellings	5500	7700	1500
schematiclayout			

Table 3: Main data and schematic layouts of selected housing estates [9, 21-24]

Figure 3. Location of the examined housing estates in Budapest [9, 23, 24]

Examined parameters and their sources

Based on the literature review, present study examines the following parameters:

- roof shape (pitched roof / flat roof),
- building height,
- number of building corners.

It should be noted that no specific plans are available to determine the height of the buildings, but they can be estimated with a good approximation from the number of levels of the buildings above ground level. The typical level height of prefabricated buildings in Hungary can be calculated at an average of 2.85 m (2.65 m ceiling height + 0.2 m slab).

Geometric data were available from the following sources:

- The footprint of the buildings comes from the freely downloadable and usable, community-edited world map, OpenStreetMap [23]. Data available for the whole country can be downloaded free of charge from https://download.geofabrik.de/ in .shp.zip format [24]. From the data, the floor area, perimeter and number of building corners can be calculated.
- The height of the buildings and their level above ground level were determined on the one hand by GIS systems enabling 3D visualization: Google Earth [25] and Apple Maps [9], as well as by visual inspections.

The process of the investigation:

1. In order to be clearly identifiable later, the unique identifiers of the buildings - parcel numbers and their address data - were manually uploaded into the attribute table of the building geometries downloaded from OpenStreetMap. (This step could be omitted in case of a data request from central building cadastre.)
2. The level levels of the buildings above ground level were recorded manually. In the case of building masses with different level numbers within a building, “broken” level numbers were also used.
3. The height of the buildings was determined from the number of levels.
4. The roof shape (0 = pitched roof, 1 = flat roof) were uploaded manually.
5. Derived from the basic geometry, a parameter called “number of corners” was determined.
6. Visualizations were made for various derived indicators.

VII. RESULTS AND CONCLUSIONS

Reference status

As a first step, the sensitivity classification of buildings in housing estates was done based on the methodology invented by Schneller et al. (2018) [4]. In the following, the results are examined against this reference classification.

It can be stated that based on the methodology - with the exception of the Káposztásmegyer housing estate - almost all buildings within a housing estate fall into the same sensitivity class, so there is no possibility to differentiate between the individual buildings.

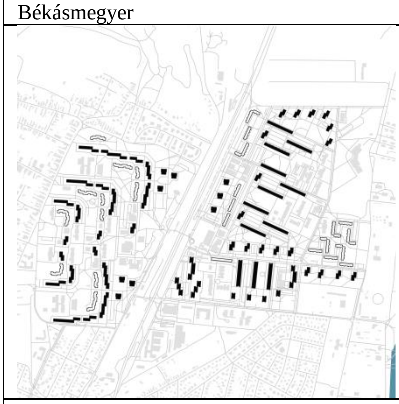
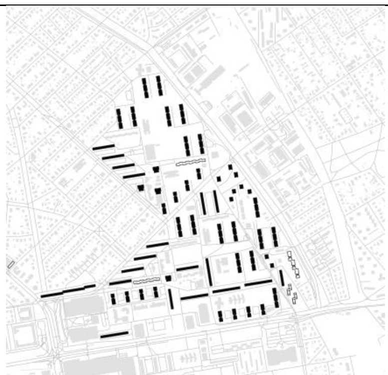
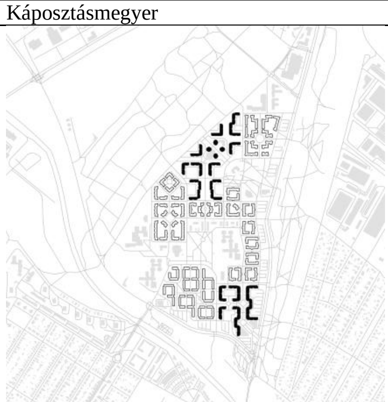
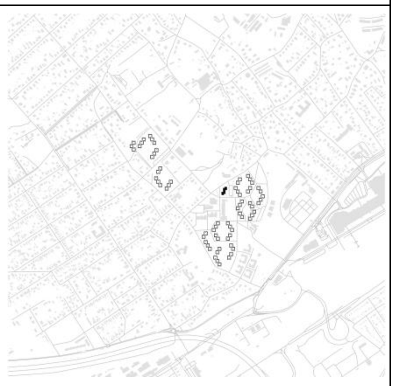
Békásmegyer	Füredi	Gazdagrét
		
Havanna	Káposztásmegyer	Budafok-Rózsakert
		
Legend: ○ white: building type No.16. (building material is prefabricated reinforced concrete, number of floors are less than 5) • black: building type No.17. (building material is prefabricated reinforced concrete, number of floors are more than 5)		

Table 4. Classification of buildings according to Schneller et al. (2018) [4]

Roof shape

Table 5 shows the classification of buildings based on roof shape. Hungarian housing estates are predominantly characterized by the fact that, for economic reasons, they typically contain only a few types of residential buildings, so only in a few cases pitched-roofed and flat-roofed buildings are mixed. Of the examined housing estates, flat and pitched-roof buildings together occur only in the Káposztásmegyer housing estate.

