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Urban Pattern Geometry and its Potential Energy Efficiency

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Abstract

Urban pattern in every city or district is a result of interconnection of the various factors, such as climate, tradition, economy and culture. Different configurations of the urban development allow to the certain extent to control the outdoor microclimate of the cities or districts. The geometrical properties of the buildings, which form the pattern, are the instrument of creation of the urban microclimate, and at the same time they influence at the energy consumption of the building. Density is an economical factor, which shapes the development of the urban districts and settlements. There is a common tendency to intensify the land use and to construct the maximum number of the dwelling units per area. Within the study there were developed six parametric models of the different urban morphologies. For each of the models the land plot is fixed, but the density of the built units and their position are changing according to the height of the building. The idealized models are compared between each other in order to find the ones with the highest economical and energy efficiency potentials. The evaluation is based on the combination of such factors, as urban density, site coverage, number of built units and surface area to volume ratio.

Keywords:	Urban pattern efficiency; Urban morphology; Building density; Surface to volume ratio

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1. Introduction

Urban forms can be distinguished at different planning levels, such as region, city, district, neighbourhood, street or urban block. The physical characteristics of urban form include shape, size and configuration of the units [1]. For the study the intermediate level is selected and the urban form is combined by the specific pattern of the tower or row houses, either by several urban blocks. Urban forms have direct influence to all sectors of infrastructure, such as energy, transport, water supply and wastewater, solid waste, social infrastructure etc. Provision of the compact urban morphology with higher density may reduce the resources needed to install and supply the urban infrastructure. Within the hypothetical model it is not possible to evaluate the residential either occupancy density, therefore the parameters, which characterize the provided habitable area and site coverage are selected. Site coverage represents the ratio of built-in land and may be evaluated as the ratio of the all buildings footprints to the land area [2]. Maximal site coverage is usually established in the urban development standards. The building density is a result of the sum of all habitable areas to the site area. Similar building density can be achieved through application of different urban patterns, which may have different ratio between site coverage and building height. There is a common tendency of reduction of the site coverage and after certain values also the density with the increase of the height of the building due to necessity to manage the minimal solar obstruction angle [2]. The amount of sky, which may be observed from the ground level increases with the decreasing of the site coverage, and the sky view factor is directly connected with the phenomena of urban heat island [3].

There is a complex relationship between the density, urban morphology and form and the energy consumption of the city. In the cities with the higher density the transport network and the following with it costs may be reduced and the social networks and community interactions may increase [4]. Urban structures with higher density tend to be more energy efficient than the ones with lover density [5]. Urban pattern is directly related with the outdoor microclimate as well as with the energy consumption of the buildings, by which it is formed. The heating and cooling loads of the building are decreasing with increasing of building compacity, which means better energy performance for the bigger buildings compare to smaller and for the building with simple footprint compare to the complicated ones [6]. The geometrical property of the building, such as relation between the surface area and the volume affects its heat loss or gain through the outer walls and roof [7]. The structures with higher urban density and compacity of the buildings are more economical and require less cost for the organization of the road and supply systems as well as for the energy demands [8].

The arrangement of the urban pattern and the shape of its units may affect at the amount of solar radiation, which is received by buildings. The increase of the solar exposure may reduce the building energy demand for heating. There is a correlation between the density of the urban pattern and the solar access, which is decreasing with the increase of the density, but the other factors, such as compacity of the buildings and character of the urban fabric with possible solar exposure may affect as well [9].

Within the paper the relation between the urban pattern, density and compacity of the buildings and the received solar energy is evaluated based on the development of the parametric model of six different urban morphologies. The series of simulations aimed to find the urban model with the highest economical performance, which may be represented by the highest building density and lowest number of buildings and highest energy performance, which is characterized by lower site coverage and lower surface to volume ratio.

