CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF ARCHITECTURE
DEPARTMENT OF DESIGN AND BUILDING

ENERGY EFFICIENCY
IN THE URBAN SCALE

PHD THESIS

Student:
Ernest Shtepani, M.arch., Dipl.Arch.
Supervisor:
Michal Kohout, doc. ing. Arch.

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The thesis named "***Energy Efficiency in the Urban Scale***"
has been submitted for the degree of Doctor of Philosophy.

I, the undersigned, hereby declare that:

• I am the sole author of this thesis.

• I have fully acknowledged and referenced the ideas and work of others, whether published or unpublished, in my thesis.

• I have prepared my study for thesis specifically for the degree of Doctor of Philosophy while under supervision at Czech Technical University in Prague.

• My study for thesis does not contain work extracted from a thesis, dissertation or research paper previously presented for another degree or diploma at this or any other university.

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ABSTRACT

ENERGY EFFICIENCY IN THE URBAN SCALE

The demand for energy efficiency is more important than ever in a time when resources are scarce and the cities are growing rapidly. Cities are the biggest energy consumers and understanding it is critical to understand the factors, which affect the urban energy balance. The study is based on the presumption that urban patterns play an indispensable role in energy consumption. Cities are a complex mass of morphological properties of many urban fragments, which play a major role in energy consumption. Urban form, urban patterns, or city fragments can also be seen as defined by algorithms or form generators. Cities are designed taking into account infrastructure, city standards and land use regulations. Energy efficiency of the urban form may be understood as the balance between gains and losses of energy, which may depend on a set of parameters mostly defined by the geometrical shape of the buildings and the distance between them.

Contemporary urbanism is based not only on design of the spatial configurations of the city, but also it deals with deals with management, logic on the things, reflect on the harmony of the space, dissonance and difference, doing things more comprehensible. Still the majority of urban decisions are ruled out by non-energy considerations. Contemporary studies emphasize the importance of city density, which is a major contributor to energy efficiency. There is a common agreement among researchers about the efficiency of compact cities in addition to other important issues, such as passive solar radiation and the ventilation factor. The study examines the relationship of morphological properties of urban pattern, such as shape and dimensions of the built units, and its energy efficiency, through testing the criteria of density, site coverage, available solar radiation, wind flow and surface-to-volume ratio.

In order to find the influence of the geometrical parameters of the urban patterns on its energy efficiency, the research starts by generating of a set of algorithmic models or samples of urban patterns including point block, slab block and perimeter block typologies, which are arranged with the use of rectangular and circular grid. Energy efficiency of urban morphology is analyzed through comparison of its performance by different criteria such as density and site coverage, surface-to-volume ratio, annual solar radiation, wind sheltering factor, building dimensions and geometry. The second part of research is based on an investigation of possibilities to find the geometrical properties and the way of spatial arrangement of the most energy efficient urban morphology. The problem of finding the urban pattern with the optimal combination of the high building density and low surface-to-volume ratio was examined with the use of the Galapagos Evolutionary Solver. At the final stage the performance of theoretical generated urban morphologies is compared with the behavior of the groups of buildings, which are extracted from the existing city. Different urban patterns of Prague, such as row houses, tower, rectangular, triangular and polygonal perimetral block are compared through the tri-fold properties of energy efficiency – surface to volume ratio, incident solar radiation and building density.

The analysis is based on the search of the balance between the energy losses and energy gains of the morphological properties of urban patterns. In some cases the enforcement of one element of this equation may contradict the other. Nevertheless, it is possible to establish the connection between the general set of parameters, such as the building envelope dimensions, height and the shape of the unit, and the potential energy behavior of urban pattern.

Keywords: algorithmic modeling, digital city, parameters of energy efficiency, morphological properties, urban pattern, Prague.

ABSTRAKT (ČESKY)

Energetická náročnost v městském měřítku

Téma energetické náročnosti nabývá vyššího významu v době rapidní urbanizace měst a současného vyčerpávání přírodních zdrojů. Města představují systémy s největší energetickou spotřebou a poznání konkrétních faktorů ovlivňujících jejich energetickou náročnost je tudíž klíčové. Tato práce vychází z předpokladu, že zastavovací systém města hraje v otázce energetické náročnosti podstatnou roli. Města jsou nahlížena jako komplexní hmota, kterou lze popsat řadou morfologických vlastností vztažených k dílčím částem měst a jejich zastavovacím systémům. Forma města, jeho zastavovací systémy, nebo fragmenty zástavby mohou být definovány pomocí algoritmů nebo generátorů tvaru. Plánování měst bere v potaz také infrastrukturu, stavební předpisy a územně-plánovací regulace. Energetická náročnost městské hmoty je chápána jako vztah mezi zisky a ztrátami energie, které ovlivňuje řada parametrů popisujících geometrickou podobu jednotlivých budov a vzdálenosti mezi nimi.

Soudobé plánování měst není jen otázkou prosté hmotové konfigurace města, zabývá se také jeho správou, tvorbou míst, vytvářením rozmanitějšího a srozumitelnějšího prostředí. Otázka energetické spotřeby měst je nicméně stále nedostatečně zohledňována. Práce zabývající se tímto tématem se soustředí především na hledisko hustoty zástavby, která energetickou náročnost měst bezpochyby významně ovlivňuje. V otázce energetické efektivity kompaktních měst a stejně i v případě dílčích faktorů jakými jsou solární zisky nebo násobnost výměny vzduchu se současné výzkumné práce v zásadě shodují. Tato práce zkoumá vztah mezi morfologickými vlastnostmi zastavovacích systémů, jakými jsou tvar a velikost jednotlivých staveb a jejich energetickou náročností – a to pomocí ověřování hustoty zástavby, zastavěnosti, solárních zisků, proudění vzduchu a poměru mezi povrchem a objemem budov.

Za účelem zjištění vlivu geometrických parametrů jednotlivých zastavovacích systémů na jejich energetickou náročnost, je v úvodní části této práce prezentován soubor algoritmických modelů, abstraktních vzorků zástavby, zahrnujících samostatně stojící domy čtvercového půdorysu, řadové domy a typologie městského bloku, které jsou organizovány pomocí ortogonální a

kruhové mříže. Energetická náročnost městské morfologie je analyzována porovnáním hodnot jednotlivých parametrů, jakými jsou hustota, zastavěnost, poměr plochy k objemu, roční solární zisky, faktor závětrnosti a rozměry stavby a její geometrie. Druhá část této práce se zabývá hledáním konkrétních geometrických vlastností a způsobu prostorové organizace zástavby, které jsou z hlediska energetické náročnosti staveb nejvíce efektivní. V případě hledání zastavovacího systému s optimální kombinací vysoké hustoty zástavby a současně nízkého poměru mezi plochou a objemem byl využit software Galapagos Evolutionary Solver. Závěr práce je věnován porovnání teoreticky modelovaných městských morfologií s městskými fragmenty vybranými v rámci skutečného města. Různé městské morfologie, které lze nalézt v Praze – zástavba řadovými domy, bodová zástavba, obdélníkové, trojúhelné a polygonální městské bloky – jsou porovnávány pomocí tří parametrů ovlivňujících energetickou náročnost – poměru mezi plochou a objemem, solárními zisky a hustotou zástavby.

Analýza je založena na hledání rovnováhy mezi energetickými ztrátami a zisky jednotlivých morfologií zastavovacích systémů. V některých případech vede posílení jednoho parametru k omezení druhého. I přesto je možné vytvořit propojení mezi obecným souborem parametrů, jakými jsou rozměry obálky budovy, výška a tvar jednotek, a potenciální energetickou náročností zastavovacího typu.

Klíčová slova: algoritmické modelování, digitální město, parametry energetické náročnosti, morfologické vlastnosti, zastavovací systém, Praha.

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CHAPTER 1

INTRODUCTION

1.1 Energy efficiency potential of urban patterns

Energy efficiency is one of the most relevant challenges of the built environment today. Sustainable building, as one of the important objects or contemporary, is energy efficient, since it collects energy from renewable sources. The building or a whole neighborhood could be considered energy efficient when it uses renewable resources as opposed to carbon related fuels. Sustainability in general could be considered to have to do with the balance between gained energy and spent energy. Energy efficiency is a way of managing and restraining the growth in energy consumption. Some activity can be considered more energy efficient if it delivers more services for the same energy input, or the same services for less energy input.

Energy efficency can be observed in different scales, from house units, to urban patterns and city scale. This study focuses more specifically on the relationship of energy efficency with Urban Patterns. Therefore it is important to define what is an urban pattern, according to a widely accepted notion. A pattern could be considered as a guide for build form and open space in the neighborhood level, and city level. A pattern can be a model, which may be repeated throughout the city, and it is composed by build form and open space, including public space and streets. The properties of urban patterns include building height, distances between building, width of open space in between, and building shapes. Urban forms can be distinguished at different planning levels, such as the region, city, district, neighborhood, street or perimeter block. The physical characteristics of urban form include shape, size and configuration of the units (Williams 2014).

In the contemporary world aiming to find and apply innovative technologies, which are connected with the use of renewable energy, finding the new energy sources and application of the smart and sustainable design solution energy efficient urban patterns become very important.

The cities are the biggest energy consumers, and the potential energy spends are defined by the development and quality of urban infrastructure from one side, and by the buildings from the other side. At the level of the building both its geometrical shape and the quality of the building infill contribute to its efficiency. Urban patterns may be designed in a way, that the distances between the buildings are optimized so the shading or sunlight and wind protection or ventilation are controlled. The climate and the geographical position of the city becomes the defining force for selection the right paradigm of the energy balance.

Braungart and McDonough (2002) describe the philosophy of biomimetic approach to design. Preservation of nature, awareness of the finiteness of the natural resources and environmental concerns in design are the key point of their theory. Also inspired by forms of nature, Salingaros in cooperation with Christopher Alexander had established the so-called “Morphogenetic” school that sees architecture as something living and changing. The contemporary architectural paradigms should be revolutionary changed (Salingaros, 2016). A look at today’s real estate building stock in China shows, that the method of construction has not changed from what it was 50 years ago. In the fastest growing urban environments in the world, real estate demonstrates similar patterns of construction. Despite the massive quantity of new construction, only the small consideration has been given to the issues of energy efficiency. The 21st century solution could be to rediscover and document the properties of responsive spaces that adapt naturally to human needs (Salingaros, 2016).

Application of specific physical properties of urban patterns is one of the factors, which may lead towards more energy efficient cities. Computer analysis is a tool in categorizing and defining energy efficient parameters**.** This study is an effort towards the optimization of urban patterns while taking into consideration energy efficiency parameters.

Tying this study with the previous studies provides the opportunity to draw conclusions that build on the state of knowledge on energy efficient urban patterns. The current studies on the subject vary profoundly both in scope and in interpretation. As an example, organizations like IBPSA (International Building Performance Simulation Association) are dedicated to improve the built environment. One of the major issues is that the methodology for tackling energy efficiency is very fragmented. It was therefore necessary to focus on one aspect through a selection of criteria on which energy efficient morphological properties are based. For instance, Castanheira et al. declare that passive solar gains, and urban ventilation are two potentially significant sustainability indicators of urban form (Castanheira, 2014). At the same time Berghauser and Haupt in their work “Space, Density and Urban Form” (2009) investigate the contribution of density into the urban sustainability. Curdes pays a lot of attention to the surface-to-volume ratio while analyzing different urban pattern. (Curdes, 2010). The outer surface of a building is stated as the most important factor for heat exchange. Ratti et al. (2005) emphasize the importance of the passive zone, i.e. the areas around and inside the building blocks which can be naturally lit and ventilated. The passive zone is crucial for passive heating and cooling and it could be considered as the “in between” or breathing zone between outside and inside.

In order to place the study into a real context, the specific city should be selected. Its several urban patterns should be distinguished and the typological and morphological properties of those patterns should be described. Reading a city through its patterns is helpful in establishing an order of understanding during an analysis of different morphological properties. It is presupposed that there should be variations of urban patterns where the driving forces are the site context, municipal regulations, or historical typological considerations. Each urban pattern can be defined by its morphological properties, and with the most typical of them the analysis of these properties can be performed.

The city of Prague is considered as a case study for two reasons. The first is, that it includes many typologies, starting from the patterns of medieval built form typologies, to the patterns ~~of~~ rectangular perimetrical block and from patterns of modernist period typologies to real estates of post-socialist period (Figure 1). Being a part of the former Eastern Bloc, Prague contains many prefabricated panel houses in the suburbs which make the city itself even more diverse. Large historical city core of Prague is preserved and left mostly unchanged. A second reason is that the city is positioned in Central Europe, thus falling into the belt of many similar cities with the same geographical position. Vienna, Zurich, Ljubiana, Munich, and many other Central European cities have similar climate conditions, cultural history and similar urban morphology.

Figure 1 Different urban patterns in Prague (Tittl, 2016)

The climate conditions of Prague can be studied with the use of weather logs, which are provided by Václav Havel Airport. The average density in the built-up area of Prague (71 persons per hectare) is located somewhere between Paris and Warsaw (Bertaud and Bertaud, 2000). The same research methodology could be applied in different sites across the world, but in general this study provides some guidelines for the models in Central Europe and in areas with similar weather conditions.

The study investigates different environments surrounding the selected morphological properties of urban patterns and assesses them based on various energy efficiency parameters. Since 2009, Google Earth has been created the three-dimensional model of the city of Prague, which made possible to extract the exact models of the buildings and neighborhoods. Like other major cities, these 3D models are predominantly auto-generated (Polderman, 2009). A high degree of accuracy can be assumed since models are constructed through street view and satellite images. Additionally, for very complicated buildings, the reports are taken from the ground (McClendon, 2012). As a conclusion, Google 3D models provide in fact, precise 3D models and give an advantage for new methodologies for studying urban patterns. Urban fragments of Prague provide a diverse set of samples for conducting the research, and in addition to it the abstracted models with specific properties, generated with the use of computer algorithms. Computer simulated models are also used for testing hypothetical solutions of case-by-case morphological properties. Combined analysis of both the existing urban patterns of Prague and the hypothetical models provide a basis for simulation, experimentation and analysis.

In conclusion, although information technologies have made possible a better understanding of the environmental conditions, the professions of architect and urban planner have to adapt alongside these shifts. The most relevant criteria to be investigated in this study are the following: surface-to-volume ratio, density, solar radiation, and wind performance. This combination of parameters which affect energy efficiency of urban patterns is tested in two different ways by using generated computer models and computer simulations. The findings of the study may be suitable for the investigation of existing cities and even for the preservation of certain areas which are thought to be energy efficient or have the potential for future development.

The abstract urban patterns are tested for all year long, with kilowatt per year as a measure to the scale of the building. The wind simulation with the abstract models is done by taking into consideration the average wind speed of Prague of 5 meters per second. The same is said about yearly solar radiation simulation, based on the geographic coordinates of Prague. The abstract models and the real models are considered to relate mostly to housing. Most of the Prague Patterns, nevertheless relate to areas which generally refer to housing.

1.2 Problem statement

Urban planning in the past has been organized in a way that either planning regulations, modernist planning standards or pre-industrial planning regulations were used in city building. Such cities offer to a certain extent a causal relationship to elements that directly influence energy consumption. The problem stated in this chapter is that there is a necessity to investigate the relationship of urban morphology in the city scale and potential energy saving. Thus, urban morphology and urban patterns are very important to be analyzed in the aspects of energy saving.

There are several branches of research in the contemporary urban studies, which address the term of efficiency. Bruno Fortier states, that the urbanism nowadays deals with management, logic on the things, reflect on the harmony of the space, dissonance and difference, doing things more comprehensible. The objectives of the profession are different from the 16th century Palladio or 19th Century Urbanism (Fortier, 2003). Owens (1986) explains, that spatial configurations of the city for evaluation are selected with varying degrees of subjectivity and the majority of them is ruled out by non-energy considerations. Salat emphasizes the importance of city density, which is a major contributor to energy efficiency, especially in relationship to transportation (Salat et al., 2012). High density cities increase the social networks development and community interactions (Doherty et al., 2009). Lower density structures demonstrate the lower level of energy efficiency (Rode et al., 2014). There is a common agreement among researchers about the efficiency of compact cities (Große et al., 2016); there are other important issues, such as passive solar radiation and the ventilation factor. With the increase of compactness, the possibility to use natural resources like passive solar energy is decreasing since the tall building may cast shadows and block the natural light and solar heat and reduce the efficiency of passive cooling (Littlefair, 1998). Christopher Alexander focuses on recognition of patterns which could be useful for designers and which could be replicated, as he identifies multiple criteria of development. Salingaros (2015) indicates the randomness by which today's design is conceived. Rob Imrie emphasizes the dominance of city regulations in the actual design.

Outer surface as a medium of energy exchange-also in the urban scale

Buildings are the major agents of energy consumption. Energy research on surface-to-volume ratio is addressed to find the building typology with the minimal surface area and consequently the minimal potential energy losses, and the maximal built volume. March (1971) suggested, that the most efficient building would be "a half Cube or half sphere". This statement is actually based on surface-to-volume ratio, where a more energy efficient structure is actually less exposed to the outer environment. Compact, cube-like building actually has the minimum of heat gains and losses, but the large part of the central floor area is not accessible for natural daylight (Behsh, 2002). Outer surface is a major medium of energy exchange that follows a linear law by which for the same volume more surface exposure means more energy spent for keeping the same temperature. A low surface-area-to-volume ratio is optimal for a passive, low-carbon building (Thorpe, 2014). Curdes compares the index of surface to volume of different typologies where very obviously modernist high-rise buildings seem to have a good ratio. Poor performance is evident in individual housing, while medieval and traditional European perimetral block structures are identified as energy efficient (Curdes, 2010). Increase of building compacity, which is higher for the structures with the simple footprint and clear undivided volume, reduces the heating and cooling loads of the building (Adolphe, 2001).

Other factors that affect energy efficiency in the urban scale

Solar radiation has a tremendous effect on energy efficiency, especially through passive solar gains, which is in fact the amount of solar energy that is absorbed by the thermal mass of the building. Exposure of the building or south facing orientation is one of the most fundamental principles which increase solar energy gains. The total gain from solar radiation is defined as the incident solar radiation during the selected period on the facades of a building (Rode et al., 2014). Wind pressure has a major effect on thermal energy exchange. The relationship is linear: the more pressure, the higher the rate of thermal energy exchanges. In winter the wind movement in the outdoor environment affects heat loss of the building, while in summer the change of wind direction and speed in the outdoor environment affects the ventilation and indoor air circulation. (Huifen et al., 2014)

Energy efficiency on an urban scale is a broad concept which is related to many factors, starting from infrastructure and transportation to density, environmental awareness, and saving electricity. It is therefore, necessary to deconstruct the relationship that the architecture of the urban patterns has on energy efficiency. Conducting different computer simulations allows an analytical interpretation of samples of urban patterns, including aspects of optimized solar radiation, surface-to-volume ratio, density and wind performance.

Comparison with energy spending data is necessary:

Cross comparison with energy spending data is necessary so that there could be drawn conclusions between of the interlink between each of the urban morphology parameters with the monthly/yearly energy spending of the apartments. Such study would make possible to precisely understand the importance of aspects such as surface to volume ratio to the actual energy spending.

The methodology could be used to scan existing cities and render possible a visual analysis of energy efficient urban patterns.

1.3 The aim of the research

The study aims to investigate the energy efficiency of different urban patterns based on the set of specific criteria, in order to find the optimal parameters such as geometrical shape and dimensions and proceeds with testing of this hypothetical set of rules using the real built forms of Prague.

The primary step in reaching this goal is to assemble some of the known criteria of energy efficiency in order to create a methodology which could be used to analyze and test urban patterns through computer simulation techniques. During the process, criteria such as surface-to-volume ratio, solar radiation coefficient, wind performance and density are put together after studying the literature and crosschecking the references.

The literature based study of the importance of these criteria is also necessary to establish the possibility to evaluate the influence and compare them one with another in order to draw a clear logical line. This study addresses precisely the criteria that render variations of the physical dimensions of built units and hypothetical urban patterns.

The second aim of the research was to test these parameters in a) hypothetical urban patterns, b) typical urban patterns from Prague. Thus it would be clearer as to which extend the parameter which were selected after studying the literature review, are present in the hypothetical models (selected typologies) and in reality.

The research is related to the topic of efficient urban design; it is an attempt to bring the awareness in connection of the built form and its energy efficiency. At the final stage of the study it aims to describe the clear design tools, such as building shape and dimensions, which contribute into the overall energy performance of the urban pattern. The findings of the study can be used in the contemporary urban design practice and also can be taken as an initial point for further theoretical studies.

Another aim would be to compare the findings from the analysis of hypothetical and real urban patterns from Prague with real energy consumption data. Unfortunately such comparison was not the subject of this study but such comparison would help in really defining the implication of aspects such as surface to volume ratio with annual energy spending per year.

1.4 Identification of the research questions and research hypothesis

The research is based on the study of the potential energy efficiency of the urban pattern. The evaluation of the energy efficiency requires establishing a set of objective criteria, which characterize the potential energy loses and gains. Within the study the urban morphology is taken not as the fixed set of units, but as flexible parametric structure, which is constructed according to the actual rules of urban design. The complex theoretical research on the varieties of urban patterns is accompanied by testing of the theoretical presuppositions on the real urban samples of Prague.

In order to conduct the study the following research questions are established:

RQ1. What are the factors, which affect the energy efficiency of urban pattern?

RQ2. What objective criteria can be used for the evaluation of the contribution of the morphological properties of the urban form into its energy balance?

RQ3. What are the typical urban patterns, which can be found in contemporary city?

RQ4. How geometrical shape of the built unit can influence to its energy losses and gains?

RQ5. What are the optimal shape and dimensions of the built unit, which will increase its energy efficiency?

RQ6. Is there any correlation between the theoretical findings and the actual performance of the samples of typical urban structures of Prague?

RQ7. What could be the correlation of urban morphology parameters to the actual energy spending consumption in Kilo Watt per year?

Answering the research question number 7 would in fact provide an answer to the actual correlation of each of the parameters with Prague Patterns.

The Research Hypothesis can be formulated as following:

There is a relationship between typological and morphological properties of urban form and its potential energy efficiency performance.

1.5 Research objectives

The work studies the relationship of morphological properties of urban patterns and its energy efficiency. In this study it is accepted, that the parameters of solar radiation, wind flow, solar access and surface-to-volume ratio are the main criteria, which allow evaluating the energy behavior of an urban pattern. Building shape and dimensions have direct implication on the capacity of urban form to alter or define the level of exposure of buildings to the natural conditions outside. In the study the urban pattern as physical system is evaluated at the level of urban tissue (Habraken, 1988), which means, that the rules of its generation are defined by the urban structure from the upper level, and as well it is necessary to consider the buildings, which form the tissue from the lower level (Figure 2).

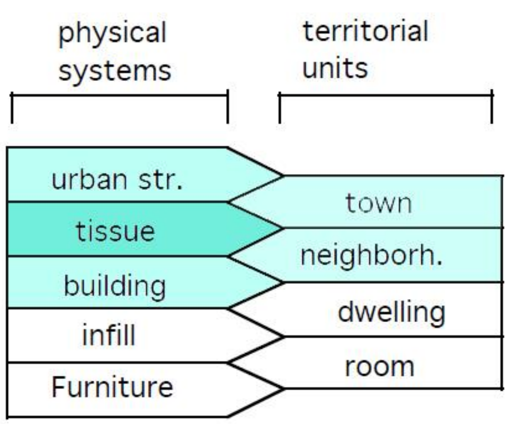


Figure 2 Urban pattern as tissue in 5-level model of physical systems (Adopted from Habraken, 1988).

The research is related to the inherent ability of morphological properties of city fragments to define certain setting of the built environment through, which creates urban microclimate and alters energy efficiency.

Based on the theory of scale of build environment the simulations are completed mostly on the Urban Block level, in the neighborhood and Pattern level. Additionally, some of the simulations could be conducted in the tissue and town level. Simulations such as wind performance or solar energy performance, as well as surface to volume ratio could be conducted in the city level as well.

The simulated urban models are in the level of locality, or urban tissue, meanwhile the urban fragments of Prague in the level of neighborhood or pattern. This is because the generated models are more generic and for utility purpose are conceptualized in a larger scale. Some of the Prague Patterns as well have a similar typology, such as Vinohradska, and could be thought as a continues tissue in a large scale.

Regarding the quality of the urban space, the quality varies depending on the pattern and specific situation. For instance one of the patterns which are frequently spread in the city, is the perimetral urban block. It is known that such pattern is very well spread in the Mediterranean, and in the cold climates, because it offers protection from wind and as well as solar radiation. Also the rectangular building block is pleasant in regards to isolation of the noises, of the traffic, creating the possibility for trees to grow in the inner courtyards. Additionally, slab blocks when constructed with adequate materials, are known to provide in general for good housing. Additionally, other areas in the city which have a more triangular shape could be adequate for high densities, high surface to volume ratio, mix use of programs.

Energy efficiency is seen as the interconnection of the following major components:

- Heating, which comes “efficiently” and in a “sustainable way” via solar exposure. The urban patterns should be organized in a way which leads to increasing potential energy gains.

- Energy preservation, for which the capacity of building envelope is largely responsible, and for which the presupposition is that the less surface is exposed, the more energy efficient the building is. Within the study the variations of surface-to-volume ratio of the generated hypothetical urban patterns and the real urban patterns of Prague are analyzed.

- Potential passive wind blocking (which is preferred in the case of Northern Europe) or wind ventilation as a consequence of a given urban pattern.

- Density and the possibilities of increasing it through variations of the building form. Site coverage, which represents the balance between the built area and the vacant land.

The objective of the study is to investigate through development of the set of parametric urban models the nature of energy efficiency parameters in relation to urban pattern and to identify how the phenomena as a whole functions in real cities, such as in the case study of Prague. Findings of research may contribute in understanding of the energy performance of existing cities and in evaluation of the potential future developments.

1.6 Overview of the research methodology

The preliminary point of research is overview of the existing studies which tackle the problem of energy efficiency on the urban scale. The result of the literature review stage is the set of specific objective criteria, such as surface to volume ratio, wind performance, solar radiation and density. These criteria directly affect to the energy performance of the urban pattern, and they are selected in way, that the particular conditions of the built units, such as building function, the quality of the building materials and the behavior of occupants can’t affect the results. A selective analysis of the existing literature provided for fragmented guidelines which have been brought together under the framework of energy efficiency.

The principal parameters which affect the energy efficiency of the urban pattern are described below:

- **Surface-to-volume**

- Surface-to-volume ratio measures the outer surface in square meters of the building envelope versus the total volume of the building. The more exposed a dwelling mass, the higher the energy exchange. Therefore, this factor has a direct effect on energy efficiency. Certainly, there could be a proportional increase of energy efficiency if the outer surface of the building is smaller, thereby reducing energy exchange. The study focuses on identifying those urban patterns which have a small surface-to-volume ratio as prescribed in the following chapters.

- **Solar radiation**

Solar radiation is considered as one of the most influential categories where more solar radiation per square meter of the built surface means potential increase of renewable energy harvest.

- **Wind performance**

The increase of the wind speed within the urban pattern leads to the higher heat losses of the building. The hypothetical models are tested in relationship to an average wind speed in Prague. The test shows the performance of different patterns and which solutions are more suitable for the wind sheltering.

- **Density**

High density urban structures are associated with higher energy efficiency due to the reduction of transportation and communication networks and increase of the social interaction. At this stage it is important to take into consideration, that the high density structures may affect the urban ventilation and reduce the gains of solar energy, therefore this parameter should be analyzed only in complex with the others.

The comparative analysis of the urban pattern starts from the description of the rules, which are form the pattern by Grasshopper algorithms. The parametric modeling and computer simulation are the main research methods at this stage.

The hypothetical model of urban pattern resembles the real model brought to abstract level, with no topographical differences, no mismatch between the order of positioning and no difference in calculations of distances. The parametric models are very flexible analysis tool since the algorithm allows to generate accurate and easily modifiable patterns. For the computer simulation 60 algorithmic models of 6 typologies of urban patterns are generated. The models vary by height, geometrical shape and distance between the buildings. The algorithms are designed in such a way that with the change of any parameter such as building dimensions or height, the distance between units and therefore the number of the buildings are automatically adjusted. Distance between the buildings are defined according to the Czech building standards. The criteria for evaluation include: dimensions of building blocks, solar radiation, surface-to-volume ratio, density and site coverage. As an outcome the behaviour of each generated pattern can be evaluated and more efficient structures can be found.

The second phase proceeds with the deeper investigation of the exact dimensions of the energy efficient urban pattern. In order to find the best solution, the genetic algorithms are used as a tool. Due to the complexity of the calculation only the surface-to-volume ratio and the density are set as defining agents, which are used for the optimization of dimensions of built units of urban. Genetic algorithms produce a spectrum of solutions, which vary from the most rational and similar to the real site situation, to other more imaginary and complex ones. At this stage the physical dimensions of the optimal built units are calculated.

At the final phase of the research, the 64 urban fragments extracted from the different districts of Prague are selected in order to evaluate their energy and economy efficiency. Prague offers an interesting case, with many diverse typologies of urban patterns, perhaps more so then other cities. In conclusion, it is evident that the 64 real models provide an example, which is closer to reality. The analysis of hypothetical models provides some presuppositions of the energy behavior of urban patterns, which could be further proved by using the real cases. Surface-to-volume ratio, density and incident solar radiation are calculated and the correlation between the hypothetical and the real models is found.

1.7 Research limitations

The challenge of this study is to move ahead from "Energy Efficient considerations" to more rational and *quantifiable* results. Nevertheless, there are certain limitations in testing and designing hypothetical models.

The first limitation is that not all the hypothetical models represent the exact reality. For instance, topographical factors and other obstructions are not taken into consideration. The attempt to consider the complex geometric shape of the real buildings of Prague is tackled in Chapter 6, but it is evident, that it is not possible to examine all the varieties of built units.

The study had been developed based on the climate conditions of Central Europe with the condition of maximization of energy gains and minimization of energy losses. In order to apply the theory to a different place, the balance between these two factors should be changed according to actual climate conditions. Thus, in severe north conditions where the issue of minimal energy losses dominates, compact building shapes and creation of the wind shelter prevails over the potential gains of solar radiation, since the intensity of northern sun is very low. In moderate climates, the issue of wind protection may be less important, but in wet climates the natural ventilation should be encouraged. In hot climates the situation is reversed and the built form should be designed in order to maximize the energy losses and maximize the shading.

Another limitation is that at the urban scale certain features of the existing buildings, such as thermal insulation, inner structure of the building and efficiency of the building systems could not be taken into account. Occupancy behavior and the use of space also have influence on the energy balance of apartment and consequently total performance of the building. As an example, in a multi-story apartment building, an apartment situated in the third floor could perform much worse than an apartment situated on the top floor of the same building, even though the surface-to-volume ratio of the top floor is bigger, which is an indicator of higher energy losses. That could be due to several reasons: the owner of the top floor may modify his roof with thermo-isolation or, the apartment in the top floor is empty, thus not consuming any energy whatsoever, or in another example, the top floor is now transformed into a gym but the owner on the third floor turns the heating on early in October. Nevertheless, such limitation is possible to overcome once there is available the energy spending diary, where comparison could be drawn with Kilo

Watt energy spending per square meter in average, and as the case study from according to the Building Research Establishment (BRE), explained in figure 10, it is possible to achieve this conclusions.

One of the most important research limitations was the issue of comparison of properties of urban morphology with the actual energy spending per year. In this regard, the comparison of parameters with the actual energy spending in Kilo Watt per year of the households, would help in drawing a line of conclusion as to which extend the morphological properties influence energy savings.

1.8 Thesis outline

The thesis is composed of seven chapters. The structural organization of the work, the interconnection of the thesis chapter with research questions and research outcomes (conference proceedings and publications) is given in Figure 3.

Within the first chapter the research is introduced and the problem of understanding energy efficiency on the urban scale is discussed. The research aim, research questions and the hypothesis are stated and the research methodology and limitations are briefly described.

The second chapter presents a review of the literature where the current state of knowledge is studied. The review starts with a history of studies connecting urban pattern and its energy consumption. The main parameters which affect the energy efficiency at the urban scale are described, and among them the objective parameters which are suitable to be evaluated through the computer generation are selected. The other important branch of knowledge is the development of parametric urbanism and the overview of the main principles of generation of the large city models. The chapter ends with the list of the definitions and terms which are used in these areas of knowledge.

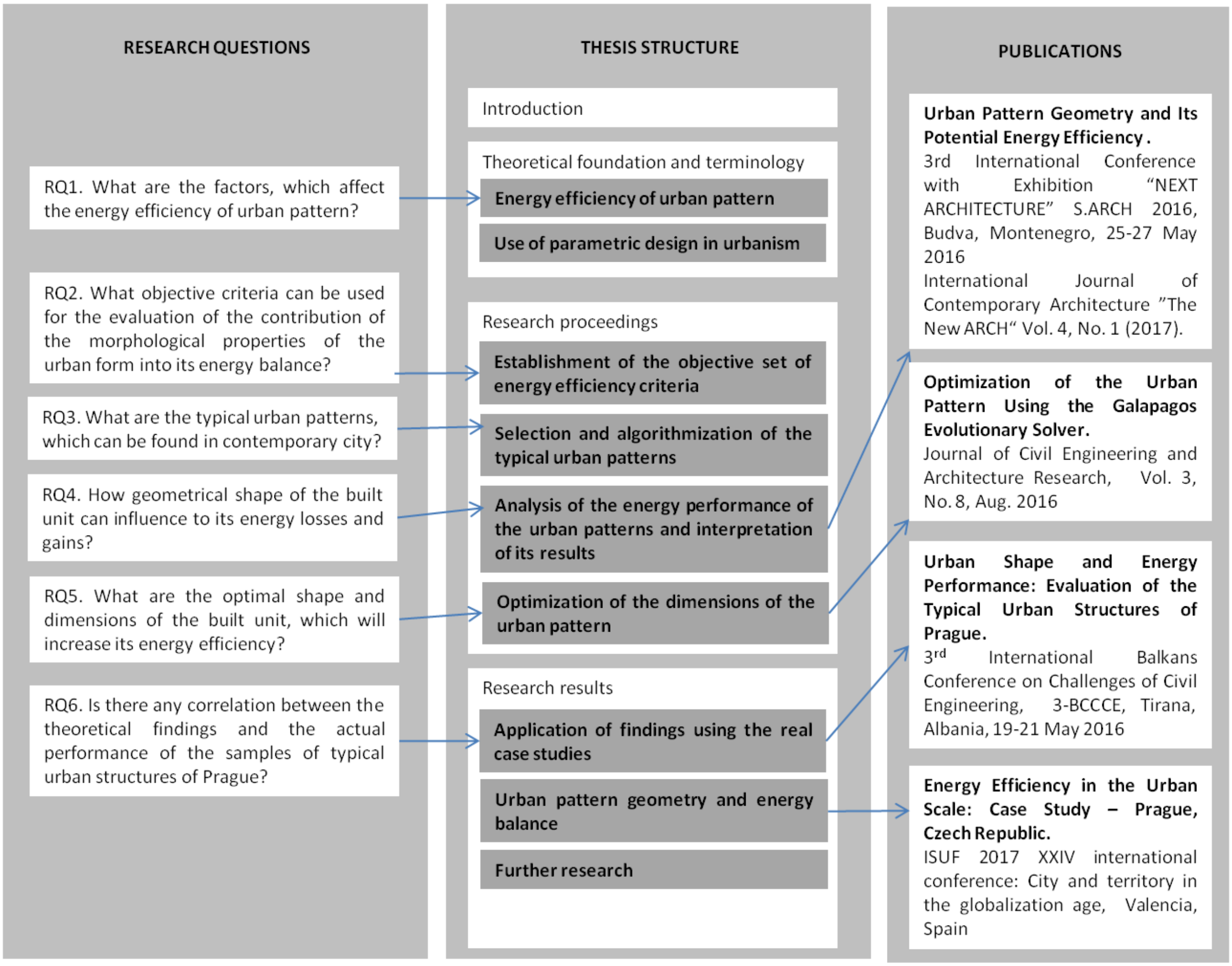


Figure 3 Structure of the thesis

The third chapter describes the research methodology. It includes the definition of rules of generation of the hypothetical urban models and the selection criteria for the real urban models of Prague. The evaluation criteria of the energy and economic efficiency are given and the software which is used for computer generation, pattern optimization and computer simulation is described.

The fourth chapter analyses the efficiency of 60 generated urban models. These models are considered again in chapter 5 with the further optimization of their physical dimensions by the use of the genetic algorithms. In these two chapters the performance of the different variations can be compared, and, as a result, the most efficient urban patterns can be selected.

In the sixth chapter the theoretical findings are tested under real conditions. The 64 most typical urban models of Prague are evaluated with the use of the same criteria such as density, surface-to-volume ratio and incident solar radiation in order to find the structures with the best performance.

The seventh chapter analyses conclusions and expresses some opinion about future possibilities and limitations due to this study, limitations, and future necessary steps to quantify the results.

The detailed information, such as plans and axonometric models of the generated urban patterns and the selected Prague case studies is given in attachments A and C. Attachment B is the demonstration of the images of the simulation of wind flow which is applied to 60 patterns. Grasshopper definitions of the six basic urban morphologies are given in Attachment D.

The last four attachments are the conference and journal articles which were published during the work on the thesis.

1.9 Research publications

During the research the three articles were written and presented in the conferences and to articles were published in journals. The papers were created in co-authorship with A. Yunitsyna, who has helped with the organization of the practical aspects of presentation and publication:

1. " Urban Shape and Energy Performance: Evaluation of the Typical Urban Structures of Prague" was presented at 3rd International Balkans Conference on Challenges of Civil Engineering, 3-BCCCE, organized by Epoka University, Tirana, Albania, 19-21 May 2016.

> European cities had been developed historically as compact and dense structures, where the specific urban microclimate was achieved through the arrangement of the units of the urban pattern. The energy flows, such as transportation energy and the heating or cooling energy, were reduced. With the further development of the cities, the various urban morphologies came to place and the city energy demands grew. One of the ways of reduction of such demand is the creation of compact urban pattern, which is exposed to the maximum of solar radiation and potentially may reduce the heating demands of the buildings. The energy, which is received by building, is defined by its shape and

orientation and the compacity depends on its geometrical properties, such as surface to volume ratio and the plot coverage. Within the study, the various urban morphologies of Prague are tested in order to find the most energy efficient ones. The urban structures are selected according to their geometrical shape and include the perimetral blocks with different proportions, perimeters and site coverage ratio, dense medieval streets and minimalistic buildings of the socialist period. The computer simulation and analysis were performed using the models extracted from the virtual Google Earth model of Prague. During the process of evaluation of samples the relation between the urban morphology and such parameters as plot coverage, surface to volume ratio and the incident solar radiation was established and potentially higher energy efficient structures were indicated.

2nd and 3rd. “Urban Pattern Geometry and Its Potential Energy Efficiency” was presented at the 3rd International Conference with Exhibition “NEXT ARCHITECTURE” S.ARCH 2016, Budva, Montenegro, 25-27 May 2016 and further published in International Journal of Contemporary Architecture ”The New ARCH“ Vol. 4, No. 1 (2017).

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.

4. Optimization of the Urban Pattern Using the Galapagos Evolutionary Solver. Journal of Civil Engineering and Architecture Research, Vol. 3, No. 8, Aug. 2016, Ethan Publishing Company.

Urban morphology is a result of the interconnection of various factors, such as climate, economy, traditions and culture. Urban districts had been developed in order to find the most efficient structure, to establish the optimal street network and to provide the high level of land use. The spatial organization of urban districts as well as the geometrical shape of the buildings have direct connection with the urban microclimate and with the energy consumption of the district. Compact urban structures with low surface to volume ratio have big potential to minimize the cooling and heating loads of the buildings. Urban patterns with high density provide the maximal economical efficiency with the reduction of the resources spent for the provision of the transport, energy, water and wastewater infrastructure. Within the research the relation between the building density and the surface to volume of the urban pattern were studied in order to generate the optimized solution. The six parametric models of the different urban patters were established. Within the algorithms the geometrical properties of the buildings, such as height, width and length could be changed, but the plot remained fixed. The Galapagos Evolutionary Solver was used as a tool in order to find the set of parameters, which brings to the urban pattern the optimal combination of density and surface to volume ratio. Among all tested patterns the rectangular and the trapezoidal perimetral blocks with relatively small dimensions of the base and bigger number of floors had demonstrated the highest economical and energy performance.

5. "Energy Efficiency in the Urban Scale: Case Study – Prague, Czech Republic" was presented at the ISUF 2017 XXIV international conference: City and territory in the globalization age, Valencia, Spain, 27-29 September 2017.

Cities are a complex mass of morphological properties of many city fragments, which play a major role in energy consumption. Urban form, urban patterns, or city fragments can also be seen as defined by algorithms or form generators. Cities are designed taking into account infrastructure, city standards and land use regulations. Energy efficiency of the urban form may be understood as the balance between gains and losses of energy, which may depend on a set of parameters mostly defined by the geometrical shape of the buildings and the distance between them. The study starts from the development and analysis of 60 hypothetical models in order to evaluate their energy efficiency potential. The Galapagos Evolutionary Solver is used as a tool in order to find the set of parameters, which brings to the morphological properties the optimal combination of density and surface-to-volume ratio. At the final stage morphological properties of 64 Prague's patterns were selected. Computer simulation and analysis is performed using the models extracted from the virtual Google Earth model of Prague. During the process of evaluation of the samples, the relationship between the urban form and such parameters as plot coverage, surface-to-volume ratio and the incident solar radiation was established and potentially higher energy efficient structures were indicated. As the result of analysis the interrelation between urban form and energy efficiency was established, which allowed to identify the urban patterns with the higher potential of energy efficiency.

The full texts of all publications are given in Attachment E.

1.10 Summary

The study is based on the search of the balance between the energy losses (minimal surface to volume ratio, density) and energy gains (incident solar radiation in kilo Watt per year), which are defined by the morphological properties of urban patterns. Such factors have been generally underestimated, but in fact, properties such as surface to volume ratio, defined by urban morphology have a primarily role in energy saving.

In some cases, the requirement which may enforce one of the elements of this equation, will contradict the other. It is estimated that for the Continental Europe and Prague location, minimal surface to volume ratio is more important than other factors. For office buildings instead a larger building envelope surface is in a higher demand, since it needs more natural ventilation and solar energy during the day. Nevertheless, it is possible to draw the general set of rules, which may be applicable for different urban solutions. Unfortunately this is also one of the research limitations that there is not a cross comparison with real energy spending data. Such comparison would make possible to check how each of the parameters influences heating demand in kilo watt per square meter per month/year.

The specificity of energy efficiency in case of urban planning is the division between the objective criteria, such as surface-to-volume ratio, density, incident solar radiation and wind performance and the parameters which are particular for each building, such as construction quality, thermal insulation and work of building systems. In addition the valuable contribution into the building energy balance in the behavior of the occupant, which could not be evaluated within the current research. The objective of study is first to delineate how each of these criteria can influence the energy efficiency in cities, looking at primarily at literature examples and latest scientific findings and then further to create a methodology in order to understand their impact. Both computer simulations and comparative analysis are used for the evaluation of performance of generated hypothetical urban models and of case studies from Prague.

Using the method through application of algorithms and simulation software is an opportunity to analyze existing cities and to understand the “rules” that could generate optimized models. As an example the desired urban pattern can combine the higher density with minimal surface-to-volume ratio and at the same time maintain adequate solar access and natural ventilation. Optimizing of these parameters together with accounting social, environmental and economic factors may contribute into increasing of sustainability and improving the quality of life in existing and future cities.

CHAPTER 2

THEORETICAL FOUNDATION AND TERMINOLOGY

2.1 Organization of the literature review and selection of the theoretical materials.

Evaluation of energy efficiency of urban pattern is a complex task, which is related with solving the multiple problems and selection of the most appropriate and measurable methods of proceedings. The urban pattern itself should be analyzed within a context of the neighbouring design levels (Habraken, 1988) – the city itself, which define the rules of the pattern composition, and the buildings as units of pattern. Therefore the literature review is structured in several parts; each of them is addressing a specific question of energy efficiency.

The first part is an overview of the contemporary studies, which tackle the issue of energy efficiency in urban scale. The notion of density becomes important at this stage since more compact and dense cities have potentially less losses of energy in organization of networks and transportation. Such valuable resource as land in this case is used in efficient way. The structural organization of the city, the shape, height of its buildings and the distance between them directly affect to the potential of benefiting from the natural environment. Available solar radiation can be calculated only at the level of urban district or neighbourhood since the buildings may cast shadows one to another. The potential of natural ventilation can be evaluated only by studying of the wind flow within group of buildings as well.

The second part of the review is addressed to the understanding of the criteria, which influence the performance of the single unit of urban pattern – the building. The primary attention is given to the measurable and objective criteria, which are examined within the current study. In relation to the notion of urban pattern, the morphological properties of the building, such as its height, building envelope and building shape become the defining ones. The surface-to-volume ration allows evaluating the potential energy loses, which are caused by the building geometry. The specific un-measurable within the scope of current study parameters, such as building materials and environmental awareness of building inhabitants.

Since development of the parametric urban models is one of the key methods of the research, the current understanding parametric urbanism becomes important. Parametric modeling means that if all or some of the parameters are fixed, for instance space, and dimensions of the building plot, there can be still dozens of variable solutions. For instance if there is a fixed plan of 200 meters to 300 meters, and the 45 degree rule of Prague Regulation applies in terms of tolerance of distance between height and distance between the buildings, what could be the potential solutions for: 1-Perimetral urban block, 2-Single urban block, 3-Row houses. The term parametric urbanism has to do with defining parameters and variables. In this case the main variable is selected as the building height. (The number of floors is the variable) Thus understanding parametric urbanism and its potential for being useful in parametric urbanism becomes very important. Although this study does not exhaust the notions of parametric urbanism and there can be seen a discrepancy between the somehow abstract theories of Neil Leich and the actual (practical) applications, still analyzing the existing trend on parametric urbanism becomes useful. At the end of the chapter the basis of the terms, which are related to the scopes of energy efficient urban design, is presented.

The literature review was completed taking into consideration Environment and Planning B review, which contains periodical articles about urban planning and energy efficiency, CISBAT 2003-2017 International Conference Journals which focus on Energy Efficiency from Nano to Urban Scale, the latter being of our interest, and IBPSA-International Building Design Simulation Association. The update was important to compare the finding of this thesis with the state of art of energy efficiency and urban form.

Environment and Planning B offers perhaps the most significant resource about the issue of energy efficiency, computation and urban form, since its start, on 1974. Some of the authors with major contributions include Michal Batty who wrote in the every single edition focusing on issues such as computation, urban form, and cyber cities and including computation technology in city planning and design.

Some of these authors are really focusing on computation design, urban planning, cities, urban sprawl, geometry, urban design, density, urban morphology and etc. The focus of the emerging science of computation technology is visible in each of the editorials from 1974 to presence. In this regard it was important to go through the yearly published articles and analyze them in general. Some of the authors indeed focus very closely in the subject of energy efficiency and urban form, such as for instance Philipp Rode. Other pioneer authors include Lionel March, R. H. Atkin, Philip Steadman etc, which are mentioned in this chapter.

Another resource library was IBPSA which focuses on themes such as: "Energy performance certification, Building envelope (walls, windows,...), heating, domestic hot water, air conditioning, cooling, ventilation, air infiltration, lighting, controls, energy management systems, thermal comfort, indoor air quality, acoustics, calculation, simulation" http://www.ibpsa.org/

An interesting case study was the international conference such as the CISBAT 2017 International Conference-Future Buildings and Districts, Energy Efficiency from Nano to Urban Scale, held between 6-8 of September in Lausanne, Switzerland.

Some of the papers of a similar topic were the following and where analyzed in detail.

1-Urban Sustainability assessment of neighbourhoods in Lombardy, Matteo Ghellere, Anna Devito Francesco, Italo Meroni.

2-Energy Procedia 122 (2017) 145-150, Smart Cities (Urban Simulation, Big Data) Integrated modeling of City GML and IFC for city/neighborhood development for urban microclimate analysis. Steve Kardinal Jusuf, Bejamin Mousseau, Gaelle Godfroid, Vincent Soh, Jin Hui.

3-Smart Cities (Urban Simulation, Big Data) Estimation of building energy performance for local energy policy at urban scale. Lorenzo, Belusi, Ludovico Danza, Matteo Ghellere, Gulia Guazzi: Italo Meroni, France.

4-Effects of the Urban Compactness on the building energy performance in Mediterranean Climate, Agnese Salvatia, Helena Coch, Michele Morgantia.

2.2 Research on urban patterns and energy efficiency

Bruno Fortier in his interview “How to fabricate a city” posits that urban design is involved with management, and it is about logical reasoning through complex problems through reflecting on the harmony of the space. Dissonance and difference is a discipline which has to do with intelligence and with doing things in a more comprehensible way. Further he explains that the “The nature of Cities has changed over time, the 16th century Palladio, 19th Century Urbanism, end of 20th for Koolhaas is not the same thing, there are not the same objectives, not the same problems, even not same taste for harmony, therefore is not the same profession, of managements, it’s a profession in transformation” (Fortier, 2003). Understanding of the rules, that govern the city’s dynamics, makes it easier to set up the properties according to the preselected criteria for a certain typology. Muratori’s late studies of urban tissue of Venice or Rome are devoted to define the laws of the tipicity *(*tipicità) of urban form, and the cycles of “the world of cities and that of man” (Salvador, 2007). Van Til (1979) stated, the future cities should be shaped accordingly to the availability of resources.

Accelerating urbanization all over the world has renewed interdisciplinary interest and public concerns over sustainable urban forms. (S S Chen, Y.Yan, Q. Gao, D. Liu, 2015)

The energy issue determines the criteria of development, sets the new values and preferences, creates the awareness in finiteness of the resources. The question that arises is to what level a city can be optimized and opened to natural renewable sources in the complicated everyday city matrix.

According to Owens (1986), another problem is related to the fact, that alternative spatial configurations for evaluation are selected with varying degrees of subjectivity. Although the majority of theoretical possibilities is ruled out by non-energy considerations in the real world, it is arguably desirable to include as wide a range of alternatives as possible in exploratory studies. Subjective selection permits examination of a small number of options in detail, but carries the obvious risk that some potential energy efficient structures will be overlooked. At the other extreme, if the objective is to evaluate all possible hypothetical structures, the typical models must be extremely simple (Owens, 1986). Sometimes there may be conflicting parameters such as the requirement of a city to be more sustainable transport-wise as opposed to the city benefiting more from renewable resources. For instance, there is a clear distinction between optimizing a city in terms of transportation energy, which would require extremely dense cities and that of using passive solar energy which would then require a low-scale density.