Thus, the shape of the roof within a housing estate is generally not an important factor in the comparison of individual buildings to each other, however, it may play an important role in the examination of the sensitivity of housing estates to each other.

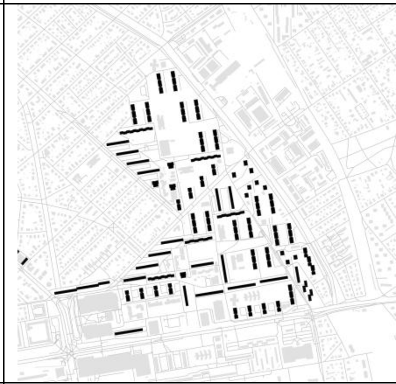
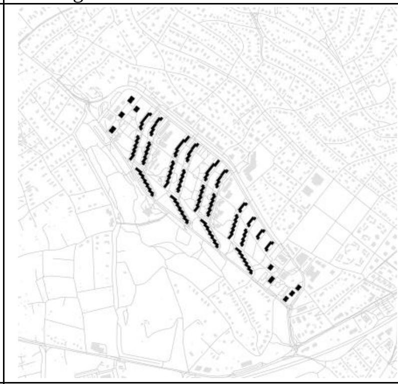
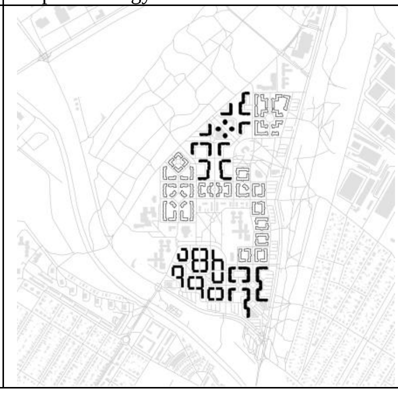
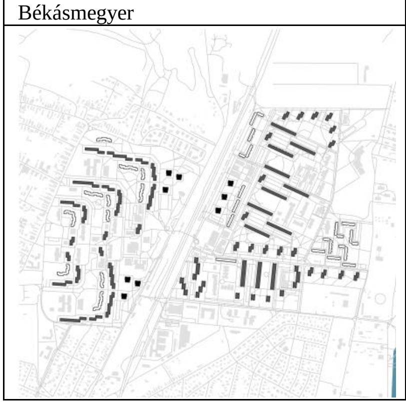
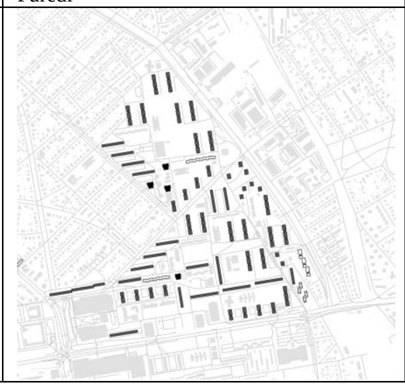
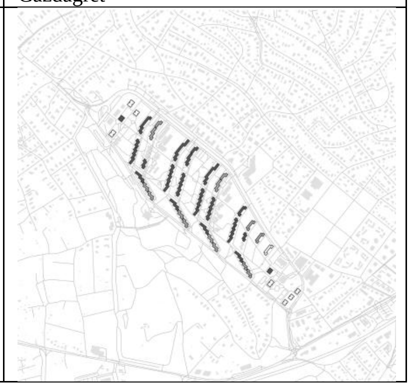
Békásmegyer	Füredi	Gazdagrét
		
Havanna	Káposztásmegyer	Budafok-Rózsakert
		
Legend – form of the roof: o white: building with pitched roof • black: building with flat roof		

Table 5: Classification by roof shape

Building Height

Based on the previously presented, the building height was determined based on the number of levels, and then the buildings were classified into 4 categories. Until the eighties, mainly ground-floor + 4-storey and ground-floor + 10-storey residential buildings were built on Hungarian panel housing estates, higher buildings being rare [6].

Table 6 shows the classification of buildings based on building height. It can be seen that with the help of a four-point scale, differences can be detected between the buildings and between the housing estates by summing up the building values.