2. Methodology

The study is based in the initial development of the six parametric models representing the common urban morphologies, such as square based house or tower, row house and urban block. The three typologies are arranged in a rectangular and circular array. For the construction of algorithms the Grasshopper for Rhino software was used. There were two sites (rectangular and circular consequently) with fixed dimensions, which were used for the generation of models. For each of the typologies the variations of built structures from 1 to 10 floors were generated. The algorithm was designed in a way that the number of the buildings, which could fit on site, was defined by the height of the buildings. For the whole structure the minimal solar obstruction angle of 45 degrees was used in order to define the minimum distance between buildings and between building and the border of the side (Figure 1). The width of the building is fixed at 14m.

As the result, 60 urban models were generated. Sample models for the six typologies are shown in Figure 2. For the square based house (tower) it was assumed to have the fixed sides of the building as 14m. The sample row house base was assumed to be 14x50m. The dimensions of urban block were calculated according to the requirement of minimal solar obstruction angle: the side of the block was not less than sum of double width of the building and its height. In the circular array this rule was applied to the smallest side of the trapezoidal block.

For every pattern the following data was collected:

- Building density – ratio between the total habitable area of all buildings and the site area
- Number of buildings – indicates the number of generated buildings per ha
- Site coverage – ratio between the sum of all footprints of the buildings and site area

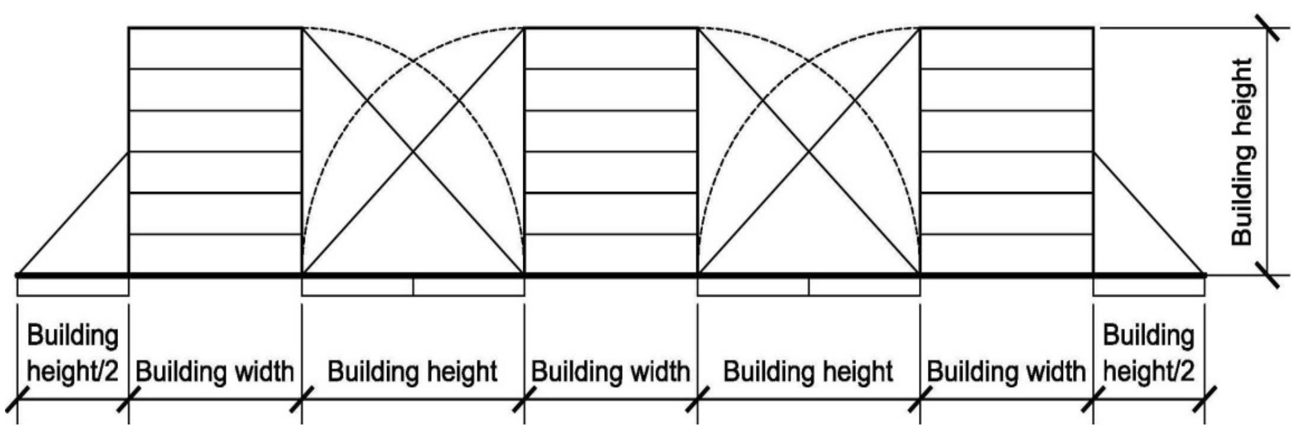

Figure 1. Sample section of the generated model with indication of the distances between buildings