Below is given the chart of transportation energy performance of various cities (Figure 4):

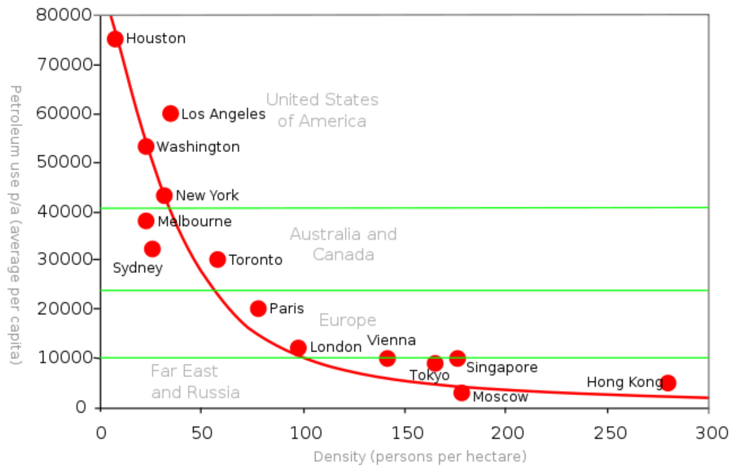


Figure 4 Urban density versus transportation energy needed in "annual gasoline use per capital" (Newman and Kensworthy, 1989)

An increasing density clearly indicates a decrease in transportation costs. Hong Kong appears to be the most efficient city, while Houston the least. From the other side in cities with high density such as in Singapore it is more difficult to create the right conditions for harvesting the passive solar energy. The same could be said about the quality of acoustic environment that the less dense a city the less acoustic problems emerge.

Salat and Bourdic define several leverages of improving the energy efficiency (Figure 5).

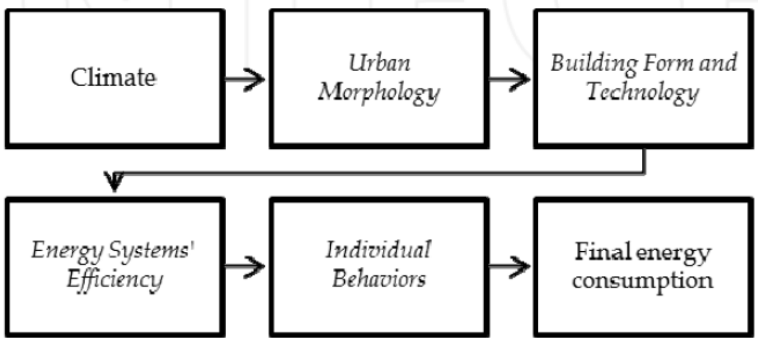


Figure 5 Four leverages to improve urban energy efficiency (Salat and Bourdic, 2011)

Contemporary focus of building design is in increasing of the efficiency of the building systems, That appropriate urban morphology may result in up to 60% of reduction of energy consumption in comparison to the "bad designed" one. This statement can be applied in case, that all other factors have equal influence (Salat and Bourdic, 2011).

The contribution of the quality of urban morphology into the environmental impact of urban energy use was further elaborated by Vandevyvere and Stremke (2012). The contribution of each of four leverages into the urban energy balance is shown in Figure 6.

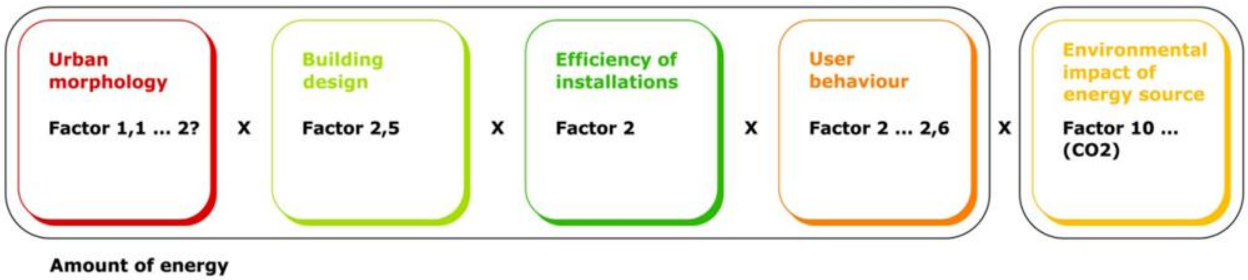


Figure 6 Contribution of the four leverages into the overall environmental impact of urban pattern (Vandevyvere and Stremke, 2012)

Urban morphology and building design identified as important factors, which should be taken in consideration in passive design. The quality of urban morphology itself may reduce energy demands in 2 times. The urban pattern is evaluated as pure geometric form, without considering the specificities of location, landscape type and vegetation.

2.2.1 Density and urban compactness.

Urban planners consider European Cities such as Vienna or Prague as examples of "good density". And indeed these cities provide maximum quality of public spaces, mobility and living conditions. These cities achieve a degree of compactness without skyscrapers, and represent the best of what is known as average density. Density relates very closely to sustainability, based on the paradox that the more dense cities are, the more sustainable they are in regard to transportation. The example of Hong Kong, New Work or Tokyo and cities alike show the advantages of this model. On the other hand, very dense cities are perceived as inhumane, as in the case of Fritz Lang's dystopian Metropolis. Such a high level of density might create environmental stress issues such as traffic jams, urban heat islands, excessive noise and other problems.

Salat emphasizes the importance of city density, which is a major contributor to energy efficiency, especially in relationship to transportation (Salat and Bourdic, 2012). He states that a city four times denser consumes four times less land and sixteen times less network infrastructure. And yet density variations between loose suburbs and historical cores are within a factor 16. Meanwhile, there is no certainty that very dense cities contribute to optimal urban microclimate conditions because very dense cities have been observed to create the phenomena of an Urban Heat Island.

Compact urban structures may have the following environmental benefits (Ludlow, 2014):

- Provision of shorter interurban distances and less automobile dependency which helps to reduce energy consumption and CO_2 emissions
- Conservation of farmland and natural biodiversity around urban areas
- Creation of more opportunities for the urban-rural links, which encourages nearby farming
- Incensement of local food consumption, which through the reduction of food transportation helps reduce CO_2 emissions

There are other benefits, which are related to social and economic factors. These include greater job opportunities, more effective use of urban land, more sustainable mobility, and others. Since compact cities offer a variety of mixed functions, compact cities offer more job opportunities and people naturally tend to go where the opportunities are.

The study on compact urban structures, which is focused on the analysis of three cities in Sweden, Finland and Estonia, provides evidence that compact urban structures and concentrated development are facilitating efficient energy use (Große at al., 2016). However, urban structure must not only be viewed from the perspective of urban form, but should include considerations of functional relations and the policy context.

The paradox between the relationship of density and solar energy use is a paradox mentioned by different authors. William T O'Brien, Christopher A Kennedy, Andreas K Athienitis and Ted J Kesik, describe this issue in their article and pose a question: "There is a paradoxical relationship between the density of solar housing and net household energy use. The amount of solar energy available per person decreases as density increases. At the same time, transportation energy, and to some extent, household operating energy decreases. Thus, an interesting question is posed: how does net energy use vary with housing density?" This question is obviously difficult to answer. (William T O'Brien, Christopher A Kennedy, Andreas K Athienitis and Ted J Kesik 2010)

However, although there is a common agreement among researchers about the efficiency of compact cities, there are also other important issues, such as passive solar radiation and the ventilation factor. With the increase of compactness, the possibility to use natural resources like passive solar energy decreases. Littlefair considers the site conditions as the main factor, which can influence to the efficiency of solar building. The natural light as well as solar radiation, which can be available for all the building surface can be reduced by tall obstructions. The second important factor is passive cooling. Lack of natural ventilation may appear due to the location of the building in dense structure, which will reduce the air flow and increase the pollution (Littlefair, 1998).

Große and Fertner (2016) explain the adverse factors in compact cities. They include:

- Potential negative effects on energy consumption, e.g. increase in energy consumption for cooling caused by urban heat island effects or inefficient energy use due to traffic congestion;

- Increased need of transportation and big infrastructure due to the reduced potential of on-site activities, e.g. farming on-site, waste treatment on-site, local water run-off, and recreation on-site.

In regard to the city as a whole compactness of urban structures is a greater factor in efficiency than dispersion. The limitation is that highly compact cities lose benefits from passive solar gains and passive ventilation and the level of noise, pollution and other problems may be increased.

In his book "A Pattern Language," Christopher Alexander nominates the 4-story housing development as the most effective for urban density. He provides an algorithm for the calculation of the dimensions and the heights of the buildings according to the desired density and urban regulations (Figure 7). The height of the building is based on the proportion between the desired built space and the site area. The site coverage is accepted no more, then 50% (Alexander et al., 1977).

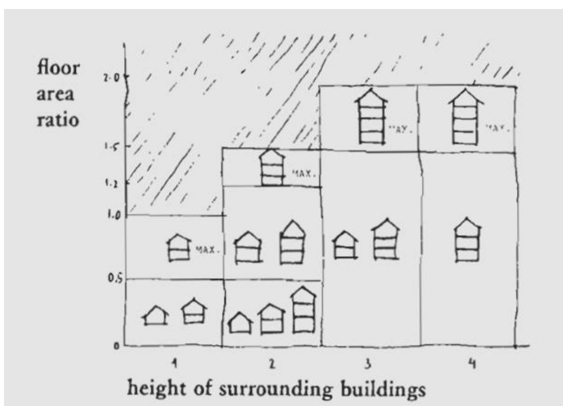


Figure 7 The relation between the floor area ratio and the height of surrounding buildings

(Alexander et al., 1977)

Compactness and density have to follow the land use properties and city regulations. It is important to verify, which level of density and compactness is provided for mix use and programs adaptation. There is also a possibility of structural changes within a given site and the adaptation of morphological properties. According to Panerai et al (1997) the urban structure is not static, and the new large parcels can replace the group of smaller ones. Same process can be applicable for the built units. Different typologies of the buildings both residential and mixed use, open spaces and gardens can occupy the plot, or one block of the urban pattern.

In the research on the most preferred cities as written in the European Barometer survey of 2015, the respondents in Wien (97%), Zurich (95%), Helsinki (94%), Leipzig, Malmo and Graz (all 93%) are the most satisfied (TNS, 2015). All of these cities are in fact of average density. Preferable is a city which is more compact but not at the extremes of density, thus making a favorable space for parks, recreation facilities, and physical space and allowing for sunlight and favorable urban microclimate. This kind of a city balances all three major factors: social, economic and environmental.

Most countries have regulations that limit the physical distance between buildings as compared to the building height, which is one of the major factors defining density. The 45-degree rule, which is the limitation according to Prague regulations, defines the density of buildings where the distance and the respective height are equal, thus creating a graphic of potential distances and heights. The rule itself finds its basis in the solar radiation conditions where the 45-degree angle creates the possibility for better solar radiation. But the regulations are still based upon the Modernist paradigm where cities should be healthier and slum-free in contrast to the traditional models. Density is one of the major factors of sustainability. Very dense cities are preferred in regard to transportation. This is must be balanced by a consideration of other parameters such as open space limitation, quality of life, environmental and social conditions, and passive solar access as defined by municipal legislation - conditions that are different from country to country.

The importance of regulations are described in the article from Rob Imrie, “It is commonly assumed that building regulation and control is a technical activity and part of a bureaucratic machine external to the design process. For many architects building regulations are no more than a set of rules to be adhered to, and are usually seen as ephemeral, even incidental, to the creative process of design.” (Imrie R., 2007)
In the chapters 3, 4 and 5, are described in detail the importance of the factors of urban regulations and how they influence urban design and planning design. Rob Imrie emphasizes that

the main argument of his paper is that: “the building regulations are entwined with, and are constitutive of, architects’ practices. Far from being an insignificant part of the design process, as some commentators suggest, I develop the argument that the building regulations influence aspects of creative practice and process in architecture and, as such, ought to be given greater attention by scholars of urban design”. (Imrie R., 2007)
Indeed the chapters 3, 4, 5 are based on the computational methods that use Prague regulations as a method for density computation. The relevance of regulations in issues such as density and surface to volume ratio are described in detail in these chapters.

2.2.2 Solar radiation and urban pattern

Sunlight has influenced building design since the beginning of architectural history. The oil crisis of 1970 revealed the delicate nature of fossil fuels as a source of energy for the world. As such, the research in alternative, renewable energy technology like that of solar and wind energy gained momentum. However, the optimization of solar gains varies tremendously. Solar energy transfers into heat from the thermal mass of the building, which ensures passive solar gains. Solar radiation has a tremendous effect on energy efficiency, which depends on the amount of solar energy that is absorbed by the thermal mass of the building. Exposure of the building or south-facing orientation alone is one of the most fundamental principles which guarantees optimized solar radiation in the northern hemisphere. Solar radiation is very complex, since it includes also direct and indirect solar radiation.

The Earth’s surface, on the average, has the potential to capture around 5.4 GW (1.5 MWh) of solar energy per square meter a year (WEC 2007). The highest resource potential is in the Red Sea area, including Egypt and Saudi Arabia, but other countries also have a lot of potential.

The phenomena are based on the fact, that thermal mass of the building can store solar energy in the form of heat which is necessary for every day temperature comfort. Well-designed materials can optimize the overall heating. The study of materials is still very complex and this study is only about the optimization of morphological properties towards solar exposure.

The solar energy systems can be active or passive. Photovoltaic panels and solar thermal collectors which harness solar energy are examples of active solar technology. Passive technology is about orienting spaces to optimize solar gains, or using other devices such as greenhouses. The principle of building orientation versus the sun exposure and site layout is the one that is explored further in this study. Building orientation, along with day lighting and thermal mass, are crucial considerations of an environment that is built based on solar energy.

The relative position of the sun is a major factor in heat gain in buildings, which makes accurate orientation of the building a fundamental consideration in passive solar construction. From Walter Gropius to Le Corbusier, many authors have proclaimed the advantages of modernist architecture versus traditional city slums. They have promoted open spaces, allowing sunlight and clean air into buildings in what would be the modernist paradigm of healthier and better cities. Only recently has there been some experimentation with Ecotect analysis and simulation programs in order to overcome the old way of orienting buildings towards the sun (with drawings made by hand in order to find the optimal angle).

Computer analysis offers a revolutionary tool, not only to optimize building position but also to calculate the energy profits in terms of watts per square meter. One of the studies conducted aimed at finding the advantages of energy performances of samples of urban patterns in four cities such Paris, London, Berlin and Istanbul. Rode et al. (2014) define the two kinds of building energy gains:

- solar radiation, which can heat the interior air;
- the heat generated from either the occupants themselves or by appliances within the building

Cheng et al. (2006) state, that potential of the collected solar energy on the roofs is defined by the plot ratio, while the solar potential of the building walls is defined by the site coverage. At the same time the maximal solar access to the building can be achieved through the application of units with variable dimensions and heights.

In addition, for the urban pattern spatial requirements for passive solar energy harvesting are more stringent than those which meet other typical planning conditions. With the two-story terraced housing on a flat site, the lighting criteria would require 6-10m between rows and sun lighting criteria of 10-16 meters. The condition of "privacy" requires 15-18 meters and the use of passive solar energy 20-23 meters and even this spacing may produce some shading during winter (Turrent et al., 1981).

The solar radiation calculation software is used as a tool for the calculation of the overall energy gains for different urban patterns. The total gain from solar radiation has to be defined as the incident solar radiation during the heating period on the different kinds of facades of a building. The report includes the sufficient methodology which is taken into consideration by this study as one of the key pillars of the literature review.

2.2.3 Effects of wind-pressure on energy efficiency

Wind pressure has a major effect on energy exchange. The relationship is linear: the more pressure, the higher the rate of energy exchanges. Wind pressure generates leaks of air through cracks or openings, and depending on the building construction, it can be very significant. Wind angles affect building's natural ventilation (Figure 8) and energy consumption of the building. In winter, the wind movement in the outdoor environment will affect heat loss of the building, while in summer the change of wind direction and speed in the outdoor environment will affect the building's ventilation and indoor air circulation (Huifen et al., 2015).

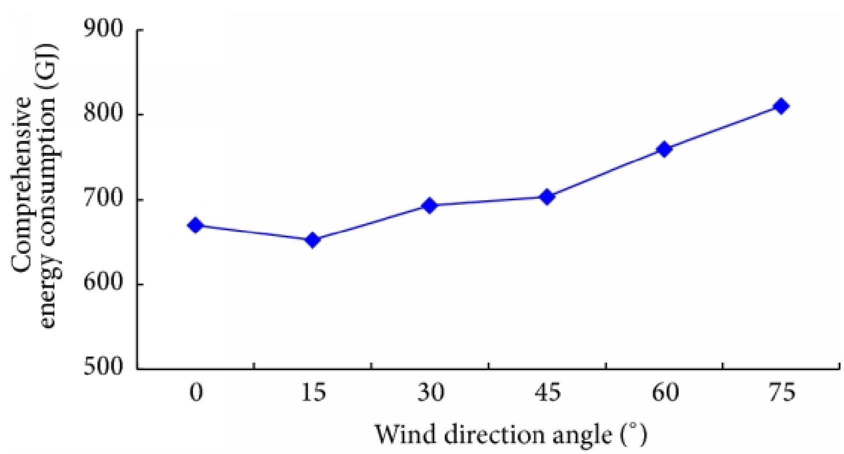


Figure 8 The comprehensive energy consumption of residence each year under different wind angles Reference (Huifen et al., 2015)

The authors find a clear correlation between direct wind exposure and energy consumption in Shenyang. The heat loss was reduced in case the building could avoid the dominant wind direction. This observation is sustained by other authors. Bhatia suggests that wind is the second greatest source of heat loss during the winter and one third of the energy during winter times is consumed for heating of the cool air, which is penetrated in the building. The heat losses may be increased in case, that the building facades have cracks and gaps. (Bhatia, 2015). When higher pressures acts on the outdoor side of the envelope, air leaks inward, causing air infiltration. If the difference in air pressure creates higher pressure on the inside of the building envelope, the air leaks outwards which is an air exfiltration. Air leakage causes many problems such as condensation, corrosion, icicles on outside surfaces, brick spalling, difficulty in controlling indoor temperature and humidity in addition to energy losses (Quirouette, 2004).

Air flow through a building shell is a combination of viscous and turbulent flow through openings and cracks. The former is proportional to the pressure difference over the envelope, whereas the latter varies with the square root of the pressure difference (Feustel et al, 1985). The resulting changes in thermal energy produce what is called the “Stack Effect.” This effect is generated by pressure changes, especially when the differences are considerable. This produces an air pressure between indoor and outdoor especially noticeable in the facades, roofs and contact surfaces. Warm air typically moves towards the top of the building while cool air enters from the bottom. The process includes both air infiltration from the bottom and air exfiltrating from the top, which creates the situation where the building seems like it is “breathing” (Figure 9). The higher the wind pressure, the more frequent and higher is the energy exchange. There is a certainty that wind pressure generates energy exchange and the relationship is linear, i.e. the more pressure, the higher the thermal energy exchange.

As wind hits the facade of buildings, its velocity is abruptly changed, causing an increase in pressure, or pushes on the building facade. The maximum increase in pressure on the facade where the wind is stopped is called the stagnation pressure. When an obstructing building impedes the wind, it will cause an increased pressure on the face of the building.

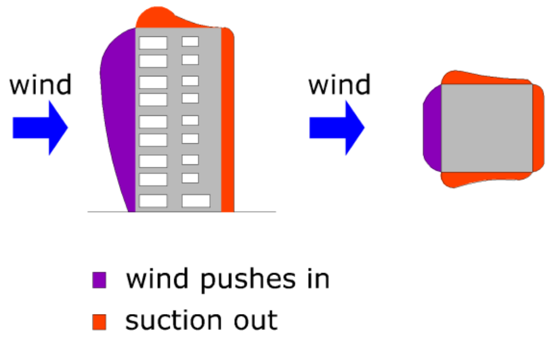


Figure 9 Wind Performance of buildings (Quirouette, 2004)

However, while the wind may stagnate on the windward side, it will most likely increase in velocity along the sides and top of the building. In these areas, the pressure will be reduced, thereby causing suction or a pull on the building façade (Quirouette, 2004). The pressure on the building facade may change in a linear way depending on the wind speed, but also depending on the typology of the building itself. With the increase in height, the wind usually gains more speed. Certain traditional urban patterns have the tendency to decrease the wind speed.

Sometimes wind can receive acceleration on the wind (spatial) tunnel, which may account wind speeds that are above average. Research studies have shown that wind is not the dominant force driving air leakage, but it can account for up to 25% of the air change rate on a seasonal basis (Quirouette, 2004). In conclusion, the higher the speed of wind, the higher the rate of air exchange, an outcome that makes it possible to understand the interrelationship between the morphological properties of urban patterns and the wind flow and wind performance.

Thus the equation is linear the more wind pressure on the fasade the more the ratio of air temperature exchange. Unfortunately for this study there is not a definite conclusion as to which extend the air exchange in the building can account to the monthly/yearly heating demand in Kilo Watt per year. In fact this analysis provides a partial answer. Since there is no conclusion as to which extent the wind speed influences the thermal energy exchange.

Housing typology, structure, thermal insulation and so forth, greatly influence the flow of the air inside. Site topography and vegetation also have a strong influence. For instance, if a site is covered by trees, they usually work as windbreakers. Hilltops or open sea corridors also may have a strong influence. Further, physical models with isolated buildings have been conducted since 1980. Models, however, are difficult to create and therefore leave the alternative of Computer simulation as an easier and much simpler task. A better understanding of the correlation of wind speed to air pressure and air leakage in the buildings provides a useful equation which may be utilized in the concept of parametric urbanism. However, the correlation of simulation of wind pressure on the facade to the actual energy spending for cooling or heating is an issue which needs further analysis. Unfortunately this study could not conclude with an analysis on how wind pressure influences, energy exchange in the meaning would difference it makes in the actual energy spending of the building/flat per month or year in kilowatt. In general the insulation of the facades makes a lot of difference, and there is not such a thing as a perfect insulation, but there is the possibility to measure an average insulation. Thus the problem is simplified as the following what is the influence of wind pressure on the thermal energy exchange for different typologies of the facades. Unfortunately this study is limited in showing the difference of the wind pressure in the facades in the height of 2 meter, in plan of different urban patterns. Connecting the first stage analysis (difference of wind pressure because of different urban patterns) with the second stage analysis. (what that difference means for the actual energy spending, is important and a step to be considered for further studies.

2.3 Buildings as the major agents of energy consumption

Together with the transport system, buildings are the highest energy consumers. In the United Kingdom, for example, building services account for at least 40%, and probably as much as half of total primary energy requirements, largely for space (and water) and heating (BRE, 1975). The situation has not changed much in the past decades. Salat and Bourdic (2011) identify the building form and the technology of its construction as valuable factor, which defines the energy consumption.

According to Susan Owens (1986), the design in use to exploit solar energy can result in rigid repetitive layouts with little aesthetic appeal. A second problem is that housing patterns for passive solar heating would be “exclusionary”, in that they would be available only to those who could afford low-density housing on large plots. As an example, BedZED Zero Energy Development, which was constructed in 2002 in the UK demonstrate heating consumption, which 10% that of conventional non-passive solar homes. The complex itself is low-density 3 floors high residential development, where the building form is optimized in order to have maximum roof surface available for the photovoltaic panels, and the distances between the buildings are set in order to exclude the shading of one building by another.

Within the building itself there are thermal isolation differences that amount to a factor of 2 or 3 in energy expenditure. And in-between apartments, for example, there can be three times more efficiency compared to a detached house of similar size. A house which is carefully oriented to take full advantage of passive solar energy could have halved the heating bills of one whose setting ignores this potential (Owens, 1986).

The difference in energy consumption for heating is evident not only for different building typologies. Within one building apartments, which are positioned at the building top spend about one third more energy, than ones in the middle of the building. Figure 10 shows the influence or **advantage of minimal surface exposure for energy efficency**. The external surface is lower in the in-between apartment, therefore this typology has a clear advantage in energy expenditure.

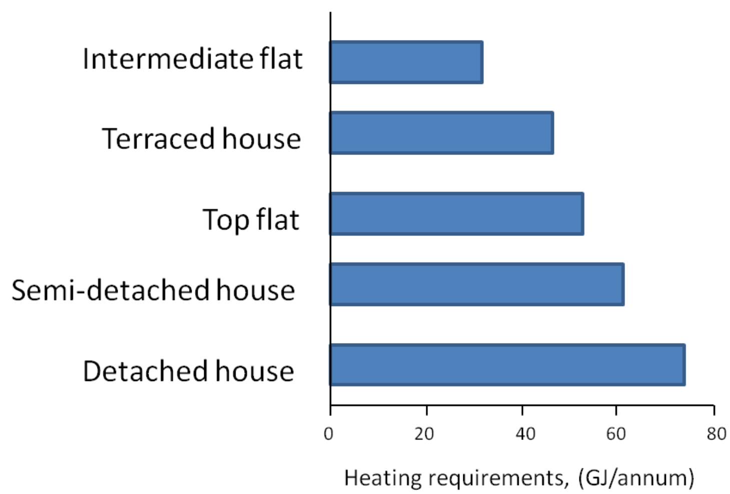


Figure 10 Influence of the built form on heating requirements in the UK according to the Building Research Establishment (BRE) (Adopted from Owens, 1986)

Built form is a very significant variable at this scale, since the basic energy requirements of a building are determined by its surface-to-volume ratio. Setting and orientation have important energy implications since they can be used to take advantage of microclimatic factors and form “free” ambient energy sources. Energy efficiency is very important as over 40% of energy is consumed by housing alone. Therefore it is crucial to identify those properties of the building which affect its energy efficiency. One of those properties is clearly the surface-to-volume ratio.

2.3.1 Surface-to-volume ratio

As early as the beginning of the 19th century, in his book Précis of the Lectures on Architecture, Durand suggests some early concepts on economy and efficiency. Durand states, that the building may have more expenses, if it has symmetrical, regular, and simple shape. Picon notes that Durand argues, that elementary forms and volumes increase economy of materials. Building, which is based at the use of the square or circle, allows minimizing the ratio between perimeter and enclosed area.” (Durand, 2000).

Research on surface-to-volume ratio is addressed to find the building typology with the minimal surface area and, consequently, the minimal potential energy losses within the maximal built volume. March states, that the most efficient building is be “a half cube or half sphere” (March, 1971). In the research he takes into consideration exclusively the surface-to-volume ratio, where the most compact shape would result in being the most efficient (Figure 11). This statement is based on surface-to-volume ratio, where a more energy efficient structure is actually less exposed to the outer environment. This statement is valid for both hot and cold climates. Compact, cube-like buildings actually have the minimum heat gains and losses, but the problem is, that a large part of the central floor area has no source of natural daylight (Behsh, 2002).

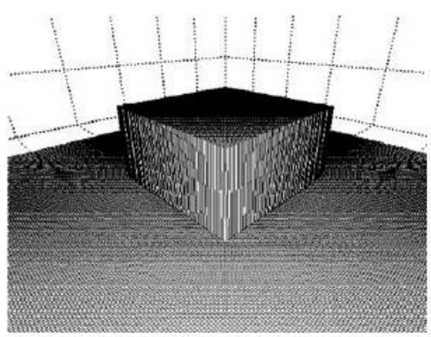


Figure 11 According to March, the most energy efficient archetype resembles half sphere or cube (March, 1971).

While March’s idea indicates a rather simple equation, i.e. that it is better to have a less exposed building surface to provide more energy efficiency; the situation is in fact much more complex. There can be found the examples of such buildings, as shopping malls or warehouses with a shape resembling a half cube, but this typology can be used only for specific purposes, as artificial lighting inside is necessary.

Outer surface is a major medium of energy exchange that follows a linear law by which for the same volume the more surface means more energy spent for keeping the same temperature. A low surface-area-to-volume (S/V) ratio is optimal for a passive building. This is the ratio between the external surface area and the internal volume (Thorpe, 2014).

The heating, cooling and lighting of buildings is accomplished not just by mechanical equipment, but mostly by the design of the building itself. It has been observed that the roof is the building’s most important component where it constitutes the major source for the thermal stress, both during cold and the high temperature periods (Behsh, 2002). The same study confirms one more time the necessity to restrict the outer surface to preserve inside temperature comfort. A building form with low s/v ratio takes more time to be affected by outdoor temperature variations than that of a higher s/v ratio of the same structure. (Behsh, 2002). In addition, Behsh emphasizes that, for the buildings with a complex floor plan, the surface-to-volume ratio should not be the only parameter characterizing energy efficiency.

The authors which are critical of L. March’s assumption that the most effective shape is a half sphere or half cube state that irrelevantly to the evaluation of the architectural qualities of the half-cube structure, it is important to evaluate not only its heat losses, but the overall energy consumption (Baker et al., 2005). As direct gain, passive solar heating of houses is one of the most utilized strategies in improving energy efficiency and reducing CO_2 emissions (Kesik and O'Brien, 2014).

Curdes in his research on the efficient urban morphology within the conditions of climate change (2011) had established the importance of surface-to-volume ratio for energy efficiency. Started firstly from description of the amount of space, which is contained in different urban envelopes, he went on to compare different typologies of different building types as shown in Figure 12.

The most common housing typologies, such as detached house, slab block and atrium building demonstrate different surface-to-volume ratio for the units with the area. Among all the typologies the building with a surface-to-volume ratio equal to 0.3 is 3 times more efficient than the one with a surface-to-volume ratio of 0.9.

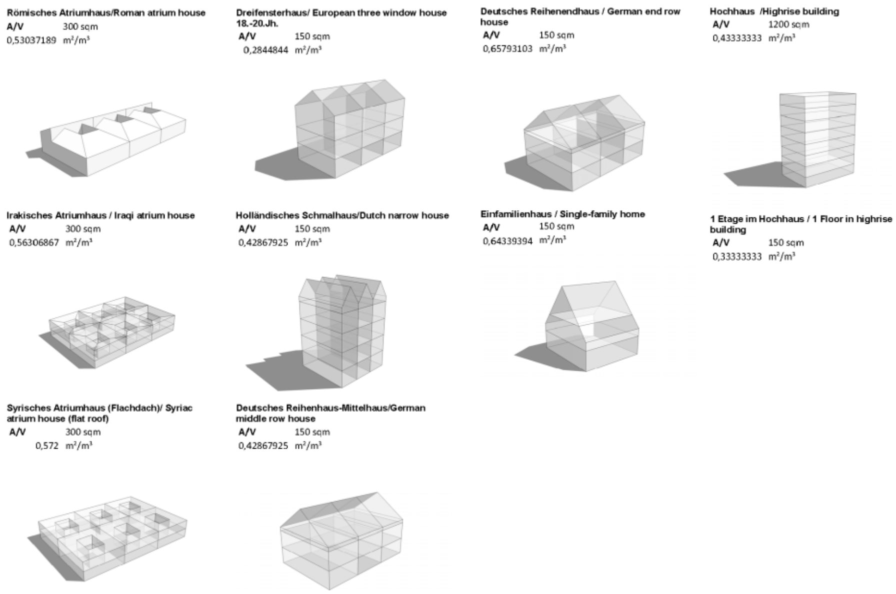


Figure 12 Building types and their surface-to-volume ratio (Curdes, 2012)

In Figure 13, Gerhard Curdes demonstrates the use of software to compare the index of s/v of different typologies where modernist high-rise buildings seem to have better ratio.

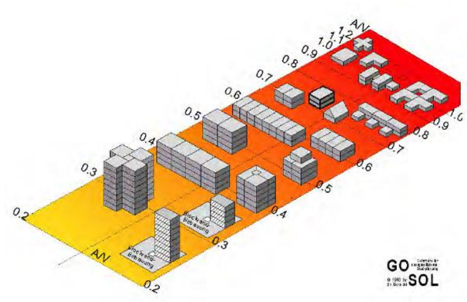


Figure 13 Distribution of building typologies from the lowest to highest surface-to-volume ratio (Curdes, 2010)

Curdes indicates as well, that the medieval urban structure is the one which provides for the greatest number of energy efficient considerations such as:

- compactness
- small plots
- narrow roads
- hierarchy of space
- gabled houses
- back gardens
- reserve land behind buildings
- wind protecting barriers
- equal height of roofs
- vertical air movement

As a conclusion, the higher the amount of surface exposed, the higher is the thermal energy exchange. This rule works equally in winter and in summer. The surface-to-volume ratio is an important parameter which can be used in the algorithmic design. From the other side low ratio results to the totally isolated space with no natural light or ventilation. Therefore, an optimized solution is needed, where the condition of natural light and ventilation is also considered. Municipality regulations and housing standards provide some information about width and heights of the buildings. The 45-degree angle, for instance, which is also applied by the Municipality of Prague, limits the height versus distance among the buildings, ensuring the minimal lighting standards. The maximal depth of the habitable room is a key parameter in defining the width of the house. Therefore, the application of housing standards and regulations makes research on the efficient building shape more realistic.

An interesting article is that of CISBAT 2017, where are described some of the issues such as compactness of urban structures and Kilo Watt spending of each of the models of urban patterns. The patterns are extracted from the cities of Rome and Barcelona. Issues such as site coverage are mentioned in articles as that of Salvati, A., Helena C., Morganti M., which in fact indeed use the methodology of analyzing the site coverage for different urban patterns. (Salvati A., Cocha H., Morgantia M., 2017)

In this graph, there can be seen that the more dense and compact an urban neighborhood is (the higher the ratio of site coverage in percentage), the more there can be seen the reduction of the annual demand of KWh/square meters. Although the study does not conclude in a final description, as to which extent the compactness reduces the energy demand, the graph shows a unique trend and obvious difference of about 10 percent.

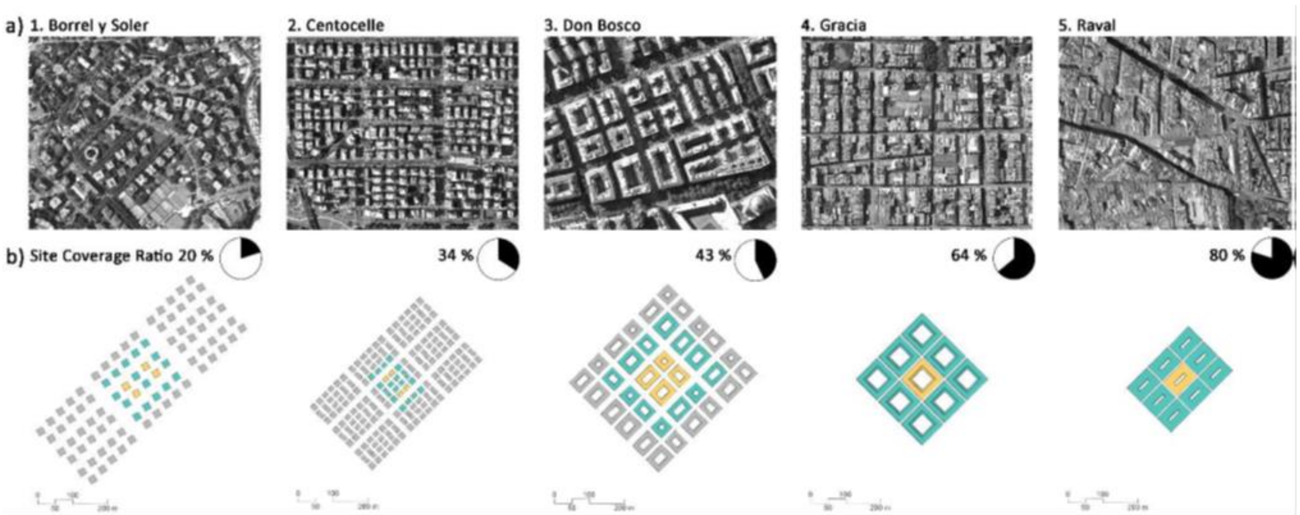


Fig. 13.2 (a) Orthographic pictures of the real urban textures, (b) Values of "Site Coverage ratio" (Salvati A., Cocha H., Morgantia M., 2017)

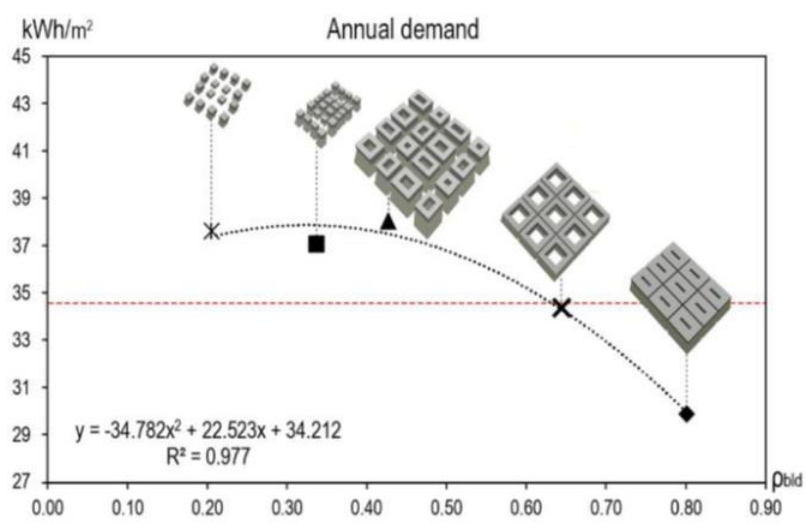


Fig. 17.2 Relationship between the texture's site coverage ratio and the apartment's annual energy demand for five case studies. (Salvati A., Cocha H., Morgantia M., 2017)

The graphic explains Barcelona; Raval neighborhood has an obviously higher density or site coverage ratio (80%) and at the same time about 10% less than the pattern of the neighborhood Borrel y Soler with a site coverage of (20%). The study focuses on Density of the actual neighborhoods/textures rather than the typology of patterns. The case is similar to the study of Prague Patterns in chapter 6.

The graphic descriptions of this article were an example for the graphs used in chapters 4 and 6, in regard to the typologies of build form and their correlation with surface to volume-ratio, incident solar radiation, density, and site coverage ratio.

2.3.2 The passive zone

Ratti, Baker and Steemers analyze the phenomena of the Passive Zone. Compact shape of the building is not the only factor, which contributes into energy efficiency since solar radiation has great impact into the building heating demands (Ratti et al., 2005). The passive zone is the area which is naturally lit and which usually extends to 6 meters or to double the height of the floor in depth from the façade (Figure 14). The naturally-lit surface (or the passive zone) extends into the depth of an apartment to about twice the height from the floor to the ceiling, or approximately 6 meters, considering that the average height of the apartment is about 3 meters.

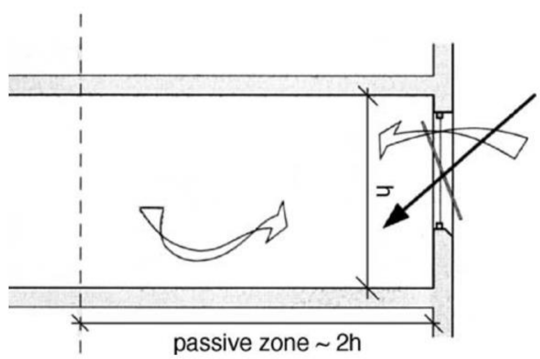


Figure 14 Section of the building with indication of passive zone area (Ratti et al., 2005).

According to the study, the passive zone is related also to other factors including:

- Distance from the facade (passive/non-passive condition);
- Orientation of the facade;
- Urban horizon angle (UHA);
- Obstruction sky view (OSV)

Housing typologies are usually designed taking into consideration the passive zone area, so, ideally, building width should vary between 12-14 meters. Baker and Steemers are the first to tackle the passive zone area among other factors, which influence the energy efficiency of the urban pattern. The passive zone may bring the difference in energy consumption about 2.5-fold variation. Building systems efficiency accounts for a 2-fold variation and occupant behavior accounts for yet for another 2-fold variation. The cumulative effect of these factors can lead to a total variance of 10-fold. In practice, variance in energy consumption of buildings with similar functions can be as high as 20-fold (Baker and Steemers, 2000).

Looking at the results from Owens and Curdes, it is clear that urban morphology plays an important role. It is very important to understand the city as a structure of Energy. Salat and Bourdic write about fractal urbanism, thinking of the city as a mega complex structure of energy. The leaf-like city structure, of which traditional cities such as Sienna are the best examples and where inside their fractal structure, a variety of microclimates occur. The city is open to solar energy and wind ventilation. Beyond their mathematical form, the structural laws of urban energy deal with the relationship between forms and processes. Aiming to create a sustainable society, it is important for each aspect of design process to follow the structural order of living systems. This structural order always results from a process (Salat and Bourdic, 2012). Salat introduces the concept of the city as an open system of energy exchange.

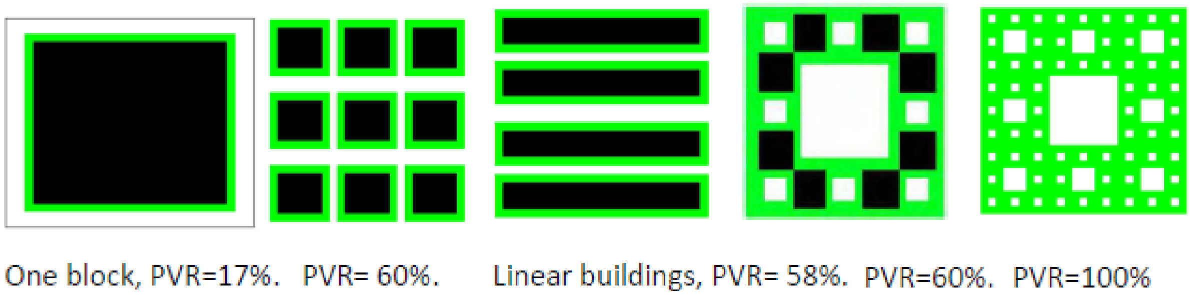


Figure 15 Passive Volume Ratios (PVR) for different perimeter blocks (Salat and Bourdic, 2012)

As it is shown in Figure 15, the passive zone ratio is the lowest in the mono-block structure, such as L. March's cube example and is higher in slab blocks. Even higher would be in cases like Middle Eastern traditional patterns, (Figure 16), where inner courtyards create the possibility for lighting.

Figure 16 Housing Study of the Mahalla, Balad, Iraq (Kohout et al., 2011).

Inspired by fractal structures, Salat describes different archetypes in terms of the use of passive zones. The first example displays a mono-block structure, typically a tower. Passive zones are in green, whereas non-passive zones are in black. The passive volume ratio (PVR) is only 17%, which is extremely low and leads to high energy consumptions, notably for lighting and ventilation. Salat demonstrates very clearly that the more fractal a structure is, the more open it is to sunlight and natural cooling. The study promotes the urban forms which are more fractal and therefore more open, as opposed to the conclusions of March. The “fractality” factor in the study seems to be applied solely with the purpose of increasing the passive zone, but there are no conclusions drawn as to how it is related to or guides towards more energy efficient urban patterns.

2.3.3 Specific parameters which influence energy performance

Together with the above-described objective factors including surface-to-volume ratio, passive zone and natural ventilation, there are other factors which affect the energy performance of the urban pattern, such as quality of building systems and occupants’ behavior (Salat and Bourdic, 2011). These include thermal insulation, building materials and human perception of thermal comfort (and therefore the occupants’ behavior), which can all be measured at the level of the single building but are hard to be considered at the scale of urban patterns. Nevertheless, some of the other factors which have a role in energy efficiency that are not linked to urban morphology can be examined.

2.3.3.1 Thermal Insulation

Thermal insulation is a factor which plays a tremendous role in energy efficiency. The decision-making for the selection of thermal insulation is based on local regulations, ownership responsibility, country standards and so forth. Thermal insulation can be defined as the extra materials which are added to the walls in order to mitigate energy exchange from inside to outside and vice versa. Thermal insulation is the reduction of heat transfer (the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiating influence. Thermal insulation can be achieved with specially-engineered methods or processes, as well as with suitable object shapes and materials. Thermal insulation varies from country to country, depending on the governmental standards as well as on the skill of the builders. Developed countries usually have far more energy efficient materials and people there can afford to buy more expensive houses.

Residential buildings have been continuously improving in insulation efficiency. Though materials with better thermal properties and more efficient systems have lowered energy consumption for space heating in recent decades, substantial differences in energy consumption are still being observed in similar dwellings (Lutzenhiser, 1992; Jeeninga et al., 2001). Thermal insulation is essential for preserving the thermal energy inside. It also differs depending on building construction time. For instance, prefabricated panel buildings have performed less well than contemporary buildings. The criteria are not part of this study since thermal insulation is taken as a “fait acomplis” which depends solely on the country’s standards and age of construction, amongst other factors.

2.3.3.2 Human perception of temperature (thermal comfort)

Thermal comfort itself is a very complex issue which depends on at least 6 other variables as described in the work of Olesen in 1982. There are two main groups of factors, which contribute into the thermal confort evaluation. From one side these are the human-based factors, such as type of activity and selection of clothing. From the other side the state of comfort is influenced by the environmental factors, such as of the air, air velocity, humidity and mean radiant temperature (Olesen, 1982).

Temperature comfort varies for different people and different ages depending on body metabolism, physical conditions, activities which people perform, and their varying perception of temperature. The “wind chill” phenomena is explained by the fact that skin preserves a certain thin layer of air which is warmed up just above it and works as insulation. Wind has the effect of taking out the thin temporary warm layer of air and replacing it with cold air, which is what creates the effect of a wind chill. It is therefore very important to differentiate between the wind chill factor, or the lower temperature perceived facing wind, and the influence of wind in air exchange in the building. Wind pressure’s effect on energy efficiency is the factor which is related to urban morphology and is considered in this study.

2.3.3.3 Occupancy behavior

From energy consumption to physical interventions in the building, occupancy behavior has a tremendous influence on energy performance. It varies from country to country. Analyzing such phenomena is quite complex and is not part of the research. Nevertheless, it should be mentioned that it affects the overall energy metabolism that buildings and cities have. Santín in the study energy consumption in dwellings states that in Europe 40% of the produced energy has been spent by the built environment and out of it large proportion is being consumed by residential buildings (Santin, 2010). The behavior of inhabitants greatly differs based on the culture, lifestyle, and physical conditions.

Santin analyses four domains of behavior or preferences, which are related to the energy consumption and are an integral part of the whole system:

- use of heating system,
- use of ventilation system, windows and grilles,
- use of rooms and presence at home,
- showering and bathing frequency

Certainly, dwelling typology and design has an influence on consumption as well. Sardianou concludes, that the owners of apartments consume more in general; space heating consumption increases with the growth of income and with the growth of the dwelling area (Sardianou, 2007).

Occupancy behavior is not directly influenced by urban morphology, but the introduction of policy of an energy efficient district or neighborhood might have a chain effect which may indirectly influence the occupants’ behavior. Bousquet et al. conclude that municipalities should design policies to influence user behavior including those that minimize the use of detached house development and encourage the construction of building residences. Such blocks may improve the on both consumer and producer sides, be the easy solution for application of energy audit policies for old dwellings. In addition the innovative technologies may be applied in design of smart grids, which allows to take more information and to establish new energy standards (Bousquet et al., 2014).

2.4 Parametric urbanism and its role in energy efficiency

Parametric urbanism can be interpreted in various ways, but this study's focus is on the display of parameters in improving the cities of today. Banham would have dubbed the present time the Cyber Age or the 5th Generation Machine Age where software and programming become indispensable tool for any profession. From Google Earth, to computer simulation, information technology has been changing really fast. Nevertheless, the profession of the architect and urban planner seems to be stagnating. A paradigm shift is desperately needed in this time of crises where resources are more and more scarce. As stated in the "manifesto" of "Peer to Peer Urbanism," centrally-planned urbanism doesn't address anything but a big-picture view and misses all the local details that significantly affect the solution. It is character for the approach of centralized urbanism to construct the structures, which are not flexible and adaptable and to dismantle at the same time the existing natural or man-made solutions (Caperna et al. 2016).

One way of taking this approach further from a theoretical perspective is to appropriate the notion of the 'rhizome' as an urban planning strategy. Deleuze and Guattari offer the theoretical model that resonates closely with the logic of emergence. They focus on morphogenesis and the algorithm of emergent organism where that simple "hidden" intelligence could be just enough for making the organism self-sufficient. The designers should understand and apply the intelligent solution, which can be found even in the simplest natural organism. Intelligent urban structures should respond positively to the natural environment.

The scientist Christopher Alexander and the mathematician Nikos Salingaros have created a new school of urban morphology based on morphogenesis and emergence. In The Nature of Order (2002) Alexander proposes that urban development is a computational process similar to that of cell growth in an organism, and that the unfolding of these processes produces the urban landscape and its typologies. Some urbanists have thought to transform this theory into a practical emergent urbanism. These abstract ideas need to be elaborated further to more constructive and utilitarian products.

A genetic algorithm can resolve optimization problems similar to natural selection through evolution. The algorithm changes perpetually through repeatedly selecting the parameters from the existing patterns and using them as a genome for producing solutions for the next generation. Over successive generations, the parameter n "evolves" toward a better solution.

The genetic algorithm differs from a classical, derivative-based optimization algorithm in two main ways as summarized in (Math Works, 2016):

> “Classical Algorithm generates a single point at each iteration. The sequence of points approaches an optimal solution. Genetic Algorithm selects the next point in the sequence by a deterministic computation and it selects the next population by computation which uses random number generators, generating a population of points at each iteration. The best point in the population approaches an optimal solution.”

Genetic Algorithm represents an intelligent exploitation of randomness to solve the optimization process. The idea is to simulate processes similar to that of nature, of almost Darwinian selection of the fittest, which happens at any given time in a dynamic process. Each individual iteration within the process of algorithm running represents a point in a search space, as well as a possible solution. The individuals in the population are then made to go through a process of evolution.

One example of use in Urban Planning is where a genetic algorithm was used to search for optimal future land-use and transportation plans for a high-growth city. Millions of plans were considered and constraints were imposed to ensure affordable housing for future residents. Objectives included the minimization of traffic congestion, the minimization of costs. The genetic algorithm provides planners and decision makers with a set of optimal plans known as the Pareto set. The value of each plan in the Pareto set depends on the relative importance that decision makers place on the various objectives (Balling et al., 1999). It is absolutely important to associate the actual abstract efforts on genetic algorithms to more practical and utilitarian practices .

In this study, the genetic algorithm was used through the Galapagos evolutionary solver which is a plug-in from Grasshopper and which applies the principle of genetic algorithms. Evolutionary algorithms take time since during the process of optimization; the multiple iterations are completed and compared. The tool represents an advanced technique in optimization since it picks up improved solutions through the consideration of dozens of variations in a dynamic and fractal process. Partially the solutions described in that chapter are to a certain extent utopic, thus as an experiment Chapter 5 can be considered a partial success.

Parametric urbanism sees urbanity or urban form as an assemblage or mass of elements which could adjust to certain conditions or elements. This study is aimed at advancing the ideas of parametric urbanism into methodologies for sustainable development. Urban Form plays an important role in the exposure to solar radiation and/or negative exposure to wind which is considered itself one of the principal factors of inside-outside thermal energy exchange. It is very important to make several virtual experiments on how different models perform in relationship to solar radiation and wind protection. So, if the goal is to have an energy efficient urban environment, it is crucial to understand first of all how those dynamic principles work in reality. Although it is supposed that, hypothetically at least, the models of living, community, information and technology will change in the future, it is nevertheless important to investigate current steps on how to approach levels of Energy Efficiency.

The implementation of parametric urbanism is still in its starting phase. However, Zaha Hadid Architects won a series of international master planning competitions with schemes that embody the style's key features. The projects include the 200 ha One-North Masterplan for a mixed-use business park in Singapore; Soho City in Beijing, comprising 2.5 million square meters of residential and retail space; the mixed-use master plan for Bilbao, including the river's island and both opposing embankments; and the Kartal-Pendik Masterplan (Figure 17), a mixed-use urban field of 55 hectares with 6 million square meters of gross buildable area comprising all programmatic components of a city.