Békásmegyer	Füredi	Gazdagrét
		

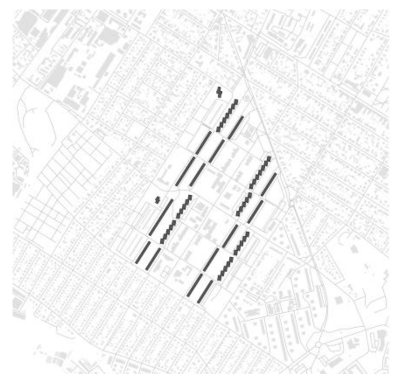
Havanna	Káposztásmegyer	Budafok-Rózsakert
		
Legend – building high [m]: 0,00 – 20,0 m 20,1 – 30,0 m 30,1 – 40,0 m 40,1 – 50,0 m		

Table 6: Classification by building height

Number of corners

In examining the number of corners, the buildings were classified into four categories based on Table 7.

The number of corners tries to represent the geometric complexity of the buildings as presented in Chapter 2.5: the more corners a building has, the more structural fractures, the more potential damage points.

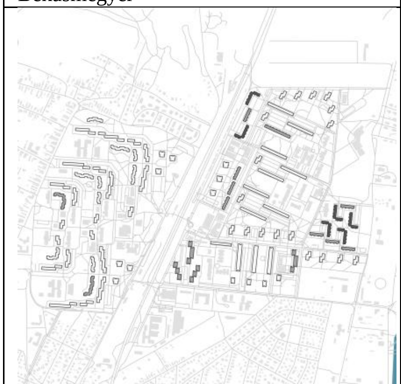
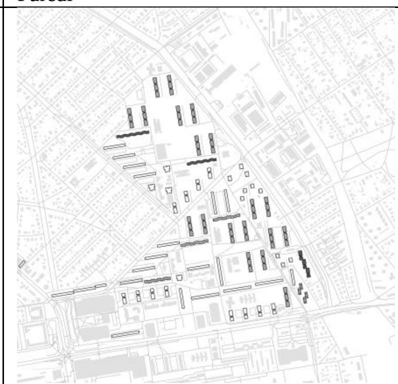
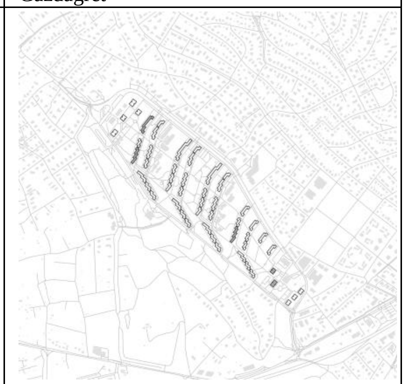
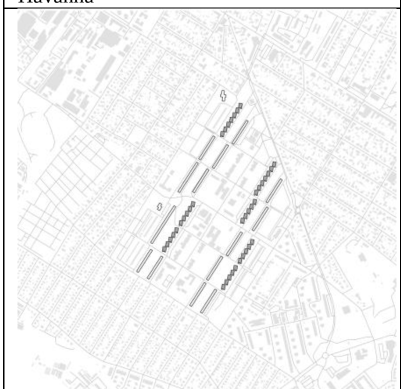
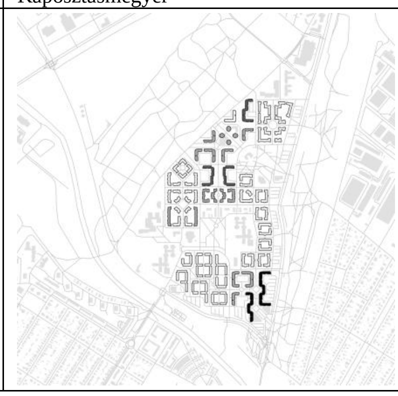
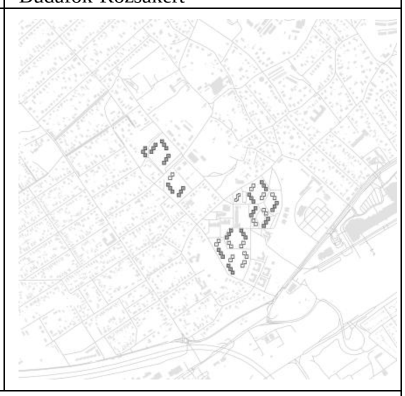
Békásmegyer	Füredi	Gazdagrét
		
Havanna	Káposztásmegyer	Budafok-Rózsakert
		
Legend – number of corners [pc]: 1 – 25 26 – 50 51 – 75 76 – 100		

Table 7: Classification by number of corners

VIII. CONCLUSIONS

The aim of the present study was to investigate the parameters suitable for sensitivity analysis derived from geometric data and simple visual inspection in case of prefabricated residential buildings. Based on the analysis, it can be concluded that both the roof shape, the height of the building and the number of corners can be suitable parameters for determining the sensitivity of these buildings. The individual parameters are also suitable for estimating the relative sensitivity of buildings and, in general, for estimating the relative sensitivity of housing estates.