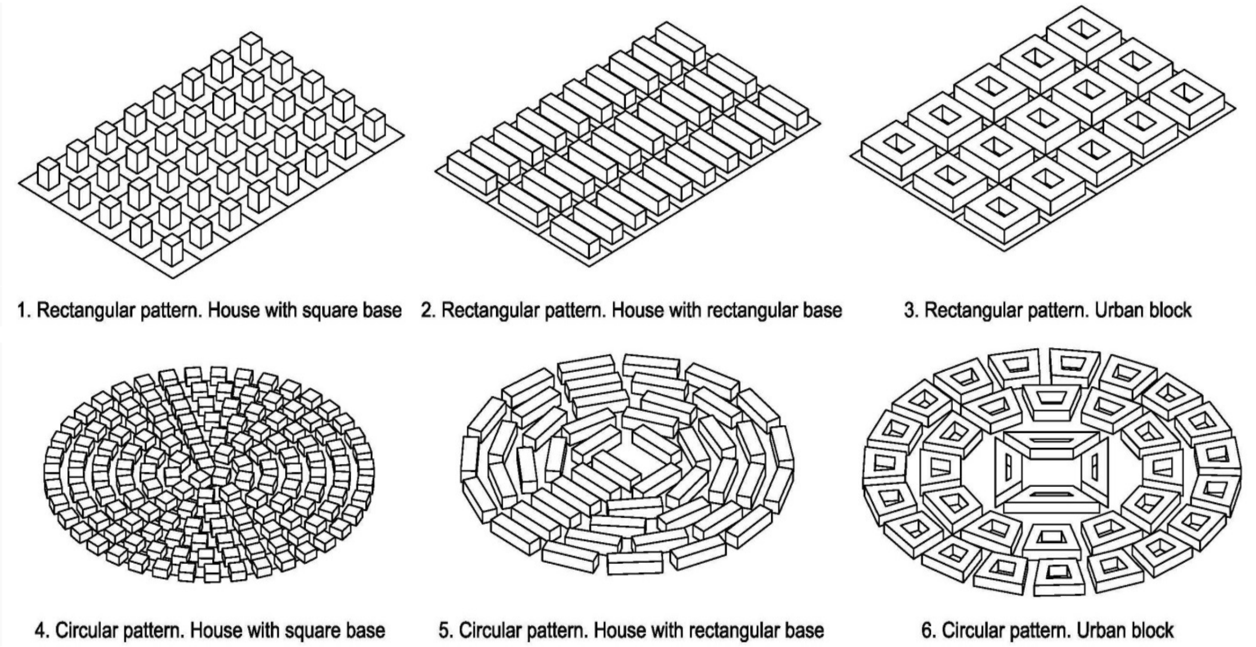

Figure 2. Samples of the six urban patterns

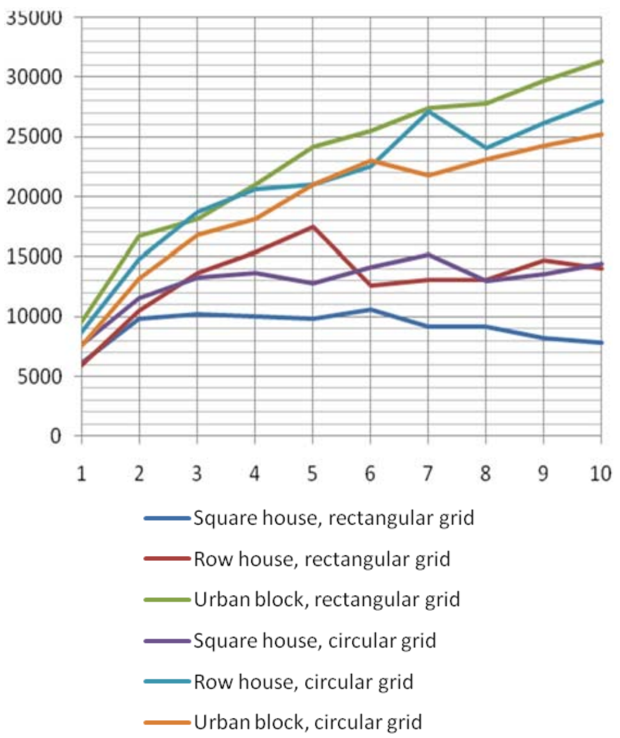

Figure 3. Building density and the number of floors for different urban patterns, m^2/ha

— Surface to volume ratio – ratio between the sum of all surfaces of the buildings and all volumes

— Building surface radiation – indicates the solar radiation per ha of the built surface of the generated urban pattern per year