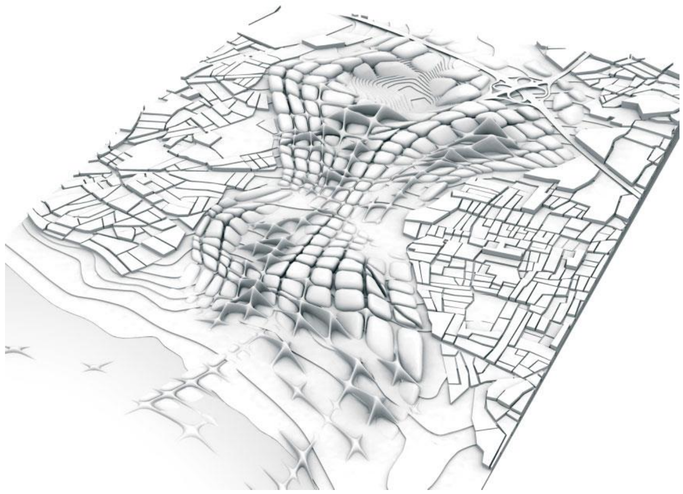


Figure 17 Zaha Hadid Archiects, Kartal-Pendik Masterplan, Istanbul, Turkey (Hadid, 2007)

This project unfortunately does not much tackle issues such as energy efficiency and it seems as the major concern remains formal algorithms which define form in a computational way, but shows an attempt to build a city from scratch using parametric urbanism. This could have potential threats similar to the modernist paradigm.

Perhaps this is one of the reasons that despite the advancement in IT technology, Google Maps, Google 3D, mobile interfaces and other computer software, little has been done in practice in changing the paradigm of how architecture and urban planning" function in reality, analyzing existing cities where software is employed to really re-frame the city based on pre-programmed algorithms.

Information technologies have a lot of potential which needs to be employed and may have a profound impact on the profession of urban planners itself. From the adjustment of existing empty apartments to client preferences, to space syntax, and issues like position the public services application of information technologies may have positive impact in improving of the existing cities. This study provides some information and an overview on how to generate an optimized solution of urban morphologies with regard to energy efficiency.

Smart cities incentive is in fact some of the most avant-garde, incentives in the attempt to use analysis of data in the city scale. Smart Cities incentive has also included Prague in the network of cities attempting to improve the energy performance. https://smartprague.eu/projects/#smart-buildings-and-energy, 2017. Further advancement on this topic is currently underway. In other words it is necessary to understand how to use parametric urbanism as a tool in a more soft-way,

2.5 Definitions and terms

Algorithm - Algorithms are a series of symbols for operating procedures and for the relations between the group of signs and operating procedures. Algorithm is a tool in any system for operating in a way that is open and directed, that is, intentional.(Gausa et al., 2003)

Building type or typology - the general characteristics of a building in terms of the possibilities of production and reproduction.

Compact City - The concept of the compact city is a key strategy to limit suburban sprawl and to obtain a more sustainable urban development. In the Netherlands, concepts for compact forms of urbanization have played a major role for more than half a century (Nabielek, 2012).

Computer simulation - A computer simulation is a simulation run on a single computer or a network of computers to reproduce the behavior of a system. The simulation uses an abstract model (a computer model, or a computational model) to simulate the system**.**

Density or Urban density -A very specific measurement of the population of an urbanized area, or ratios of open space and built form.

Floor area ratio - the total floor area of buildings divided by the land area of the lot upon which the buildings are built.

Fractal urbanism - Fractal structures are something between uncontrolled chaos and absolute disorder. Fractal geometry represents a series of experiences that encompass everything from patterns of natural processes to abstract numerical simulations obtained using computation techniques.

Galapagos - Evolutionary problem-solving mimics the theory of evolution, employing the same trial-and-error methods that nature uses in order to arrive at an optimized result. When automated for specific parameters and results, this technique becomes an effective way to computationally drive controlled results within the iterative design process, allowing designers to produce optimized parameters resulting in a form, graphic or piece of data that best meets design criteria (Aweida, 2011).

Generated model - Using computer graphics and interactive modeling and rendering systems to assist in the design, visualization, and simulation of complex 3D city models is of significant interest to a wide variety of stakeholders from scientists to engineers, politicians, and concerned citizens (Aliaga, 2012).

Genetic Algorithm - A morphogenetic paradigm predicated on the generative formation of architecture based on an internal principle (Gausa M., Guallart V., Muller, Soriano,F., Porras F., Morales, J. and Cros S., 2003).

Genome -The nuclear information that defines the patterns or logic of the development of evolutionary form (Gausa et al., 2003).

Google Earth model – A virtual globe, map and geographical information program that was originally called EarthViewer3D that was acquired by Google in 2004. It maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and geographic information system (GIS) onto a 3D globe.

Grasshopper - A graphical algorithm editor tightly integrated with Rhino's 3D modeling tools. Unlike Rhino Script, Grasshopper requires no knowledge of programming or scripting, but still allows designers to build form generators from the simple to the awe-inspiring (Davidson, 2016).

Incident solar radiation - The amount of solar radiation energy received on a given surface during a given time. Values are given in units of energy per area (W/m2 or BTU/hr/ft2) and are usually the single most valuable metric for early design studies (Autodesk, 2011).

Morphogenetic urbanism - Morphogenetic model of urban design in which matter and form are placed in a dynamic rather than a fixed relationship (Trummer, 2009).

Occupancy behavior - Occupant behavior here may include occupant's presence, activities, and how they operate appliances and other human-related subjects in relation to energy spending (Duan and Dong, 2014).

Parametricism – A style within contemporary avant-garde architecture promoted as a successor to post-modern architecture and modern architecture (Schumacher, 2008)

Parametric modeling - A process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between design intent and design response. (Wassim, 2013)

Parametric urbanism - According to Neil Leach, within the Parametric Urbanism methodology, classic Geometric Shapes will lose its dominant position for its inflexibility and difficulty to adapt to different problems and are replaced by more intuitive, adjustable and intuitional solutions (Leach, 2009).

Passive zone - The zone that is naturally-lit and ventilated inside the building, usually about 6 meters deep from the outer facade in residential houses.

Rhizomatic urbanism - Rhizomatic process supposes that every object is self-contained and generates its proposal from the immediacy of the surrounding with which it is in contact.

Site coverage -The proportion of a site that is covered by buildings and structures. Managing the total site coverage of dwelling houses and ancillary development stops residential sites from becoming too overdensified

Space Syntax - A method for describing and analyzing the relationships between spaces of urban areas and buildings. In Space Syntax, the spaces are understood as voids (streets, squares, rooms, fields, etc.) between walls, fences and other impediments or obstructions that restrain (pedestrian) traffic and/or the visual field (Klarqvist, 1993).

Stack effect - The movement of air into and out of buildings, chimneys, flue gas stacks, or other containers, resulting from air buoyancy. Buoyancy occurs due to a difference in indoor-to-outdoor air density resulting from thermal energy exhange and moisture differences. The result is either a positive or a negative buoyancy force.

Surface-to-volume ratio - The ratio of the envelope of a building (external facades and roof) to the entire volume of that building [m^3/m^2] (Rode et al., 2014).

Thermal comfort - The term ‘thermal comfort’ describes a person’s state of mind in terms of whether they feel too hot or too cold. Environmental factors (such as humidity and sources of heat in the workplace) combine with personal factors (ie clothing) and work-related factors (how physically demanding one’s work is) to influence ‘thermal comfort’ (HSE, 2015).

Urban morphology - The spatial structure and form of a metropolitan area, city, town or neighborhood and its constituent parts (Rode et al., 2014).

Urban form - Defined by three fundamental physical elements: buildings and their related open spaces, plots or lots and streets (Rode et al., 2014).

Urban pattern - Patterns are guides that serve as samples to create urban form (Gausa et al., 2003).

Wind pressure - When wind flows around a building it can produce high suction or pressure zones. This occurs mainly at the leading edges. Air exchange and also energy exchange are consequences of wind pressure.

A wind tunnel - A tool used in aerodynamic research to study the effects of air moving past solid objects. A wind tunnel consists of a tubular passage with the object under test mounted in the middle. Air is made to move past the object by a powerful fan system or other means.

2.6 Summary of the literature review

Energy consumption of the city according to Salat is defined by the urban morphology, building form and technologies, building systems and occupant's behavior. The task of the present research is examining the issue of energy efficiency at urban scale, which gives the major importance into the evaluation of contribution of the morphological properties of the urban pattern to its effect on energy saving. This thesis started by taking into consideration some of the most important contributions and articles on the issues of energy efficiency and urban morphology, starting with authors such as Lionel March, to Gerhard Curdes, H. Atkin, Philip Steadman, and later Philipp Rode. Studying the pioneer work of Lionel March and other authors of the 1970s and 1980s were important for creating a base of literature review. March supports the view that the most energy efficient space is half a cube or sphere with the minimal contact with the outdoor environment. Here already surface to volume ratio already is mentioned as "the factor" contribution to energy saving. Figure 10, in this chapter shows clearly that the Energy Spending of a terraced flat is at least 50 % in average more than a top flat of a similar size, following a study from Building Research Establishment (BRE).

Other later authors like Rati, Baker and Steemers have some important input finding out the phenomena of the passive solar zone or the area which is allowed by the urban pattern (volume-space relationship) to be naturally-lit and ventilated thus putting a limit to thickness or depth of the building. Serge Salat defines so-called fractal urbanism, a notion where the city could be imagined as a leaf like structure collecting energy from the sun and opening to the wind. Another input comes from Gerhard Curdes, who analyses existing housing typologies. According to surface-to-volume ratio, urban morphology of the 19th century should be the most energy efficient. In conclusion, while Curdes' methodology does not allow for a final proof, it is possible to measure the index of surface-to-volume ratio as one of the factors of energy efficiency, if compared with annual spending per square meter. Although different studies target various topics, which are diverse and the analysis of each of the topics would be very difficult and to a certain extent chaotic, it was important to underline the parameters that these studies conclude do influence energy efficiency from the urban morphology perspective. In order to do that it was important to frame: a) the concept of energy efficiency b) the parameters of urban form that influence energy saving. c) Cross comparison of each of the parameters.

The concept of energy efficiency in urban form is seen through energy gains and energy loses in its relationship with urban morphology. The parameters of urban form which influence energy saving are selected from the literature review as mentioned above, starting with Surface to Volume ratio (arguments from Lionel March, Gerhard Curdes), Density (arguments from Salvati A., Cocha H., Morgantia M., 2017), Incident Solar Radiation (arguments from Philiph Rode, Carlo Rati, Serge Salat and etc).

Wind pressure according to Quiroette, shall be considered as the major medium of thermal energy exchange accounting for a total of 25% of air exchange within the building. Consequently, it is possible to map energy exchange through measuring the wind pressure on the facades. The phenomena according to the references is linear, that is the more pressure on the built form, the higher the frequency of energy exchange independent of the weather conditions.

Other factors such as thermal insulation, human perception of the temperature, and occupancy behavior towards energy spending are not taken into consideration since those factors work independently from urban morphology and are related to cultural factors, standards and regulations, varying by country and the availability of resources.

c) Cross comparison between different parameters is analyzed in various studies such as that of Philiph Rode and Salvati A., Cocha H., Morgantia M.), where factors such as density are compared with kilo-watt per year spending. Unfortunately during this study was not possible to make a comparison with real energy data spending from Prague.

Overall the literature review helped in resolving two of the research questions that were:

RQ1. What are the factors, which affect the energy efficiency of urban pattern?

RQ2. What objective criteria can be used for the evaluation of the contribution of the morphological properties of the urban form into its energy balance?

Additionally the literature review was important in understanding the concept of computation and information technology in advancing the science of sustainable urbanism. Such articles were written by the pioneers of this field since the beginning of Environment and Planning B journal, visible in the work of Michael Batty.

Another important author was Neil Leach who wrote about Parametric Urbanism is a term established in the early 2000s, which got much support from scholars around the world, but has yet been widely applied into practice. Parametric urbanism is important for this study since its methodology is based on the computer generations and analysis of urban patterns. Incentives such as Smart City Amsterdam show the possibilities of advancing these studies to practice. These examples were important for drawing conclusions in Chapter 7. A stronger emphasis could have been the focus on urban patterns typologies, and cross-comparison with real energy data which remain the weak point of this study and could be advanced further in the future.

CHAPTER 3

METHODOLOGY OF THE RESEARCH

3.1 Organization of the research

The research starts by defining morphological properties of urban patterns and selection the criteria, which are necessary for construction of algorithm for its generation. Energy efficiency of urban pattern has been evaluated according to the criteria, which have been discussed at the literature review. Further on, the generated typical urban models are tested with the use of wind and solar simulation software, optimized with the application of the genetic algorithms and evaluated by the measurable parameters, surface-to-volume ratio, density and site coverage. Finally, the findings of the theoretical research are applied by testing the existing morphological properties of the urban fragments of Prague. The study is based on the investigation of the following research steps:

- Definition of the set of measurable parameters which influence the energy efficiency of the urban pattern
- Analysis of energy efficiency of the urban patterns according to the selected properties.
- Analysis of energy efficiency of the models based on the computer simulation of the solar access and wind flow
- Optimization of the dimensions of the main six typologies according to the selected criteria of efficiency with the use of genetic algorithms
- Analysis of energy efficiency of morphological properties of city fragments of Prague.

The present chapter describes the main steps of research, with the emphasis on the establishment of the measurable criteria of energy efficiency of the urban pattern. A description of the set of rules which restrict the construction of the urban pattern is followed by a description of the three main steps of analysis. Finally, a presentation of the software which is selected for the generation of the models, their analysis and optimization is made. The proceedings of the research are shown in Figure 18.

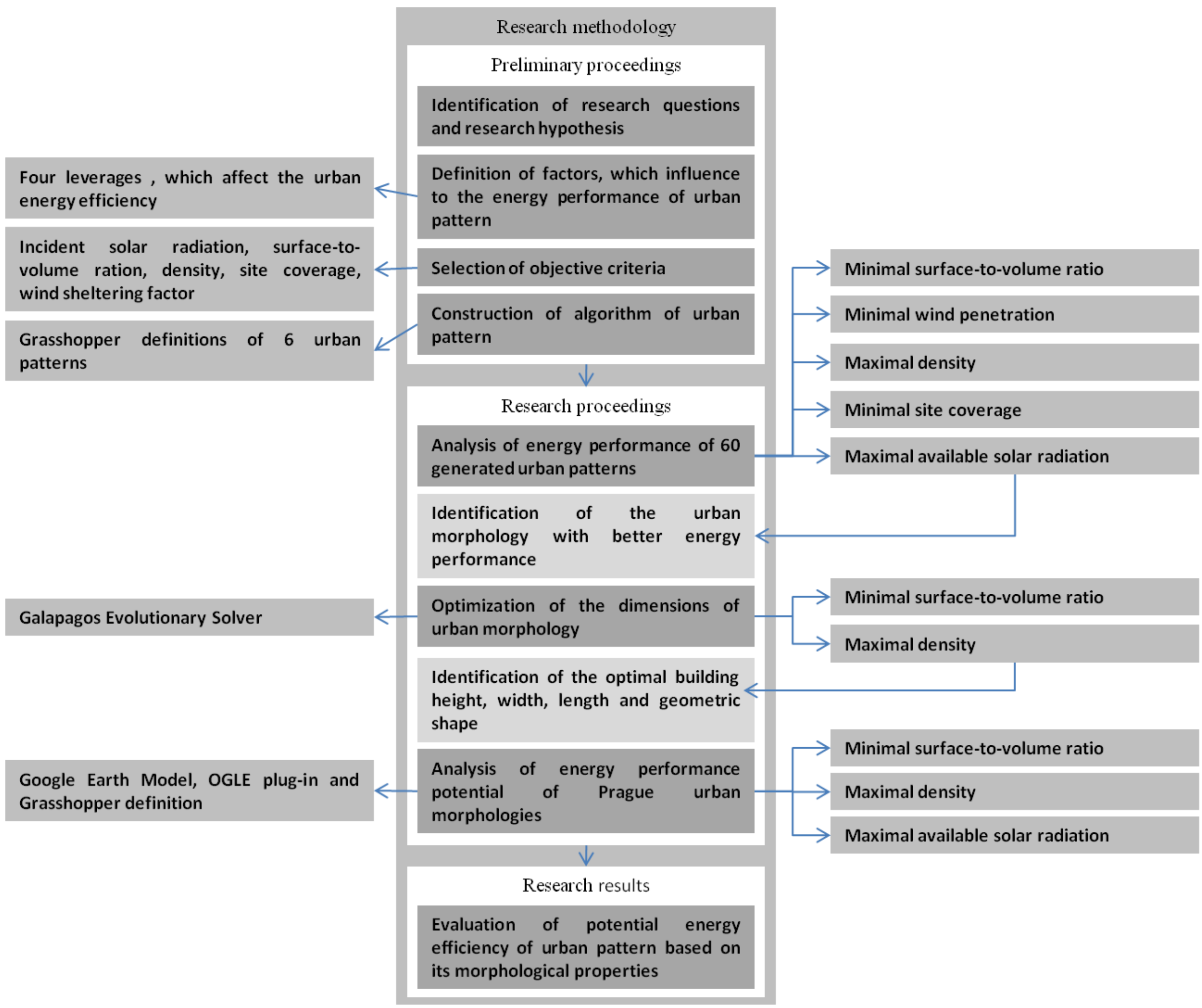


Figure 18 Methodology of research and research proceedings

3.2 Parameters which influence the energy efficiency of the urban pattern

The selection of the criteria which affect the energy efficiency of the urban pattern is based on the inquiry of the recent studies which are described in Chapter 2. All criteria (Figure 19) can be subdivided into several categories which are related in some way with the physical dimensions of the built units, and the ability to gain energy (solar radiation) and to lose energy (surface-to-volume ratio) and ability to control the wind flow.

ENERGY EFFICIENCT URBAN	
MAXIMUM ENERGY GAINS	MINIMUM ENERGY LOSSES
- Maximum of available incident solar radiation	- Maximum density - Maximum of wind sheltering - Minimal surface-to-volume ratio

Figure 19 Criteria, which influence to the energy balance of the urban pattern

3.2.1 Physical dimensions of the built volumes

The physical dimensions of the built volumes or mass of the urban pattern include the height, the width and the length of the building. At the first stage of the research, the three physical dimensions are fixed and the distance between the units is set according to the Czech urban standard. The horizontal dimensions of the buildings, such as width and length are flexible at the second stage where the optimization algorithm is applied. Efficiency is understood as a combination of two factors: maximal built density and minimal surface-to-volume ratio. At the last stage of the research, the dimensions are given since the real detailed models of Prague buildings are used.

3.2.2 Morphological properties of urban pattern.

Density is the parameter which is directly related to the energy efficiency of the urban pattern. Density is defined as the relationship between the total sum of the area of all floors of all built units and the site area. An increase of the density is directly connected with the economy of resources and materials and a reduction of the transportation and energy networks. From the other side, the connection between the increase of the physical dimensions and height of the buildings and the density is not linear. The width of the building and its height and the distance between the units of urban pattern are limited by the urban regulations. During the first stage of the multiple iterations of the six main urban patterns, the ones with the highest density can be found. Maximal density becomes the defining parameter for the optimization stage. Density is also measured for the selected urban patterns of Prague.

Site coverage is another parameter which helps to control the arrangement of the built units. Site coverage is calculated as the relation of the sum of areas of all footprints of the built units to the total site area. The maximum site coverage is defined by the urban standards. As is shown in the next chapter, some generated low-rise urban patterns may have high site coverage which is not allowed by the regulations. Site coverage is also an instrument which may indirectly control the potential solar gains of the building. Lower site coverage means a bigger distance between buildings, less shadows and therefore more available solar radiation. Site coverage is calculated at the first and third stages of research and not taken into consideration at the stage of building optimization due to the significant increase in the complexity of calculation.

3.2.3 Potential energy losses

Surface-to-volume ratio is a parameter which is related to the potential energy losses of the buildings. In the present study, this parameter is calculated as the relation between the sum of all the surfaces of the walls and roofs of the buildings, to the total sum of all the building volumes. Higher surface-to-volume ratio also means higher energy losses. Lower energy losses are achieved by the reduction of the exposed surface of the built units or by the increase of building volumes. This parameter is crucial for understanding of the energy efficiency. Therefore, it is calculated for all the three stages of research. In the case of the evaluation of morphological properties of perimeter blocks of Prague, this parameter becomes very important since real buildings with a complex geometry are observed.

3.2.4 Potential energy gains

Potential energy gains are evaluated with the use of computer simulation programs. The incident solar radiation per year is calculated using the Autodesk Ecotect Analysis and an evaluation is conducted for the 60 urban patterns generated and for the examples of Prague urban patterns. The objective of the study is to find the dimensions of the built units of the urban patterns with the highest energy gains and to test the real examples using the weather conditions of Prague.

3.2.5 Natural ventilation

The starting point of the analysis is that wind pressure on the facades creates thermal energy variation through air leaking. That creates the precondition for considering wind pressure and wind speed along the facade as an agent which contributes to thermal energy variation. Based on the data analysis, the average wind speed for Prague is 5 meters per second. The 60 generated patterns are analyzed using Autodesk Flow Design simulation software. Differences in wind pressure could be observed in the facades at the outer edge of different built forms. The program generates maps of wind pressure measured from various colors ranging from red to green, demonstrating the change of wind speed. Maps of the 60 generated urban patterns provide an idea of the wind flow where the accelerations or wind exposures as well as wind sheltering can be indicated.

3.3 Generated models as a case study

The study is based on the initial development of the six parametric models such as square-based house or tower, slab block and perimeter block. The three models 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 height of one floor is accepted to be 3m. The algorithm was designed in such 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 the building and the border of the side (Figure 20). The width of the building is fixed at 14m.

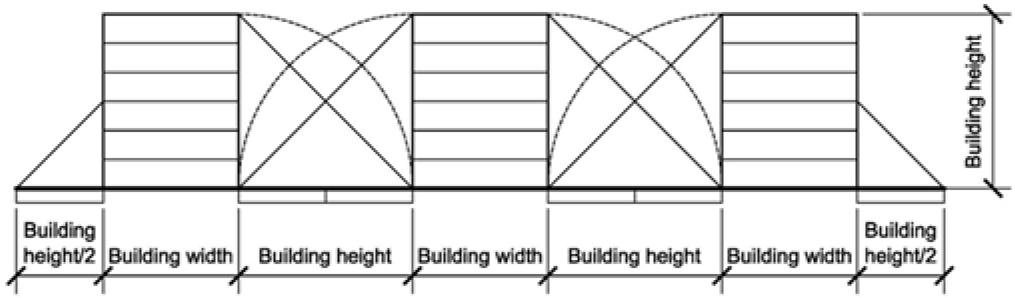


Figure 20 Sample section of the generated model with indication of the distances between buildings

As a result, 60 urban models were generated (Figure 21). For the square-based house (tower) it was assumed to have the fixed sides of the building as 14m. The sample slab block base was assumed to be 14mx50m. The dimensions of the perimeter block were calculated according to the requirement of minimal solar obstruction angle: the side of the block was not less than the sum of a double width of the building and its height. In the circular array, this rule was applied to the smallest side of the trapezoidal block.

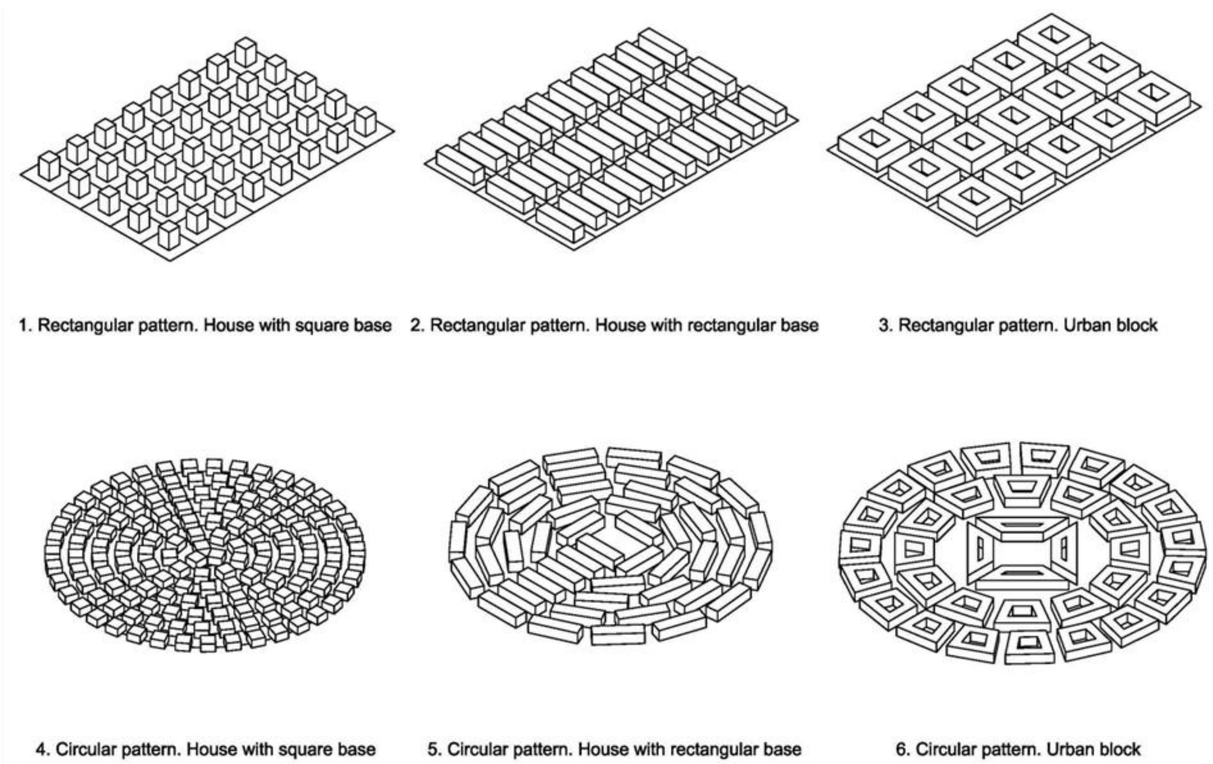


Figure 21 Samples of the six models

The six models even seemingly very abstract, are in fact a product of algorithm of taking into consideration the 45 degree angle of Prague municipal regulation and differentiation of height from 1-10 floors. The first three patterns, which are modeled to a rectangular base and can be found almost in every city. Models 4, 5 and 6 are modeled according to the circular base. As it is shown in Figure 22, there can be found parts of cities, where it resembles real life situation. In addition, analysis of the pattern, which is based on a circular grid, allows neglecting the factor of orientation, which is crucial for the calculation of direct solar access to the built structures.

It is important to notice that some of the urban patterns have a similarity to other urban patterns which can be found in real life situation, such as the districts in the images below. Fragments, of some of the urban patterns can be found in reality. Such are the samples of the Prague districts, which can be found in real life as the examples below. In this regard, partially some of the fragments, of virtual models can resemble for instance the example show in figure. nr. 4 below.

Figure 22 Samples of the Prague districts corresponding with the six parametric urban patterns

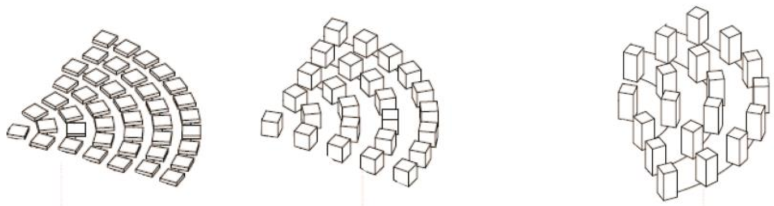


Fig 22.1 The image above shows the defragmentation of the circular based pattern, which shows that this circular pattern is similar with the pattern explained in the 4rth image in the page.

Some of the patterns resemble exactly the urban patterns which can be found in cities and Prague in particular. Other idealized forms, show areas where partially there is some relationship with real models, but not such a direct one. The image below shows the connection of hypothetical models with real life models.

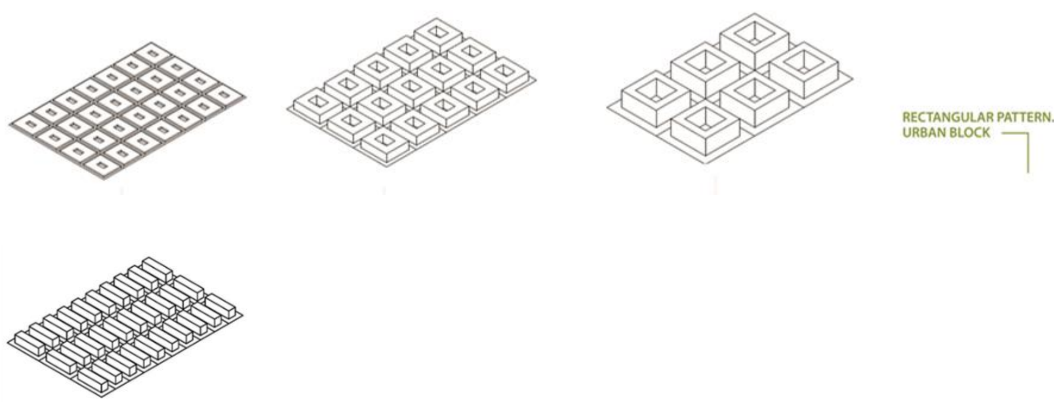


Fig 22.1 b The image shows hypothetical models which have a direct link or resembling with real life models.

Some of these models are quite useful in making an analysis especially related to urban patterns and distances related to the height of each buildings and how the height influences urban density, which is based on the 45 degree rule of Prague, and indeed reflects the changes in urban density with the increase of building height from 1-10 floors.

The models that are represented in the circular patterns in fact are not susceptible to the cardinal points. The hypothetical models have always a North-South orientation. The Prague patterns have a casual orientation. This is due to the fact that it is impossible to calculate the cardinal points for each of the patterns. Nevertheless the causality also shows the actual orientation in the city. In the case of analysis of existing cities it is important to analyze and understand the city as it is.

Typology and use of the building is taken into account.

Most of the analyzed typologies refer to Housing typologies. That is evident also by a quick analysis of Prague, where most of areas are housing, except for the historical areas, the castle, and large shopping malls. A zoning map of Prague is still missing.

In general in the housing areas can be seen in the section that the ground floor is usually offered for shops or restaurant, offices but most of upper floors are residential. Office buildings in Prague are not very often found, except for specially designated areas.

The office buildings operate with a different shift in time. South facing facades are always pleasant. The temperatures of Prague during the daytime are higher than during the night. That is true for most of continental climates. In this regard, the surface to volume ratio should have a certain lower role than in the case of housing. Minimal surface to volume ratio for a northern climate is essential, in the housing. Meanwhile for day-operating offices the most important is natural light and ventilation. The limits towards the extremes are always valid. During January and February there can be seen a 7-10 Celsius difference between night and day temperatures. During summer time the average day temperatures are high. That makes ventilation and cooling more important than heating. In this regard indeed, intelligent façades should prevail and surface to volume ratio should have a trend towards the average. Further studies should be conducted precisely analyze and understand this shift.

The study focuses only on possibilities for heating and cooling in regard to passive heating or cooling related to Urban Morphology. Because the study focuses mostly in the continental type of climate such as that of Prague, the content of the findings of the study relate more on the possibilities of heating gains, and energy saving through different types of urban morphology. The study does not take into consideration, issues such as domestic hot water, lighting or ventilation in the sense of windows or openings in the facade.

For every pattern, the following data was collected:

- Building density – ratio between the total habitable floor-surface of all buildings and the site area
- Site coverage – ratio between the sum of all footprints of the buildings and site area
- Surface-to-volume ratio – ratio between the sum of all surfaces of the buildings and all volumes
- Exposure to solar radiation – indicates the solar radiation per ha of the built surface of the generated urban pattern per year.
- Wind flow - wind pressure and wind speed along the façade indicating possible thermal energy variation

All 60 generations of urban models, the top views and the axonometric views can be seen in Attachment A. The generated wind analysis images can be seen in Attachment B.

3.4 Galapagos Evolutionary Solver as a tool for finding the optimal dimensions of urban patterns

The problem of finding the urban pattern with the optimal combination of the high building density and low surface-to-volume ratio was examined with the use of the Galapagos Evolutionary Solver. The Evolutionary Solver requires variables or genes, which are allowed to change. The Generation Zero of the model is based on the random selection of the variable combinations, but with further generations the preferred genomes are selected. The higher the number of generations that are performed, the higher the likelihood of finding the combination with better fitness (Rutten 2010). During the process of computation, the multiple models were generated in order to find the optimal solution, first independently from the building density and surface-to-volume ratio and secondly, from the combination of the two parameters. For each typology, the two variables or genes defined the number of floors and the shape of the building base.

For the square-based house (tower), the side could be selected within the range between 10 and 20m. The sample model of slab blocks has a fixed width of 14m and the length could vary from 20 to 50m. The side of the perimeter block was between 50 and 200m. In the circular array, this rule was applied to the smallest side of the trapezoidal block. For each case, 25 generations were performed and the top 25% of the best fitting solutions were selected and analyzed.

The evaluation of the urban patterns is based on the following parameters:

- Surface-to-volume ratio – ratio between the sum of all surfaces of the built form and all volumes
- Building density – ratio between the total habitable area of all buildings and the site area
- The fitness value – the coefficient indicating the maximal density and minimal surface-to-volume ratio. (Maximal density means, the effective use of land, in building volumes and minimal surface to volume means less surface exposure.)

3.5 Evaluation of the energy performance of the typical urban structures of Prague

The study is based on the evaluation of the geometrical parameters such as surface-to-volume ratio and site coverage, and computer simulation in order to calculate the solar access of the 64 urban structures located in different districts of Prague, Czech Republic. The urban forms are selected according to their geometrical shape.

The samples of the urban patterns are chosen mainly in correspondence with the six hypothetical models. In addition some specific urban elements typical for the old city of Prague are taken into consideration.

Briefly, the urban patterns can be categorized as follows:

- Rectangular shapes
- Triangular shapes
- Trapezoidal shapes
- Linear shapes
- U-Form Shapes
- L-Form shapes
- (Medieval) Organic shaped blocks

Different types of the European perimeter block, such as square, rectangle, trapezoid, pentagon and triangle are presented by 43 cases. Within the geometrical groups, the samples are subdivided according to the level of openness of the built structure and the estimated level of compactness. The building heights of perimeter blocks range between 3 and 6 floors. The samples with a high site coverage ratio are evaluated as closed perimeter blocks with additional structures built in the courtyard. The narrowness of the structure was estimated according to the ratio between the main dimensions of the courtyard and between the building heights. The 7 irregular organic patterns of the medieval city are 3-4 floors high and subdivided according to the shape and the presence of courtyards. The last group of 14 cases is formed by contemporary urban structures with a simple geometry such as L-shapes, U-shapes, bars and towers. In this group, the height of the building is usually larger and reaches to 8 floors for the typical buildings and 12 floors for the towers.

The footprints of the selected cases are shown on Table 2.

The study proceeded with the extraction of the 3D models from the virtual model of Prague provided by Google Earth. The selected 3D models were elaborated in order to make them appropriate for the calculation of the geometrical properties and solar access using the Autodesk Ecotect simulation.

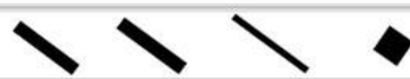
For every sample, the following data was calculated:

- Surface-to-volume ratio – the ratio between the sum of all surfaces of the sample and all volumes.
- Building surface radiation – indicates the solar radiation of the built surface of the selected urban structure per year.
- Site coverage – the ratio between the footprint of the building and the site area

All images of the analyzed Prague patterns can be seen in Attachment C.

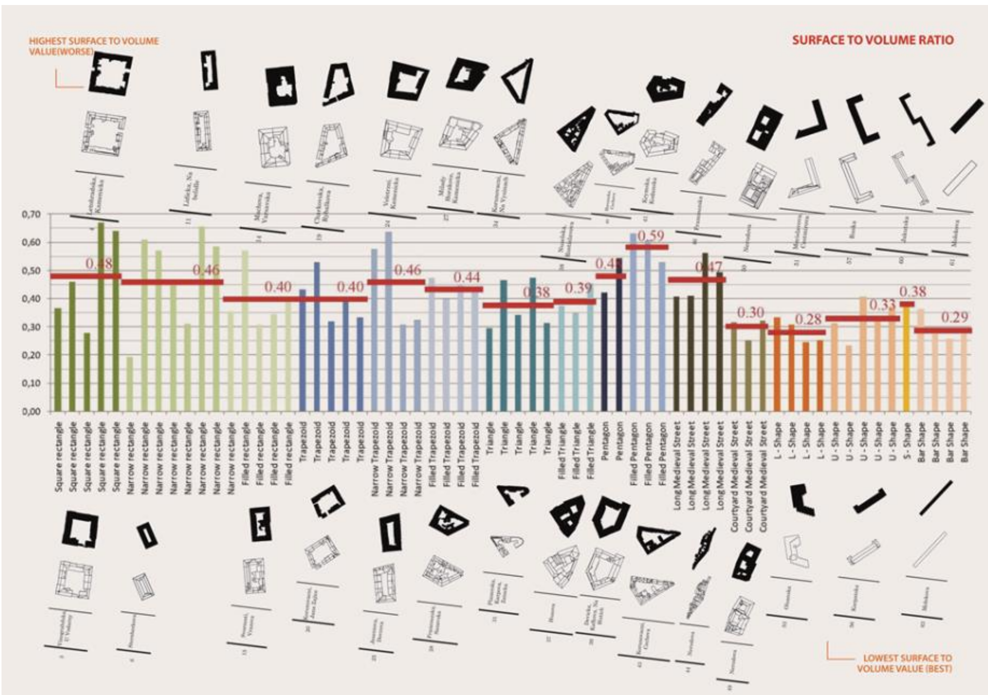
The models in the software calculations are in 1:1 scale. In the table, the models are symbolic representation-footprint, of the real models.

Table 1 **Footprints of the selected samples of urban patterns**

Typology	Footprint
Square Block Typology	
Oblong Rectangle	
Rectangle	
Trapezoid	
Oblong Trapezoid	
Filled Trapezoid	
Triangle	
Filled Triangle	
Pentagon, Filled Pentagon	
Oblong Medieval Block	
Medieval Block with Courtyard	
L - Shape	
U - Shape	
S - Shape	
Bar shaped Block and Tower	

Some of the parameters are in fact calculated in a more precise way, such as the Surface/ Volume ratio which is calculated in square meters/cubic meter. As shown in the image below, there can be seen the parameters of each of the blocks where surface to volume ratio, is analyzed. Likewise that can be advanced in the analysis of the whole city or large parts of fragments of the city. Smart city Amsterdam, shows a further advancement of solar radiation analysis in the city scale.

In this regard each of the parameters can be compared case by case and one by one, since in each of the cases it needs interpretation. For instance, as the graph below shows it is obvious that the square rectangle at U Vodarny with a surface to volume of 0,25, is much more energy efficient than Letobranska Kamenica with a surface to volume ratio of 0.68, and it is indicated a strong difference between the two. As to which extend this ratio is related to the energy consumption bill at the end of the month, that study would require further attention to precisely understand the difference between surface to volume ratio to energy efficiency of the building itself.



Graph. 1- Surface-to-volume ratio and the average value for different samples of built structures, m2/ m3.

The same analysis has to be conducted in each of the parameters, including solar radiation, or wind exposure to the building surface, and unfortunately none of the parameters has a direct link with energy spending diary of each of the neighborhoods. Smart city incentives are already progressing towards such comparison of each of the parameters in a city scale. It is important to emphasize, that these parameters are the ones which are in fact observed to relate to Urban Form.

As mentioned above, still there is the necessary importance to relate each of the parameters to energy spending of the apartments per year. By relating to this link it will be possible, to measure and understand how the relationship of each of the parameters affects energy efficiency. It is difficult to describe in advance whether the parameters are mutually in conflict or not, or whether a certain parameter has a many-fold priority over another one, for instance if surface to volume ratio would mean much more than for instance incident solar radiation. Further studies need to be conducted that show a clear link between energy spending diaries and each of the parameters that are tested in this study. That can be completed with cooperation, with the municipality of Prague and other institution where there is comparison between energy spending and parameters such surface to volume/ratio.

3.6 Software Tools

For this study, it was necessary to select the appropriate software tools which would allow for the construction of the geometry in order to analyze it, to modify it and to exchange the data between the 3D modeling and simulation programs.

Rhinoceros is a basic program in which both the hypothetical generated models and real urban geometries of Prague were elaborated. Rhinoceros is used to create a catalog of hypothetical models of various urban patterns. Grasshopper for Rhino is the main tool for the generation of the parametric models of urban patterns as well as at the same time an instrument of analysis. Simple Grasshopper definitions allowed the evaluation of geometrical properties of models such as surface, volume, footprint area etc. Optimization of the physical dimensions of the built units was conducted with the use of the Galapagos for Grasshopper plug-in.

Collecting the data of Prague 3D examples from Google Earth is one of the main advantages of the study. It results in a detailed catalog of Prague 3D typologies which include parameters of height, width, and shape in real scale format. Transferring information from Google 3D Map to Rhinoceros is possible with the use of GLIntercept and OGLE plug-ins.
Solar radiation simulation is tested for the generated models with Autodesk Ecotect Analysis and the wind flow with Autodesk Flow Design.

The software used during the research can be divided into five categories.

3.6.1 Programs for 3D Modeling – Rhinoceros 5.0

Rhino 5 for Windows is design modeling software. It allows the user to produce highly complicated shapes and to create, edit, document, analyze, and translate curves, surfaces, polygon meshes and solids (McNeel, 2016). Rhino has a variety of plug-ins which can be used for advanced 3D modeling, rendering, animation, parametric modeling, simulation and analysis. The software is used not only in architecture, but also in the design of objects and jewelry, mechanical design, prototyping, reverse engineering, marine design, 3D printing and other applications.

The program was used to create large 3D models of urban patterns and further to produce the 2D drawings of plans and axonometric views such as the ones which are shown in Attachment A and Figure 19. The example of the 3D model of urban pattern which is processed in Rhino, is given in Figure 23. Further, the program showed high compatibility with models of urban patterns taken from Google Earth.

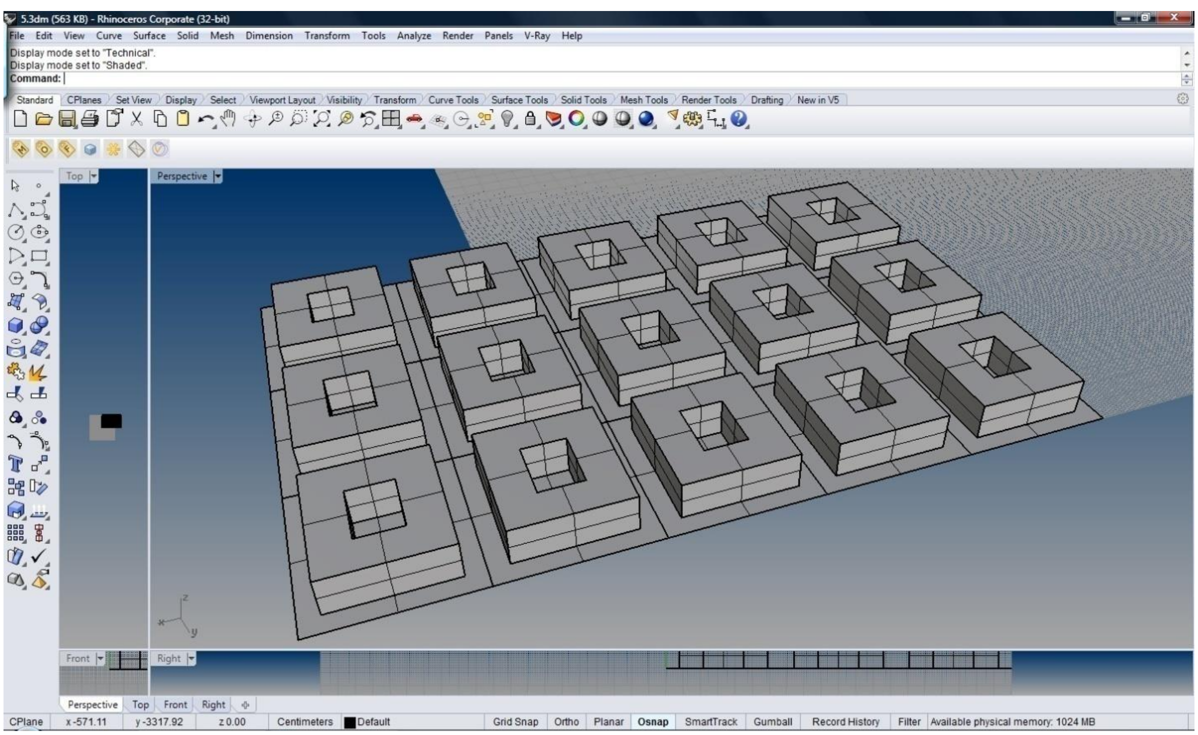


Figure 23 Sample 3D model of urban pattern

3.6.2 Programs for the extraction of city models – Google Earth, Gl intercept and OGLE

Google Earth is free software, which is based on 3D maps. It contains a large collection of the models of existing buildings, which are positioned on the aerial photographs of land. The first city which was shown in 3D was Hamburg in 2007. Further on, with the expansion of technology large3D models have been developed for most of the big cities. The 3D models of cities include the terrain, detailed models of the buildings covered by photorealistic textures, trees and the engineering structures. Google Earth allows everyone to contribute to the process of the creation of the large city models. Users can construct the building model at the real site with the use of real textures via Google Building Maker. The prepared models are stored in 3D Warehouse and included further into Google Earth (GoogleEarth, 2014). Each object, therefore, is scaled and the real dimensions of it can be extracted. The large city models are used by architects for the positioning of their projects into the actual context with further rendering and visualization. The StreetView of Prague and of its 3D models was released by Google in 2009. (Mellen, 2009) The sample view of the GoogleEarth3D model of Vinohrady district is shown in Figure 24.

Figure 24 A screenshot of the GoogleEarth3D model of Vinohrady district

The building models are available for downloading in 3D Warehouse one by one, but for the task of this study it was not enough since the whole streets with the preserved distances between buildings were needed. The solution was found with the use of the two plug-ins GLIntercept and OGLE (Belcher, 2009). GLIntercept is an OpenGL function call interceptor for Windows that will intercept and log all OpenGL calls (Trebilco, 2003)**.** A combination of them allows the user to export the whole 3D city from Google Earth and elaborate on it further in Rhinoceros. The whole method was developed by Daniel Belcher in 2009 and further elaborated upon by Brian Horning in 2013 (Horning, 2013)**.** The exported models don't preserve textures which are not important for this study that evaluates only the geometrical properties. The result of the export of the group of Prague buildings from Google Earth to Rhino is given in Figure 25.

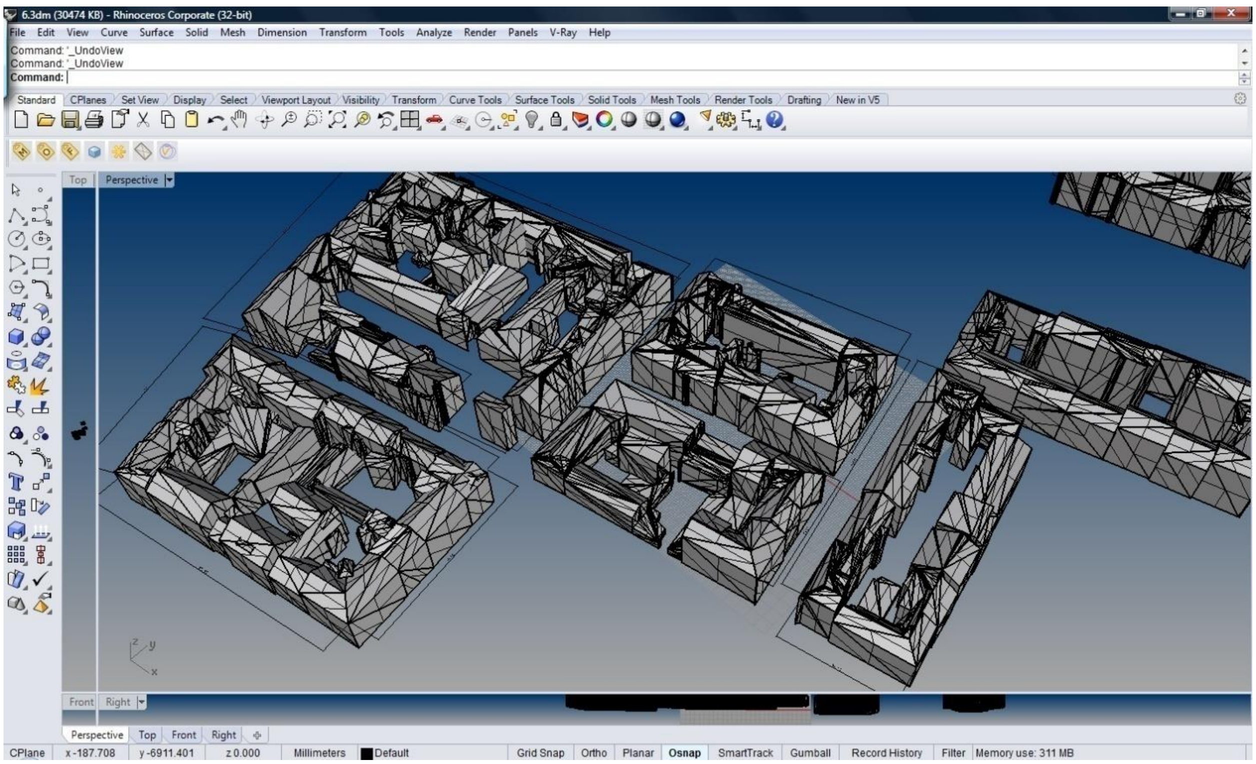


Figure 25 Group of Prague buildings exported from Google Earth to Rhino using GLIntercept and OGLE plug-ins

3.6.3 Plug-in for parametric modeling – Grasshopper for Rhino

Grasshopper is a graphical algorithm editor, which is a plug-in for Rhinoceros using its 3D modeling tools. Grasshopper allows the creation of adaptable parametric models based on the defined combination of rules or parameters. It is relatively easy to operate and doesn’t need any knowledge of programming or scripting (Davidson, 2013). In this study Grasshopper replaced the scripting techniques in order to generate, control and optimize urban morphology according to the set parameters.

The 6 patterns including the tower building pattern, the slab block and the perimeter block applied to the rectangular and circular sites were created using the defined consequence between width, length, height and distance between buildings and the shape of the buildings. A sample screenshot of the process of the development of the algorithm of one of the patterns using Grasshopper for Rhino is shown in Figure 26.