The present research is the first part of a longer study aimed at setting up a complete vulnerability analysis methodology for the selected prefabricated building type. The aim of the next step of the research is to examine the parameters suitable for the analysis of adaptability.

In the following, it may be worth examining the effect of the building form, which can be analyzed from several sides, e.g. from the structural side (wind twisting effect) and from the energy side (building compactness, surface-to-volume ratio as an indicator).

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REFERENCE

[1] InnovációsésTechnológiaiMinisztérium, MásodikNemzetiÉghajlatváltozásiStratégia (Budapest, InnovációsésTechnológiaiMinisztérium, 2018).

[2] I. Láng, L. Csete, and M. Jolánkai, A globálisklímaváltozás: hazai hatásokésválaszok (A VAHAVA Jelentés) (Budapest, SzaktudásKiadó, 2007).

[3] ESPON and IRPUD, ESPON Climate - Climate Change and Territorial Effects on Regions and Local Economies (Dortmund, TU Dortmund, 2011).

[4] K. Schneller, M. Cebei, M. Csőszi, A. Devecseri, A. Horkai, C. T. Jaschitzné, et al., Magyarországiépületállományéghajlatváltozásisérülékenység-vizsgálatáttelepülésiszintenlehetővétevőmódszertan (Budapest, Lechner Nonprofit Kft., 2018).

[5] P. Kajner, T. Czira, P. Selmeczi, and A. Sütő, National adaptation geo-information system in climate adaptation planning, Idojaras, vol. 121, 2017, 345-370.

[6] P. Birghoffer and L. Hikisch, A paneloslakóépületekfelújítása (Budapest, MűszakiKönyvkiadó, 1994).

[7] A. Dési, Panelkalauz (Budapest, ÉpítésügyiTájékoztatásiKözpontKft., 1996).

[8] KözpontiStatisztikaiHivatal, 12. Lakásviszonyok (Budapest, KözpontiStatisztikaiHivatal, 2014).

[9] Apple Maps. URL: https://www.apple.com/ios/maps/

[10] NATéR. NemzetiAlkalmazkodásiTérinformatikaiRendszer (NATéR) - ENG: National Adaptation Geo-information System (NAGiS). URL: https://map.mbfsz.gov.hu/nater/

[11] S. Roaf, D. Crichton, and F. Nicol, Adapting Buildings and Cities for Climate Change (Oxford, Elsevier Ltd., 2009).

[12] M. Osztroluczky, Épületkárok (Budapest, CserKiadó, 2011).

[13] T. Pálvölgyi, A klímaváltozásfigyelembevétele a környezetiértékelésekben, 2010).

[14] MBFSZ-NAKFO, Klímabiztosépület (Budapest, Magyar BányászatiésFöldtaniSzakszolgálat, NemzetiAlkalmazkodásiKözpontFőosztály, 2019).

[15] M. Alwetaishi and G. Sonetti, Influence of Orientation in Complex Building Architecture in Various Climatic Regions in Winter, International Journal of Architectural and Environmental Engineering, vol. 11(5), 2017, 660-663.

[16] N. M. Bhandari, P. Krishna, and K. Kumar, Wind Storms, Damage and Guidelines for Mitigative Measures, Department of Civil Engineering, Indian Institute of Technology Roorkee, 2005).

[17] J. Ginger, D. Henderson, M. Edwards, and J. Holmes, Housing damage in windstorms and mitigation for Australia, Proc. 2010 APEC-WW and IG-WRDRR Joint Workshop: Wind-Related Disaster Risk Reduction Activities in Asia-Pacific Region and Cooperative Actions, Incheon, Korea, 2010, 1-18.

[18] S. E. Horváth and T. Pálvölgyi, Buildings and climate change: impacts on roofs and vulnerability to wind storms, Építôanyag, vol. 2011, 2011, 62-66.

[19] N. Peiris and M. Hill, Modeling wind vulnerability of French houses to European extra-tropical cyclones using empirical methods, Journal of Wind Engineering and Industrial Aerodynamics, vol. 104–106, 2012, 293–301.

[20] P. Heneka and B. Ruck, A damage model for the assessment of storm damage to buildings, Engineering Structures, vol. 30, 2008, 3603-3609.

[21] T. Nagy, A budapestilakótelepekfőbbadatai (1947-1985) (Budapest, BUVÁTI, 1987).

[22] KormányszóvivőiIroda, Budapest paneloslakótelepei).

[23] Open Street Map. URL: https://www.openstreetmap.org/

[24] Open Street Map Data Extracts. URL: https://download.geofabrik.de/

[25] Google Earth. URL: https://www.google.com/intl/hu/earth/