3. Analysis of the generated patterns

3.1. Building density

In the generated model the building density is the result of the parametric approach and it depends on the controlled distances between the buildings. The distance between buildings is defined by the number of floors and consequently by the height of the generated forms. As it is presented in Figure 3, the different urban patterns demonstrate different trends in changing of the built density. The densest patterns are the rectangular and trapezoidal urban blocks and the row houses, which are arranged in the circular grid. For these patterns it is evident the growth of the density with increasing of the building heights. The two patterns generated with use of the square base building are evidently less dense. For these patterns the density is decreasing with the increase of the building height. The row house rectangular array pattern has evident growth up to the 5th floor and with further increase the density is decreasing. This behaviour could be explained by the influence of the site borders: for the first five samples there are generated three rows of buildings, but for the higher buildings only two rows could fit due to the necessity to provide the adequate distance between the buildings.

3.2. Number of the buildings

Since the generated patterns require two different sites – rectangular and circular – it is possible to compare the quantity of produced buildings only in relation to the area of the site. The distance between buildings increasing with the building height, therefore within the fixed site borders the number of the generated volumes is decreasing. The connection between the building height and the number of the buildings for the given site is given in Figure 4.

The two urban patterns with the use square based are characterized by the highest number of built units and the significant decrease of the parameter with increasing of the building height. For the models generated by the rectangular and trapezoidal urban block the lowest number of the built structures is evident and the number of the remains almost constant with the slight decrease. The two row house patterns demonstrate the intermediate results.

3.3. Site coverage

Site coverage represents the intensity of the land use and is defined by the relation of the sum of building footprints to the total site area. Site coverage is the constant value for all the points of the urban patterns based on the rectangular grid, but it varies for the circular patterns. In circular patterns the center is always left empty due to specificity of the generation algorithm and the character of spaces between buildings varies with changing of the radius.

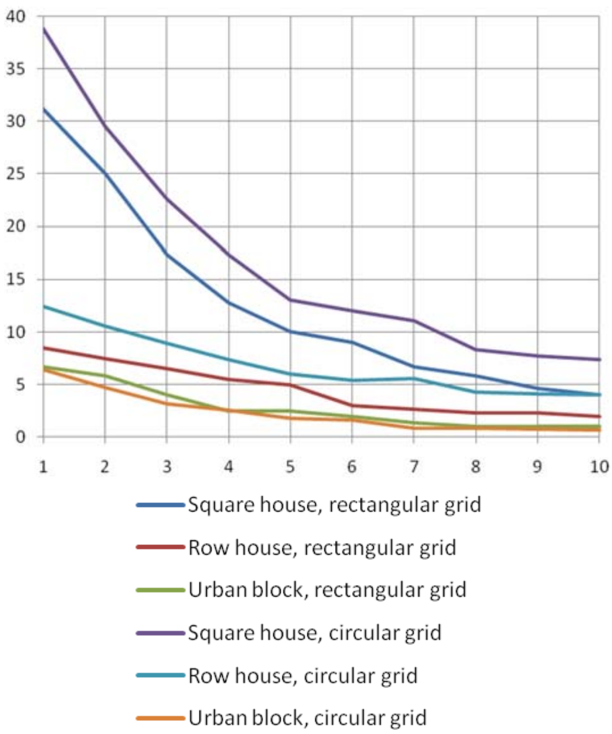

Figure 4. Number of buildings and the number of floors for different urban patterns, unit per ha

As it is shown in Figure 5, site coverage ratio is decreasing with the increase of the height of the building for every examined urban pattern. The highest values are noticed for the rectangular and trapezoidal urban blocks, and lowest are character for the patterns generated by square based buildings. For all the patterns the use of low-rise and especially single floor buildings results with the highest ration of at least 60%, which is usually not permitted by the urban regulations.

3.4. Surface to volume ration

Surface to volume ratio is an indicator of the energy performance of the building and it is defined only by its geometrical properties. For the urban patterns, which are based on the use of square and rectangular based buildings the surface to volume ratio is similar for every unit and the charts are identical.