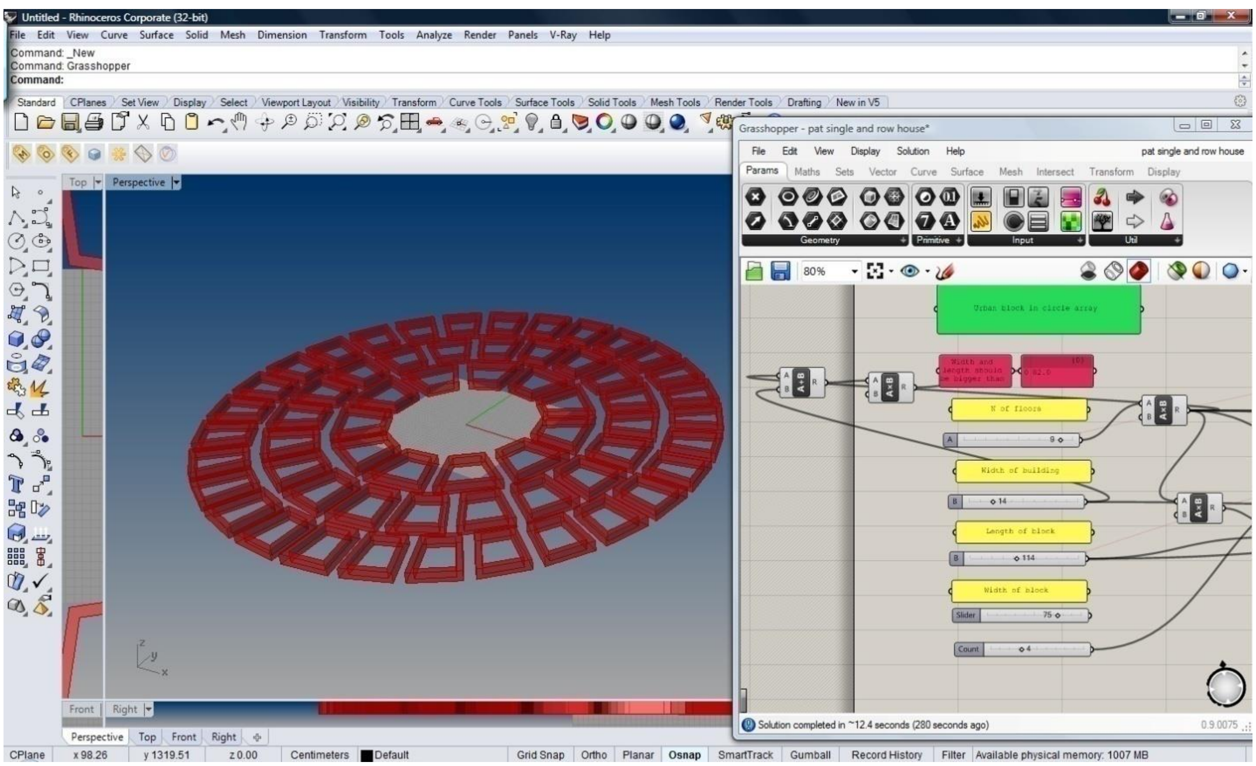


Figure 26 Screenshot of the Grasshopper definition and the 3D model of an urban pattern

The Grasshopper definitions of all six patterns are presented in Attachment D. The resulting 60 patterns were “baked” a process done in Grasshopper for further analysis in Rhino.

In the research, Grasshopper is used not only for the algorithmic generation of patterns, but also for the calculation of the geometrical properties of the built units. Simple Grasshopper definition (Figure 27) allows for the display of such parameters as the number of the buildings in the pattern, footprint area, built area, building volume and building surface, which are used for the further analysis.

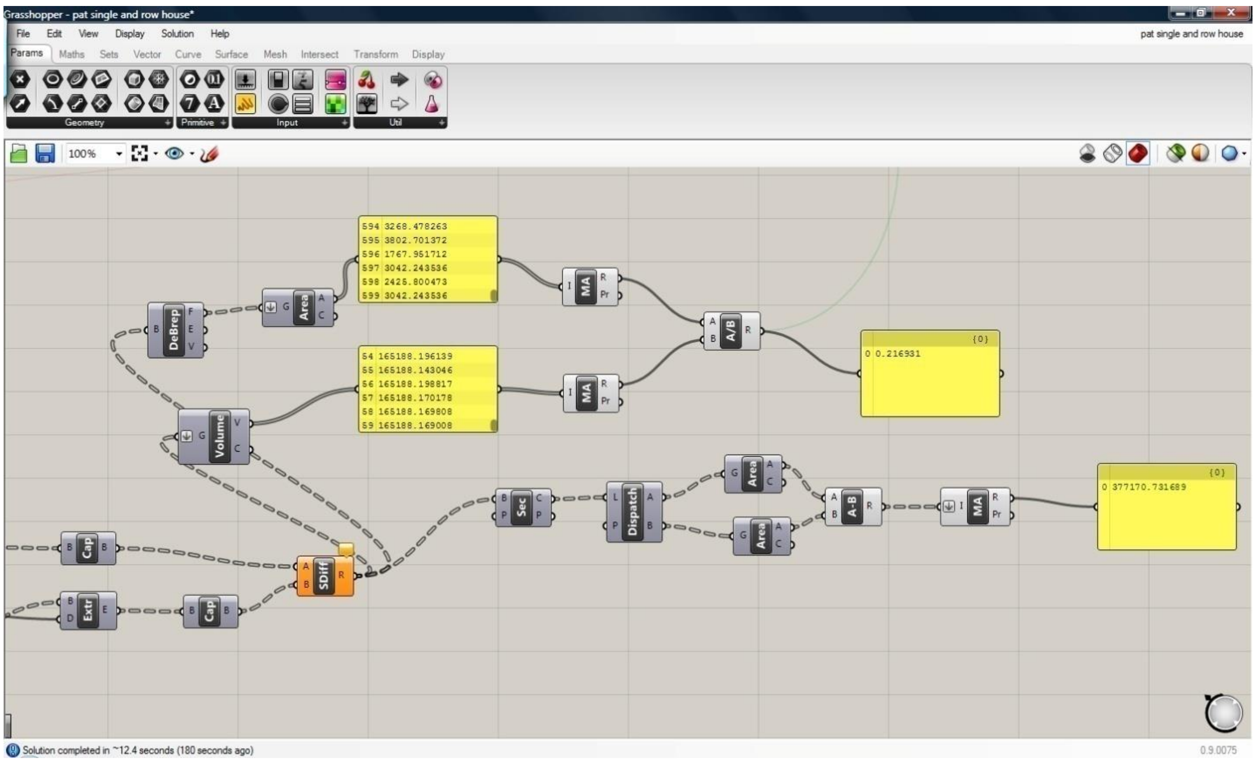


Figure 27 Part of Grasshopper definition indicating the calculation of building volume, building surface, surface-to-volume ratio and the built area

3.6.4 Plug-in based on the use of genetic algorithms – Galapagos for Grasshopper

The Galapagos evolutionary solver is a plug-in for Grasshopper which is based on the use of genetic algorithms. It applies the principles of genetics, which are used in nature in order to find an optimal solution of a problem (Perez, 2014). Evolutionary computing started in the seventies, but up to now it is mostly used by programmers. After the addition of the Galapagos plug-in into Grasshopper by David Rutten, the situation changed, and the evolutionary solver started to be applicable in an easier way. Evolutionary algorithms take time since during the process of optimization the multiple iterations are completed and compared. The solution, which is offered at the end, is not guaranteed to be the best since there are millions of possible combinations of parameters. But after the appropriate large number of combinations, the final result may be acceptable (Rutten, 2010). The evolutionary solver may tackle a large variety of problems. For the reduction of the time of calculation in the case of urban pattern, only two parameters are selected to be defined. The algorithm tends to find the solution with the best fitness value, which is composed of the maximal density and minimal surface-to-volume ratio. The flexible parameters of the urban patters are the building dimensions – length, width and height, which are the objects of research at this stage. During the process of optimization (Figure 28), every step is recorded which allows the user to document and model not only the best solution, but also the top 25% of generations.

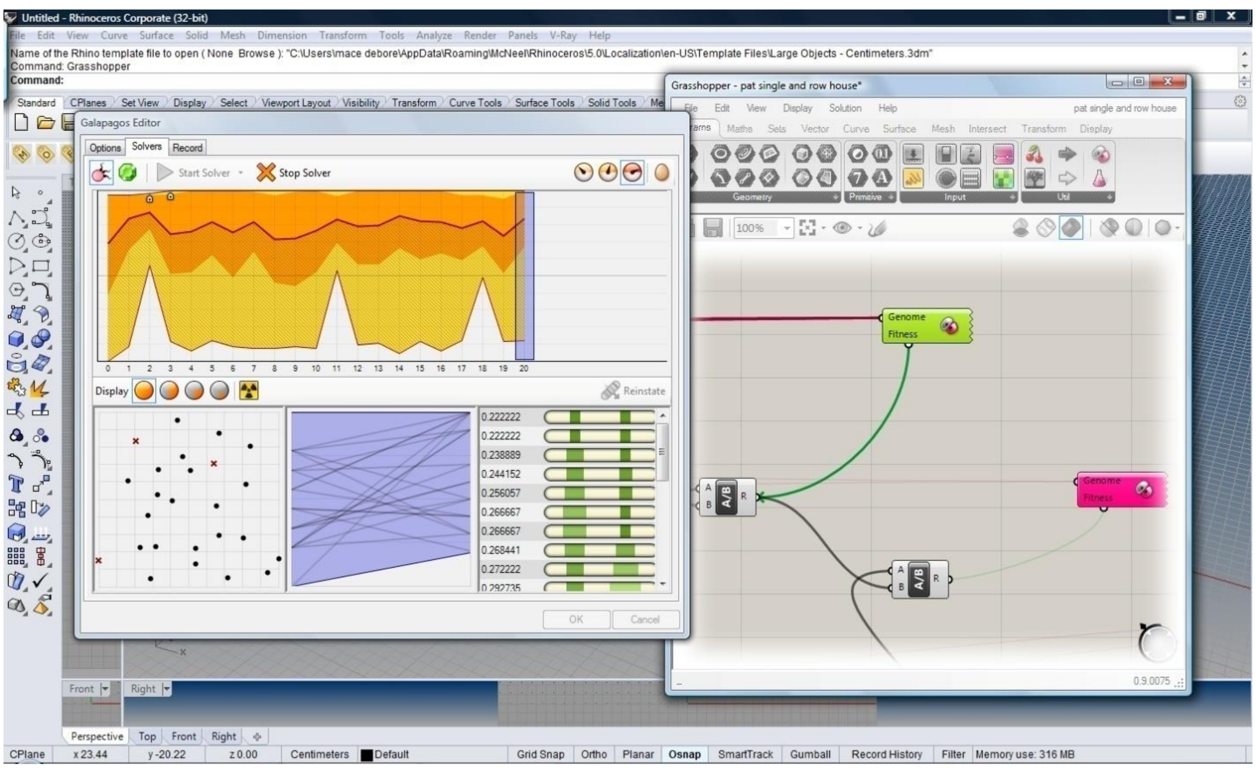


Figure 28 Sample screenshot of Galapagos Editor during the process of a search for the best fitness value for the urban pattern

3.6.5 Simulation programs – Autodesk Ecotect Analysis and Autodesk Flow Design

Autodesk Ecotect Analysis2011 is a tool which displays the environmental performance of the building model using computer simulation. In the study, Ecotect is used in building simulation to calculate solar radiation exposure (Figure 29). The annual energy gains are calculated for the unit of built surface. For the generated models as well as for the real examples, the weather conditions are selected for Prague. A comparison between the energy gains of different urban patterns is one of the parameters which helps to define the most efficient one.

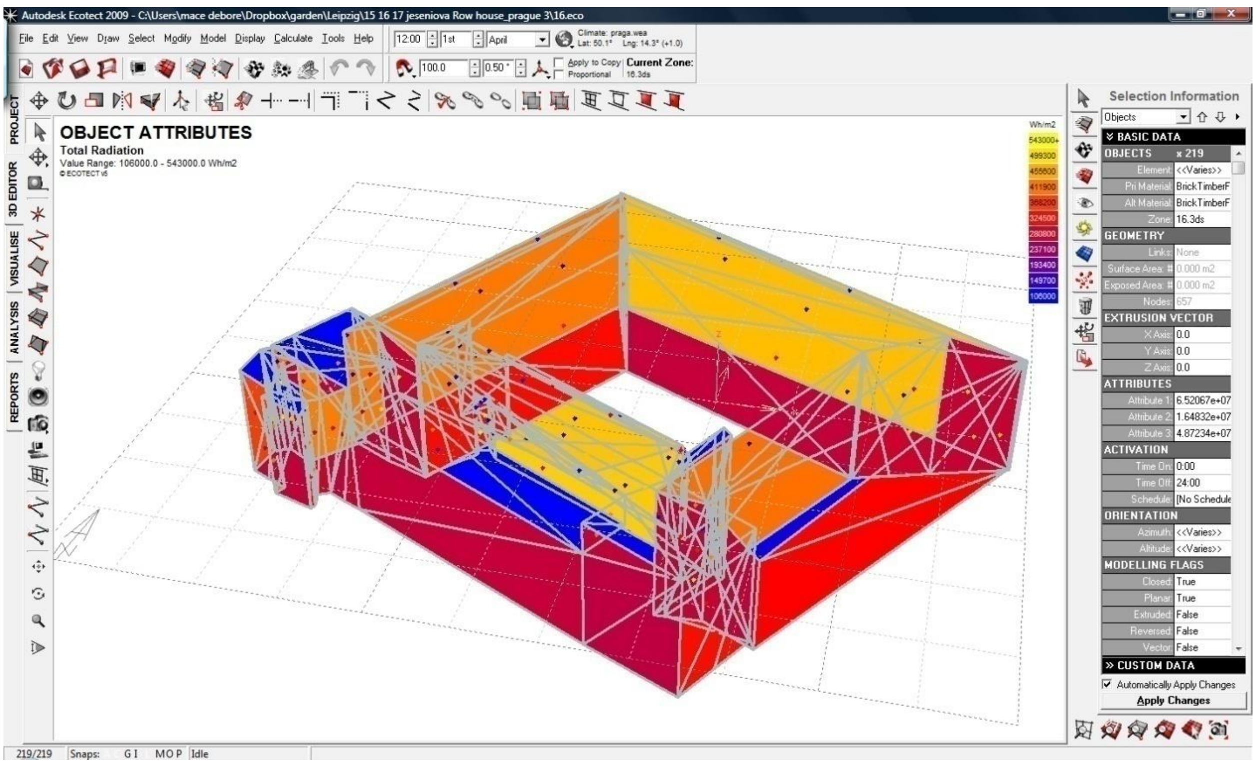


Figure 29 Calculation of the solar radiation of the unit of urban patterns using Autodesk Ecotect Analysis

Autodesk Flow Design is a wind tunnel simulator, which is used in the study for visualizing the airflow around the buildings of generated urban patterns. The program may identify the areas of the wind acceleration (red color) or the still air areas (dark blue color) within the urban form (Autodesk, 2015). For the simulation, the Rhinoceros models are resaved and exported into Flow Design. The wind speed in the virtual wind tunnel is accepted to be the average speed for Prague.

A screenshot of the wind simulation for the sample urban pattern is given in Figure 30. The results of the wind simulation for 60 generated urban patterns are presented in Attachment B.

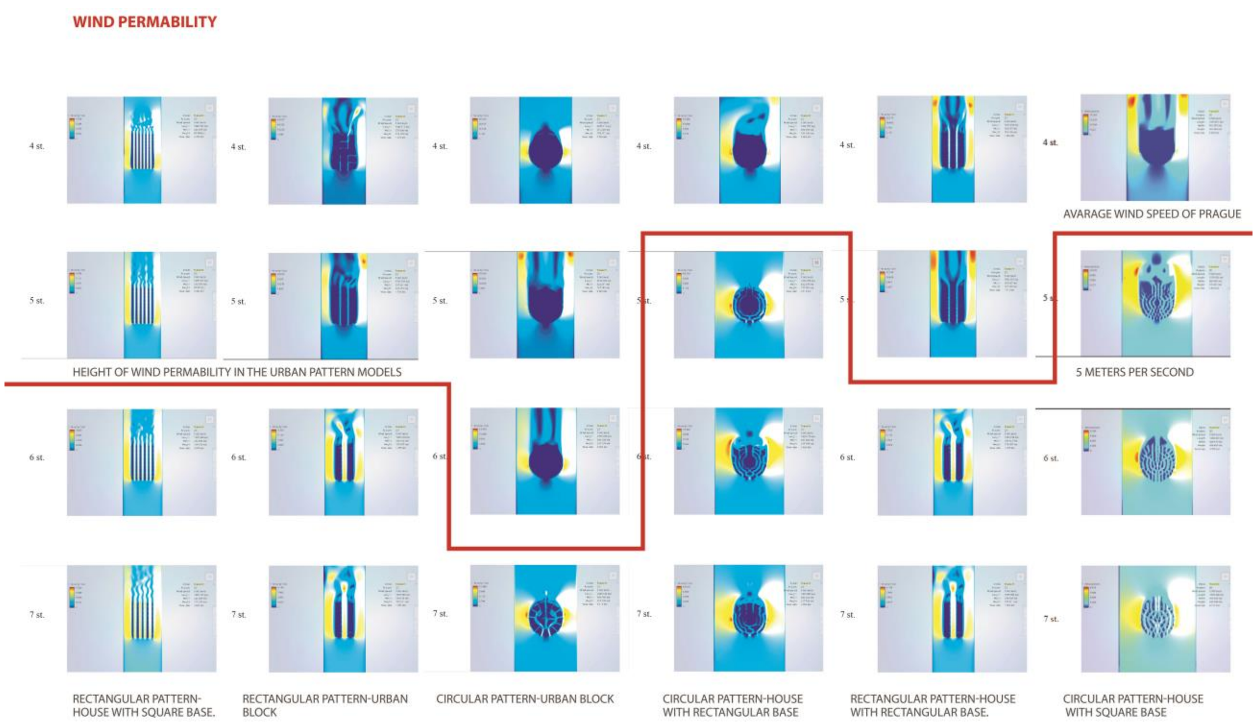


Figure 30 Wind simulation for the sample urban pattern using Autodesk Flow Design

The Urban patterns are tested according to the Geographical Position of Prague. Thus Solar Radiation is tested with Ecoteck analysis for precisely the Geographical altitude of Prague. Also the wind speed of Prague of 5 meters per second in used with the program "AutoCAD Wind Flow Analysis" in order to analyze the wind flow. In this regard can be said that these two parameters from Prague location are taken into consideration. Since climatology is a very complex issue which involves many parameters, it is more adequate to specifically mentioned that it is taken into consideration only the Geographical Position of Prague for Ecoteck Solar energy simulation and the wind speed of Prague of 5 meters per second. Other issues are not the subject of this thesis.

The wind design simulation shows the permeability of the wind in each of the urban patterns. It is evident that below 4 floors the wind flow has obstacles with some wind blocking but with increase of the floor, with more distance between the buildings, the more the distance between the buildings increases. It is evident that after the 4rth floor the permeability of the build form increases and so does the wind-speed. The more permeable the structure as can be seen in the graph, the more the color of the wind-performance changes towards, light blue, yellow or red, which is the color which shows the increase of the wind-speed in the 4-5-6-7 floor. As is can be seen from the graph above, the permeability of the patterns differs and for instance: the circular pattern-perimetral block is less permeable. Meanwhile, there are other patterns such as Circular Pattern-house with square base which is in fact more compact and shows less permeability of the build form. Another larger version of the diagram of Figure 30, is attached in the Appendix.

On the other hand can be seen the fraction and the wind pressure which can be seen in the facades of the build form, on the external perimeter on all cases.

Such simulations help understand the importance of street trees and other wind-blockers in the external and surrounding parts of the neighborhood blocks, which create the possibility for more wind-sheltering.

On the other hand, there is the possibility to choose between various typologies. For instance the courtyard typology obviously creates more wind-sheltering effect. The other possibility is the creation of some means, and different tools for creating wind-blocking and wind divisions in each of the sites which creates the possibility for lowering the wind-speed.

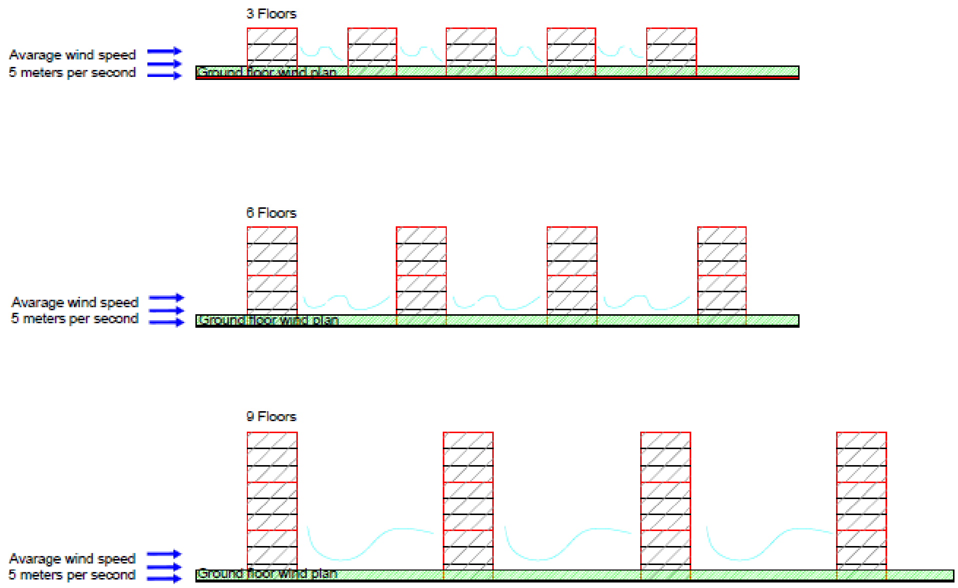


Fig-30.1 Wind speed of Prague, projected in the section with 3, 6 and 9 Floor buildings.

The section shows the increase of distance with the 45 degree rule of Prague, for each of the buildings, and shows the obvious difference between the internal spaces between the buildings in the case of the increase of wind speed. Obviously very wide distances may need greenery and other barriers to mitigate the wind speed which becomes stronger with the increase of building height. Also it is obvious that certain typologies allow for more protection for the wind shelter than other. Depending on the patterns it can be distinguished the following typologies:

Circular pattern, perimetral block, is showing the most “resistance” towards wind performance, meanwhile the circular block with rectangular pattern shows the most opened typology with wind permeability visible already in the 4rth floor.

Note: the plan of the wind is calculated from the ground floor, in the plan showed with green color in the sketch. With the increase in height the wind vortex gains speed.

Another aspect is wind accelerations, which are more obvious in the yellow and red color of the neighborhood block, more visible in the perimetral part of the neighborhood. The acceleration speed varies and sometimes, overcomes the average of 5 meters per second of the wind of Prague.

As can be seen from the graph, there are some hotspots where the wind acceleration becomes more obvious, and the speed increases steadily. On the other hand, there could be the possibility to find out depending on the morphology, the hotspots, of different areas. These areas with more hotspots of wind, show the possibility for creating small interventions which would mitigate the wind and create the possibility for wind-shelter.

The study does not include, balconies, or facade windbreakers but considers the volumes as a whole. Simulations show the possibility to visualize in a small scale, but with strong computers also in the city scale wind performance for various spaces in Prague.

Some principles that affect wind flow.

-Buildings shape

The location of sharp edges relative to each other affects the vortex structures at the wake areas where the wind. This can be seen in the perimeter around the building blocks as in the image is specified with more red or dark color. Wind flow goes over or above the buildings. Building roof shape profiles can determine whether wind flow can enter the spaces between the buildings. As can be seen from the image below, the vortex of wind achieve speeds which are above 8 meters per second. Such an issue could be mitigated by using trees and a park around the buildings in order to mitigate wind speed, but at the same that do not act as wind breaker, which creates accelerated vortex, but through trees allows for smooth ventilation. This is especially true for colder climates. Traditional European cities in fact resembles such structure, especially the houses made of stone and build in the hill tops.

On the other hand in the south and Mediterranean countries, ventilation is encouraged and will improve the possibility to for more ventilation and thermal energy exchange.

It is recommended that in such case there will be some openings in the build structure which would allow for more ventilation.

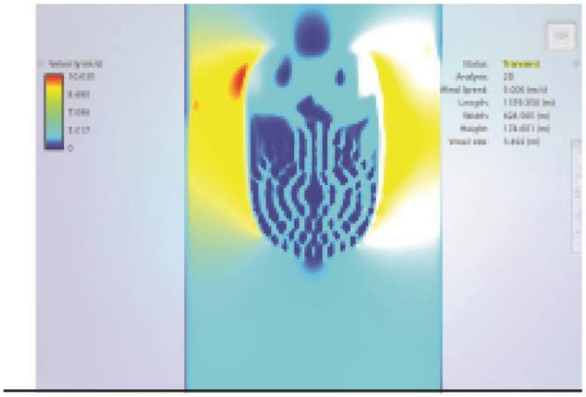


Fig-30.2 Wind speed of Prague, projected in the point block-circular grid pattern

-Geometry: Wind flow will increase in speed when the canyons are longer. This means that, as a general rule, we should never build long slabs that shield wind from entering, but creating openings in the buildings will mitigate the effect of wind vortexes which create perturbation. The geometry of the buildings that allows for openings is known both in the slab buildings of modernist period, but also in the postmodernist period. The courtyards and the perimetral block, provides for wind sheltering in most of the cases. The enlargement of the courtyard increases the chance for providing wind perturbation. The increase of the wind speed inside large inner courtyards can be mitigated by positioning trees inside the courtyard.

4 st.

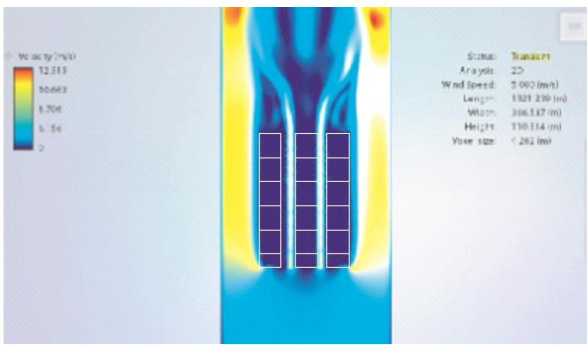


Fig-30.3 Wind speed of Prague, projected in the wind speed of Prague for the Slab Block

-The image shows the wind flow and the colors which show the with white color, wind channels in between the buildings which have a speed of up to 8 meters per second, and as well wind perturbations in the corners, of the buildings, which show the speed of more than 10 meters per second. The corridors in the sides of the buildings could be protected, with trees and vegetations, on the sides of the buildings.

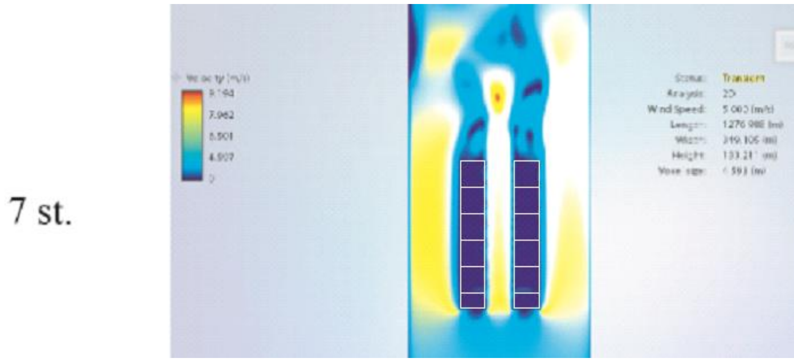


Fig-30.4 Wind speed of Prague projected in the wind speed of Prague for the Slab Block, 7 floors high

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The Perimetral block for the 7th floor buildings show the perturbations in the building structures, and which, increases the perturbations in space between the buildings, and which through the yellow color shows the increased vortex and speed of the wind. The 7 floor high buildings in fact, show the necessity for mitigating the wind activity, even in the ground floor.

In the image it can be seen that the orientation of the buildings site really matters, and it is visible the wind-shadowing on the rear side of the longitude, buildings.

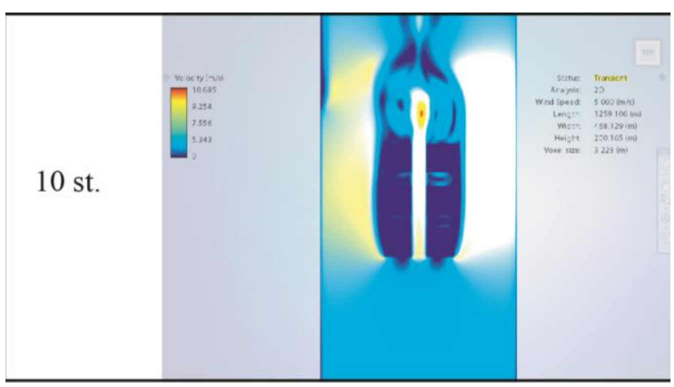

Fig-30.5 Wind speed of Prague projected in the wind speed of Prague for the Slab Block-10 floors.

The inner courtyard is still sheltered in the ground floor, but the speed of wind in the courtyard increases with increasing in height. The image shows that the inner courtyards could be more sheltered in the inside, in the ground floor, which allows a pleasant stay. Trees which grow from the ground towards height, in fact create the possibility for sheltering the wind perturbations on the windows of the inner courtyards.

Orientation: Buildings need to be oriented to allow the predominant wind directions to flow through the entire city. This is true especially for the Mediterranean countries.

Buildings need to be oriented to allow for predominant wind directions to flow through the entire cities. The case study of Barcelona describes the possibilities, for the wind flow through the city. In the case that there is more wind-flow through the city, depending on the climate, the layout of the city could be changed and adapted accordingly.

Site Coverage and façade areas: Generally, the higher the site coverage, the more obstacles of facades blocking the predominant wind directions. This will slow and block wind from flowing through the city, especially relevant for colder climates, where using greenery to block to minimize the wind effect could be very much relevant.

3.7 Summary: energy efficiency in the urban scale and other aspects.

One of the ways to see a direct implication of the research into practice is an energy scan of the city which would reveal the profound difference between different areas of the city and would raise some concern about the importance of urban morphologies in calculating energy efficiency. Height, dimensions, and distances are some of the parameters that could differentiate urban patterns. As it is seen from the previous researches, these simple questions will have no definite answer. Although people would prefer to live according to their lifestyles, it is quite important to know what city areas are more energy efficient.

It is possible to examine the criteria of energy efficiency being applied one by one to the single building or the group of the units of urban pattern in order to find the tendencies which may result in an optimal solution.

This study does not imagine it will build a utopian low-emission ideal city, but it is still possible at least to keep in consideration certain criteria.

Topologically speaking, Prague is combined by many examples of different urban patterns and the idea is to survey as many shapes as possible.

The programs could be adjusted to respond to the necessities of programming future urban schemes. Algorithms which include the information for dimensions of optimized urban patterns related to solar radiation and wind performance, optimized density models, efficient transportation schemes and others could possibly provide an effective tool for future city planning or urban renewal. Further, even if not used for building new cities, the analysis of existing cities is also possible so certain mapping of optimization could be completed according to the selected criteria.

The typology of use is mostly housing. A study needs to be conducted that defines per each urban pattern taken into account the typology of use that is actually in use. A visual survey in the city of Prague shows that most of buildings are housing and have a mix use functionality only in the ground floor.

Theory of Scale of build environment shows the difference, between different fragments in the city, in different city scales, district level, neighborhood level, pattern level or urban block level.

The hypothetical models are on the Urban Pattern level. (see also the scales of build environment at fig. 2 Urban Pattern, adapted from Habraken, page 27). In this sense the patterns preserve the same quality and information independently of the scale. It is true that the urban patterns are designated for an area which is between 200x300 meters, but in fact the same pattern could be applied for areas which are much bigger or to another extend smaller. In this regard the application of urban patterns could be said that applies in the urban pattern level. The pattern contains all the information that is necessary for applying it to larger scales.

Some of the patterns are on the neighborhood level or urban block level. This is the case for Urban Patterns from Prague. Some of the patterns from Prague could be applied in the same way, such as hypothetical patterns, such as the case of Vinohradska and it is the same as the perimetral block pattern. Other patterns include sketchier and simple patterns which are positioned occasionally in the city. Although some of these patterns are sketchier, they also include the possibility to be analyzed in the level of patterns or locality, and sometimes just urban block. The urban Block can have triangular, rectangular, pentagonal, or other shapes. Other patterns include somehow more informal medieval urban shapes which show nothing really replicable, but might be analyzed in the level of locality.

For the parameters of L-Shape, U-Shape, Bar-Shape, the foot-print is selected from the exact footprint of the shape of the building, which means the very shape of the building itself, and it is therefore for these models specifically 100%.

While analyzing the relationship of the abstract models with space, it is obvious that some of the models have been for a long time in the analysis of urban patterns. The Perimetral Block, for instance with its courtyard is one of the typologies which is the most in use, and as a typology it is known to have a very high quality of semi-private space. Also is one of the most spread typologies of urban patterns. On the other hand the circular pattern also can offer some quality of urban space especially in large metropolis where sometimes ring-roads correspond to the actual circular patterns even though partially.

Although this thesis does not reflect on the quality of urban space, it is obvious that working with density and working on the aspects of building height, influences the actual quality of the urban space. On the other hand it is possible to see that the maximum quality of urban space is achieved between floors 4-7, in terms of density, open space and build form and inner courtyards or front-yards. It is obvious that for courtyards which are too large, such as for perimetral block-urban pattern level.

The Medieval space structures show some difficulty and problems in adapting to new public space usage in the city scale.

Typologies of patterns, which in fact differ very much, and another study could be conducted to put in evidence the importance of the quality of urban space for each of the specific typologies.

The Urban Forms, with courtyard certainly have a design which allows for an inner courtyard which positively reflects upon the quality of semi-public or public space, and to the perimetral division of streets. Such a city division offers maximal quality and also protection from noise and pollution. On the other side row houses and simple shapes allow for creation of distances and good solar exposure.

Also row houses allow for a good space in between which is quite relevant for houses and the layout composition creates the space in between in order to have a green and open space area. Such a space, in the case that is included greenery, trees and other plantation, offers a high quality standard for green areas and this typology of housing is always preferable.

CHAPTER 4

ANALYSIS OF THE GENERATED URBAN PATTERNS

4.1 Analysis of energy efficiency of 60 generated urban patterns

Provision of the compact urban pattern with a 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 occupancy density either, 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 (Cheng, 2009). 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 an application of different urban patterns which may have a different ratio between site coverage and building height. There is a common tendency of towards reduction of the site coverage, and after certain values also the density with the increase of the height of the building due to the need to manage the minimal solar obstruction angle (Cheng, 2009). 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 an Urban Heat Island (Cheng et al., 2006).

There is a complex relationship between the density, morphological properties of urban patterns and the energy consumption of the city. In the cities with a higher density, the transport network and the ensuing costs may be reduced and the social networks and community interactions may increase (Doherty et al., 2009). Urban structures with a higher density tend to be more energy efficient than the ones with a lower density (Rode et al., 2014). Urban pattern is directly related with the outdoor microclimate as well as with the energy consumption of the buildings from which it is composed. The heating and cooling loads of the building decrease with an increase in building compacity, which means better energy performance for the bigger buildings as compared to the smaller ones and for the building with a simple footprint as compared to the complicated ones (Adolphe, 2001). The geometrical property of the building, such as the relation between the surface area and the volume affects its heat loss or gain through the outer walls and roof (Steadman et al., 2009). The structures with a higher urban density and compactness are more economical and require less cost for the organization of the road and supply systems, as well as for the energy demands (Curdes, 2010).

The arrangement of the urban pattern and the shape of its units may affect the amount of solar radiation which is received by the buildings. The increase of the solar exposure may reduce the building's energy demand for heating. There is a correlation between the density of the urban pattern and the solar access which decreases with the increase of the density, but the other factors, such as compactness of the buildings and character of the urban fabric with possible solar exposure may affect it as well (Mani 2012).

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

The detailed top views and axonometric views of the 60 generated urban patterns can be seen in attachment A.

4.1.1 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 is shown in Table 2, different urban patterns demonstrate different trends in the changes in the built density.

Table 2 Building density and the height of built unit for different urban patterns, m^2/ha

№ of floors	Point Block, rectangular grid	Slab block, rectangula r grid	Perimeter block, rectangular grid	Point Block, circular grid	Slab block, circular grid	Perimeter block, circular grid
1	6107	5950	9520	7616	8708	7486
2	9800	10500	16660	11559	14836	13195
3	10192	13650	18144	13275	18707	16766
4	10061	15400	21000	13606	20642	18152
5	9800	17500	24150	12794	20964	21001
6	10584	12600	25536	14088	22577	23039
7	9147	13067	27440	15172	27092	21757
8	9147	13067	27776	13004	24082	23153
9	8232	14700	29736	13546	26125	24293
10	7840	14000	31360	14449	27952	25226

The correlation between building density and the number of floors for different urban patterns is shown in Figure 31. The densest patterns are the rectangular and trapezoidal perimeter blocks and the slab blocks, which are arranged in the circular grid. For these patterns, a growth of the density with an increase of the building height can be seen. The two patterns generated with the use of the square base building are clearly less dense. For these patterns, the density decreases with an increase of the building height. The slab block rectangular array pattern evidences growth up to the 5th floor and with a further increase, the density decreases. This behavior can be explained by the influence of the site borders: for the first five samples three rows of buildings are generated, but for the higher buildings only two rows could fit due to the need to provide an adequate distance between the buildings.

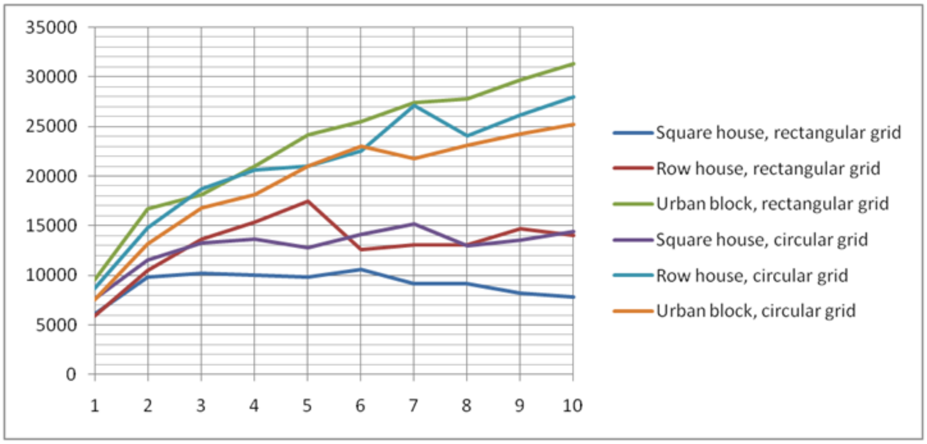

Figure 31 Building density and the number of floors for different urban patterns, m^2/ha.

4.1.2 Number of 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 connection between the height of the built units and the overall number of buildings is shown in Table 4.

Table 3 The height of building and the total number of buildings

№ of floors	Point Block, rectangular grid	Slab block, rectangular grid	Perimeter block, rectangular grid	Point Block, circular grid	Slab block, circular grid	Perimeter block, circular grid
1	187	51	40	253	81	127
2	150	45	35	192	69	92
3	104	39	24	147	58	62
4	77	33	15	113	48	51
5	60	30	15	85	39	35
6	54	18	12	78	35	32
7	40	16	8	72	36	17
8	35	14	6	54	28	16
9	28	14	6	50	27	15
10	24	12	6	48	26	14

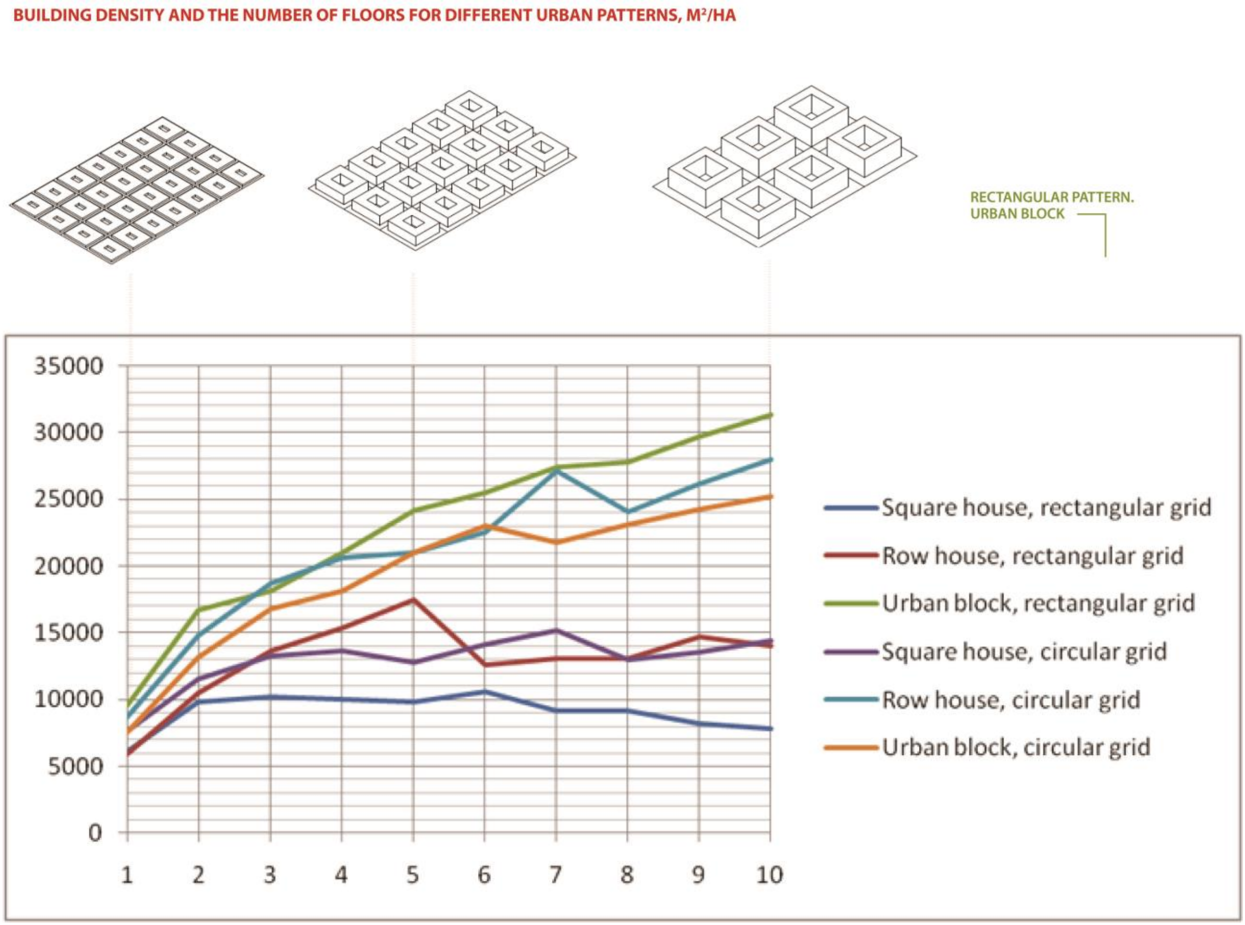

Fig. 31.2. The Graph above shows the differentiation of building density in square meters/ hectare, which shows the differentiation of a square meters per hectare, from different urban typologies. Apparently and consistently the perimetrical block brings the advantage of more square meters/hectare.

The distance between buildings increases with the building height, therefore within the fixed site borders the number of the generated volumes decreases. The relation between the building height and the number of buildings per Ha is presented in Figure 32:

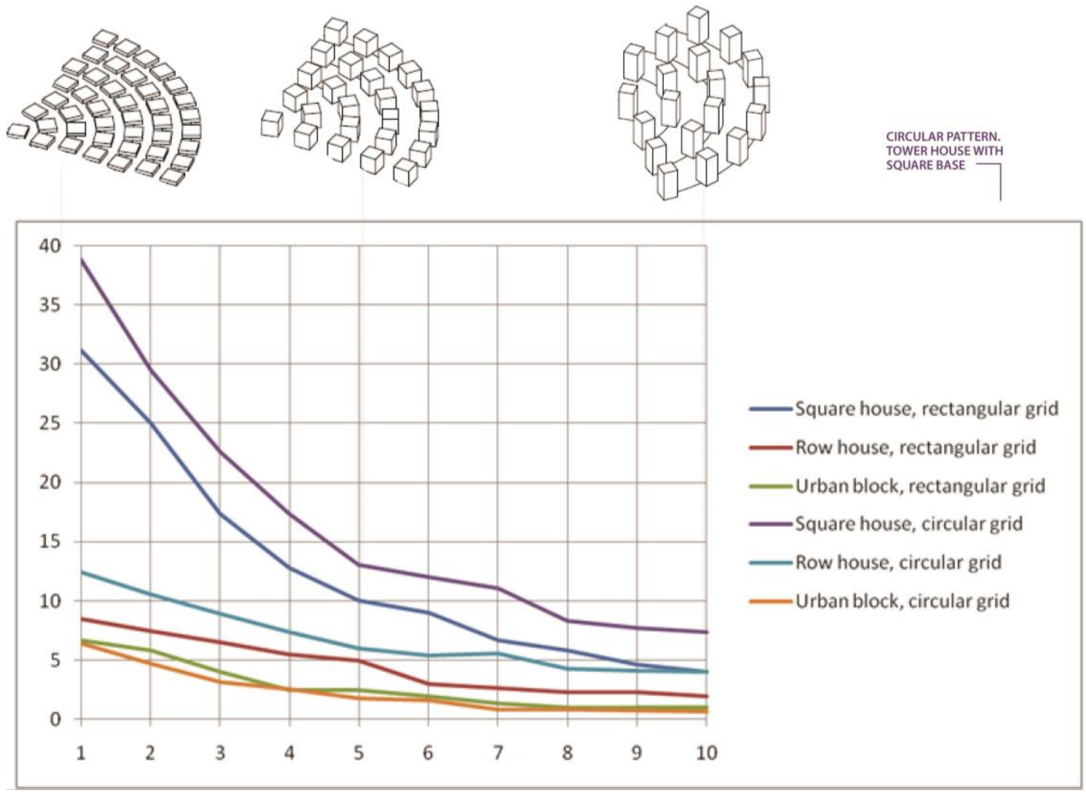

Figure 32 Number of buildings and the number of floors for different urban patterns, unit per ha

According to the graph, it's obvious that the number of buildings, which are in the Circular Grid Pattern, is higher than that of other patterns. Circular pattern, create the possibility for a larger number of buildings and the number of floors for different urban patterns, unit per hectare.

The two urban patterns with the square-base are characterized by the highest number of built units and a significant decrease of the parameter with an increase of the building height. For the models generated by the rectangular and trapezoidal perimeter block, the lowest number of the built structures is evident and the number remains almost constant with a slight decrease. The two slab block patterns demonstrate intermediate results.

4.1.3. 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. As is shown in Table 4, site coverage is lower for all the urban patterns based on the rectangular grid, and higher for the similar circular patterns.

Table 4 The height of the built unit and site coverage for different urban patterns, %

№ of floors	Point Block, rectangular grid	Slab block, rectangular grid	Perimeter block, rectangular grid	Point Block, circular grid	Slab block, circular grid	Perimeter block, circular grid
1	61	60	95	76	87	75
2	49	53	84	58	74	66
3	34	46	60	44	62	56
4	25	39	53	34	52	45
5	20	35	48	26	42	42
6	18	21	43	23	38	38
7	13	19	39	22	39	31
8	11	16	35	16	30	29
9	9	16	33	15	29	27
10	8	14	31	14	28	25

In circular patterns, the center is always left empty due to the specificity of the generation algorithm. The character of spaces between buildings varies with changes in the radius.

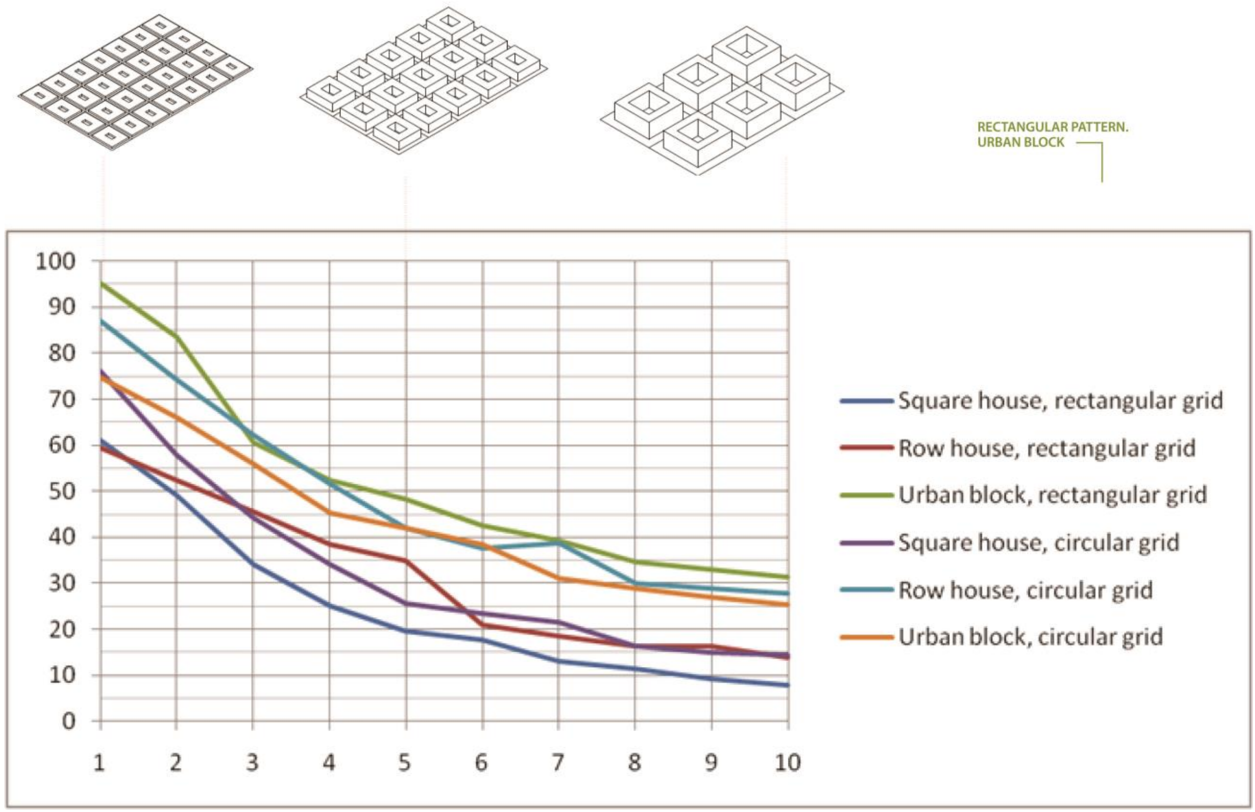

Figure 33 Site coverage and the number of floors for different urban patterns, %

Site coverage ratio, as it is shown in Figure 33, 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 perimeter 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.

4.1.4. Surface-to-volume ratio.

Surface-to-volume ratio is an indicator of the energy performance of the building and it is defined only by its geometrical properties. The relation between the type of urban pattern, height of the built unit and surface-to-volume ratio is given in Table 5.