For the trapezoidal urban blocks in a circular array the coefficient differs from building to building and it is evaluate for the whole pattern as the ratio between the sum of all surfaces to sum of all volumes. According to Figure 6 the highest surface to volume is noticed for the low-raised buildings. With the growth of the height the change of the ratio is minor. The performance of the two patterns with square based units and the two patterns with rectangle based units is identical. The urban blocks are characterized by lower coefficient and the performance of the rectangle based pattern is better, then circular.

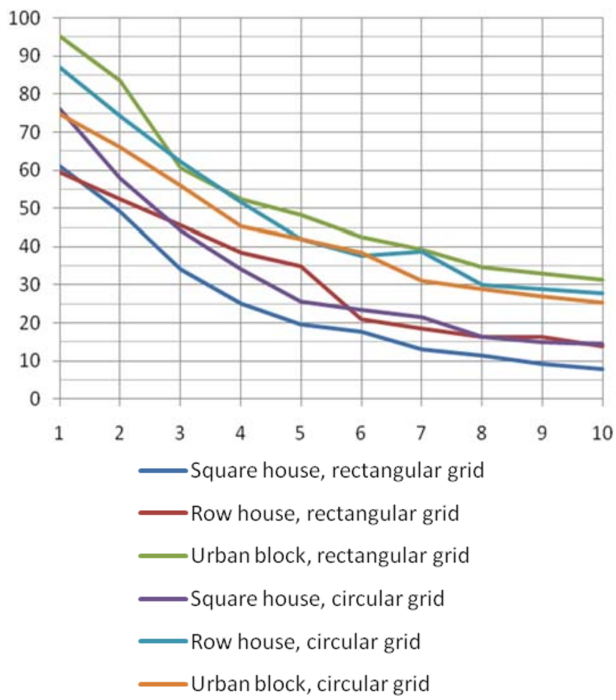

Figure 5. Site coverage and the number of floors for different urban patterns, %

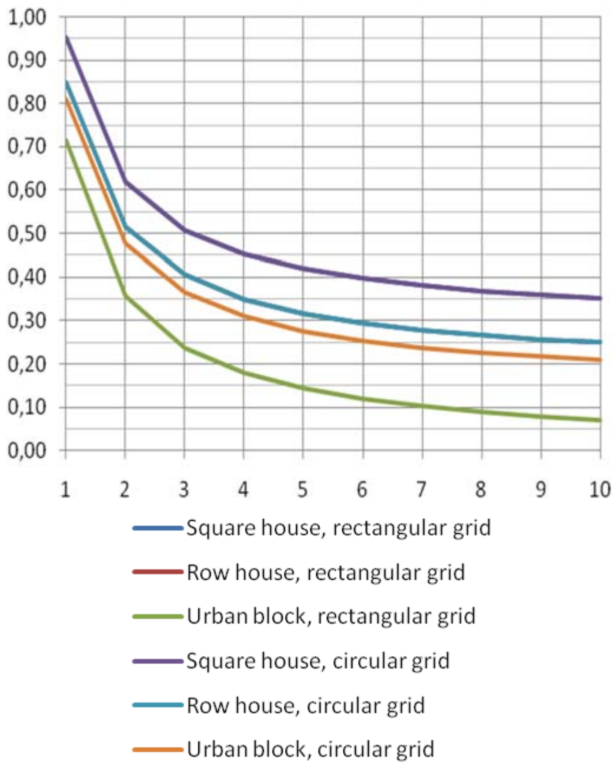

Figure 6. Surface to volume ratio and the number of floors for different urban patterns, m^2/m^3