Table 5 The height of building and the surface-to-volume ratio for different urban patterns

№ of floors	Point Block, rectangular grid	Slab block, rectangular grid	Perimeter block, rectangula r grid	Point Block, circular grid	Slab block, circular grid	Perimeter block, circular grid
1	0.95	0.85	0.71	0.95	0.85	0.81
2	0.62	0.52	0.36	0.62	0.52	0.48
3	0.51	0.41	0.24	0.51	0.41	0.37
4	0.45	0.35	0.18	0.45	0.35	0.31
5	0.42	0.32	0.14	0.42	0.32	0.28
6	0.40	0.29	0.12	0.40	0.29	0.25
7	0.38	0.28	0.10	0.38	0.28	0.24
8	0.37	0.27	0.09	0.37	0.27	0.23
9	0.36	0.26	0.08	0.36	0.26	0.22
10	0.35	0.25	0.07	0.35	0.25	0.21

For the urban patterns, which are based on the use of square and rectangle-based buildings the surface-to-volume ratio is similar for every unit and the charts are identical (Figure 34).

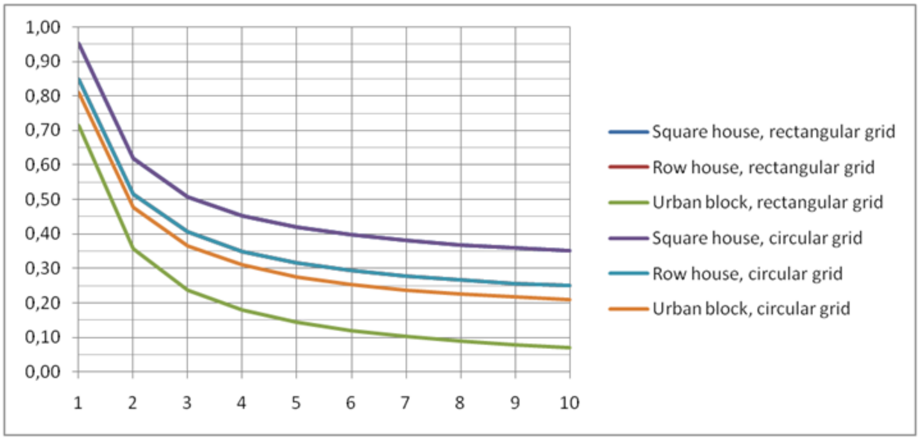

Figure 34 Surface-to-volume ratio and the number of floors for different urban patterns, m^2/m^3

The surface to volume ratio is one of the most important factors and shows, the efficiency of the materials. Again the perimetral urban patterns, shows one of best performances with the most effective surface to volume ratio, which represents the lower line in the graph, and also shows a high performance with values lower than 10%, represented in the graph.

For the trapezoidal perimeter blocks in a circular array the coefficient differs from building to building and it is evaluated for the whole pattern as the ratio between sums of all surfaces to sum of all volumes. 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 perimeter blocks are characterized by a lower coefficient and the performance of the rectangle-based pattern is better, than circular.

4.1.5 Building surface incident solar radiation

Solar radiation indicates the energy which is received by the all surfaces of the built elements of the urban pattern. The generated urban patterns were evaluated using the Autodesk Ecotect Analysis. The weather conditions were assumed for Prague, Czech Republic. Incident solar radiation, which is received by different urban patterns per year, is shown in Table 6.

Table 6 Height of built units and incident solar radiation for different urban patterns, kW per year

№ of floors	Point Block, rectangular grid	Slab block, rectangular grid	Perimeter block, rectangular grid	Point Block, circular grid	Slab block, circular grid	Perimeter block, circular grid
1	335403	335025	283257	336217	334902	
2	330091	331871	281082	331640	336612	
3	326931	328208	278276	327078	330165	279779
4	325880	325850	276324	326823	326236	276068
5	324149	322335	274111	325138	325610	279936
6	320528	320945	271558	322998	321007	274018
7	319397	317010	269498	319664	317179	276552
8	323649	317662	267588	322799	315831	280155
9	323559	313116	264324	319016	314982	271896
10	319831	310847	260460	312086	310802	270321

According to the results of a simulation there is a difference evident in the performance of the perimeter block in comparison to the other patterns (Figure 35). Both circular and rectangular patterns receive less solar radiation, which can be explained by the complex shape of the building with the courtyard, which causes 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 the generated model. For the two patterns based on the use of the square-based building and for the circular perimeter block pattern there is a segment between 3 and 9 floors, where the difference in values is minimal.

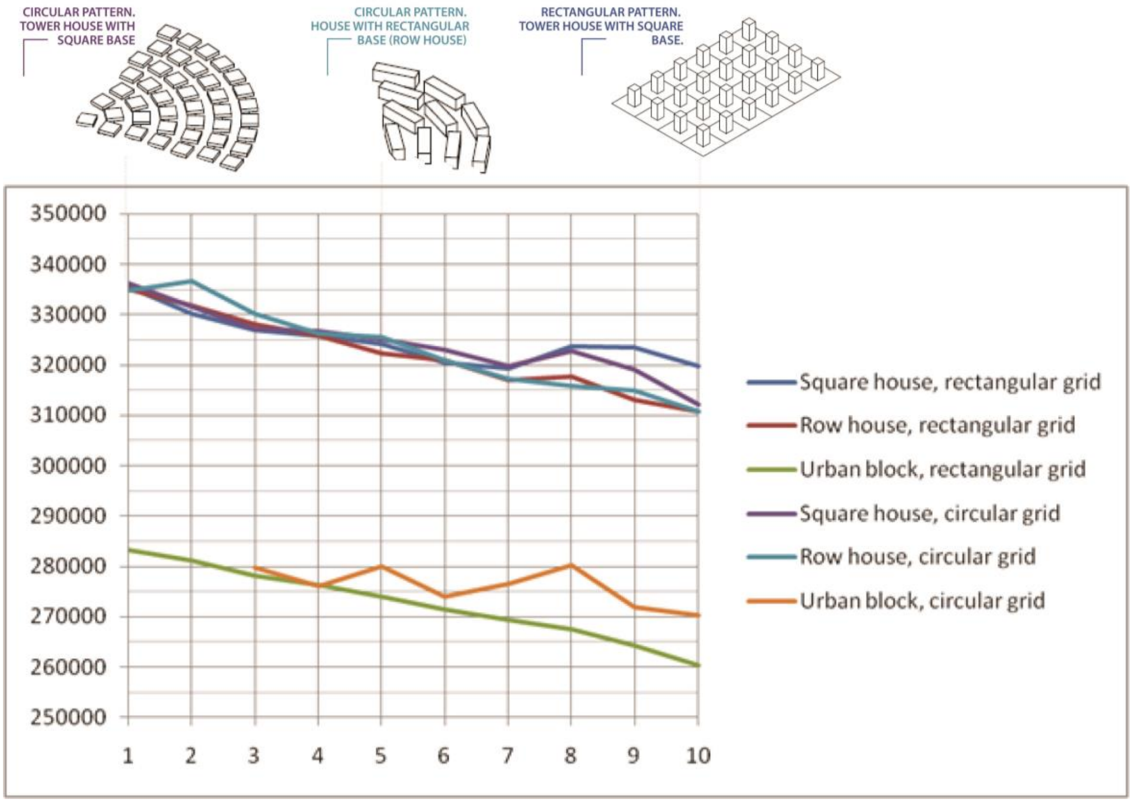

Figure 35 Incident solar radiation and the number of floors for different urban patterns, kW per year

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

4.2 Analysis of wind performance of 60 generated urban patterns

In order to analyze urban patterns and wind performance, 60 simulations were done over the 6 virtual models-rectangular grid, row-houses, rectangular blocs and circular patterns. Wind flow analyses were completed using the Autodesk Flow Design, which allows simulation with virtual wind conditions including, speed, wind pressure, and orientation, and at the same time with analyzing the results in a given urban form. Although the program is also used for cars and aerodynamic simulations, it is very suitable for wind flow simulations on the urban scale. Graphically, different colors show the differentiation of wind speed in section and plan. The speed of wind is calculated according to the Prague average of 5m/sec.

The study is based on two fundamental assumptions. The first is that wind pressure on the surface of the buildings contributes to thermal energy exchange within the building and the second is that the wind speed has a measurable influence on the thermal energy exchange.

60 simulations are done over the 6 virtual models: rectangular grid, row-houses, rectangular blocs and circular patterns. The images showing the results of the wind simulation for all the generated urban patterns are given in Attachment B.

The change of the color of the scale from red (wing acceleration) to blue (wind shade) shows the areas where urban form can create perturbations and wind accelerations, wind corridors and so forth, something which is already known but not spatially defined. Each model is tested in the 1 to 10 story building height while the section plan of wind pressure is kept horizontal just above the surface. Following the 45 degrees rule, the distances in low-story buildings are much smaller than a 10 to 10-story distance.

In the rectangular and circular pattern, a wind shadowing effect is noticed in low height structures. The wind speed accelerates more than average along the perimeter of the buildings, indicating the necessity and importance of the reinforcement of thermo-insulating along the edge of the build format the outer side facades of the blocs. In the circular pattern the phenomena is more evident.

The study is based on the principle that wind pressure or speed results in thermal energy exchange in the facades. Another principle observed is that for heights of up to 4 floors, or for rather dense structures during the simulation the areas of wind sheltering are found within the contours of the perimeter block. In this regard, it can be observed that 4 story blocs are more efficient than taller structures for the prevention of air exchange and air cooling.

Because the blocks were generated following the 45-degree rule, it can be seen that with the increase in height, there is a linear increase in width or distance between the buildings, resulting in an increased wind canyon. The wind shelter shadow increases with wind pressure and speed. Another finding is that wind tunnels tend to be sharper with an increase in height. The acceleration speed in the periphery decreases when other sources of penetrability are found.

In the high-rise buildings, there are wind tunnel corridors inside urban patterns which should be more thermo-insulated, especially in the exposed facades. A circular arrangement of the perimeter block seems to be the most efficient where no wind penetration can be found. In this way, the urban pattern creates a compact shape which diminishes wind exposure. For any given pattern, the height of the building is also related to street width and therefore wind exposure. There is an optimum relationship (1-6 floors) for which the simulation demonstrates that there is no significant wind acceleration within the given blocks of urban patterns and the wind sheltering effect is more evident.

4.3 Summary of findings

Within the study, the sixty algorithmic urban patterns were generated and evaluated in terms of the urban parameters such as building density, site coverage, and the number of built units per ha in terms of the potential energy gains and losses, such as received solar radiation and surface-to-volume ratio.

The highest building density, the lowest number of built units, the highest site coverage and the maximal building capacity are registered for the urban patterns based on the use of the European perimeter block. In all cases, the performance of a rectangular pattern is higher than that of the circular pattern. By an analysis of the same parameters, the use of the slab block pattern is preferable to the square-based one. The constant growth of density with the increase of the building height only characterizes the perimeter blocks and the circular pattern of the slab blocks. For the rest, the decrease in density is evident after reaching 5 floors of 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, the parameters have very minor change.

The potential solar gains of the perimeter block are the lowest of all the examined cases, meanwhile the four other models demonstrate very similar results. All the generated patterns received solar radiation decreases with an increase in building height.

Evaluation of the urban patterns and the potential energy gains and losses allow for the control of some of the parameters which define the overall energy performance of the urban form. During the computer simulation, simplified models were used and the factors of building environment, building materials, and the occupants' behavior were neglected. For the real urban pattern, the performance could be different due to the fact that the buildings will have a 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 most reduce the energy demand of the city.

As a general conclusion, it can be written that less wind acceleration, less wind speed and more protection with wind sheltering is achieved with urban patterns up to 5-6 floors, the most optimal solution being between 5-6 stories. The rule of 45 degrees which has been adapted in many countries including Czech Republic implies that buildings should have the same distance to one-another as the height itself; therefore, high buildings increase the distance of the urban canyon and thus create the possibility for higher wind acceleration. There is an optimal height of 5-6 stories which creates adequate wind sheltering, while maintaining a certain degree of density.

CHAPTER 5

OPTIMIZATION OF THE DIMENSIONS OF THE URBAN PATTERN

5.1 Application of the genetic algorithm for finding the most energy efficient urban pattern

Within the previous part of study the algorithms describing the six common urban patterns were developed. The typical buildings, such as square based tower, row house and perimeter block were arranged in a rectangular and circular array. The algorithms were designed using Grasshopper plug-in for Rhinoceros software. For the generation of models the two sites (rectangular and circular) with fixed dimensions were used. For each pattern the height of the building is ranged between 1 and 10 floors and the length and the width of the built units varies, which gave the possibility to generate numerous variations of urban patterns. The distance between the buildings and from the site border to the building is defined by the minimal solar obstruction angle of 45 degrees. According to the settings of Grasshopper definitions the number of the buildings, which could fit on site and the density of the pattern directly depends on the height of the building and the dimensions of the base.

Galapagos Evolutionary Solver is a part of Grasshopper plug-in. Evolutionary computation is used for solving of the optimization problems due to the simplicity of the approach, flexibility, applicability to the wide variety of problems and the self-optimization ability (Fogel, 1997). Evolutionary algorithms need the specification of the target, or fitness function, which can be expressed through the parameter, or through the combination of parameters to be optimized (Streichert, 2002). The Galapagos Evolutionary Solver requires variables or genes, which are allowed to change. The Generation Zero of the model is based on the random selection of the variables combinations, but with the further generations the preferred genomes are selected. The higher the number of generations is performed, the more probable is the opportunity to find the combination with better fitness (Rutten, 2015).

Surface-to-volume ratio and density are accepted as the key parameters, which affect the energy efficiency of urban pattern. The analysis is performed in three steps. Among all generations there were selected the solutions with the highest density; the solutions with minimal surface-to-volume ratio; and the solutions with the best fitness value. Calculation of the fitness value is based on combination of maximal density and minimal surface-to-volume ratio.

5.2 Rectangular pattern. Tower block with square base

The urban pattern is based on the population of the units with the square base and variable length of the building side. The height of the building ranges from 1 to 10 floors. The distance between the buildings was calculated to be not less than the height of the building. The site border limited the amount of buildings which could be placed on one side and the building density varied with increases in height. The results of surface-to-volume ratio are given in Table 7.

Table 7 The parameters of a rectangular pattern with square-based buildings with the minimal surface-to-volume ratio

N of generation	Surface/Volume ratio, m^2/m^3	Side of the square building, m	№ of floors
1	0.267	20	10
2	0.274	20	9
3	0.277	19	10
4	0.278	19	10
5	0.279	18	10
6	0.283	20	8
7	0.285	19	9
8	0.287	19	9
9	0.289	18	10
10	0.294	19	8
11	0.294	19	8
12	0.295	20	7
13	0.296	18	9
14	0.302	17	10
15	0.306	18	8
16	0.309	17	9
17	0.317	16	10
18	0.319	17	8

19	0.319	17	8
20	0.322	19	6
21	0.324	16	9
22	0.324	16	9
23	0.330	17	7
24	0.333	16	8
25	0.341	15	9
26	0.344	19	5
27	0.345	16	7
28	0.346	17	6
29	0.350	15	8
30	0.352	14	10
31	0.364	16	6

Within 25 generations 31 patterns were selected which represent the top 25% of the best-fitting solutions. The coefficient ranged between 0.267-0.364 sq.m/cub.m. The lower coefficient characterizes the higher and wider buildings. Within the selection, the side of the building ranged between 20 and 14 meters and the height between 10 and 6 floors. The surface-to-volume ratio is directly connected with the dimensions of the building and gets the lowest value with the maximum dimensions of the building base and height.

The data of the optimization of building density is presented in Table 8.

Table 8 The parameters of the rectangular pattern with square-based buildings with the maximal building density

N of generation	Building density, m^2/Ha=FAR	Side of the square building, m	№ of floors
1	16000	20	10
2	14741	19	7
3	14580	18	5
4	14440	19	10
5	14400	19	6
6	14000	20	6
7	13333	20	5
8	13230	18	7
9	13067	20	7
10	13005	17	5
11	12996	19	4

12	12960	18	4
13	12960	18	4
14	12800	20	8
15	12635	19	3
16	12288	16	3
17	12150	15	6
18	12096	18	8
19	12033	19	5
20	11947	16	4
21	11800	17	7
22	11664	18	9
23	11552	19	8
24	11127	17	3

The building density was examined for the 24 patterns and was seen to range between 16,000 and 11,127 sq.m/ha. The width of the building ranged between 15 and 20 meters, and the height between 10 and 3 floors. The connection between the density and the building dimensions is not linear –as demonstrated by the high level of density in the patterns of buildings with 5-7 floors.

The generated patterns were optimized in order to have the lowest surface-to-volume ratio and the highest density, which is also called fitness value. The Evolutionary Solver generated 37 patterns with the highest fitness value, which are shown in Table 9.

Table 9 The parameters of rectangular pattern with square-based buildings with the maximal fitness value

N of generation	Fitness value	Side of the square building, m	№ of floors
1	60000	20	10
2	52541	20	9
3	52094	19	10
4	48210	19	7
5	48210	19	7
6	45664	19	9
7	45176	20	8
8	45000	20	6
9	44895	19	6
10	44862	18	10
11	44258	20	7
12	41675	18	7
13	41006	18	5

14	40000	20	5
15	39587	18	8
16	39366	18	9
17	39311	19	8
18	39273	20	4
19	38880	18	6
20	38283	17	10
21	35840	16	8
22	35703	17	7
23	35279	17	5
24	34995	19	5
25	34601	16	7
26	34454	19	4
27	33861	17	8
28	33371	17	6
29	33326	18	4
30	32162	15	6
31	30052	16	5
32	30000	15	8
33	29197	19	3
34	29013	15	7
35	28759	17	4
36	28672	16	4
37	23241	13	9

The building side ranged between 20 to 14 meters and the height between 10 and 4 floors. The graphical distribution of the patterns is presented at the figure 36:

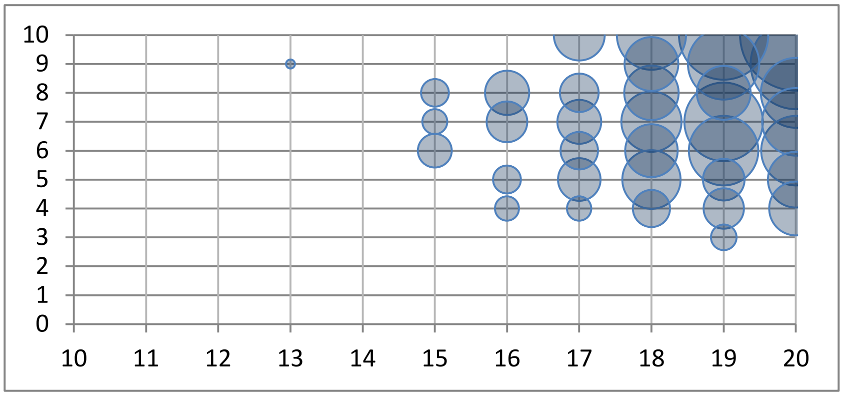

Figure 36 The distribution of the parameters of rectangular pattern with square-based buildings based on the maximal fitness value, number of floors/building side, m

The best values belong to the series of patterns with buildings of 6-10 floors and with a side of 19-20 meters.

5.3 Rectangular pattern. House with rectangular base (slab block)

For the slab block pattern, the width of the building was fixed at 14m and the length and height were variable. The parameters of optimized patterns with the lowest surface-to-volume ratio are shown in Table 10.

Table 10 The parameters of the rectangular pattern with rectangle-based buildings with the minimal surface-to-volume ratio

N of generation	Surface/Volume ratio, m^2/m^3	Building length, m	№ of floors
1	0.2495	50	10
2	0.25	49	10
3	0.251	48	10
4	0.252	47	10
5	0.253	46	10
6	0.254	45	10
7	0.255	44	10
8	0.256	43	10
9	0.257	42	10
10	0.257	50	9
11	0.258	41	10
12	0.258	49	9
13	0.259	47	9
14	0.259	48	9
15	0.2595	40	10
16	0.26	46	9
17	0.261	39	10
18	0.261	45	9
19	0.262	44	9
20	0.263	43	9
21	0.264	37	10
22	0.265	42	9
23	0.265	36	10
24	0.266	41	9
25	0.266	50	8
26	0.267	40	9
27	0.267	49	8
28	0.267	35	10
29	0.2677	46	8
30	0.268	34	10
31	0.268	39	9
32	0.269	47	8
33	0.27	33	10
34	0.27	45	8

35	0.271	37	9
36	0.272	44	8
37	0.272	32	10
38	0.272	32	10
39	0.273	43	8
40	0.274	31	10
41	0.274	22	8
42	0.274	35	9
43	0.275	41	8
44	0.275	41	8
45	0.276	33	9
46	0.276	40	8
47	0.2762	30	10
48	0.277	39	8
49	0.278	50	7
50	0.278	29	10
51	0.279	38	8
52	0.279	32	9
53	0.279	49	7
54	0.28	48	7
55	0.281	28	10
56	0.282	46	7
57	0.282	36	8
58	0.283	44	7
59	0.283	35	8
60	0.283	30	9
61	0.283	45	7
62	0.284	27	10
63	0.285	43	7
64	0.285	34	8
65	0.286	26	10
66	0.288	28	9
67	0.288	40	7
68	0.289	32	8
69	0.2895	25	10
70	0.291	38	7
71	0.292	37	7
72	0.294	50	6
73	0.296	23	10
74	0.3	22	10
75	0.301	32	7
76	0.311	35	6

The surface-to-volume ratio was calculated for 76 patterns and ranged between 0.25 and 0.311 sq.m/cub.m. There were selected patterns of buildings with lengths varying from 22 to 50m and from 6 to 10 floors high. The minimal coefficient is recorded for the set of 10 floor buildings with lengths of 40-50 meters.

The results of the optimization of building density are shown in Table 11.

Table 11 The parameters of a rectangular pattern with rectangle-based buildings with the maximal building density

N of generation	Building density, m^2/Ha	Building length, m	№ of floors
1	18144	48	6
2	17766	47	6
3	17640	45	7
4	17500	50	5
5	17388	46	6
6	17248	44	7
7	17199	39	9
8	17150	49	5
9	17010	45	6
10	16758	38	9
11	16758	38	9
12	16632	44	5
13	16464	42	7
14	16450	47	5
15	16333	35	5
16	16138	32	6
17	16100	46	5
18	16072	41	7
19	15876	42	6
20	15867	34	5
21	15856	43	7
22	15750	45	5
23	15680	40	8
24	15624	31	6
25	15498	41	6
26	15435	35	9
27	15400	33	5
28	15288	39	8
29	15288	39	8
30	15195	37	4
31	15157	29	7
32	15120	30	6
33	15092	49	4

34	15050	43	5
35	15050	43	5
36	14994	34	9
37	14896	38	7
38	14784	48	4
39	14700	35	10
40	14635	28	7
41	14616	29	6
42	14504	37	7
43	14476	47	4
44	14467	31	5
45	14406	49	9
46	14280	34	10
47	14112	48	9
48	14000	30	5
49	13963	34	3
50	13860	22	6
51	13720	35	8
52	13650	39	5
53	13589	26	7
54	13524	23	9
55	13417	23	5
56	13230	21	6
57	13104	24	3

The building density was calculated for 57 patterns and ranged between 18144-13104 sq.m/ha. The maximal values are demonstrated by the patterns with 5-7 floor buildings with lengths of 45-50m. The overall distribution of lengths ranged between 21 and 50 meters and heights of between 3 and 10 floors. The highest densities are noted for the two families of patterns: one with buildings with lengths from 38 to 50 meters and heights from 5 to 9 floors, and another with lengths from 28 to 37 meters and heights from 5 to 6 floors.

The fitness value was calculated for 87 patterns. The parameters of the buildings such as height and length are presented in Table 13.

Table 12 The parameters of a rectangular pattern in rectangle-based building with the maximal fitness value

N of generation	Fitness value	Building length, m	№ of floors
1	18144	48	6

2	17766	47	6
3	17640	45	7
4	17500	50	5
5	17388	46	6
6	17248	44	7
7	17199	39	9
8	17150	49	5
9	17010	45	6
10	16758	38	9
11	16758	38	9
12	16632	44	5
13	16464	42	7
14	16450	47	5
15	16333	35	5
16	16138	32	6
17	16100	46	5
18	16072	41	7
19	15876	42	6
20	15867	34	5
21	15856	43	7
22	15750	45	5
23	15680	40	8
24	15624	31	6
25	15498	41	6
26	15435	35	9
27	15400	33	5
28	15288	39	8
29	15288	39	8
30	15195	37	4
31	15157	29	7
32	15120	30	6
33	15092	49	4
34	15050	43	5
35	15050	43	5
36	14994	34	9
37	14896	38	7
38	14784	48	4
39	14700	35	10
40	14635	28	7
41	14616	29	6
42	14504	37	7
43	14476	47	4
44	14467	31	5
45	14406	49	9
46	14280	34	10
47	14112	48	9
48	14000	30	5

49	13963	34	3
50	13860	22	6
51	13720	35	8
52	13650	39	5
53	13589	26	7
54	13524	23	9
55	13417	23	5
56	13230	21	6
57	13104	24	3

The highest coefficient belongs to patterns with 9 and 7 floors with the building lengths of 39 and 45 meters respectively.

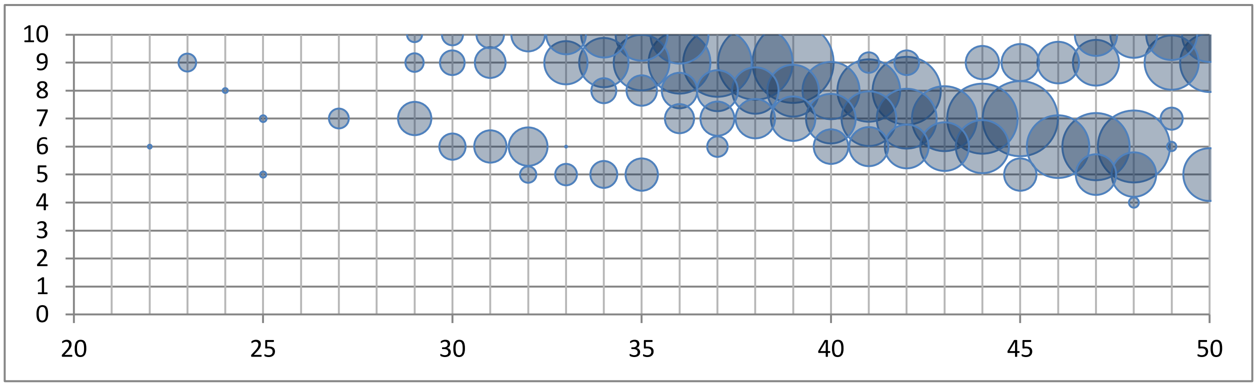

Figure 37 The distribution of the parameters of rectangular pattern with rectangle-based buildings based on the maximal fitness value, number of floors/building side, m

According to Figure 37, the high coefficient characterizes the three families of patterns: the first and the biggest – buildings with lengths from 30 to 50 meters and heights from 6 to 9 floors, and the second of buildings with lengths from 44 to 50 meters and 9 floors, and the third of buildings with lengths from 24 to 35 meters and having between 5 and 6 floors.

5.4 Rectangular pattern. Perimeter block

A perimeter block is defined by the length and the height of the building with the fixed width of 14m. During the generation it appeared, each site could be populated by one, two or six buildings of various dimensions due to the limitation of the site. The parameters of the generated patterns with the minimal surface-to-volume ratio are given in Table 13.

Table 13 The parameters of a rectangular pattern with perimeter blocks with the minimal surface-to-volume ratio

N of generation	Surface/Volume ratio, m^2/m^3	Perimeter block side 1, m	Perimeter block side 2, m	№ of floors
1	0.209524	170	120	10
2	0.209524	70	70	10
3	0.216931	273	173	9
4	0.216931	173	123	9
5	0.216931	73	73	9
6	0.22619	276	176	8
7	0.22619	76	76	8
8	0.22619	176	126	8
9	0.238095	279	179	7
10	0.238095	79	54	7
11	0.238095	179	129	7
12	0.253968	82	82	6
13	0.253968	182	132	6
14	0.27619	85	60	5
15	0.27619	85	85	5
16	0.309524	88	88	4

The surface-to-volume ratio was calculated for the 16 patterns and ranged between 0.209 to 0.309 sq.m/cub.m. The recorded dimensions are between 54 and 273m and 4 to 10 floors. The highest values belong to two patterns with 70mx70m and 120mx170m bases and which are 10 floors high. The ratio was directly connected with the height of the building, but the correlation with the building base was not established due to the complex shape of the plan.

The dimensions of the optimized patterns with the highest building density are shown in Table 14.

Table 14 The parameters of the rectangular pattern with perimeter blocks with the maximal building density

N of generation	Building density, m^2/Ha	Perimeter block side 1, m	Perimeter block side 2, m	№ of floors
1	31360	70	70	10

2	29736	73	73	9
3	29568	76	51	8
4	27776	76	76	8
5	27440	79	54	7
6	25480	79	79	7
7	24864	82	57	6
8	24453	170	120	10
9	22848	82	82	6
10	22512	173	123	9
11	21840	85	60	5
12	20459	176	126	8
13	18293	179	129	7

The density value ranged between 31360 and 18293 sq.m/ha for the 13 patterns. The parameters of perimeter blocks such as height, width and length with the best fitness value, are given in Table 15.

Table 15 The parameters of the rectangular pattern with perimeter blocks with the maximal fitness value

N of generation	Fitness value	Block width	Block length	№ of floors
1	149672	70	70	10
2	137075	73	73	9
3	122799	76	76	8
4	116709	170	120	10
5	115248	79	54	7
6	107016	79	79	7
7	103744	173	123	9
8	97902	82	57	6
9	91763	270	170	10
10	90449	176	126	8
11	89964	82	82	6
12	80928	273	173	9
13	71979	85	85	5

The maximal density characterizes the small-sized perimeter block with sides of 51-79m and 8-10 floors in height.

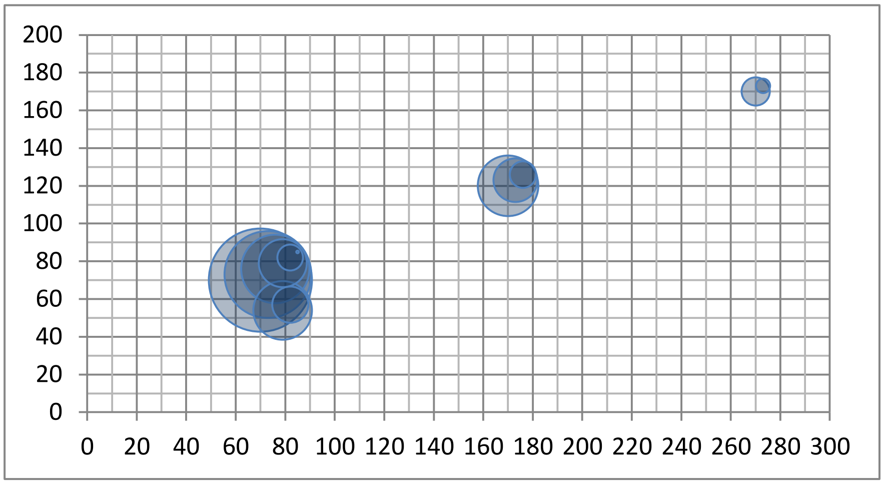

Figure 38 The distribution of the parameters of rectangular pattern with perimeter block based on the maximal fitness value, block length/block width, m

According to Figure 38 there is an evident division of patterns in the three groups by the fitness value. The most efficient are the small-scale units with sides between 70 and 80m. The second group has sides of 130-170m, and the third between 170 and 270m.

5.5 Circular pattern. Tower block with square base (point block)

The circular pattern is based on the repetition and rotation of the same building unit as in the rectangular pattern, and therefore it results in the surface-to-volume ratio which characterizes only the geometrical property of the unit that is the same as in the rectangular pattern. The results of the optimization of building density are given in Table 16.

Table 16 The parameters of a circular pattern with square-based buildings with the maximal building density

N of generation	Building density, m^2/Ha	Side of the square building, m	№ of floors
1	24867	20	9
2	23578	20	9
3	22942	19	9
4	22104	20	5
5	21490	20	7
6	21490	20	7
7	21279	19	8

8	21187	18	6
9	20780	19	5
10	20590	18	9
11	20171	19	7
12	19963	17	10
13	19894	20	6
14	19648	20	10
15	19496	18	8
16	19164	17	6
17	19157	20	4
18	18650	18	5
19	18452	18	7
20	18452	18	7
21	18076	16	10
22	17954	19	4
23	17745	17	8
24	17733	19	10
25	17683	16	6
26	17622	19	3
27	17301	17	5
28	17301	17	5
29	17165	15	7
30	16769	17	7
31	16662	16	4
32	16512	18	4
33	15915	16	5

The building density was calculated for 33 patterns and ranged between 24,851 and 15,915 sq.m/ha. The side of the building ranged between 15 to 20 meters, and the height between 3 and 10 floors. The highest density was noted for the buildings with bigger sides and with the optimal height of 9 floors.

The height and the side dimensions of the built unit of the generated patterns with the best fitness value are shown in Table 17.

Table 17 The parameters of a circular pattern with square-based buildings with the maximal fitness value

N of generation	Fitness value	Side of the square building, m	№ of floors
1	90734	20	9
2	83218	20	8
3	80611	19	9
4	73682	20	10
5	72791	20	7

6	72414	19	8
7	69493	18	9
8	66314	20	5
9	66112	17	10
10	65970	19	7
11	63973	19	10
12	63946	20	6
13	63806	18	8
14	63562	18	6
15	61948	17	9
16	60934	19	5
17	60434	19	5
18	58123	18	7
19	57084	16	10
20	56813	18	10
21	55822	19	6
22	55692	17	8
23	55325	17	6
24	52455	18	5
25	52384	16	9
26	52247	20	4
27	50734	17	7
28	49043	16	8
29	48970	16	6
30	47600	19	4
31	47600	19	4
32	47431	15	7
33	46935	17	5
34	43026	16	7
35	42460	18	4
36	40983	14	10
37	39989	16	4
38	37631	14	9
39	37083	20	3
40	31176	13	5
41	30061	14	4
42	27078	12	10
43	26019	20	2
44	23936	11	8

Within the examined 44 patterns, the highest fitness value is registered for the widest building with 9 floors. The overall distribution of values is between 11 and 20 meters for the building side and 2 to 10 floors (Figure 39).

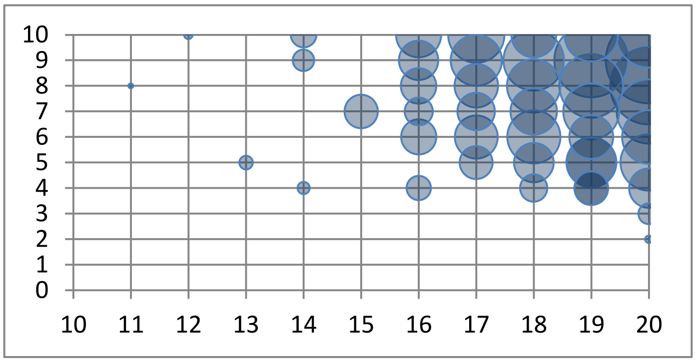

Figure 39 The distribution of the parameters of a circular pattern with square-based buildings based on the maximal fitness value, number of floors/building side, m

The preferred patterns have the building sides of 18-20m and the height of 7-9 floors.

5.6 Circular pattern. House with rectangular base (slab block)

The surface-to-volume ratio for the circular pattern with slab blocks is identical to the one of the rectangular pattern. The results of the optimization of building density are presented in Table 18.

Table 18 The parameters of a circular pattern with rectangle-based buildings with the maximal building density

N of generation	Building density, m^2/Ha	Building length, m	№ of floors
1	27938	50	10
2	27852	48	10
3	27680	46	7
4	27379	49	10
5	27271	47	10
6	27078	45	7
7	26536	49	7
8	26476	44	7
9	26453	47	9

10	26433	41	10
11	26175	42	10
12	26160	47	7
13	26111	50	9
14	25995	48	7
15	25874	43	10
16	25874	43	7
17	25788	40	10
18	25453	47	9
19	25445	37	10
20	25316	38	10
21	25288	41	7
22	25273	49	6
23	25144	39	10
24	24757	40	9
25	24680	44	9
26	24641	39	7
27	24641	39	7
28	24583	41	9
29	24583	41	9
30	24581	38	7
31	24241	47	6
32	24241	47	6
33	24220	35	7
34	24138	39	9
35	24069	50	8
36	23932	48	8
37	23829	36	7
38	23657	43	8
39	23588	49	8
40	23528	34	7
41	23519	38	9
42	23332	33	7
43	23275	46	6
44	23210	45	8
45	23106	32	7
46	22694	32	10
47	22651	31	10
48	22581	31	7
49	22565	30	10
50	22049	38	6
51	22006	40	8
52	21813	29	7
53	21701	33	9

54	21662	28	10
55	21585	31	9
56	21585	31	9
57	21482	34	6
58	21456	39	8
59	21121	26	7
60	21043	34	8
61	20953	50	5
62	20684	25	7
63	20416	25	10
64	19818	29	6

The building density for the 64 cases ranged between 27,938 and 19,818 sq.m/ha. The length of the building is registered to be between 50 and 25 meters and the height between 10 and 5 floors. The best results are demonstrated by the units with the biggest length and height, but within the data two main groups of patterns can be seen: the group based on the use of 10 floor buildings with the length of 37-50m and the group based on 7 floor buildings with the length of 31-50m.

The height and the length of the slab block of the generated patterns with the best fitness value are presented in Table 19.

Table 19 The parameters of a circular pattern with rectangle-based buildings with the maximal fitness value

N of generation	Fitness value	Length of the square building, m	№ of floors
1	111965	50	10
2	110880	48	10
3	109406	46	10
4	109368	49	10
5	108188	47	10
6	106621	45	10
7	103839	44	10
8	102956	49	9
9	102335	41	10
10	101794	42	10
11	101627	50	9
12	101060	43	10
13	100524	48	9

14	100524	48	9
15	99370	40	10
16	98305	46	7
17	98093	47	9
18	97371	50	7
19	96569	45	9
20	96569	45	9
21	96537	37	10
22	96409	39	10
23	95839	45	7
24	95665	46	9
25	95665	46	9
26	95144	49	7
27	94710	43	9
28	94710	43	9
29	94060	44	9
30	93375	44	7
31	93215	47	7
32	92919	48	7
33	92748	40	9
34	92748	40	9
35	92518	41	9
36	92120	42	9
37	90422	50	8
38	90261	35	10
39	89997	39	9
40	89346	48	8
41	88343	49	8
42	87196	47	8
43	87133	34	10
44	85734	49	6
45	85153	39	7
46	84508	37	9
47	84390	42	8
48	84012	33	10
49	83830	37	7
50	83743	48	6
51	83544	44	8
52	83427	32	10
53	82657	31	10

54	82033	41	8
55	81771	36	9
56	81083	34	9
57	78326	29	10
58	78113	33	7
59	77524	32	9
60	76870	32	7
61	75513	31	7
62	75088	41	6
63	74042	30	7
64	73834	34	8
65	73657	27	10
66	72591	29	9
67	72174	26	10
68	70516	25	10
69	68686	24	10
70	68043	28	7
71	65031	26	9
72	65020	23	10
73	62948	22	10
74	62736	30	6
75	61843	23	9
76	59350	22	7

Figure 40 presents the graphical distribution of the parameters.

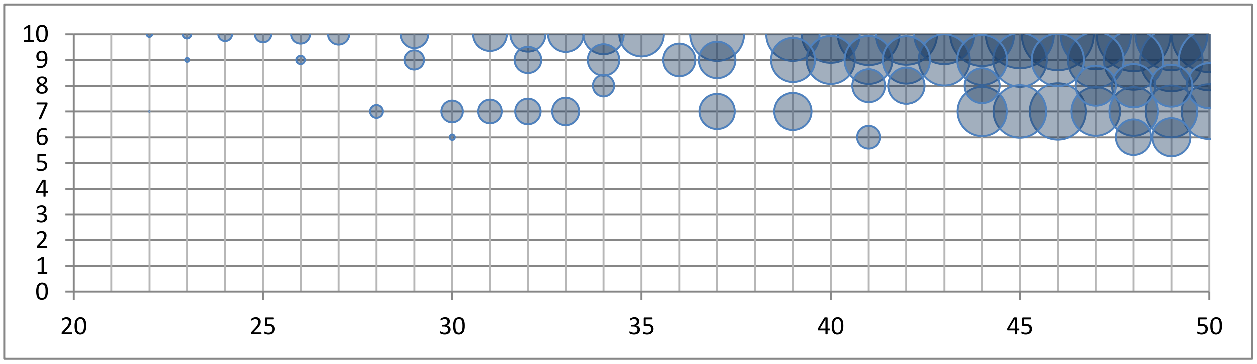

Figure 40 The distribution of the parameters of rectangular pattern with circular-based buildings based on the maximal fitness value, number of floors/building side, m

The best fitness value is noted for the bigger buildings of 10 floors height and 45-50m length. Among the 76 cases, the height parameters are 6-10 floors and the length 22-50m.

5.7 Circular pattern. (Perimeter block)

In the circular pattern, each block has a trapezoidal shape, where the size of the smallest side is defined as the sum of double the width and height of the building. The dimension of each block is different; therefore the surface-to-volume ratio is calculated for the overall pattern. The optimized dimensions of the sides of perimeter block are given in Table 20.

Table 20 The parameters of circular pattern with perimeter blocks with the minimal surface-to-volume ratio

N of generation	Surface/Volume ratio, m^2/m^3	№ of floors	Perimeter block side 2, m	Perimeter block side 1, m
1	0.1666	10	150	70
2	0.1719	10	152	66
3	0.174	9	156	71
4	0.1777	10	154	66
5	0.1793	9	65.5	65
6	0.1833	8	69	64
7	0.1843	10	156	64
8	0.1851	9	66.5	63
9	0.1885	8	70	62
10	0.1916	10	54	62
11	0.1917	9	67.5	61
12	0.1944	8	71	60
13	0.1952	7	73.5	61
14	0.199	9	68.5	59
15	0.2	10	65	60
16	0.2005	7	74.5	56
17	0.2009	8	72	56
18	0.2009	8	72	56
19	0.2063	7	75.5	57
20	0.2074	9	69.5	57
21	0.2083	8	73	56
22	0.2095	10	66	56
23	0.2111	6	78	56
24	0.2128	7	76.5	55

25	0.2163	6	79	56
26	0.2166	8	74	54
27	0.2169	9	70.5	55
28	0.2205	10	67	56
29	0.2222	6	60	54
30	0.2261	8	75	52
31	0.2333	10	68	54
32	0.2361	6	62	50
33	0.2371	8	76	50
34	0.238	7	79.5	49
35	0.2407	9	72.5	51
36	0.2484	10	69	46
37	0.25	8	77	56

Included within the 37 best cases there are the patterns of 6-10 floors height and 11-20m wide. The coefficient ranged between 0.166 and 0.25 m^2/ m^3. The higher values are registered for the wider buildings of 8-10 floors height.

The parameters of the optimized patterns with highest building density are shown in Table 21.

Table 21 The parameters of rectangular pattern with rectangle-based buildings with the maximal building density

N of generation	Building density, m^2/Ha	№ of floors	Perimeter block side 2, m	Perimeter block side 1, m
1	579961	7	77.5	53
2	567913	8	69	64
3	560701	9	66.5	63
4	550965	8	70	62
5	544635	9	67.5	61
6	543817	10	64	62
7	532813	8	71	60
8	527122	7	73.5	61
9	523443	9	68.5	59
10	520259	10	65	60
11	516509	7	74.5	59
12	513455	8	72	56
13	500895	9	69.5	57
14	499547	7	75.5	57

15	498784	8	73	56
16	495310	10	66	56
17	483909	6	78	56
18	481450	7	76.5	55
19	477347	8	74	54
20	476992	9	70.5	55
21	473885	10	67	56
22	462217	7	77.5	53
23	459650	6	80	54
24	454611	8	75	52
25	452377	6	54	46
26	451733	9	71.5	53
27	448585	7	78.5	51
28	446470	10	68	54
29	442987	6	81	52
30	442764	5	53	47
31	439728	7	47	45
32	437926	4	54	52
33	432699	6	51	44

The building density for the 33 patterns is between 29,454 and 22,043 sq.m/ha. Among the patterns of buildings 4-10 floors high and 12-20m wide, the highest density is considered for the buildings with from 7 to 9 floors and is the maximum for a 7 floor building that is 16m wide.

The height and sides of the trapezoidal perimeter blocks with the best fitness value are given in Table 22.

Table 22 The parameters of a circular pattern with perimeter blocks with the maximal fitness value

N of generation	Fitness value	Building width, m	№ of floors	Side 1, m	Side 2, m
1	3097710	20	8	69	64
2	3027789	18	9	66.5	63
3	2921400	19	8	70	62
4	2840767	17	9	67.5	61
5	2840767	17	9	67.5	61
6	2837309	16	10	64	62
7	2740182	18	8	71	60
8	2699896	20	7	73.5	61
9	2629389	16	9	68.5	59
10	2629389	16	9	68.5	59

11	2601296	15	10	65	60
12	2576088	19	7	74.5	69
13	2554754	17	8	72	56
14	2542587	20	10	150	70
15	2415033	15	9	69.5	57
16	2394165	16	8	73	56
17	2371699	19	10	152	68
18	2363980	14	10	66	58
19	2292201	20	6	78	58
20	2268414	20	9	156	67
21	2261550	17	7	76.5	55
22	2203140	15	8	74	54
23	2200618	18	10	154	66
24	2198819	14	9	65.5	65
25	2167372	19	6	79	56
26	2149013	13	10	67	56
27	2098717	16	7	77.5	53
28	2068429	18	6	80	54
29	1936489	17	6	81	52

Graphical distribution of the parameters is shown in Figure 41.

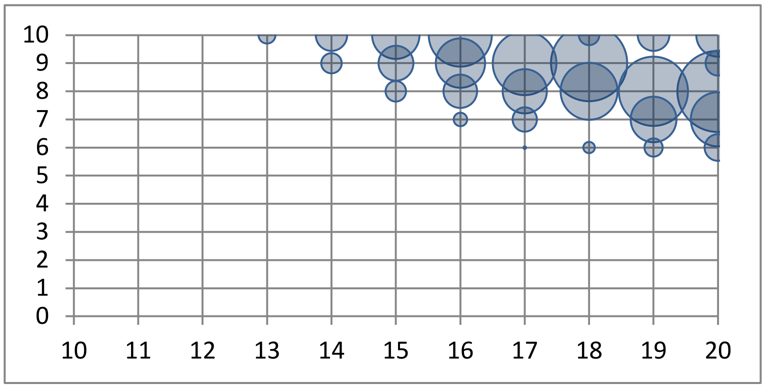

Figure 41 The distribution of the parameters of a circular pattern with perimeter blocks based on the maximal fitness value, number of floors/building width, m

The fitness value was calculated for 29 patterns within the range of 6 to 10 floors and 13 to 20m in building width. The maximal values characterize the patterns of 8-9 floors and a width of 17-20m.

5.8 Summary of findings

Within the research, the multiple variations of the six urban patterns were generated based on the use of the parametric algorithms. In order to find the optimized urban pattern with the highest energy and economic efficiency, the Evolutionary Solver was applied. The three parameters including building density, surface-to-volume ratio and the fitness value are compared for the different urban patterns.

The surface-to-volume ratio is similar for the slab block, tower block and circular patterns. The ratio of the perimeter block is the lowest, which shows its potential in the minimization of the heating and cooling losses of buildings. The ratio is seen to decrease with the growth of the physical dimensions of the buildings. The maximal ratio belongs to the patterns with tower units, which shows the lowest efficiency of such a type of urban development.

The relationship between the physical dimensions of the built units and the density is more complex due to the application of the algorithm to the site with fixed dimensions. The highest building density is recorded for the two perimeter block patterns, the lowest being for the tower pattern. The high level of density does not mean the population of the site by the widest and tallest units. The optimal density can be achieved by the use of the 6, 7 or 9 story buildings and the width of the units may vary as well. Calculation of the building density does not show the results which are applicable to every urban structure due to the use of the specific site, but it allows us to evaluate the overall tendency.

The best fitness value is demonstrated by the perimeter block patterns. The optimal dimensions of the perimeter block are relatively small: 70mx70m for the rectangular unit and 64mx69m for the trapezoid. The optimal height of the block is 10 and 8 floors respectively. The dimensions on the units of tower and slab block patterns tend to be maximal, but the use of the specific site provides the different solutions with the best fitness value.

The use of the perimeter block in the city development is most preferable according the results of a comparison between the different urban patterns. The dimensions of the building base are relatively low, but the height is maximized. Application of the compact urban pattern may reduce the overall energy demands of the urban district and make urban development more sustainable.

The findings of the study are based on the computer simulation which required the application of some limitations. Patterns were selected with the most common building dimensions and heights, the average solar obstruction angle, and the dimensions of the site were limited. The establishment of different ranges of the main parameters, changes made to the site borders or the use of the built units with a complicated geometrical shape or with the prevailing vertical dimension may affect the results of the study.

CHAPTER 6

EVALUATION OF THE ENERGY PERFORMANCE OF TYPICAL URBAN STRUCTURES OF PRAGUE

6.1. Selection of urban patterns

European cities had been developed historically as compact and dense structures, where the specific urban microclimate was achieved through the arrangement of the units of the urban pattern. The energy flows such as transportation and heating or cooling, were reduced. With the further development of the cities, the various urban patterns emerged and the city energy demands grew. One of the ways of reducing such demands is the creation of compact urban patterns which are exposed to the maximum amount of solar radiation and may potentially reduce the heating demands of the buildings. The energy which is received by a building is defined by its shape and orientation, whereas the compactness depends on its geometrical properties such as surface-to-volume ratio and the plot coverage. Within the study the various urban patterns of Prague are tested in order to find the most energy efficient ones. The urban structures are selected according to their geometrical shape and include the perimeter blocks with different proportions, perimeters and site coverage ratio as well as the dense medieval streets and minimalistic buildings of the socialist period. The computer simulation and analysis were performed using the models extracted from the virtual Google Earth model of Prague. Within the study the connection between the urban morphology, building compactness, site coverage and the received solar energy is evaluated based on the evaluation of the parameters of 64 samples of different urban patterns of Prague, Czech Republic, subdivided in 16 groups. The computer based simulations of the solar access analysis in comparison with the geometrical properties of the structure aimed to select the cases with the highest energy performance, as defined by higher solar gains and a lower surface-to-volume ratio.

The list of the selected areas with indications of the district, boundary streets and the main parameters of analysis are given in Table 23.

Table 23 The main parameters of the selected urban patterns of Prague

N	Typology	District	Boundary streets	Surface/Volume ratio, m^2/m^3	Incident solar radiation, kW / year	Site coverage, %
1	Square rectangle	Prague 3	Jeseniova, Ceskobratska	0.36	358654	0.71
2	Square rectangle	Prague 3	Jeseniova, Zelivskeho	0.46	311441	0.71
3	Square rectangle	Prague 3	Vinograhdska, U Vodarny	0.28	127092	0.64
4	Square rectangle	Prague 7	Letohradska, Kamenicka	0.67	373866	0.56
5	Square rectangle	Prague 7	Letohradska, Ovenecka	0.64	375376	0.65
6	Narrow rectangle	Prague 7	Sternbekova	0.19	127106	0.85
7	Narrow rectangle	Prague 7	Veletrzni, Ovenecka	0.61	370921	0.83
8	Narrow rectangle	Prague 7	Veletrzni, Socharska	0.57	373749	0.75
9	Narrow rectangle	Prague 5	Vltavska, Nadrazni	0.44	372183	0.82
10	Narrow rectangle	Prague 7	Snirchova, Simackova, Strojnicka	0.31	295000	0.71
11	Narrow rectangle	Prague 5	Lidicka, Na belidle	0.66	344186	0.69
12	Narrow rectangle	Prague 7	Dobrovskego, Ovenecka	0.58	365759	0.73
13	Narrow rectangle	Prague 5	Svornosti, Na belidle	0.35	562519	0.74
14	Filled rectangle	Prague 10	Machova, Varsavska	0.57	375208	0.80
15	Filled rectangle	Prague 5	Svornosti, Vrazova	0.31	341757	0.60
16	Filled rectangle	Prague 5	Svornosti, J. Plachty	0.34	127119	0.63
17	Filled rectangle	Prague 8	Sokolovska, PrvnihoPluku, Vitkova, Krizikova	0.39		0.46
18	Trapezoid	Prague 10	Machova, Rybalkova	0.43	378461	0.82
19	Trapezoid	Prague 10	Charkovska, Rybalkova	0.53	367803	0.59
20	Trapezoid	Prague 7	Korunovacni, Jana Zajice	0.32	349748	0.55

21	Trapezoid	Prague 4	U Krizku, V Horkach	0.40	311441	0.70
22	Trapezoid	Prague 10	Litevska, Na hroude	0.33	302875	0.31
23	Narrow Trapezoid	Prague 7	U Studanky, Socharska	0.58	382264	0.85
24	Narrow Trapezoid	Prague 7	Veletrzni, Kamenicka	0.64	386479	0.77
25	Narrow Trapezoid	Prague 3	Jeseniova, Dovcova	0.31	353370	0.48
26	Narrow Trapezoid	Prague 10	Krymska	0.32	340922	0.39
27	Filled Trapezoid	Prague 7	Milady Horakove, Kamenicka	0.47	354158	0.76
28	Filled Trapezoid	Prague 10	Francouzska, Sazavska	0.40	371178	0.69
29	Filled Trapezoid	Prague 5	Vltavska, Nadrazni	0.44	372183	0.82
30	Filled Trapezoid	Prague 5	J. Plachty, Nadrazni	0.43		0.54
31	Triangle	Prague 1	Planerska, Karpova, Zatecka	0.29	410066	0.26
32	Triangle	Prague 3	Seifertova, Vita Nejedleno, Vikova	0.46	477217	0.77
33	Triangle	Prague 4	Mojmirova, Rostislavova	0.34	353669	0.68
34	Triangle	Prague 7	Korunovacni, Na Vysinach	0.47	317797	0.67
35	Triangle	Prague 10	V predpoli, Na hroude	0.31	329775	0.57
36	Filled Triangle	Prague 4	Nuselska, Cestmirova	0.37	343900	0.97
37	Filled Triangle	Prague 1	Husova	0.35	311440	0.86
38	Filled Triangle	Prague 4	Nuselska, Rostislavova	0.45	413179	0.63
39	Pentagon	Prague 6	Devicka, Kafkova, Na Hutich	0.42	299245	0.47
40	Pentagon	Prague 7	Havanska, Cechova	0.54		0.54
41	Filled Pentagon	Prague 10	Krymska, Kodanska	0.63	377701	0.86
42	Filled Pentagon	Prague 10	Francouzska, Slovenska	0.61	369038	0.62
43	Filled Pentagon	Prague 7	Korunovacni, Cechova	0.53	376760	0.70

44	Long Medieval Street	Prague 5	Nerudova	0.41	210533	0.74
45	Long Medieval Street	Prague 5	Zameckeschody	0.41	312686	0.76
46	Long Medieval Street	Prague 10	Francouzska	0.56	358268	0.82
47	Long Medieval Street	Prague 10	Francouzska	0.49	354613	0.63
48	Courtyard Medieval Street	Prague 5	Nerudova	0.32	205717	0.47
49	Courtyard Medieval Street	Prague 5	Nerudova	0.25	127917	0.81
50	Courtyard Medieval Street	Prague 5	Nerudova	0.32	193623	0.90
51	L - Shape	Prague 4	Mecislavova, Cestmirova	0.33	317796	0.61
52	L - Shape	Prague 3	Jeseniova, Dovcova	0.31	353370	0.48
53	L - Shape	Prague 3	Olsanska	0.25	127119	0.42
54	L - Shape	Prague 3	Malesicka, Zelivskeho	0.25	309191	0.47
55	U - Shape	Prague 3	Husitsky	0.31	127119	0.36
56	U - Shape	Prague 10	Karpatska	0.23	309212	0.84
57	U - Shape	Prague 10	Ruska	0.41	222315	0.49
58	U - Shape	Prague 3	Jeseniova, Ceskobratska	0.32	353670	0.46
59	U - Shape	Prague 3	Olsanska, Zelivskeho	0.37	333974	0.31
60	S - Shape	Prague 10	Jakutska	0.38	204731	0.43
61	Bar Shape	Prague 8	Molokova	0.36	552136	1.00
62	Bar Shape	Prague 8	Molokova	0.28	338717	1.00
63	Bar Shape	Prague 8	Molokova	0.26	343793	1.00
64	Bar Shape	Prague 8	Molokova	0.27	338835	1.00

The detailed top views and footprints of the 64 selected urban patterns can be seen in Attachment C.

6.2 Surface-to-volume ratio

The surface-to-volume ratio of the structure is measured as the ratio between the sum of the total surface of the building (including outer walls and roofs) and the volume of the building (Rode et al., 2014). High surface-to-volume ratio or low compactness is an indicator of the potential heat losses though the external surfaces of the building and its low energy performance. For the sample cases, the average value for every group of buildings is calculated

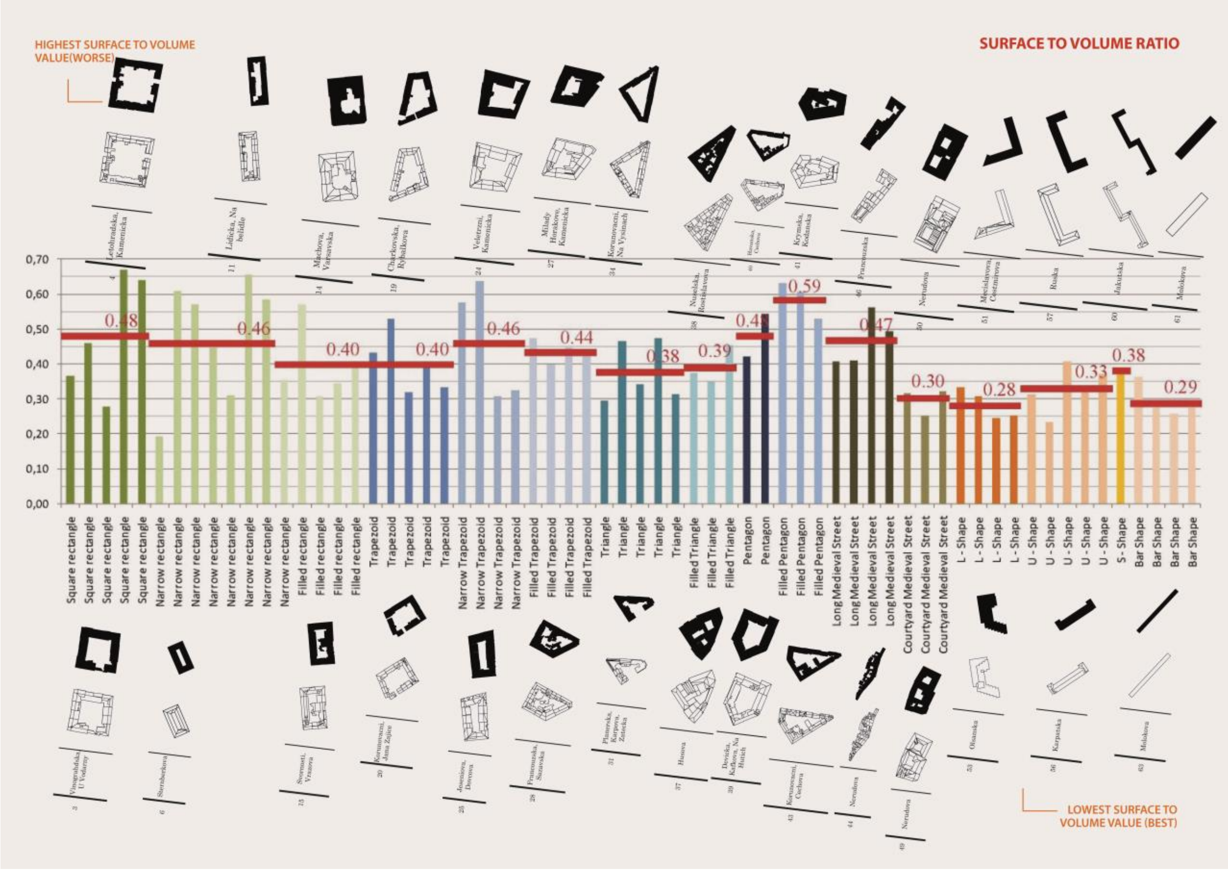

Figure 42 Surface-to-volume ratio and the average value for different samples of built structures, m^2/m^3

The Graph shows the lowest surface to volume and the highest surface to volume ratio for each pattern typology. According to the given typology, there could be understood based on each typology, the patterns, or urban blocks which have the lowest surface to volume ratio. It can be noted that patterns with lower surface to volume ratio are simpler in shape and some of the optimal values can be observed in the case of :

1-Square rectangular pattern-Vinohradska, U Vodarny, **surface/ volume =0.25**

2-Narrow rectangular pattern-Sternberkova, **surface/ volume =0.18**

Letohradska Kamenica is one of the blocks with the highest surface to volume ratio of 0.64, which shows that this urban block contains many surfaces which make the lose of thermal energy in a higher quantity that the case of a similar typology such as U Vodarny.

According to Figure 42, simple-shaped contemporary built structures are characterized by the lowest ratio, which may be explained by the use of the compact volume with a simple geometry and a lack of building details. (the 4 typologies towards the end of the graph) Most of these typologies of build form are housing of the period between 1930-1990s.

Fig.42.1 Karpatska Street[1]

The energy losses of the buildings are minimized. The parameters of the variations of perimeter blocks including square, rectangle, triangle and trapezoid are similar, while the pentagon shape demonstrates higher surface-to-volume ratio. In all cases the footprints of the urban patterns with the lowest surface to volume ratio, are obviously more compact in shape. The triangular perimeter block may be considered as the most compact structure. Within each group, the distance between the two buildings which formed the courtyard or the narrowness of the pattern and the level of courtyard infilling slightly influenced overall performance. The long medieval

[1] Homesweethome.cz

street has a performance equal to the perimeter block groups, while the courtyard medieval street is closer to the contemporary structures.

6.3 Building surface incident solar radiation

The computer-based simulation was used to calculate the solar radiation which is received by the all surfaces of the built elements of the building. The selected urban structures were evaluated using the Autodesk Ecotect Analysis. The weather conditions were applied for Prague, Czech Republic. The average value for every group of the built structures indicates the energy performance of the urban pattern.

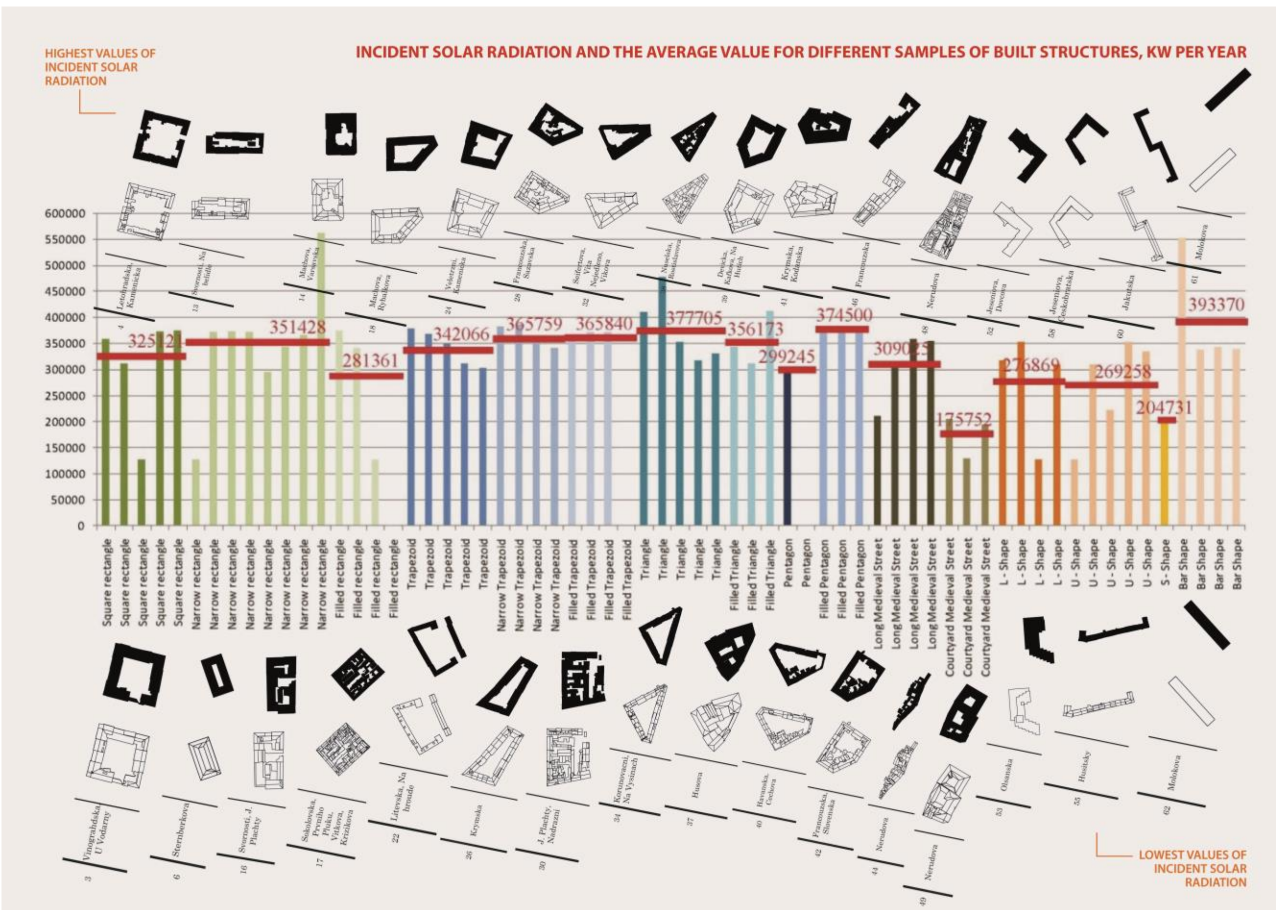

Figure 43 Incident solar radiation and the average value for different samples of built structures, kW per year

The Graph above shows the different performance of different typologies, where are described the best and the lowest performances for each pattern group. Thus can be seen that a main factor for the performance is orientation, and another strong factor is the density of the build form in the courtyard, which sometimes becomes an obstacle and obviously affect the sunlight penetration in the courtyard. As can be seen in the graph, some of the "simple shapes" typologies have a good performance. These urban typologies are the ones without courtyards. The rest of typologies have to be examined carefully comparing different parameters.

The pentagon at Machova-Rybalkova is one of the typologies who receives a high amount of solar radiation.

As is shown in Figure 43, solar energy which is received by different typologies of perimeter blocks is higher than that of the contemporary simple buildings. The medieval urban structures perform the worst. Among the morphological properties of the perimeter block, the filled structures have relatively smaller levels of incident solar radiation. For the contemporary buildings, the simple bar or tower-like building is more efficient than the L-shape or U-shape.

6.4 Site coverage

Site coverage represents the ratio of built-on land and may be evaluated as the relation between the building footprint and the land area (Cheng, 2009). Site coverage represents the intensity of the land use. The dimensions of the site are estimated according to the maximal dimensions of the sample building.

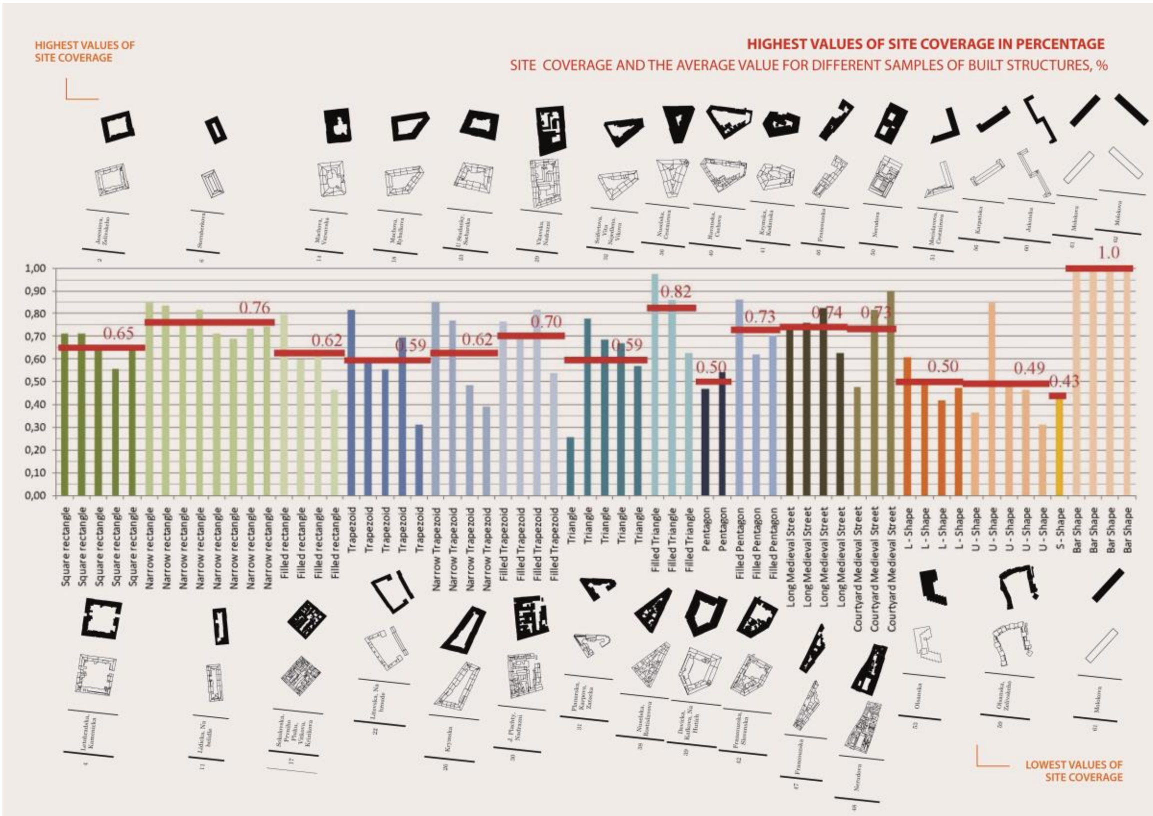

Figure 44 Site coverage and the average value for different samples of built structures, %

The average value of site coverage (Figure 44) reaches the maximum value for the bar or tower-shape buildings since there is no closed or semi-closed courtyard available. For all typologies, perimeter blocks' coverage ratio is the highest for the filled structures and for the urban patterns with narrow units. The two groups of the medieval streets have high values of site coverage.

The courtyard buildings are the ones who have the lowest ratio of site coverage, explainable by the space in between, which reaches the minimum value with the "U" shape. Also lower values can be seen also by the Pentagon Shape as can be seen from the graph. Narrow rectangles and other shapes of similar typology also have a site coverage ratio. The site Livitowska has one of the smallest values of site coverage. The pentagon shape at Devicka na Kafkova, na Hutich, has the lowest value of site coverage, explainable by the large courtyard which this block has.

Fig 44. Devicka na Kafkova, na Hutich (https://mapio.net/s/58270208/)

6.5 Comparison between the three parameters.

For every type of urban pattern, the average values of the site coverage, incident solar radiation and surface-to-volume ratio are calculated. The overall information is presented in Table 24.

Table 24 The average values of the site coverage, surface-to-volume ratio and incident solar radiation for different samples of built structures

Typology	Site coverage, %	Surface/Volume ratio, m^2/m^3	Incident solar radiation, kW/ year
Square rectangle	0.65	0.48	325121
Narrow rectangle	0.76	0.46	351428
Filled rectangle	0.62	0.40	281361
Trapezoid	0.59	0.40	342066
Narrow Trapezoid	0.62	0.46	365759
Filled Trapezoid	0.70	0.44	365840
Triangle	0.59	0.38	377705
Filled Triangle	0.82	0.39	356173
Pentagon	0.50	0.48	299245
Filled Pentagon	0.73	0.59	374500
Long Medieval Street	0.74	0.47	309025
Courtyard Medieval Street	0.73	0.30	175752
L - Shape	0.50	0.28	276869
U - Shape	0.49	0.33	269258
S - Shape	0.43	0.38	204731
Bar Shape	1.00	0.29	393370

The diagram given below allows the evaluation of the relationship between the type of urban pattern and site coverage, surface-to-volume ratio and incident solar radiation. The most energy efficient urban pattern is characterized by a low surface-to-volume ratio and a high level of received solar radiation. The site coverage is the parameter which is usually established in the urban standards. According to the way of estimating the site area for the sample cases, the lowest site coverage is preferable. The optimal value found in Figure 45 represents a combination between the three parameters.

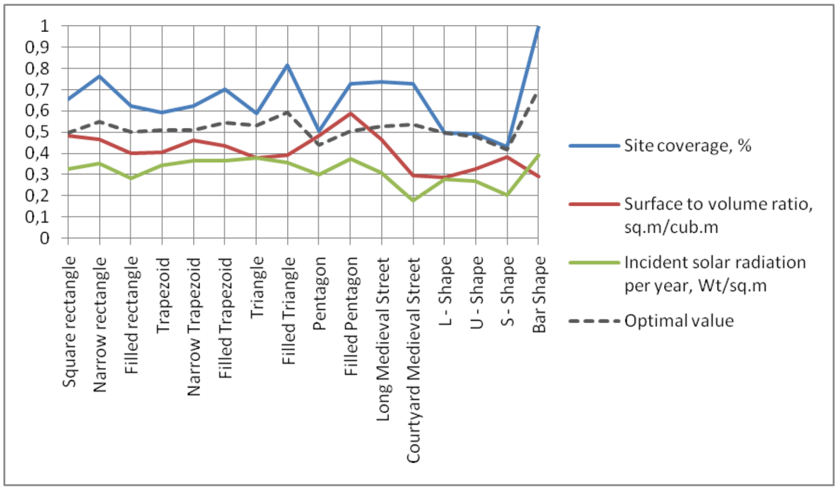

Figure 45 The relation between the average values of the site coverage, surface-to-volume ratio and incident solar radiation for different samples of built structures

According to the analysis, the energy performance of the perimeter blocks is higher than the one of simple-shaped buildings. Among the perimeter block patterns, the ones with irregular orientation of sides such as triangle blocks and trapezoids are more preferable. The perimeter block with a smaller number of sides has a higher potential than the one with more sides, such as a pentagon. The parameters of the medieval street are comparable to the ones of a rectangular perimeter block.

Within the study, the energy performance of different built structures which represent the typical units of various urban patterns of Prague was evaluated. The analysis proceeded from the evaluation of the three parameters including surface-to-volume ratio, site coverage and incident solar radiation in order to find the parameter which would characterize their optimal relationship.

From the three main subcategories of the urban patterns, the European perimeter block has shown a higher solar access than the medieval street and the simple shape units. Within the four geometrical shapes of the perimeter block, the highest performance is found for the triangle, the structure with the lowest number of sides. There is a connection between the physical shape of the unit and its solar potential. The blocks based on the use of the inclined grid are more preferable, then the rectangular ones. The bar and tower buildings demonstrate the highest surface-to-volume ratio and the highest solar incident solar radiation.

The study is based on the evaluation of the virtual models of Prague, which leads to some limitations, based primarily on the quality of the building models which are provided. The computer simulations are conducted for the individual built units, and the influence of the real urban environment such as trees and other buildings is neglected. The amount of the solar radiation which is absorbed by the building depends on the physical properties of the walls such as materials used and the number and character of the openings. Evaluation of the potential of the building shape for the gain of solar radiation and the mitigation of energy losses is an approach towards the reduction of the building energy demands together with the quality of the building design and systems and the environmentally-aware behavior of the inhabitants.

CHAPTER 7

CONCLUSION AND DISCUSSION

7.1 Conclusion

Prague is very rich in urban forms with different layers of urban patterns, starting from the European City Block to prefabricated row-houses of the communist era buildings, to postmodern typologies, thus it is an exemplary site for the experiment. Different urban patterns in Prague, including urban patterns of different morphological properties and models from triangular patterns to hexagons, and from row housing to towers and perimeter blocks are compared through the four-fold properties of energy efficiency.

In order to find the influence of the geometrical parameters of the urban patterns on its energy efficiency, this study starts by generating of a set of hypothetical models or archetypes of urban pattern which may create possibilities for further testing or computer simulations. At this stage, some other properties which work independently of urban geometry such as occupant behavior, thermal-insulating materials or human feeling of the temperature are omitted. These properties, although important, are dismissed as not being part of the focus of this study, and are more culturally, politically or standard-oriented.

60 generated patterns in the variation of 1-10 stories include the following typologies:

- Point Block, rectangular grid
- Slab block, rectangular grid
- Perimeter block, rectangular grid
- Point Block, circular grid
- Slab block, circular grid

- Perimeter block, circular grid

The thesis is based on an investigation of possibilities to define the criteria and parameters of energy efficient urban patterns which when understood make it possible to generate computer algorithms that optimize the relationship of morphologic properties to solar radiation, surface-to-volume ratio, density and wind exposure. The algorithms or form generators could be used in designing the cities of the future or scanning and analyzing existing cities. The concept further advances the ideas of parametric urbanism in an era where information technology could help us as a tool to improve cities and urban form not only perceived as half-hazardous or cosmic (historical cities), rational cities (Le Corbusier and the modernist movement), capitalist or based on maximizing profit for developers, but as a city of dozens of optimized algorithms which generate an optimized city which could be energy efficient and socially and economically viable in the threshold between open space and built form.

Energy efficient properties of urban patterns are analyzed through different properties such as density and site coverage, surface-to-volume ratio, annual solar radiation, wind sheltering factor, building dimensions and geometry.

7.1.1 Density and site coverage

Density is a key parameter in understanding the energy efficiency potential of the urban patterns. The highest efficiency is usually associated with the highest density, which means at the same time reduction of the length of the urban road networks, reduction of the network of energy supply, and a rational organization of the urban space. There is no direct connection between the density and the height of the building. At it is seen after the comparison of 60 generated patterns from 1 to 10 floors high, for the square- and rectangle-based buildings, density is increasing only up to 5 floors. The density is clearly increasing with the increase of the building height for the patterns which are based on the use of the rectangular and trapezoidal perimeter block. At this stage, it is important to understand that the building height cannot grow without limits. Tall buildings are negatively perceived by inhabitants. An increase in height requires the increase of the space between buildings, which results in the existence of wide streets and large areas with the dimensions which are far from a human scale.

For every generated urban pattern, the site coverage ratio decreases with the increase of the height of the building. The highest values are noticed for the rectangular and trapezoidal perimeter blocks, and the lowest values characterize the patterns generated by square-based buildings. Site coverage is restricted by urban regulations and for all the low-rise and especially single floor building patterns, it is at least 60%, which is usually not permitted.

The task of finding the variety of urban patterns with the maximal density was investigated at the second stage of the research. The dimensions of the same six generated patterns were set as flexible. With the application of genetic algorithm, the set of the most optimal solutions for the given site was found. The conclusion from the first stage, that the highest density is typical for the rectangular and trapezoidal perimeter block patterns, is proven by the results of optimization. The optimal density is achieved by the application of the 6, 7 or 9 floor buildings though the width of the units may vary slightly. According to this statement, there is no need to use the buildings with maximal height in order to achieve maximal density. For Prague models the density calculation of the built space was complicated by the fact that real buildings could have different heights of floors and floor plan configurations at different levels. Therefore, in this case the site coverage is a value which is more objective. The average value of site coverage reaches the maximum value for the bar or tower-shape buildings since there are no closed or semi-closed courtyards available. On the other side, it is an indicator of the lack of private space which is associated with the specific building. For rectangular, triangular and trapezoidal perimeter blocks, the site coverage ratio is the highest for the filled structures and for the urban patterns with narrow units. In this case it may be observed, that the inner courtyard of the built unit is filled by one or two floors of uninhabited structures which reduce the private open space. The two groups of the medieval streets have the highest value of site coverage.

A high level of density for the urban pattern is associated primarily with the economy of resources and energy. For the real urban situation, the connection is not direct. The statement that higher density may minimize energy losses is valid only for the generated abstract models, where the distance between buildings is set to provide the minimal solar obstruction angle of 45 degrees. In this case the building received the maximal solar radiation. In the real city, the distances are smaller in many cases and buildings may cast shadows upon one another. The balance between energy gains and losses will be different.

7.1.2 Surface-to-volume ratio

More surface exposure means more thermal energy exchange. Thus, it is considered highly efficient to expose less surface area. Urban patterns vary greatly in this regard so it was necessary to understand these variations well. High surface-to-volume ratio shows the potential heat losses though the external surfaces of the building. The more compact the outer envelope of the building is, the smaller the surface-to-volume ratio is and therefore the better is its energy performance.

60 generated models of the six basic typologies are designed in a way that the built unit has a simple box-like shape, or in case of the perimeter block – the perimetric trapezoidal or rectangular building with open courtyard. At this stage, it is easy to conclude that the surface-to-volume ratio and, therefore, the potential energy losses of the perimeter block are higher than the compact building due to the presence of a void. The performance of the rectangle-based perimeter block pattern is better than the circular-based pattern. For the tower and slab block patterns the surface-to-volume ratio does not depend of the type of the spatial arrangement – rectangular or circular. The highest surface-to-volume ratio is found for the low-raised buildings, which makes this typology less energy efficient. The ratio decreases with the growth of the physical dimensions of the buildings, which shows the bigger and taller buildings to be more efficient. The pattern of the tower unit has the highest ratio, which shows that type of urban development as having the lowest efficiency.

Minimal surface-to-volume ratio was used as a parameter for the optimization of morphological properties with the use of a genetic algorithm. The lowest ratio, the lowest potential energy losses and consequently better energy performance was demonstrated by the perimeter block patterns. The optimal dimensions of the perimeter block in application to the given site are relatively small: 70mx70m for the rectangular unit and 64mx69m for the trapezoid and the optimal height - 10 and 8 floors respectively. This correlates with the conclusion from the previous phase that it is not necessary to apply maximal dimensions to the buildings in order to achieve density and minimize the energy losses. For the units of tower and slab block patterns, dimensions tend to be maximal, but the use of the specific site provides multiple solutions with the best fitness value.

In the case of the Prague examples, the minimal surface-to-volume ratio is registered for the simple-shaped contemporary build structures. These buildings are characterized by the use of the compact volume with a simple geometry, a flat roof and a lack of building details. The parameters of the variations of perimeter blocks, such as square, rectangle, triangle and trapezoid are similar. Examining the variations between the geometries of the perimeter block, the pentagon shape demonstrates a higher surface-to-volume ratio, making it less efficient. The triangular perimeter block may be considered as the most compact structure with minimal energy losses. The specificities such as the distance between the two buildings which formed the courtyard, or the narrowness of the pattern and the level of courtyard infilling, slightly influenced the overall performance. The long medieval street has a performance equal to the perimeter block groups, while the courtyard medieval street is closer to the contemporary structures.

It is important to note that the surface-to-volume ratio cannot be observed as the only parameter which affects the energy efficiency of the urban patterns. It indicates the potential energy losses, but there are also potential energy gains of solar radiation. In this case it may be predicted that the perimetric perimeter block will always cast a shadow on to one of its walls, which will reduce the possible energy gains.

7.1.3 Annual solar radiation

Solar radiation indicates the energy which is received by all the walls and roofs of the built units of the urban pattern. The higher level of received solar radiation indicates the pattern with higher energy gains, which gives to it the potential to be more efficient. The computer simulation was conducted for the 60 generated urban patters and for the 64 samples from Prague.

In the first stage of the research, the results of the simulation show the perimeter block performs worse in comparison to the other generated patterns. Both circular and rectangular perimeter block patterns receive less solar radiation, which can be explained by the complex shape of the building with the courtyard that causes an extra shading of the walls. Incident solar radiation increases with the decrease of the building height for all cases. The relation is not linear and can be explained by the adaptation of the distances between units according to the heights in the generated model. For the two patterns based on the use of the square-based building and for the circular perimeter block pattern, there is a segment between 3 and 9 floors where the difference in values is minimal.

In the case of the Prague examples, the solar energy which is received by different typologies of perimeter blocks is higher than the one of the contemporary simple buildings. The blocks with the irregular orientation of sides, such as triangular or trapezoidal are more preferable than rectangular. The structures with an open courtyard gain more radiation than the ones with the filled one. The medieval street structures perform the worst. For the contemporary buildings, the simple bar or tower-like building is more efficient than the L-shape or U-shape.

7.1.4 Wind sheltering factor

Simulation of the virtual wind tunnel was conducted for an analysis of wind performance of 60 generated urban patterns. The acceleration of wind speed is connected to a decrease in air temperature and accompanying potential energy losses. The study was based on the presupposition that in the conditions of central Europe, it is preferable to create the wind shadow and therefore to prevent the cooling of the building surface by air flow. As a result, the images of the behavior of different urban patterns allowed us to select the ones which are more preferable for wind sheltering. **Wind performance is different depending on the urban morphology.** For instance there are some hotspots of wind where the speed arrives to more than 10 meters per second or more. Generally, the perimetral block for instance creates a windbreak and wind-sheltering which is very important not only for the inhabitants, but also for the lifestyle in the city. Cases like Scotland where the inner courtyard, protected from wind, but exposed to the sun, show the importance of having a lifestyle with a courtyard. Other cases can be noticed in Italy, France, or South Mediterranean.

In both rectangular and circular form, low story buildings create a wind shadow for the entire examined area. Up to 5-6 floors the wind speed is still lower than the average, but for the high-rise buildings it is significantly higher, resulting in the appearance of wind tunnels between the buildings. The wind speed accelerates more than average along the perimeter of the patterns, indicating the necessity of additional thermal insulation and wind protecting membranes in the building facades. In the circular pattern, this phenomenon is more evident.

7.2 Discussion: building geometry and energy balance

The study is based on the search of the balance between the energy losses and energy gains of the morphological properties of urban patterns. In some cases, the requirement which may enforce one of the elements of this equation, will contradict the other. Nevertheless, it is possible to draw the general set of rules, which may be applicable for different urban solutions.

Low energy losses characterize compact urban structures with high density. For the simple-shaped box-like buildings, the highest reasonable level of density is achieved for the built units of 5 floors. The same height is the best solution for the wind sheltering. Simple-shaped buildings have a low surface-to-volume ratio which decreases with the increase of height and perimeter of the building. In this case, it is important to note that building dimensions cannot increase endlessly; building height is usually controlled by the urban regulations and building width is accepted according to the necessity of direct lighting of the rooms. Potential energy gains of the simple-shaped buildings are higher. Incident solar radiation decreases with the increase of the building height, but it may be noticed that it remains stable from floors 5 to 7.

The perimeter block demonstrates an increase of the density with the increase of the building height. Application of the genetic algorithm allowed the identification of its optimal dimensions. In order to minimize the energy losses, the side of the perimeter block should be about 60-70m. The perimeter block demonstrated the best results in its ability to create a wind shelter. The courtyard remains protected with the use of the building of any height. Meanwhile, in order to create a comfortable flow through the streets, the height of the built unit should not be more than 6-7 floors. The energy gains of the perimeter block are smaller than of a similar pattern which is combined by the simple-shaped buildings.

The study had been developed based on the climate conditions of Central Europe with the condition of a maximization of energy gains and minimization of energy losses. In order to apply the theory to a different place, the balance between these two factors should be changed according to actual climate conditions. Thus, in severe north conditions where the issue of minimal energy losses dominates, compact building shapes and creation of the wind shelter prevails over the potential gains of solar radiation since the intensity of northern sun is very low. In moderate climates, the issue of wind protection may be less important, but in wet climates natural ventilation should be encouraged. In hot climates, the situation is reversed and the built form should be designed in order to maximize the energy losses and maximize the shading. The building shape in this case becomes less compact and more porous.

Selection of the type of urban form depends in every case not only on the requirements of energy efficiency, but on the urban context, climate, tradition and other factors. Different typologies from the individual houses and slab blocks to the residential towers can be applied within the borders of one city, but the factor of selection of the morphological properties with the correct balance between the energy gains and losses can advance the urban planning towards more sustainable solutions.

7.3 Overview of research contributions

This study has focused mainly on delineating, understanding and analyzing the major contributions to energy efficiency on the urban scale and focusing on particular properties such as density, surface-to-volume, solar exposure and wind performance and their relationship to urban patterns. The study brings together a thorough understanding of these properties after an analysis of the state of knowledge of existing literature was conducted. Thus, this research brings together for the first time all these factors which were studied apart from one another and with fragmented methodologies.

Many simulations were done on the city level through an analysis of Google earth models of existing urban patterns of Prague, which itself is an innovative tool using 3D satellite drawn models and hypothetical examples. Computer simulations were performed over various morphological properties to understand the best conditions and performance related to density, surface-to-volume, wind performance, and solar exposure. The results were described in chapters 4, 5 and 6.

This study creates a bridge between the pioneer ideas of algorithmic urbanism which are preparing the ground for future hyper-dense cities where millions could live with optimized living conditions, with a more practical but also a narrower concept of Energy Efficient properties of Urban Patterns. Taking Prague as a Case Study, an analysis was made of about 50 different existing urban patterns and other hypothetical examples generated through scripting in a second phase.

The results could be used in estimating the energy performance of existing cities, generating information for making decisions as to which urban patterns could perform better, which areas to preserve and if there would be a choice as in the case of shrinking cities. In future growth, intelligent city structures and urban patterns could be generated using a set of criteria which may overlap with other social, economic and environmental decision-making. Energy efficient urban form could be generated through these set of algorithms.

Although the results of this study were mostly on a narrow spectrum of parameters precisely searching for minimal surface to volume, maximal solar exposure, wind sheltering and appropriate density, the research may be taken forward in many ways.

First of all, the extrapolation of 3D Urban Patterns from Google Earth 3D and performing computer analysis of different cities is in itself something new and a methodology that might be used further, especially on the city scale.

Second, the 45-degree rule, is nothing other than an application of parametric modeling to actual city regulations, in the particular case, the height VS distance according to the building regulations in Prague. The methodology maybe used since its principle is, to “accept” and freeze certain algorithms, which are fixed, such as the 45-degree rule, and to further elaborate other relationships. Even the same methodology could be used to investigate whether the 45-degree rule is at all the best algorithm for solar exposure according to different geographic zones.

Third, surface economization and reducing waste goes along with the principle of low surface to volume. In this regard, how to tackle surface economization on the city scale could be one “big” topic which could be investigated further and which could simply use the methodology of this thesis.

Fourth, wind performance in parametric modeling may be quite revolutionary especially in controlling and improving the airflow to avoid pollution and lower CO2 levels and so forth.

Fifth, Solar Exposure, a more solid investigation of build form and solar exposure, or built form-photovoltaic materials, and solar exposure could be conducted following the same principles of the methodology used in this thesis.

It is understandable that in order to provide "good cities" it is necessary to improve a lot of relationships between parameters, where the parameters mentioned above have only a partial role. Nevertheless, the theoretical approach and methodology used for this thesis could potentially open the path for further investigation. Just such an approach is described more in detail below.

7.4 Future research

Cities create the conditions of spaces where all social interactions occur. The overall population of cities has now reached 50 percent of the World, and it is predicted, by 2050, to rise to as much as 70 percent. Taking into account population growth, this means we will have 7 billion people living in cities in 2050. Sometimes existing cities just expose their incapacity to handle the growing number of people living in them. Mobility problems, environmental injustice, lack of technological capacities to ship the products, social violence and marginalization, disparity in education and sport and recreation facilities, and a lack of jobs are some of the phenomena that emerge and manifest themselves in today's cities, accompanied by other social problems.

It reminds the quote from Bruce Mau in his book "Massive Change" that for most of us "the design is invisible, until it fails" the word design, in the meaning of how cities are framed, organized and what are the algorithms behind that complex organization called "city" (Mau, 2004).

"Bad" design brings with it all sorts of problems from economic disparities to extreme poverty, marginalization, closed neighborhoods and ghettos, or simply walls built to avoid conflict which is inescapable, xenophobia usually due to lack of jobs and opportunities, where "the others" are taking everything, gender disparity, lack of employment, traffic jams, and environmental stress. Research by Newman describes how crime and delinquency is much higher in cities which have no green spaces (Newman, 1972). All the widely-known and agreed-upon theory, which for some reason still needs to be put into practice in many countries, is based on the assumption that the built environment has a tremendous impact on social life.

Indeed, urban planning influences in the society can be seen in various examples throughout history. Let us give one example which best describes the influence of planning where a city takes on a role as an emancipator. Urban planning plays a role as a life-changing instrument in obtaining social balance, equity and an improved lifestyle for everyone.

This new way of designing cities is called "Algorithmic Urbanism." The idea is to use the new paradigm of Information Technology in order to optimize cities through a better design which is guided by software and could improve, for instance, traffic and transportation in general, and where to place hospitals, kindergartens, and other education facilities.

Similar methodologies were used in calculating the allocation for asylum seekers in different Federal States in Germany, calculated each year based on tax receipts and population numbers. The IT revolution could really make a change in today's situation by simply optimizing the way cities are designed or even renewing existing ones.

For instance, the economization of build-material or the low surface to volume ratio, if applied on the scale of the city, could contribute e great deal to sustainability at large. Other properties that might contribute to "good cities" could vary by category, for example related to materials, improved urban design conditions, services or any other sector. The equalized distribution of green surfaces in the city through the creations for small open gardens and improved microclimatic conditions, or optimized distance to green areas falls into the three categories mentioned above. The placement of garbage bins in the city optimized by software that analyses both the population size per neighborhood and accessibility could of course improve the services in the city. The list may be long and ranges from the placement of newspaper shops, to the plug-in connection for using electricity and free wireless in public spaces.

Through Galapagos revolutionary solver a set of parameters can be chosen, such as X, that the choice of parameters is based on the optimal solution (lowest losses) and an algorithm has to be designed in grasshopper, which after running over the optimal dimensions and the type of the urban pattern, the set of the best solutions will be generated.

Nevertheless, as this dissertation shows, the advanced information technology could be used at least in the quantitative estimation, formal analysis and the simulation generation to provide better conditions for future cities. There needs to be a thorough understanding of what "improved conditions" means and whether is feasible to implement. Only then the methodology could be used to investigate those models.

The advanced urban design approach may be oriented towards the optimized urban patterns, which is based not only on the control of balance between the energy gains and losses, but also on taking into consideration different agents, including people, and defining within the algorithm their needs, specifying the climate conditions and cultural trends.

In principle, any parameter that contributes to energy efficiency can be modified, starting from materials, openings, distances, density, surface exposure, wind and sun exposure, and so forth. While this study focused specifically on parameters related to morphological properties of urban patterns focusing on Prague and Central Europe Conditions, other studies could be conducted in the future, perhaps using similar methodologies but with different climatic zones, using algorithmic design.

A new paradigm similar to what Modernism brought may advance greatly and correct existing regulations of Urban Design and architecture using Information Technology. Putting into practice those methodologies is now more crucial than ever in a time of limited resources and an ever-expanding built environment.

What has been done? What are the limitations, what has been resolved and which issues are still requiring attention?

One of the issues that this study has resolved has to do with the indirect implications of urban morphology in energy saving. Why indirect? In each of the cases there is an attempt to measure the differences that are created from urban morphology and variations of urban patterns. There is a strong emphasis that the difference of surface to volume ratio, solar energy exposure, density and wind exposure has a strong correlation to energy efficiency. There is an attempt to emphasize what actually contributes to energy saving, i.e. low surface to volume ratio, high exposure to solar energy and low exposure to wind, and as well as a moderate density, would help in saving energy. Nevertheless this is just a partial answer, so while making evidence that such differences exist that a difference of surface to volume ratio of 0.2 and 0.7 are observed in various patterns in Prague, there is no definite answer as to how much these difference contributes to energy efficiency in each of the apartments. In other words, what would mean an extra 0.1 addition to the "surface to volume ratio" for the monthly energy spending, if all other factors are same? That would need a comparison with energy spending diary database. An indicator such as Kilo Watt per square meter would help, thus there could be a comparison between Kilo Watt per square meters, of different patterns and the surface to volume ratio, which is expected to have a major contribution to energy saving. The same could be said for solar radiation exposure, wind exposure and density. Due to this fact, there is no possibility in analyzing which of the parameters has priority over another and the scale of importance. The pre-supposition is that surface to volume ratio is the most important, by far more important than other factors. A quantitative measure would mean to analyze how each factor results in the Kilo Watt per square meter spend per month/year. That would help in a clearer understanding whether a building facing south, or a building with a minimal surface to volume has priority for energy saving. The fitness value as a method could help, as a concept by analyzing how these parameters interrelate.

In a short description can be said that meanwhile the study puts evidence and compares different properties of energy efficiency in urban scale, it does not conclude on how these external factors contribute to internal energy spending.

Smart cities incentives could be a platform to resemble data and compare figures such as urban patterns with energy spending diaries. The term energy saving would mean strictly, saving on the energy heating demand, for location in continental Europe. This can be seen as advanced in an avant-garde incentive such as "Amsterdamsmartcity" (projects/energy-atlas, 2015). A similar analysis could be done for density and wind simulation (meters per second)

The variations of each pattern are described in the tables and graph. The graphs show the performance of each of the patterns, showing the highest and lowest performance, also indicating the locations and streets in Prague. This contribution relies in the fact of accumulation of previous studies conducted by others and makes evidence of the differentiation between urban morphological changes, manifested in various urban patterns and parameters that indicate a change in energy efficiency. In this regard, there is a description of performance for urban patterns in Prague and hypothetical models. The hypothetical models indeed are used to describe the difference in height, which in fact has a contribution to the layout and density following the 45 degree rule of Prague Urban regulations. Such a test, in fact is an original contribution. Further analysis could be conducted with more typologies, adaptation of typologies of apartments, and other tests which allow for a better approximation with reality.

More can be done in incorporating the analytical tools in a city scale, analyzing each urban pattern and the methodology shows, that with powerful computers such analysis is possible. Such analysis would create a simulation tool in the city scale in such a way that parameters such as surface to volume ratio/incident solar radiation, density or wind performance are scanned and automatically it is known which area of city performs in which way.

Such issues need further attention to see in reality and with further analysis what is for instance the “real correlation” between surface to volume with energy spending, in a given city, and that can be different for different cities of different geographical positions. In this sense, if the city’s data are compared with the energy spending of different neighborhoods, and an automatic correlation is advanced to the next step and the proof that surface to volume ratio is influencing energy spending is clearly indicated. This is perhaps the limitation that this study does not overcome, and that is a cross checking of indicators in the city scale. Such a cross-checking could obviously be completed very easily using the same methodologies and city scale data. Conferences such as Smart City Expo, indicates that there is good will and already incentives moving towards implementation of such methodologies. (smart-city-expo-world-congress-on-13th-15th-of-november-2018-barcelona, 2017)

Incident Solar Radiation simulation in city scale is very helpful in analyzing incident solar radiation in the city and not only for comparing different Urban Patterns, and seeing how solar energy influences energy saving in different neighborhoods, but also where there is more need for instance for placing solar panels, where could be useful to increase the amount of thermal insulation and where could be possible to reconstruct or partially reconstruct existing neighborhoods to make them more energy efficient.

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ATTACHMENT A

60 GENERATED URBAN PATTERNS

The attachment show the 200meters to 300 meters virtual urban model plot and possibility for "population" with build form depending on the urban pattern typologies.