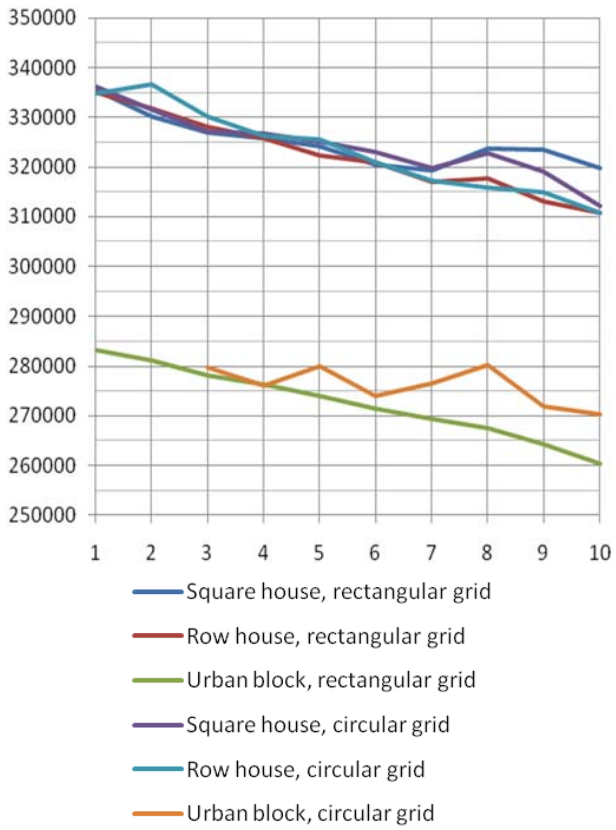

Figure 7. Incident solar radiation and the number of floors for different urban patterns, KWt per year

3.5. Building surface incident solar radiation

Solar radiation indicates the energy, which is received by the all surfaces of the built elements of urban pattern. The generated urban morphologies were evaluated using the Autodesk Ecotect Analysis. The results of simulation are presented in Figure 7. There is an evident difference in performance of the urban block in comparison to the other morphologies. Both circular and rectangular patterns receive less solar radiation, which can be explained by the complex shape of the building with the courtyard, which cause an extra shading of the walls. Incident solar radiation is decreasing with the increase of the building height for all cases. The relation is not linear, which can be explained by the fact of adaptation of the distances between units according to the heights in generated model. For the two morphologies based on the use of the square based building and for the circular urban block pattern there is a segment between 3 and 9 floors, where the difference in values is minimal.

The picks on the diagram prove the necessity on the examination of the performance of patterns with different height on the specific site in order to find the maximum.

4. Conclusion

Within the study the sixty algorithmic urban morphologies were generated and evaluated in terms of the urban parameters, such as building density, site coverage and number of the built units per ha, and in terms of the potential energy gains and losses, such as received solar radiation and surface to volume ratio. There is a clear relation between the behaviour of all parameters and the urban morphology and the height of the built units.

The highest building density, the lowest number of built units, the highest site coverage and the maximal building compacity are registered for the urban morphology based on the use of the European urban block. In all cases the performance of rectangular pattern is higher, then the circular. By the analysis of the same parameters the use of the row house pattern is more preferable to the square based one. The constant growth of density with the increase of the building height is character only for the urban blocks and the circular pattern of the row houses. For the rest it is evident the decrease of density after reaching of 5 floors the built units. The site coverage, number of built units and the surface to volume ratio decrease intensively, but after reaching the height of 5 floors there parameters have very minor change.

The potential solar gains of the urban block are the lowest from all the examined cases, meanwhile the four other morphologies demonstrate very similar results. For all the generated patterns received solar radiation decreases with the increase of the building height.

Evaluation of the urban parameters and the potential energy gains and losses allows to control some of the parameters, which define the overall energy performance of the urban morphology. During the computer simulation there were used the simplified models, where the factors of building environment, building materials, and the occupants' behaviour were neglected. For the real urban pattern the performance can be different due to the fact, that the buildings will have complex shape, and the distances between them may vary. Information, which is provided in the study, may be used for the selection of the urban pattern with the optimal performance, which will reduce the energy demand of the city.

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