Rectangular and Circular models are used for this purpose. The three typologies are:

- Perimetral Block
- Slab Block
- Point Bloc

On the side can be observed the change in number of floors and height and the apparent decrease of the number of buildings, as well as distances between the buildings. The circular grid while offering a rather utopic standard does partially envision certain zones or areas in the city where such urban pattern are possible. Also the circular grid helps avoiding the cardinal orientation points. Examples of similarity with real urban patterns are shown in the images below:

Annex A- Fig.1 Example of Row Houses from Pendrecht Rotterdam[1]

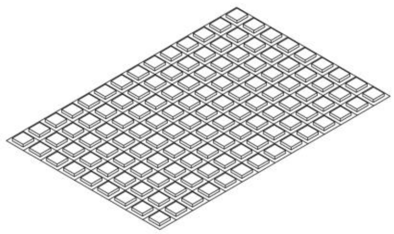
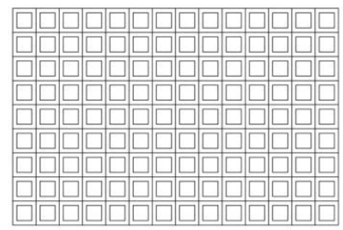
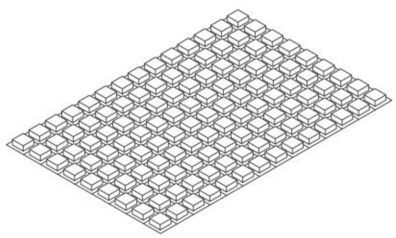
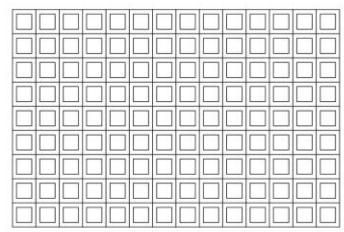
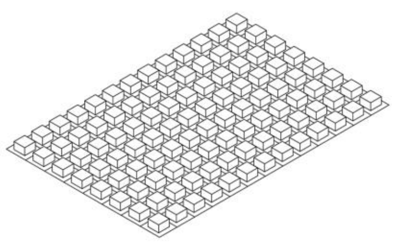
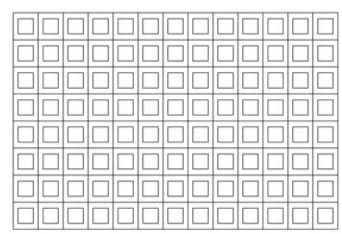
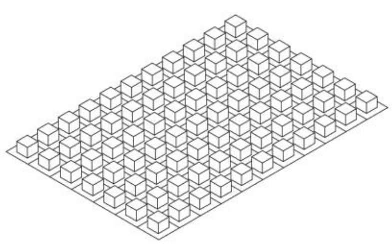
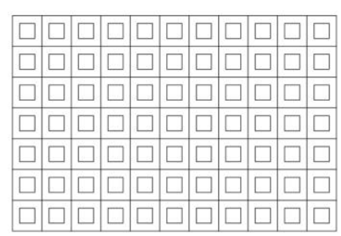
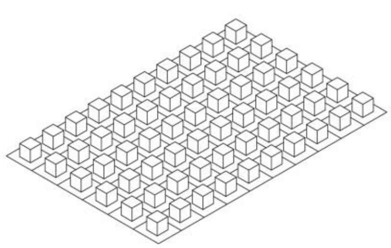
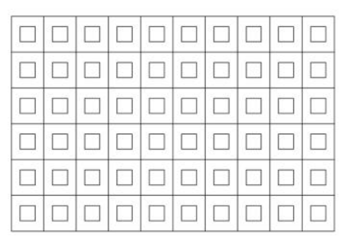
[1]**Kleinpolder, 1955, https://couvreur.home.xs4all.nl/engl/rdam/Architectuur/100jaar/1955.htm**

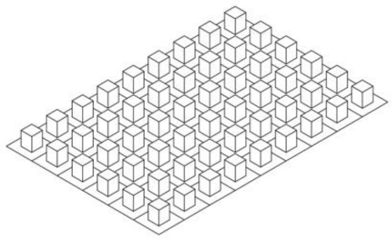
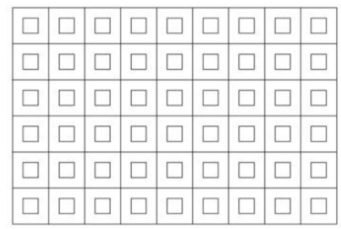
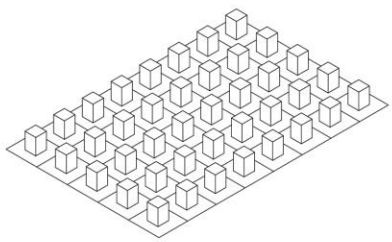
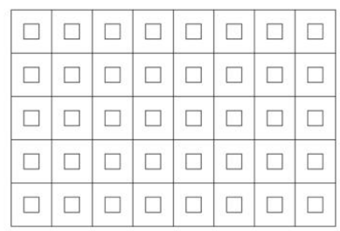
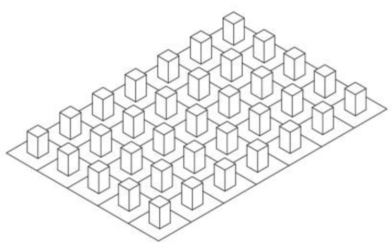
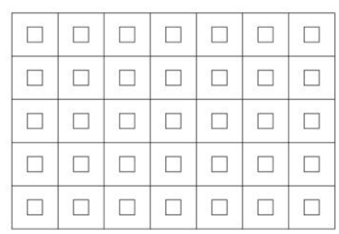
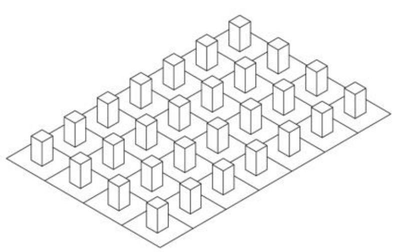
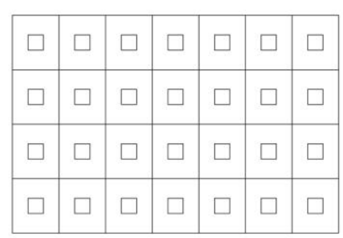
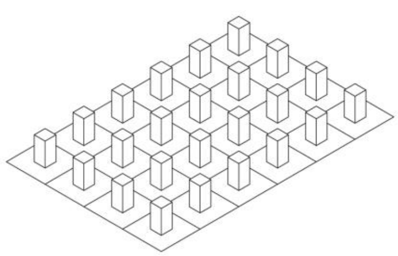
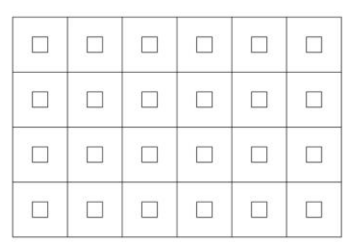
The Example of Pendrecht shows a distribution of urban pattern according to the Slab block example. As for the perimetrical block the example is more common and can be found in most of the cities.

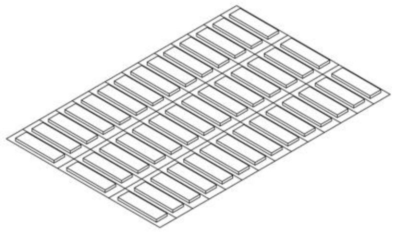
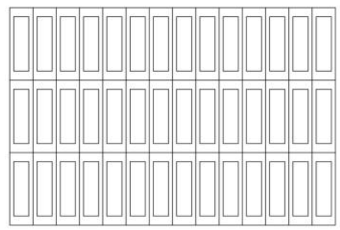
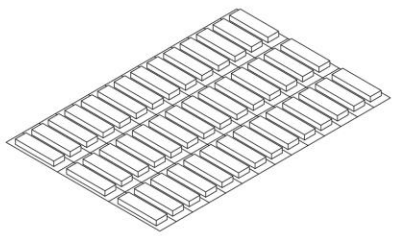
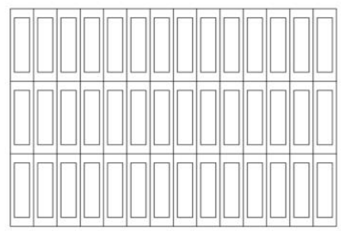
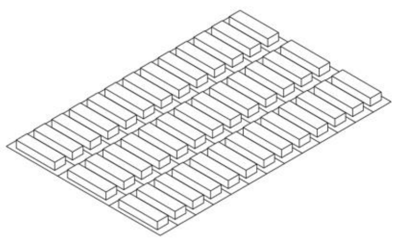
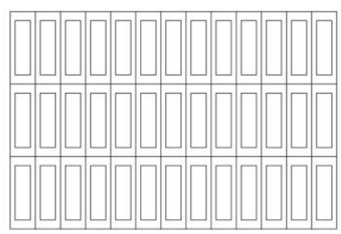
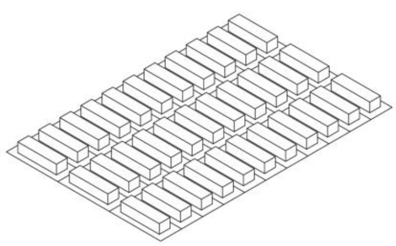
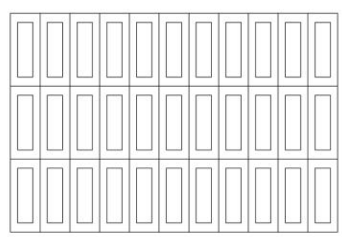
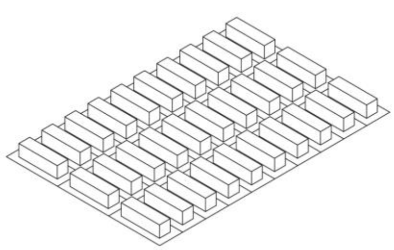
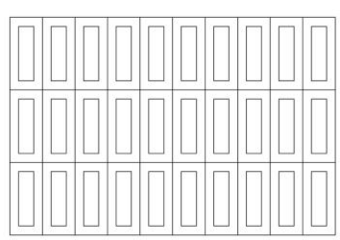
The Circular Pattern virtual model on the other hand, offers a more complex layout, mostly utopic and with limited applicability if the application is taken into consideration as a whole. Nevertheless as the example Circular pattern urban block shows it may have partial similarity with real life situation such the case of European Cities with circular grid.

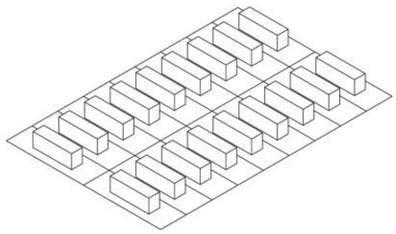
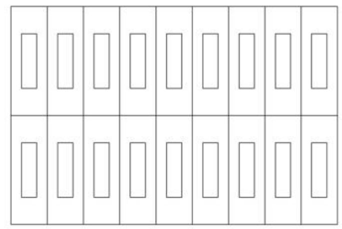
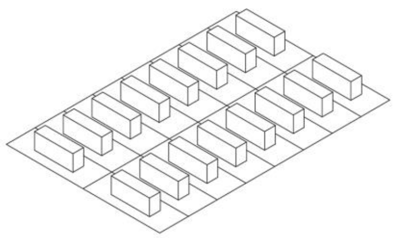
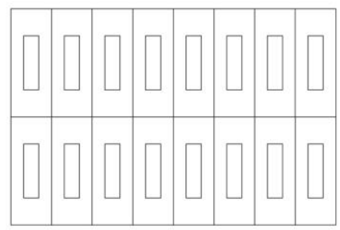
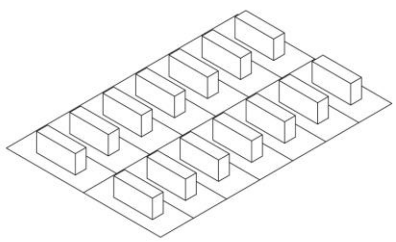
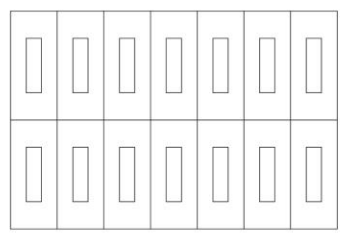
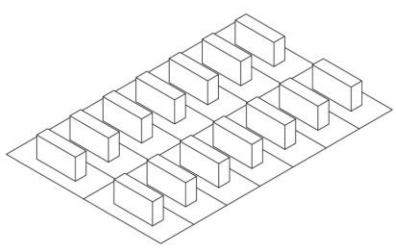
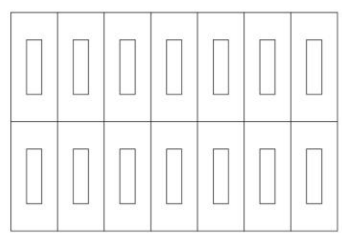
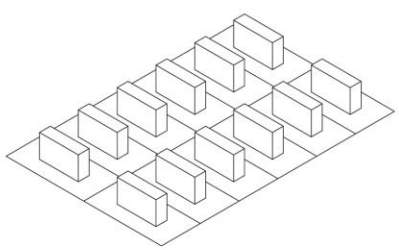
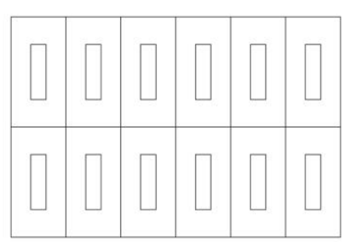
Fig 2- The perfect circle of Charles de Gaulle square in Paris.

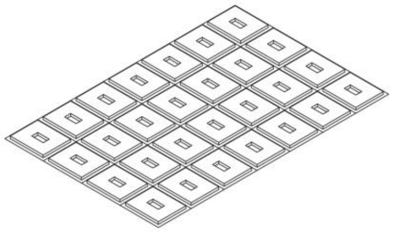
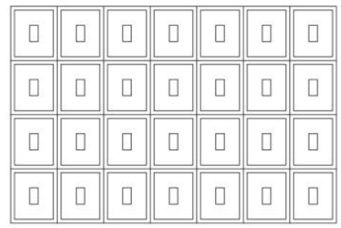
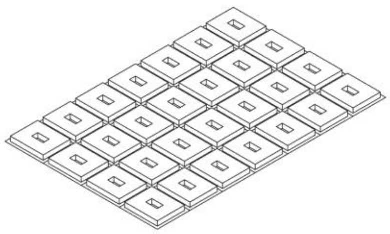
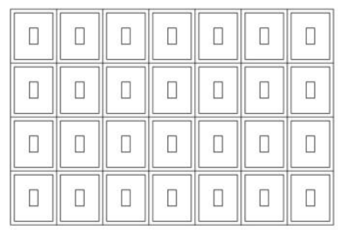
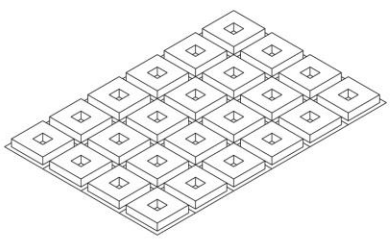
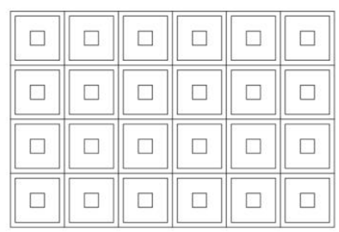
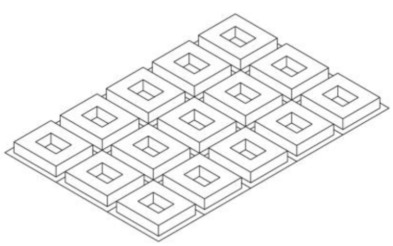
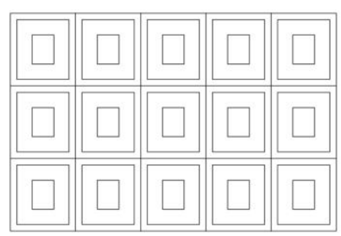
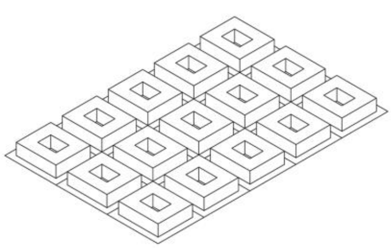
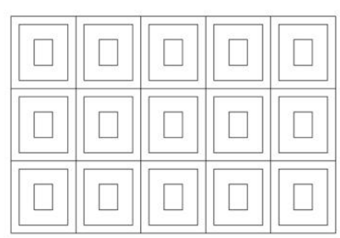
Fig 3- Vinohrady Perimetrical Block Pattern in Prague.

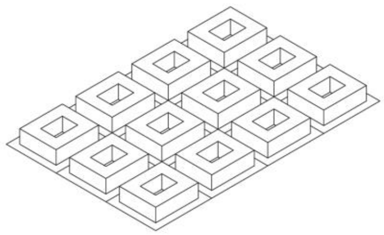
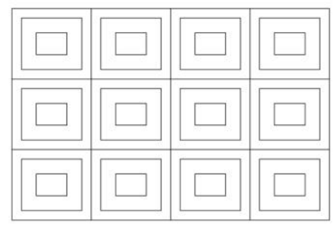
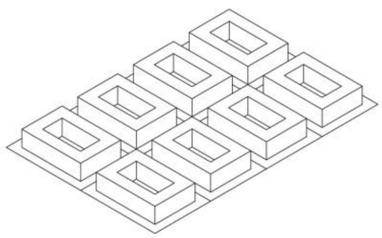
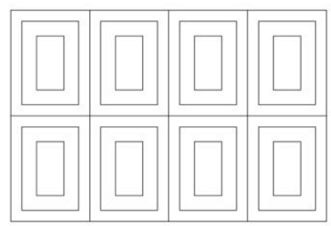
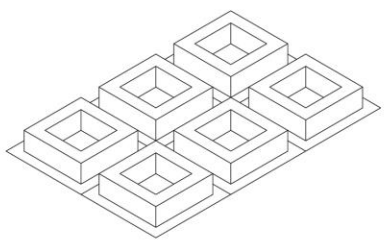
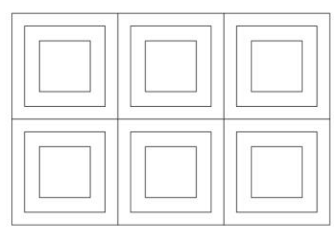
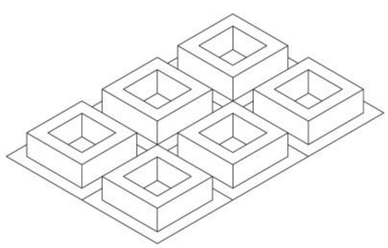
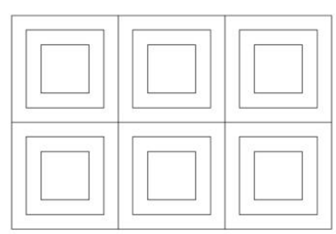
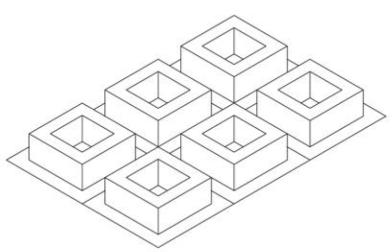
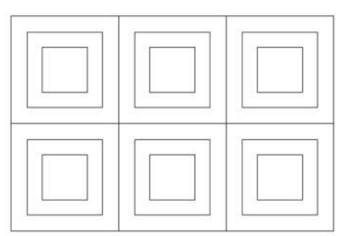
Rectangular pattern. Tower house with square base		
N of floors	Axonometric view	Top view
1		
2		
3		
4		
5		

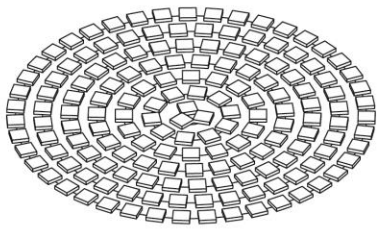
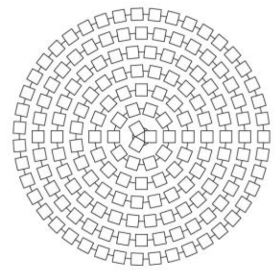
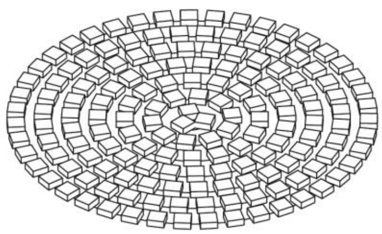
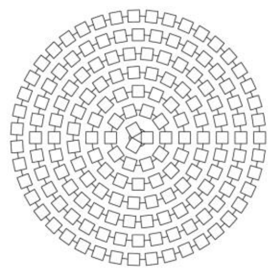
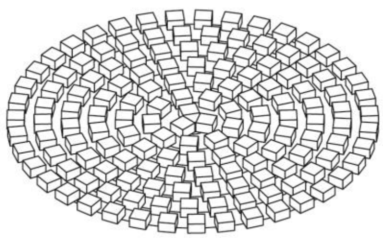
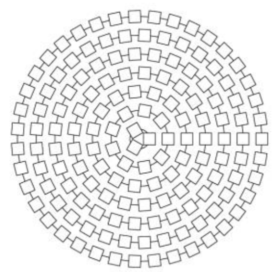
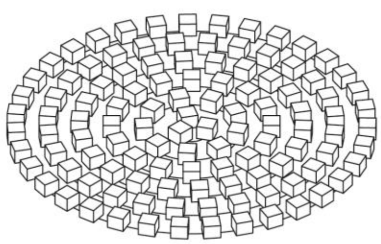
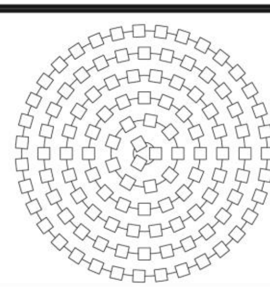
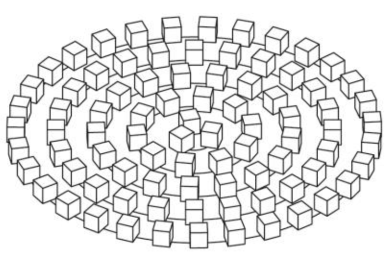
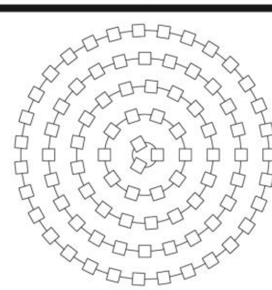
Rectangular pattern. Tower house with square base		
N of floors	Axonometric view	Top view
6		
7		
8		
9		
10		

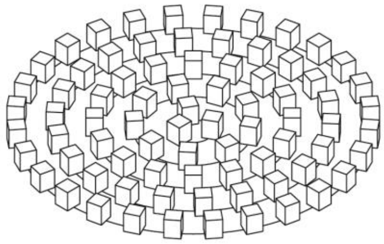
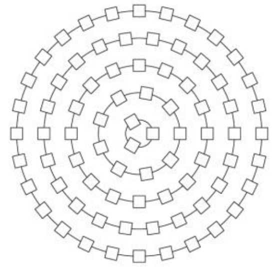
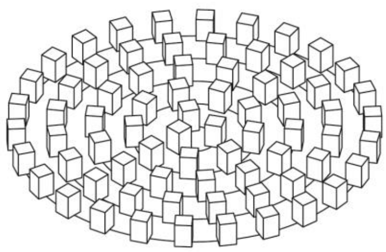
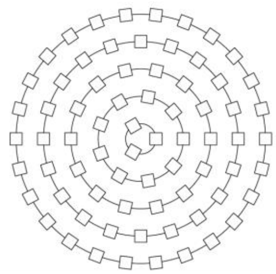
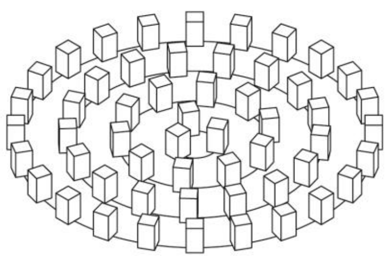
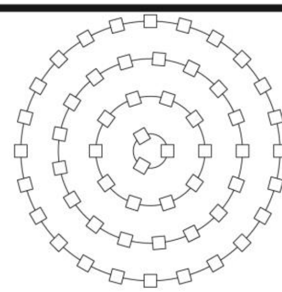
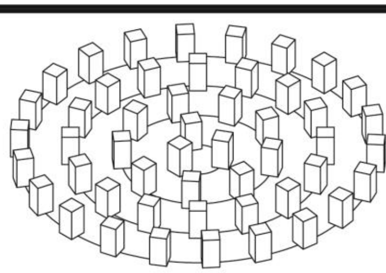
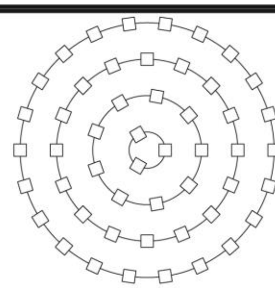
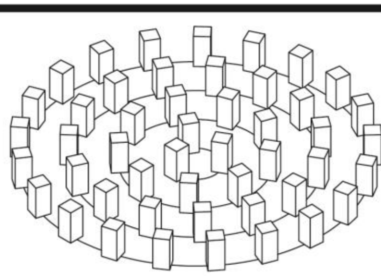
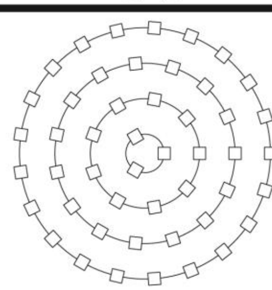
Rectangular pattern. Tower house with rectangular base (row house)		
N of floors	Axonometric view	Top view
1		
2		
3		
4		
5		

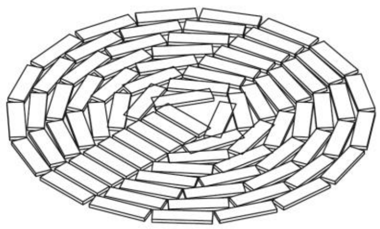
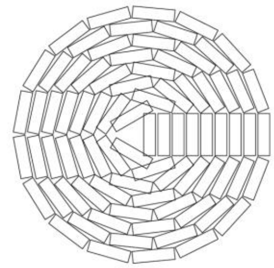
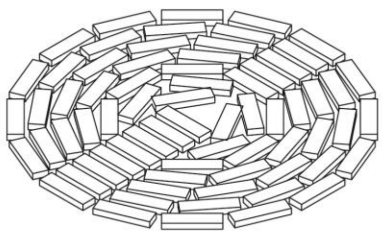
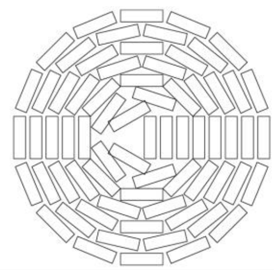
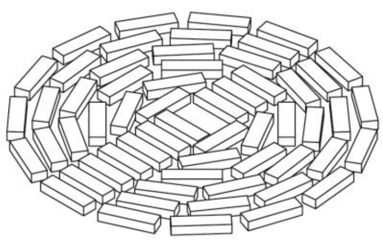
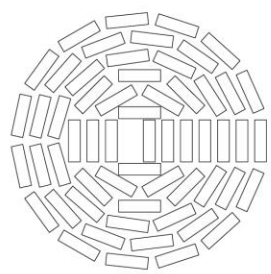
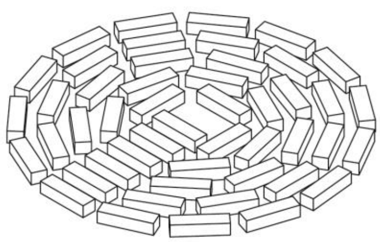
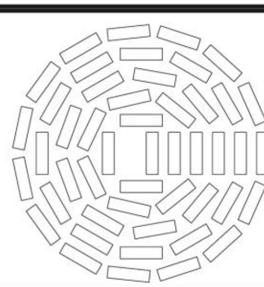
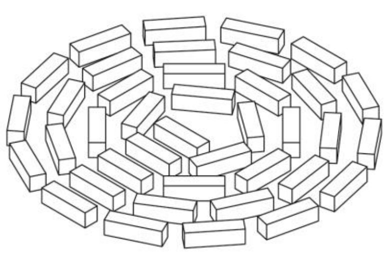
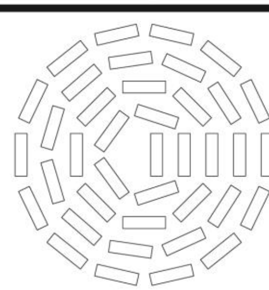
Rectangular pattern. Tower house with rectangular base (row house)		
N of floors	Axonometric view	Top view
6		
7		
8		
9		
10		

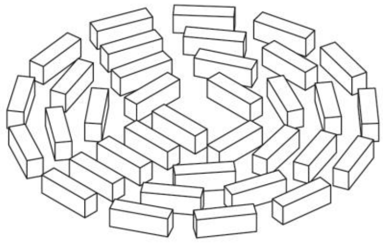
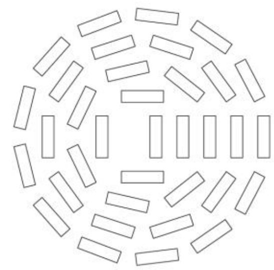
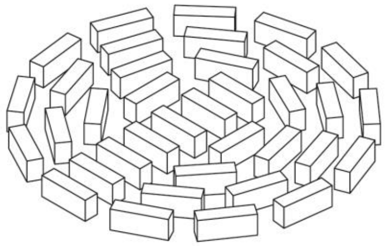
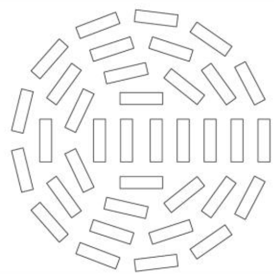
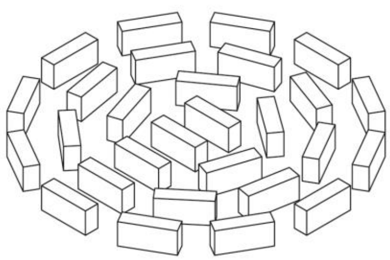
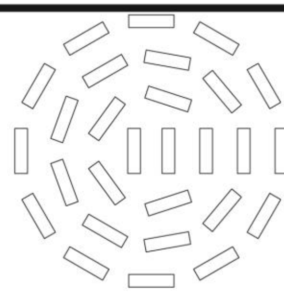
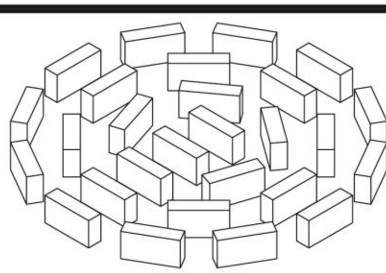
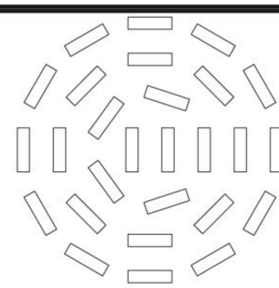
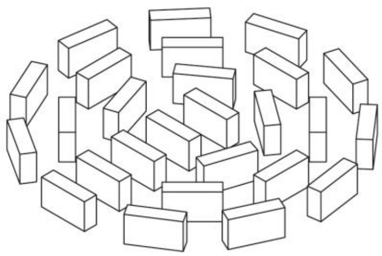
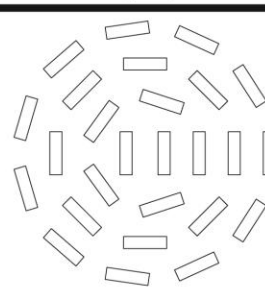
Rectangular pattern. Urban block		
N of floors	Axonometric view	Top view
1		
2		
3		
4		
5		

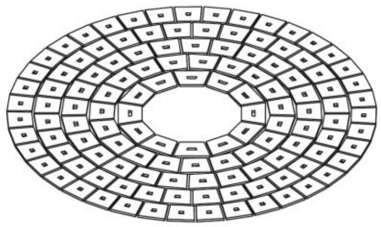
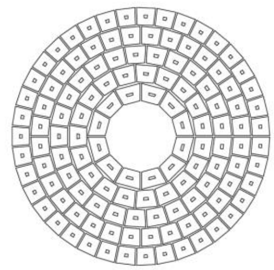
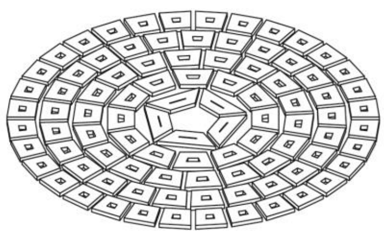
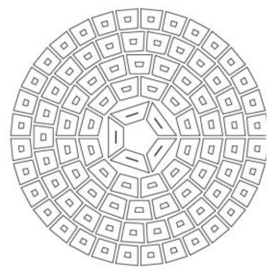
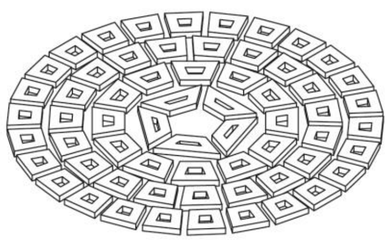
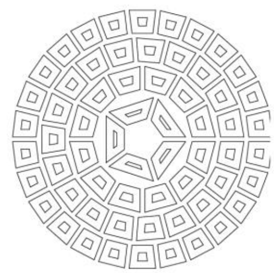
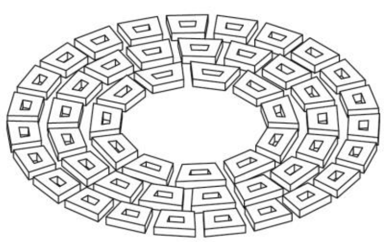
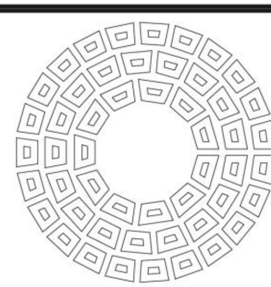
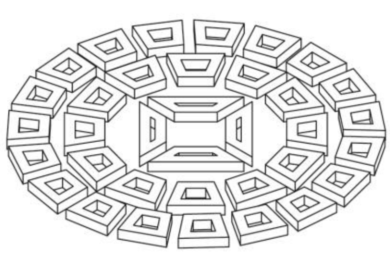
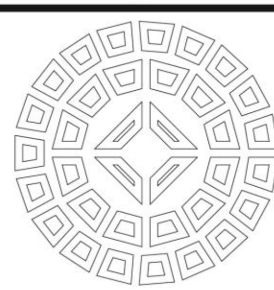
Rectangular pattern. Urban block		
N of floors	Axonometric view	Top view
6		
7		
8		
9		
10		

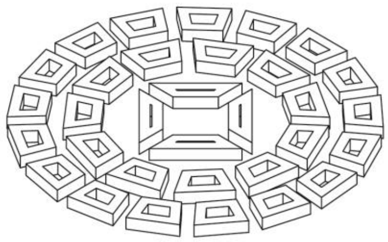
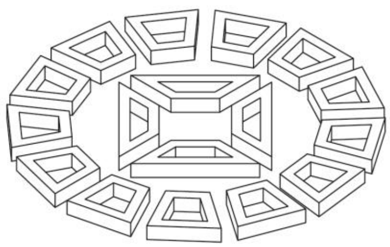
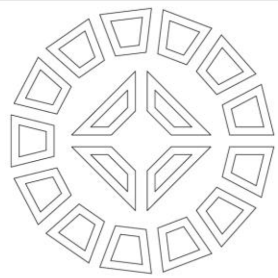
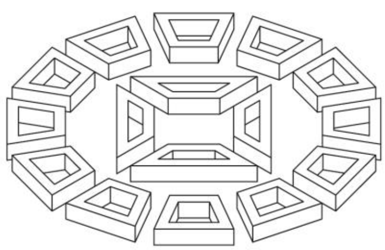
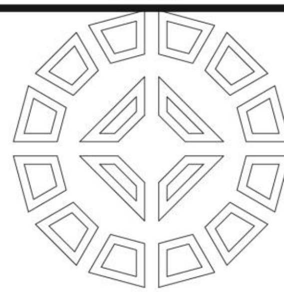
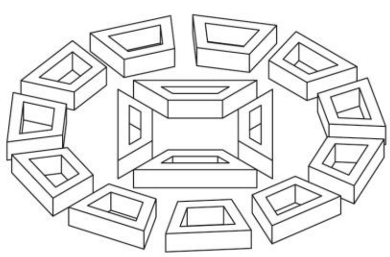
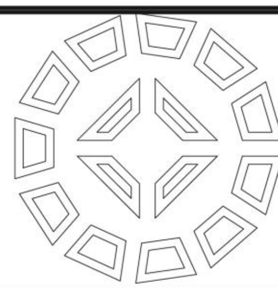
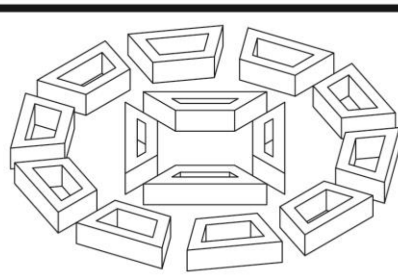
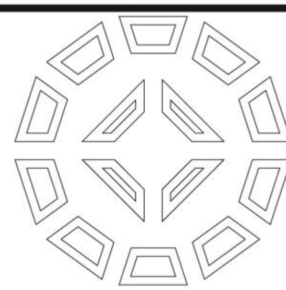
Circular pattern. Tower house with square base		
N of floors	Axonometric view	Top view
1		
2		
3		
4		
5		

Circular pattern. Tower house with square base		
N of floors	Axonometric view	Top view
6		
7		
8		
9		
10		

Circular pattern. House with rectangular base (row house)		
N of floors	Axonometric view	Top view
1		
2		
3		
4		
5		

Circular pattern. House with rectangular base (row house)		
N of floors	Axonometric view	Top view
6		
7		
8		
9		
10		

Circular pattern. Urban block		
N of floors	Axonometric view	Top view
1		
2		
3		
4		
5		

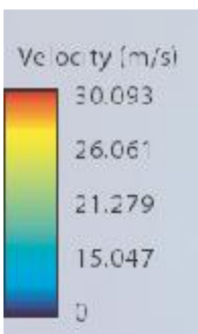
Circular pattern. Urban block		
N of floors	Axonometric view	Top view
6		
7		
8		
9		
10		

ATTACHMENT B

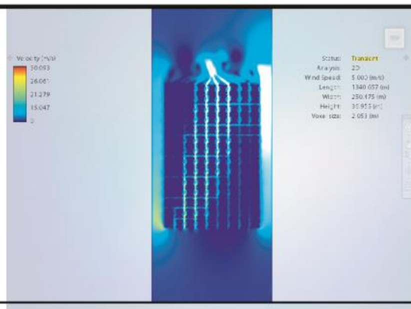
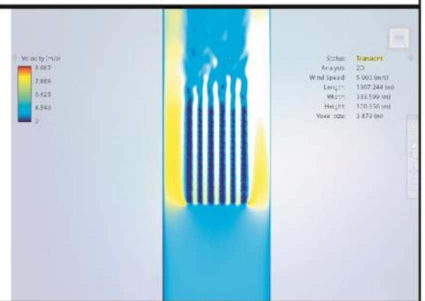
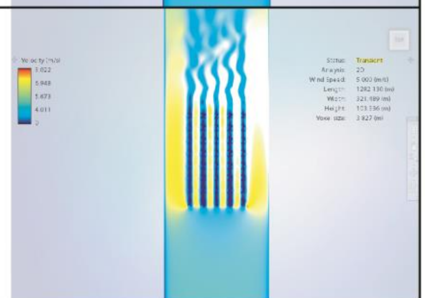
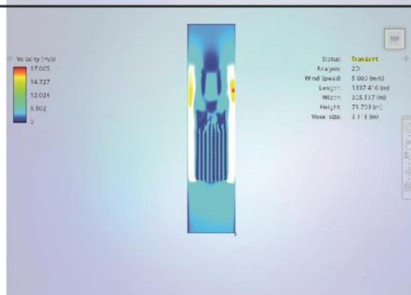
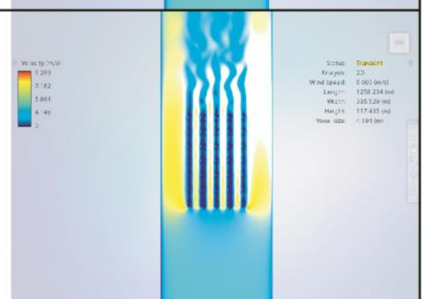
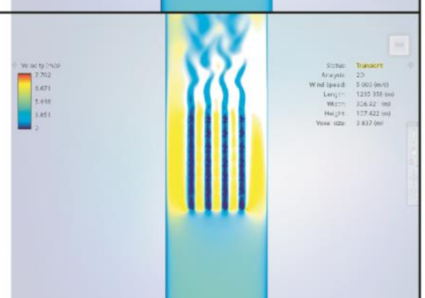
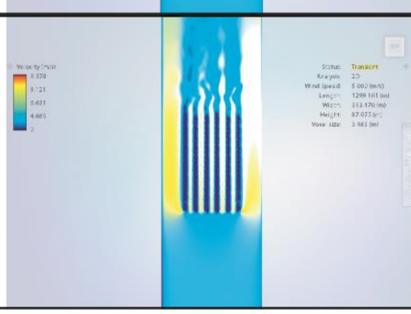
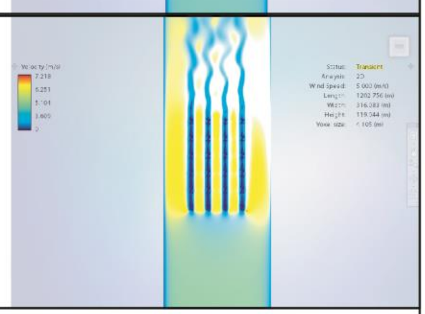
WIND ANALYSIS OF 60 GENERATED URBAN PATTERNS

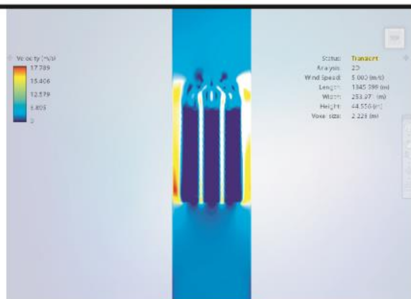
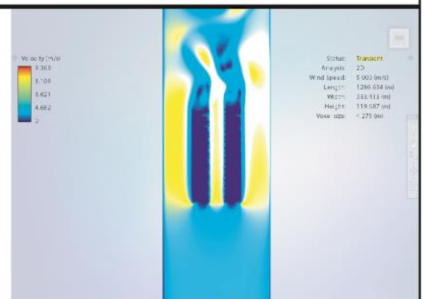
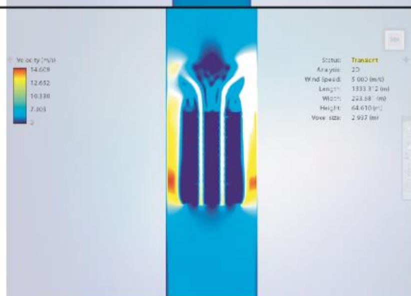
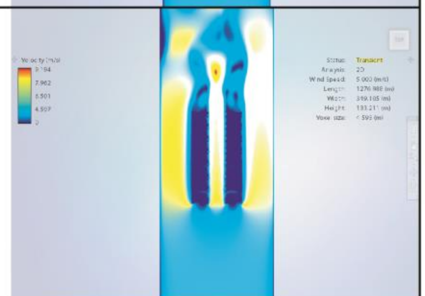
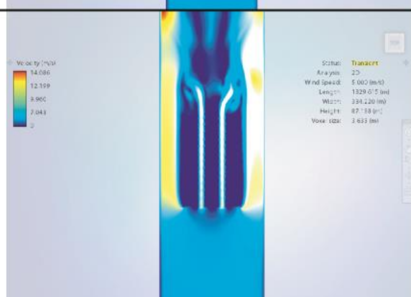
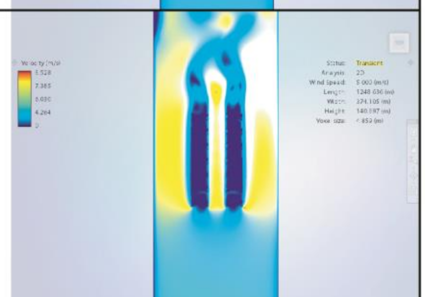
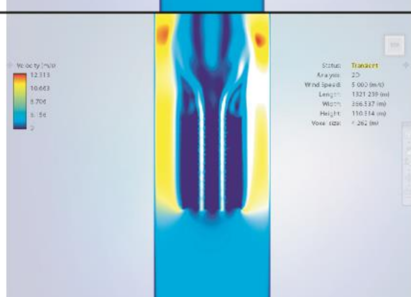
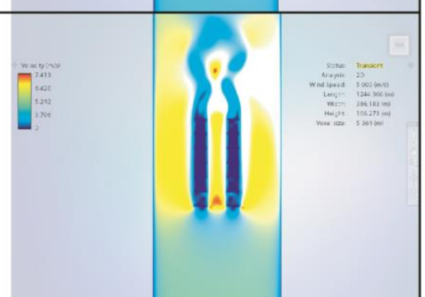
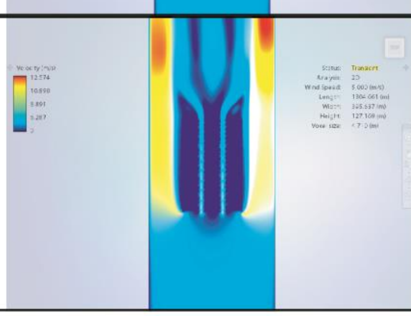
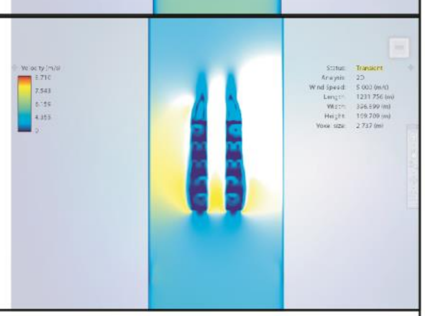
The wind performance is applied using Autodesk wind flow analysis, using a computer program which in fact, can create the simulation the wind performance taking into account the average wind speed of Prague which is 5 meters per second.

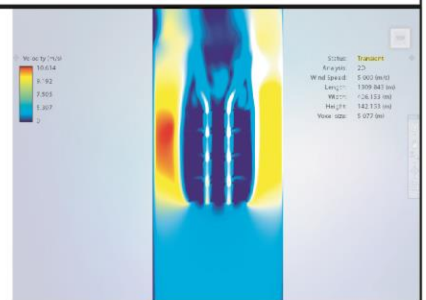
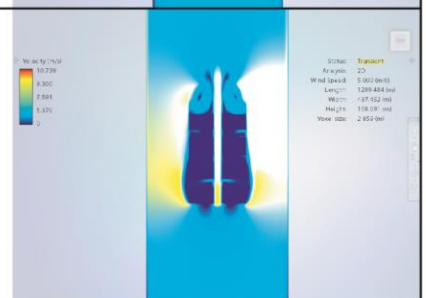
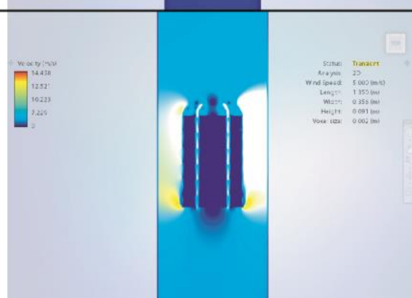
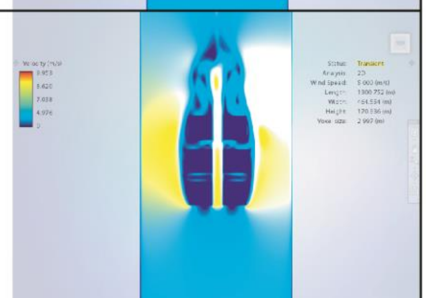
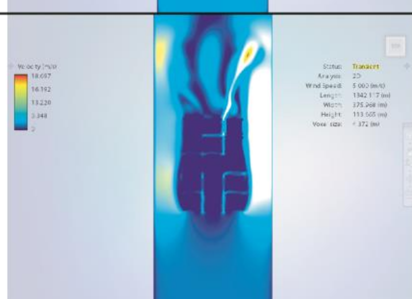
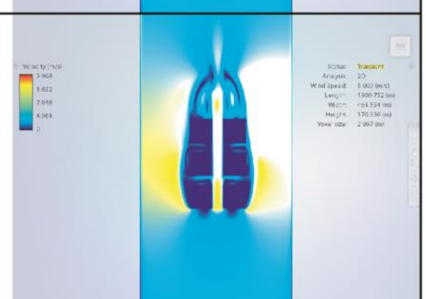
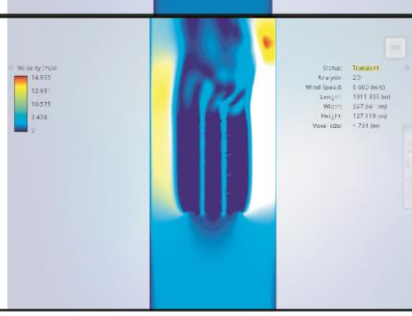
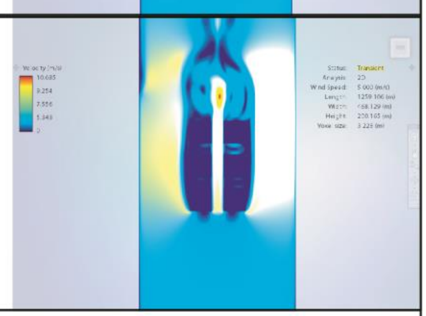
The diagrams show the performance of each of the patterns with the average wind speed of Prague, and with different colors is shown the scale of wind speed.

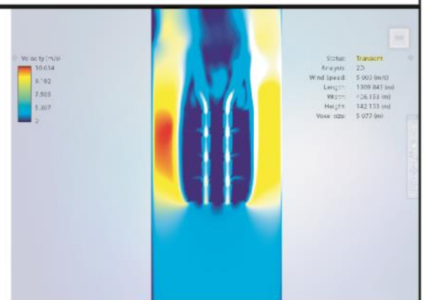
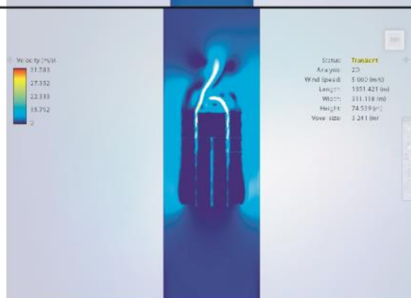
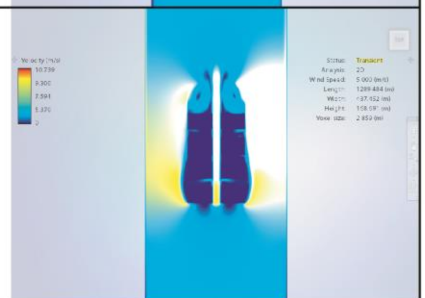
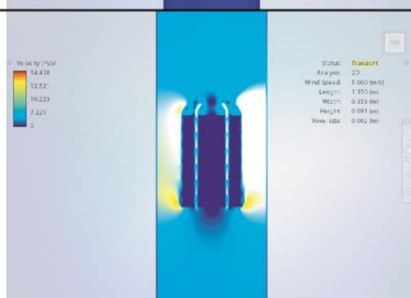
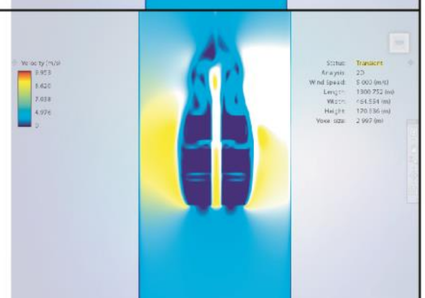
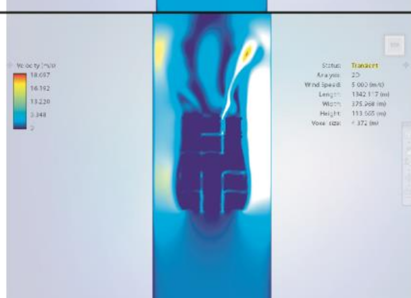
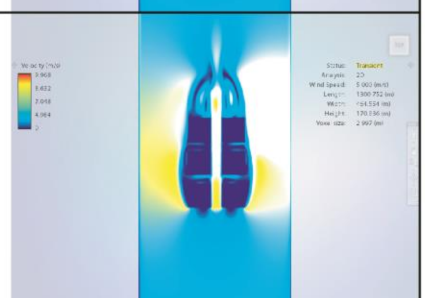
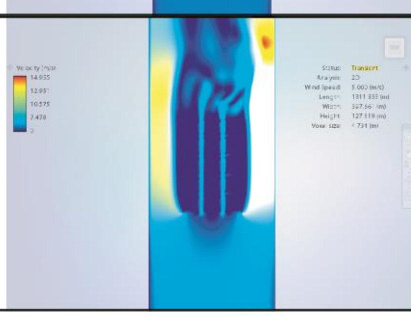
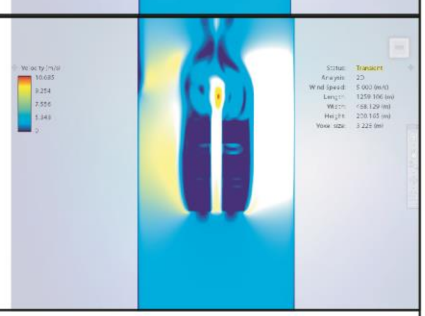


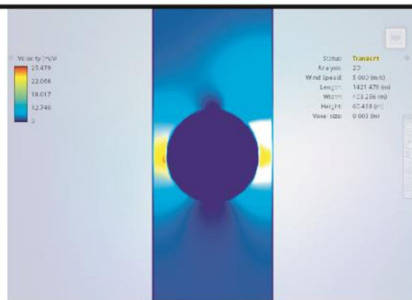
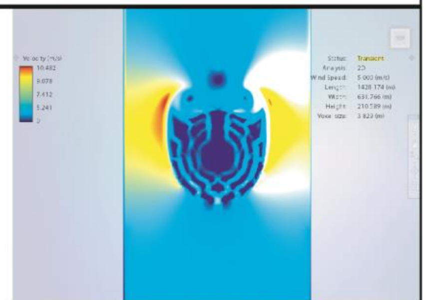
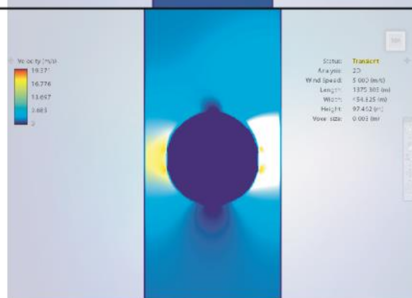
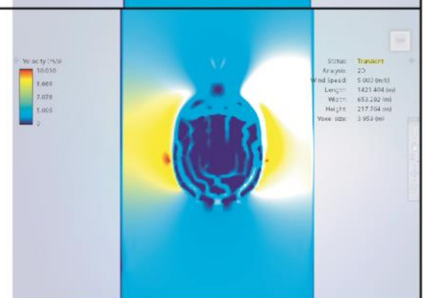
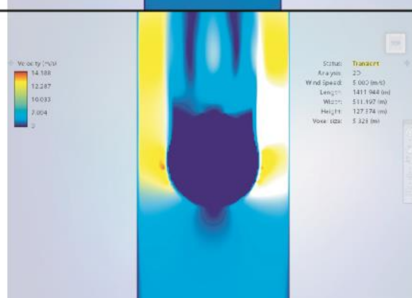
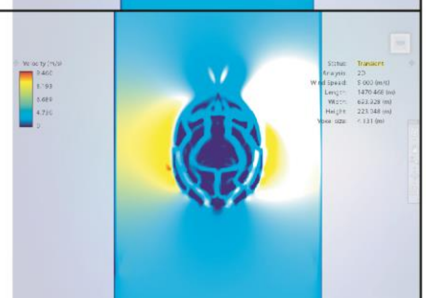
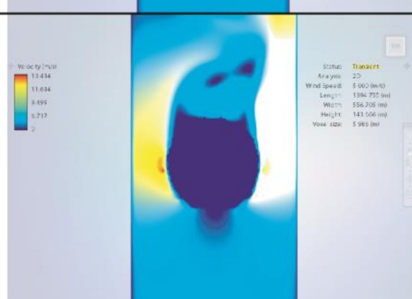
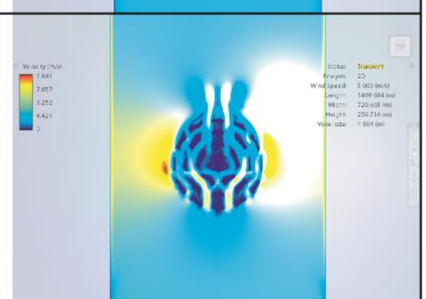
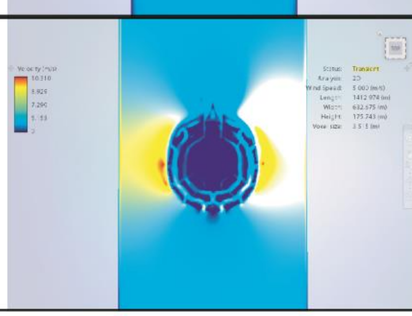
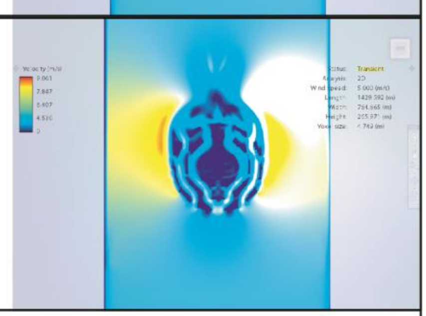
Attachment B-fig.1, the diagram shows the color-scale of wind speed in the facades of the buildings. Even thought the average wind speed should have a light blue color, there can be observed in the diagrams wind speeds which are much higher. The effect of perturbations and wind speed accelerations due to the complex urban pattern is evident. The stack effect is the effect of wind pressure in the façades of the buildings has an effect on air exchange outside-inside, especially the winter period and therefore an effect that is considered to have a direct impact on energy efficiency of the urban pattern typology. The graphs below show the performance of the patterns according to building height. (1-10 floors) Also, it can be analyzed that up to a certain height the patterns allow for almost perfect wind shadowing, not excluding urban ventilation at low speed. The simulation is just an indicator in plan, and certainly is not considered perfect. It needs further simulation and simulation analysis to precise the information. Also the simulation indicates, certain areas which needs to be protected with windbreakers, vegetation, or better thermal insulation.

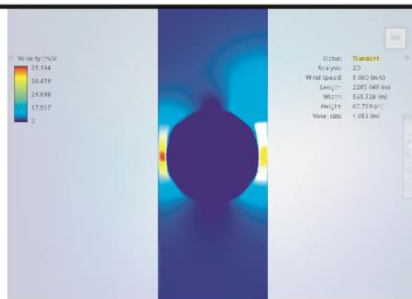
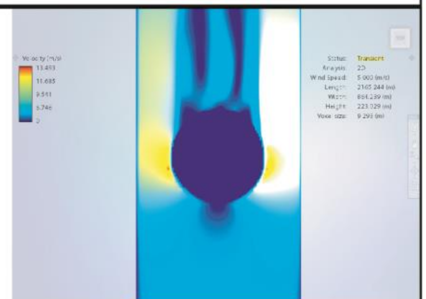
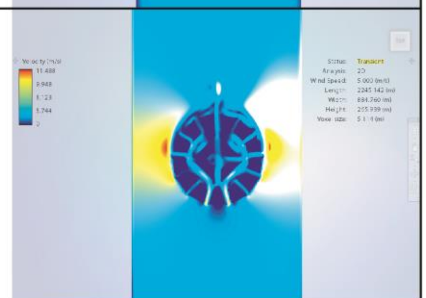
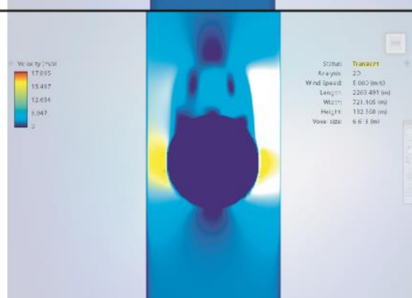
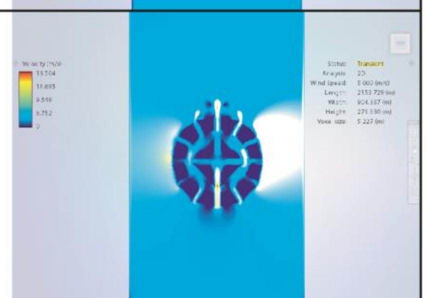
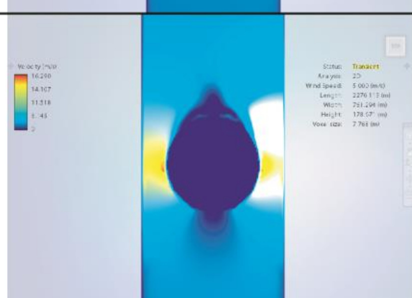
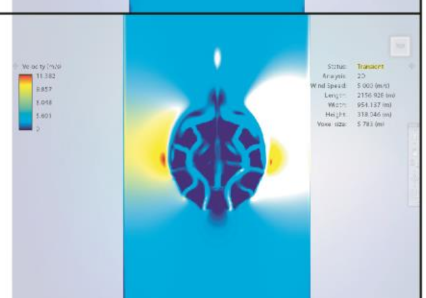
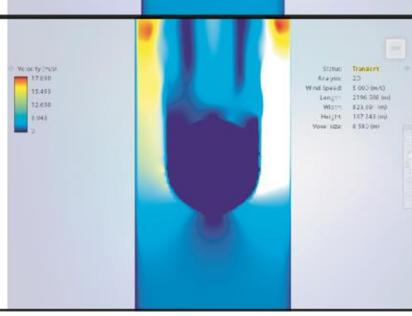
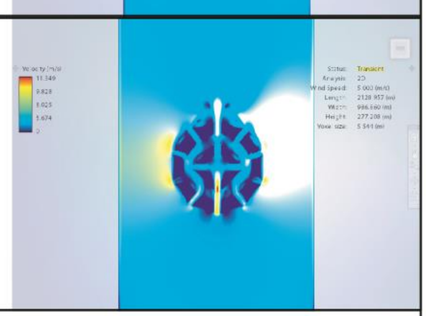
Rectangular pattern. House with square base			
1 st.		6 st.	
2 st.		7 st.	
3 st.		8 st.	
4 st.		9 st.	
5 st.		10 st.	

Rectangular pattern. House with rectangular base			
1 st.		6 st.	
2 st.		7 st.	
3 st.		8 st.	
4 st.		9 st.	
5 st.		10 st.	

Rectangular pattern. Urban block			
1 st.		6 st.	
2 st.		7 st.	
3 st.		8 st.	
4 st.		9 st.	
5 st.		10 st.	

Rectangular pattern. Urban block			
1 st.		6 st.	
2 st.		7 st.	
3 st.		8 st.	
4 st.		9 st.	
5 st.		10 st.	

Circular pattern. House with rectangular base			
1 st.		6 st.	
2 st.		7 st.	
3 st.		8 st.	
4 st.		9 st.	
5 st.		10 st.	

Circular pattern. Urban block			
1 st.		6 st.	
2 st.		7 st.	
3 st.		8 st.	
4 st.		9 st.	
5 st.		10 st.	

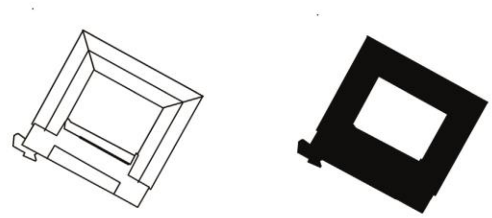
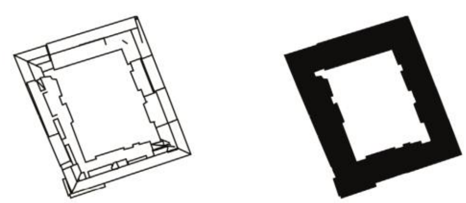
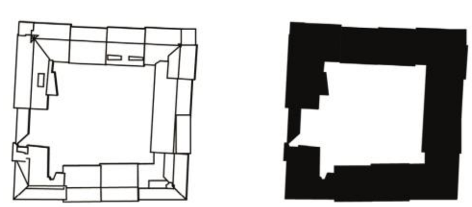
ATTACHMENT C

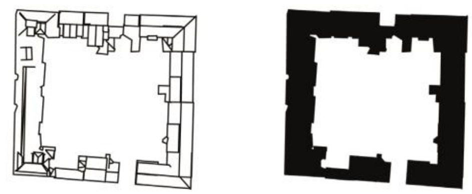
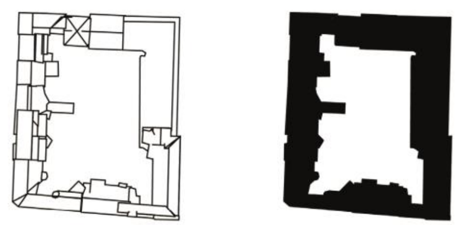
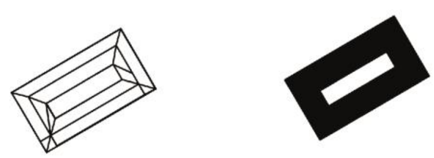
SAMPLES OF 64 URBAN PATTERNS OF PRAGUE

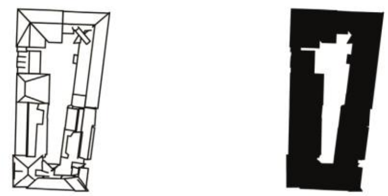
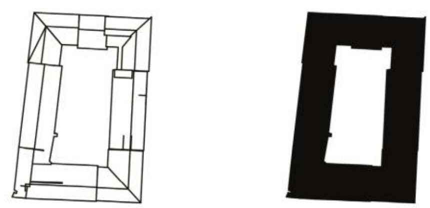
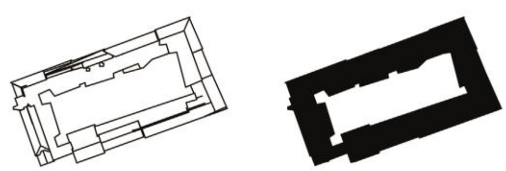
The urban patterns of Prague are subdivided into various categories each of them depending on the typology of Urban Patterns.

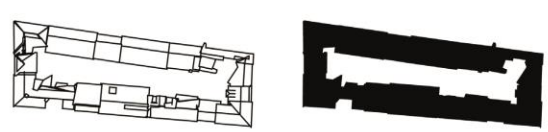
Categories used are listed below:

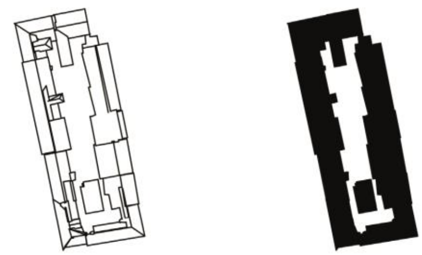
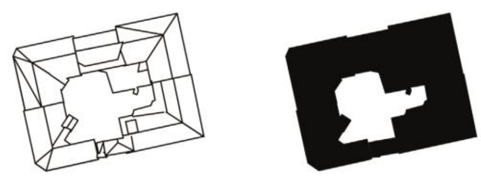
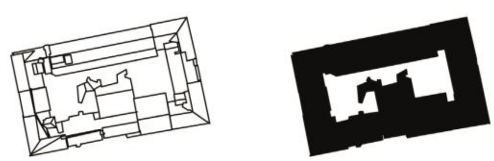
- Square rectangle
- Narrow rectangle
- Filled rectangle
- Trapezoid
- Narrow Trapezoid
- Filled Trapezoid
- Triangle
- Filled Triangle
- Pentagon
- Filled Pentagon
- Long Medieval Street
- Courtyard Medieval Street
- L-Shape
- U-Shape
- S-Shape
- Bar Shape

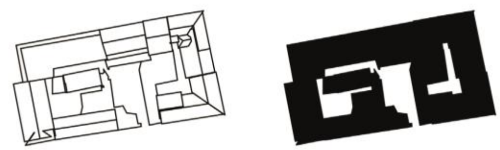
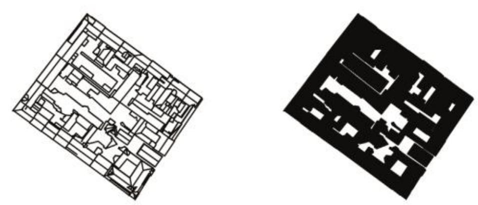
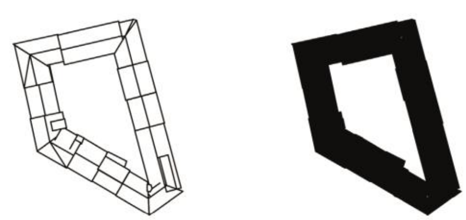
Typology	N	Street	Top view + Footprint
Square Resctangle	1	Jeseniova, Ceskobratska	
Square Resctangle	2	Jeseniova, Zelivskeho	
Square Resctangle	3	Vinograhdska, U Vodarny	

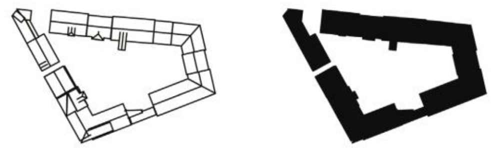
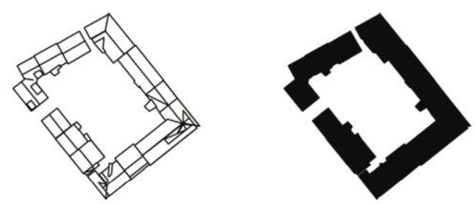
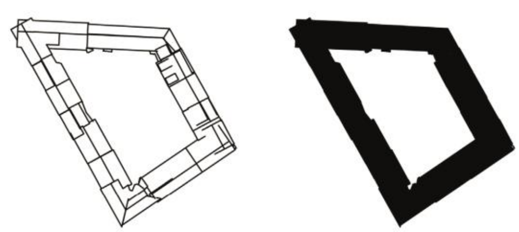
Typology	N	Street	Top view + Footprint
Square Resctangle	4	Letohradska, Kamenicka	
Square Resctangle	5	Letohradska, Ovenecka	
Narrow Resctangle	6	Sternberkova	

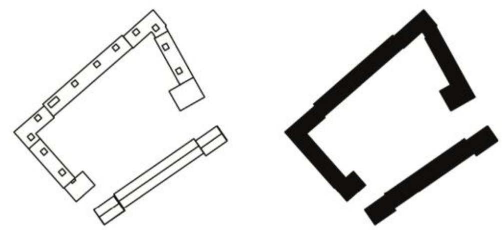
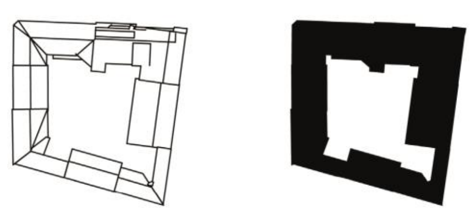
Typology	N	Street	Top view + Footprint
Narrow Resctangle	7	Veletrzni, Ovenecka	
Narrow Resctangle	8	Veletrzni, Socharska	
Narrow Resctangle	9	Vltavska, Nadrazni	

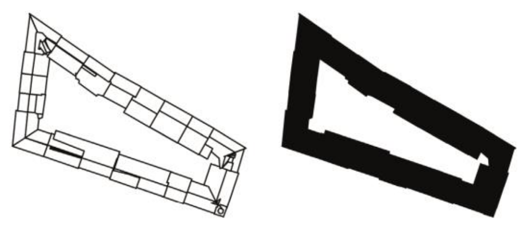
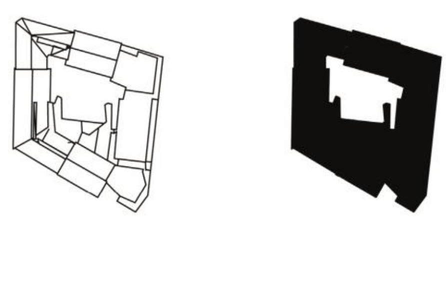
Typology	N	Street	Top view + Footprint
Narrow Resctangle	10	Snirchova, Simackova, Strojnicka	
Narrow Resctangle	11	Lidicka, Na belidle	
Narrow Resctangle	12	Dobrovskego, Ovenecka	

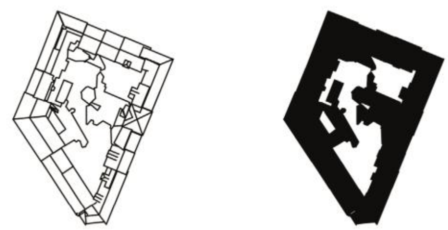
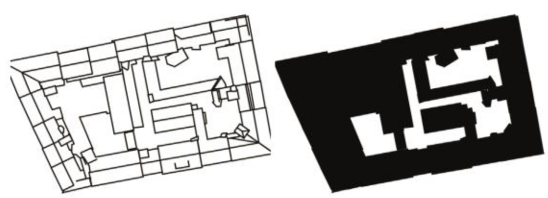
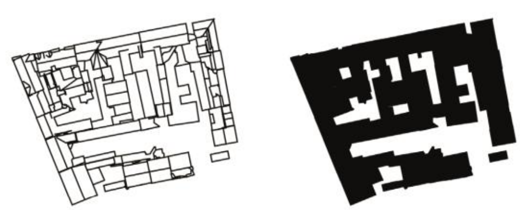
Typology	N	Street	Top view + Footprint
Narrow Resctangle	13	Svornosti, Na belidle	
Filled Resctangle	14	Machova, Varsavska	
Filled Resctangle	15	Svornosti, Vrazova	

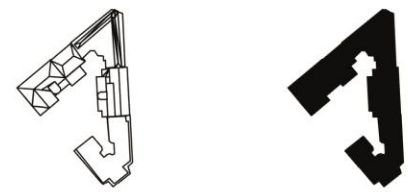
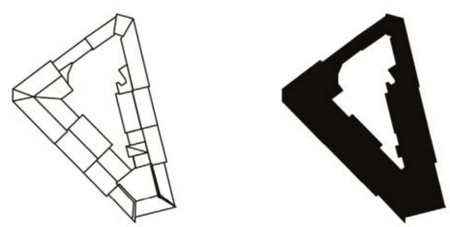
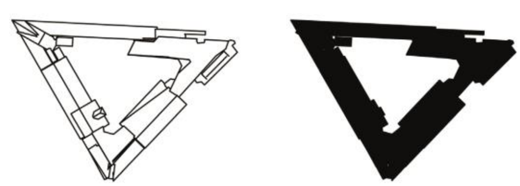
Typology	N	Street	Top view + Footprint
Narrow Resctangle	16	Svornosti, J. Plachty	
Filled Resctangle	17	Sokolovska, Prvniho Pluku, Vitkova, Krizikova	
Trapezoid	18	Machova, Rybalkova	

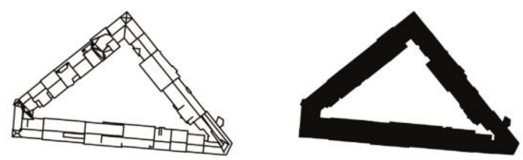
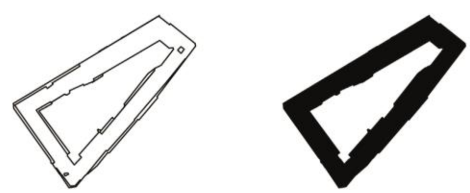
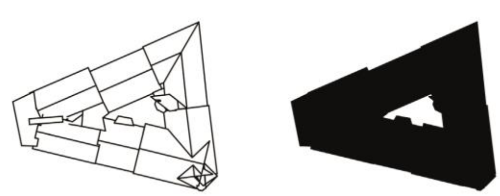
Typology	N	Street	Top view + Footprint
Trapezoid	19	Charkovska, Rybalkova	
Trapezoid	20	Korunovacni, Jana Zajice	
Trapezoid	21	U Krizku, V Horkach	

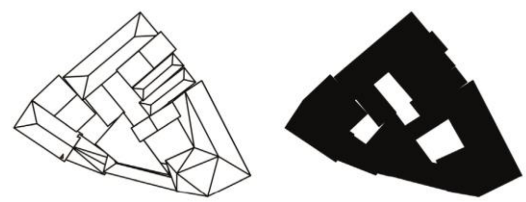
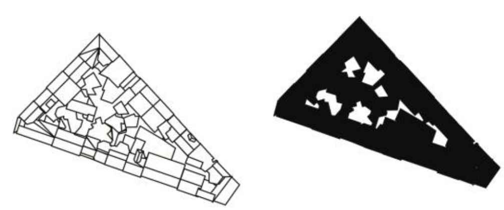
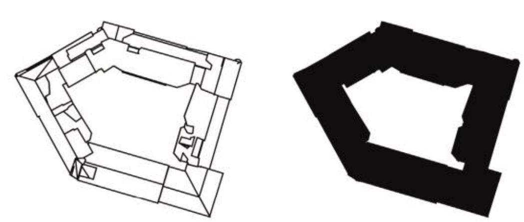
Typology	N	Street	Top view + Footprint
Trapezoid	22	Litevska, Na hroude	
Narrow Trapezoid	23	U Studanky, Socharska	
Narrow Trapezoid	24	Veletrzni, Kamenicka	

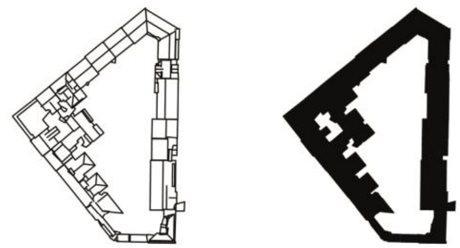
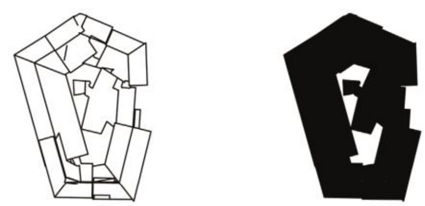
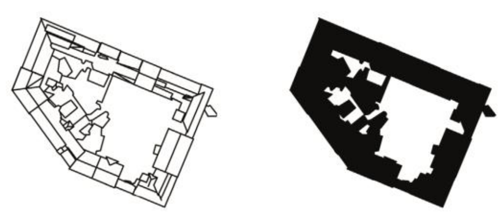
Typology	N	Street	Top view + Footprint
Narrow Trapezoid	25	Jeseniova, Dovcova	
Narrow Trapezoid	26	Krymska	
Filled Trapezoid	27	Milady Horakove, Kamenicka	

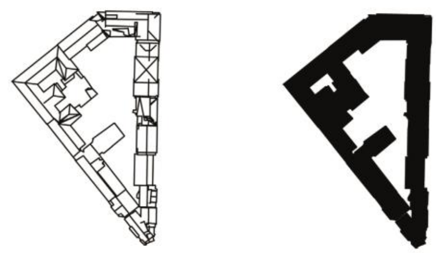
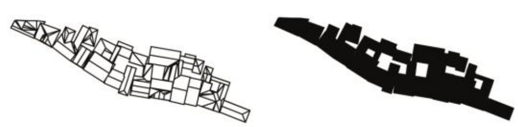
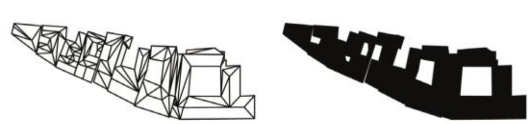
Typology	N	Street	Top view + Footprint
Filled Trapezoid	28	Francouzska, Sazavska	
Filled Trapezoid	29	Vltavska, Nadrazni	
Filled Trapezoid	30	J. Plachty, Nadrazni	

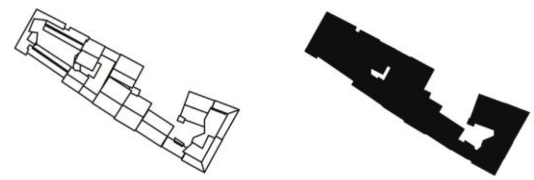
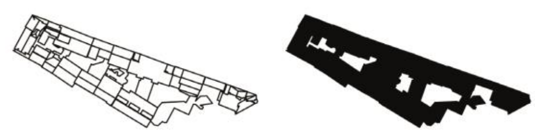
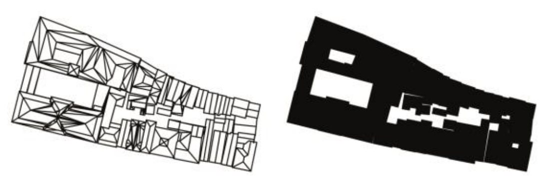
Typology	N	Street	Top view + Footprint
Triangle	31	Planerska, Karpova, Zatecka	
Triangle	32	Seifertova, Vita Nejedleno, Vikova	
Triangle	33	Mojmirova, Rostislavova	

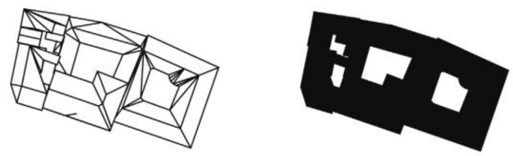
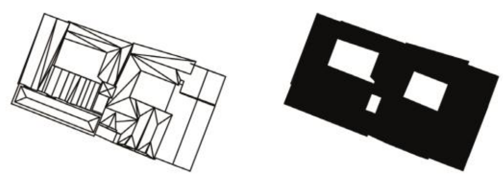
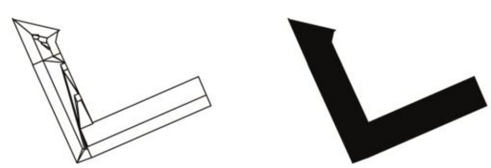
Typology	N	Street	Top view + Footprint
Triangle	34	Korunovacni, Na Vysinach	
Triangle	35	Ruska	
Filled Triangle	36	Nuselska, Cestmirova	

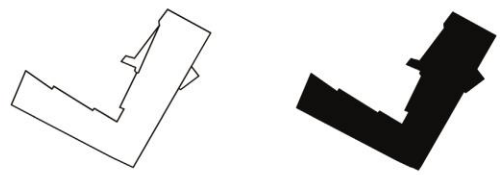
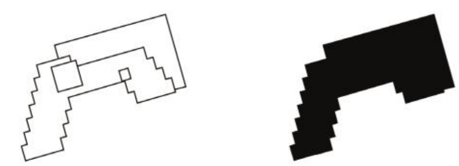
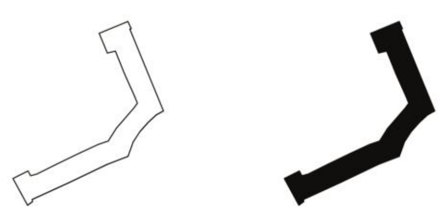
Typology	N	Street	Top view + Footprint
Filled Triangle	37	Husova	
Filled Triangle	38	Nuselska, Rostislavova	
Pentagon	39	Devicka, Kafkova, Na Hutich	

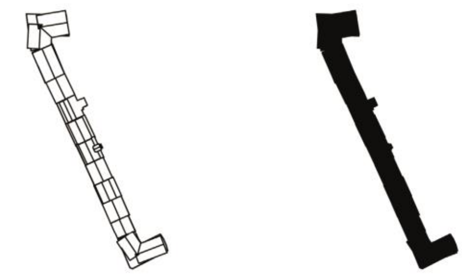
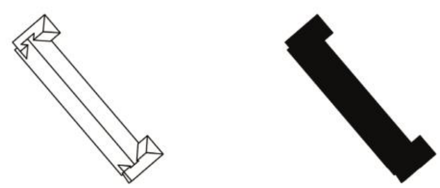
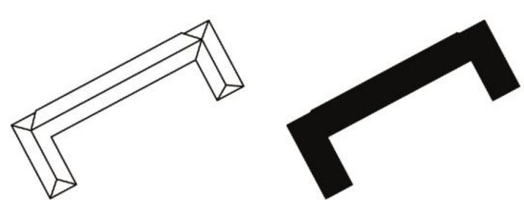
Typology	N	Street	Top view + Footprint
Pentagon	40	Havanska, Cechova	
Filled Pentagon	41	Krymska, Kodanska	
Filled Pentagon	42	Francouzska, Slovenska	

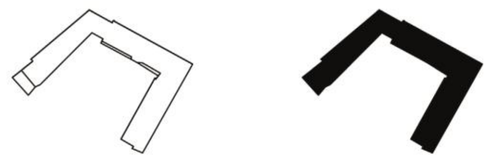
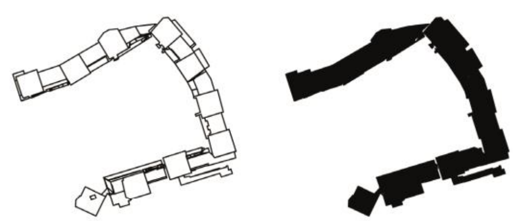
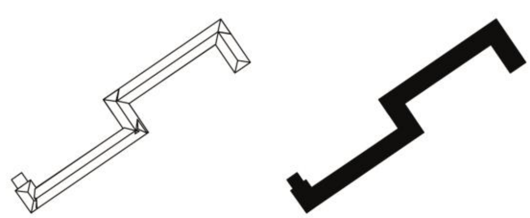
Typology	N	Street	Top view + Footprint
Filled Pentagon	43	Korunovacni, Cechova	
Long Medieval Street	44	Nerudova	
Long Medieval Street	45	Zamecke schody	

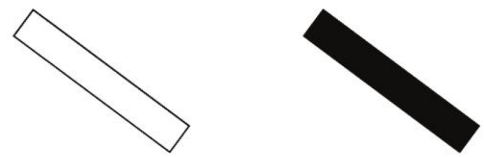
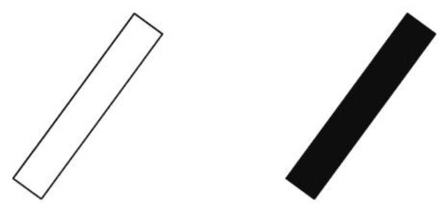
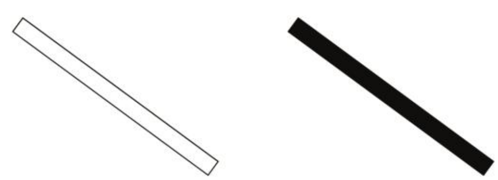
Typology	N	Street	Top view + Footprint
Long Medieval Street	46	Francouzska	
Long Medieval Street	47	Francouzska	
Courtyard Medieval Street	48	Nerudova	

Typology	N	Street	Top view + Footprint
Courtyard Medieval Street	49	Nerudova	
Courtyard Medieval Street	50	Nerudova	
L - Shape	51	Mecislavova, Cestmirova	

Typology	N	Street	Top view + Footprint
L - Shape	52	Jeseniova, Dovcova	
L - Shape	53	Olsanska	
L - Shape	54	Malesicka, Zelivskeho	

Typology	N	Street	Top view + Footprint
U - Shape	55	Husitsky	
U - Shape	56	Karpatska	
U - Shape	57	Ruska	

Typology	N	Street	Top view + Footprint
U - Shape	58	Jeseniova, Ceskobratska	
U - Shape	59	Olsanska, Zelivskeho	
S - Shape	60	Jakutska	

Typology	N	Street	Top view + Footprint
Bar Shape	61	Molokova	
Bar Shape	62	Molokova	
Bar Shape	63	Molokova	

Typology	N	Street	Top view + Footprint
Bar Shape	64	Molokova	

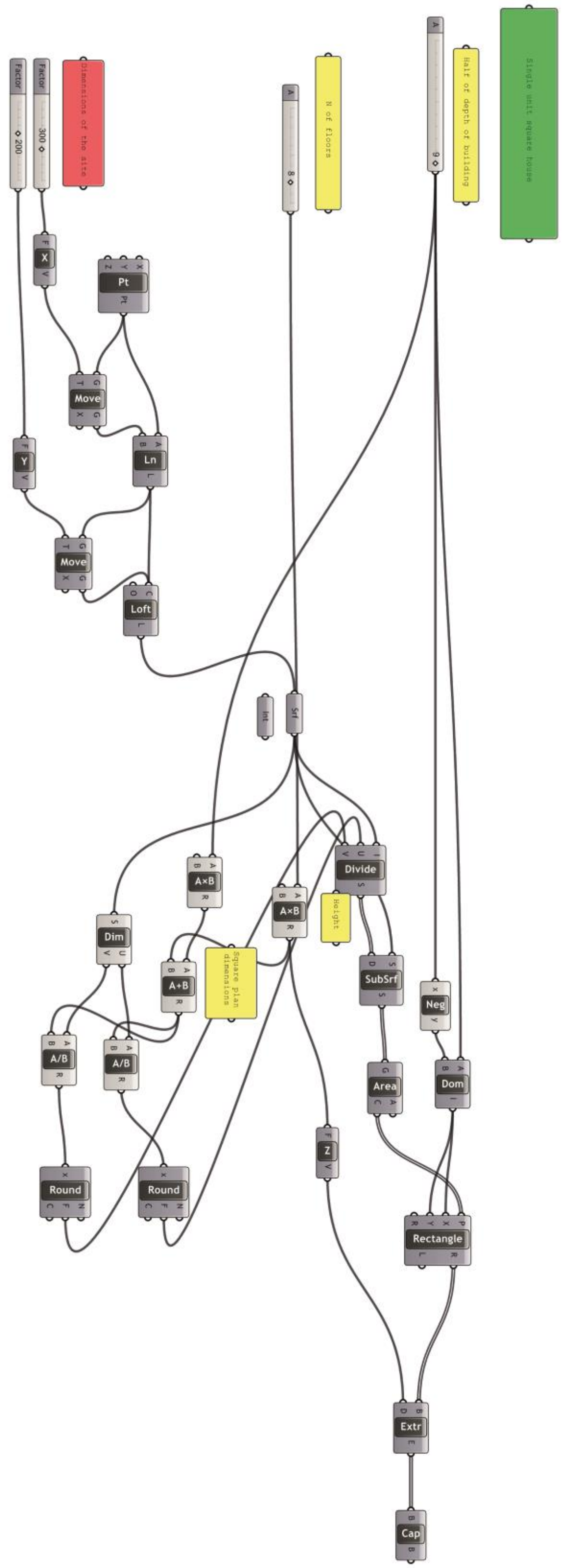
ATTACHMENT D

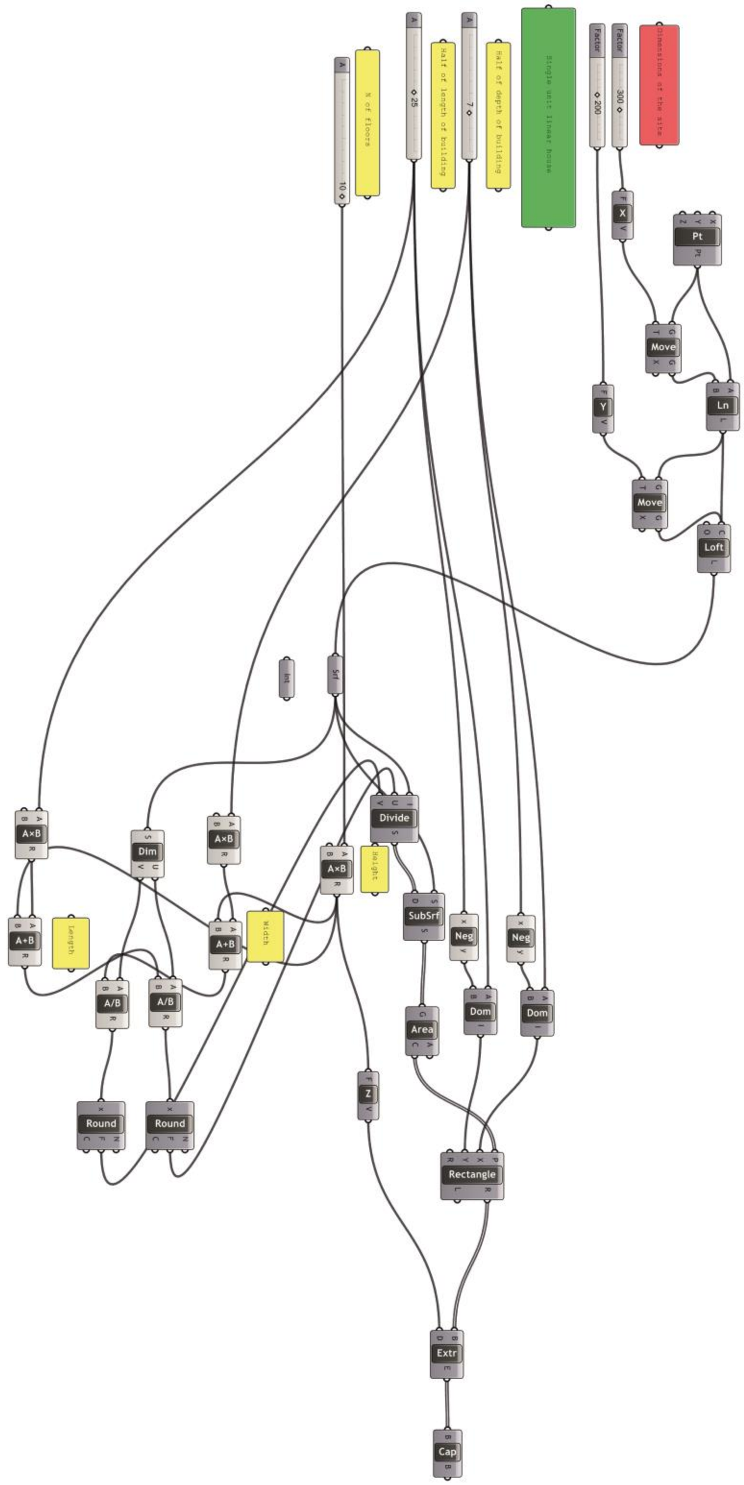
GRASSHOPPER DEFINITIONS OF URBAN PATTERNS

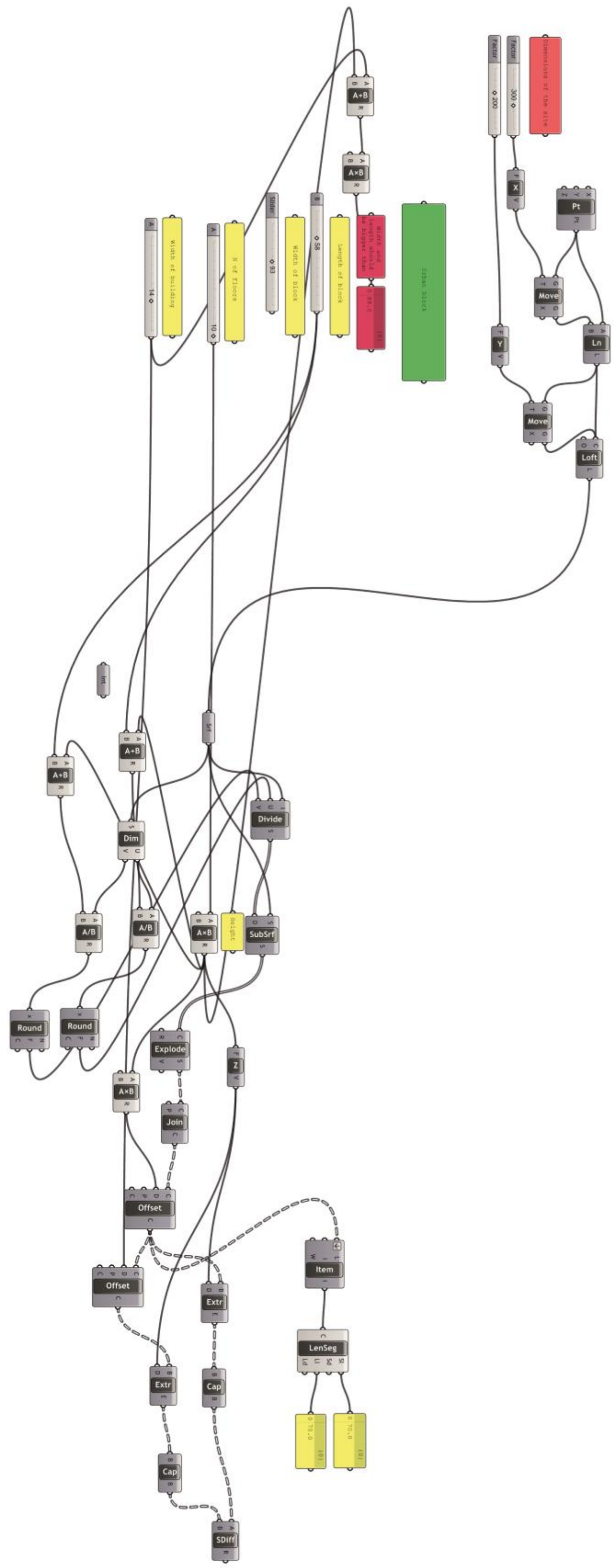
- In the images below are some of the grasshopper schemes which were used as a tool for generating the Rhinoceros models.
- Each of the rectangles of the scheme shows the command that is used to perform a certain action in designing the urban patterns in an algorithmic way. Grasshopper was an evolution of earlier versions of scripting which allows for compact information actions, instead of long and difficult algorithms. The schemes below show the step by step design tool that is conducted to design the virtual urban patterns in a parametric way, thus the variables are:

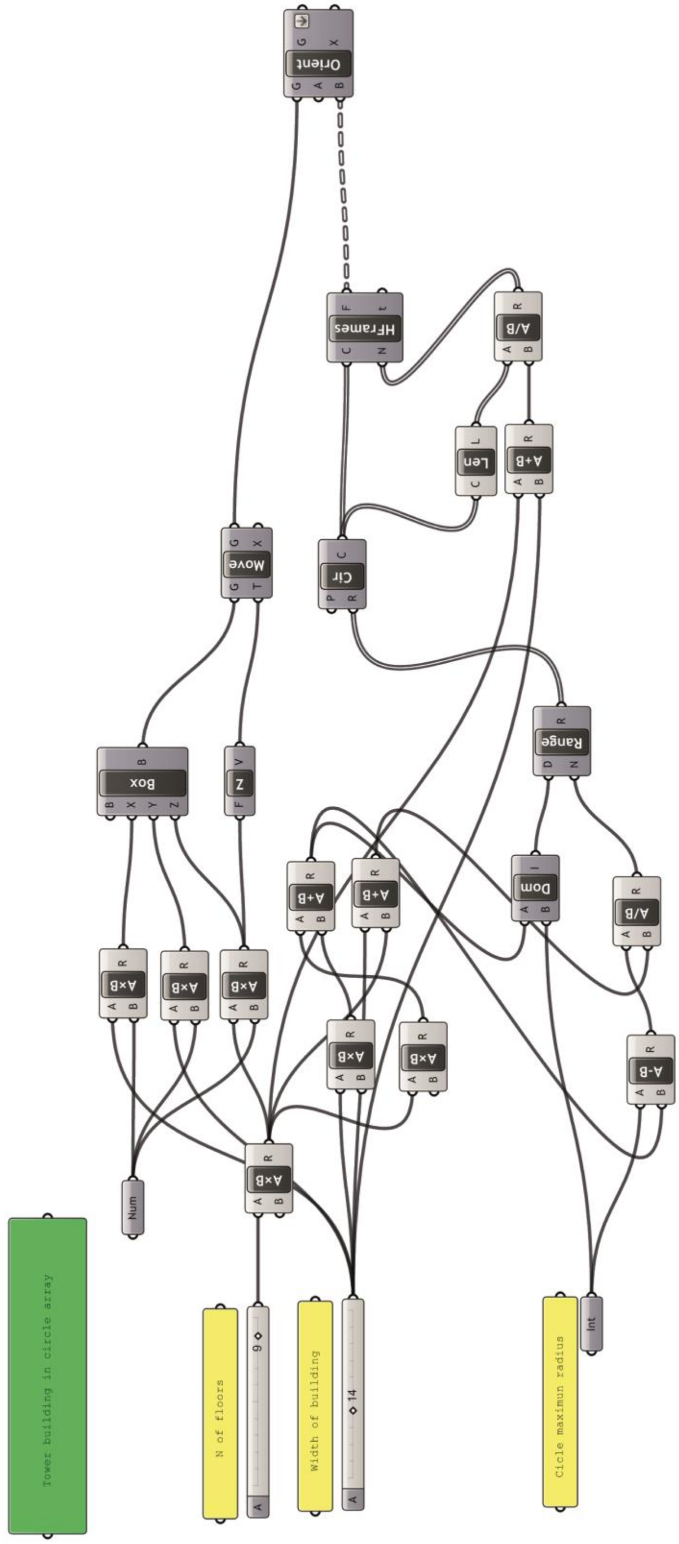
  -Dimensions of buildings (width and length)
  -Height (1-10 floors)
  -Population density of the urban patterns taking into account the 45 degree rule.

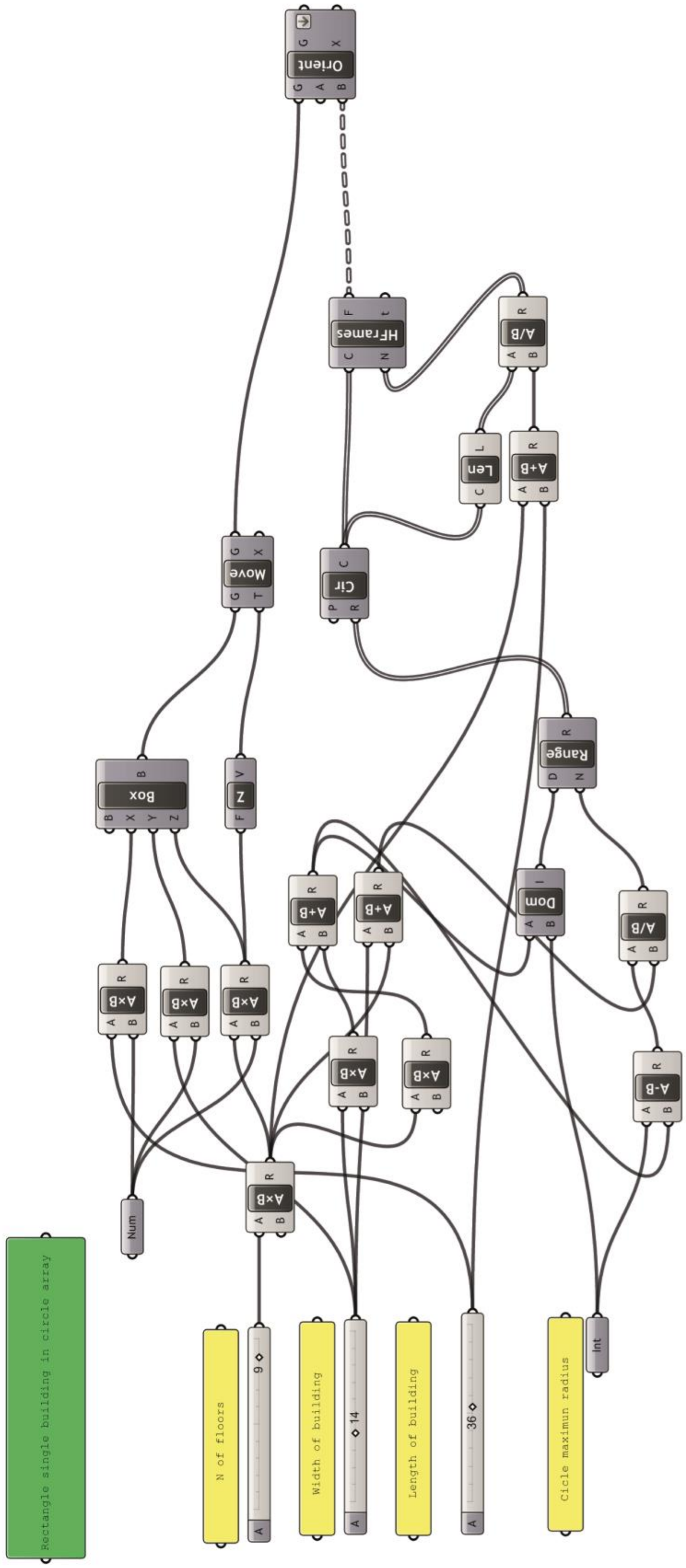
  The parametric approach allows for differentiation of variables and creation of various modifiable models.
  The advantage is precisely in the modification and variability of the dimensions which is an advantage compare to the conventional design. (paper models, axonometric drawings etc. precisely because of the sequences of variation, made possible by parametric design)

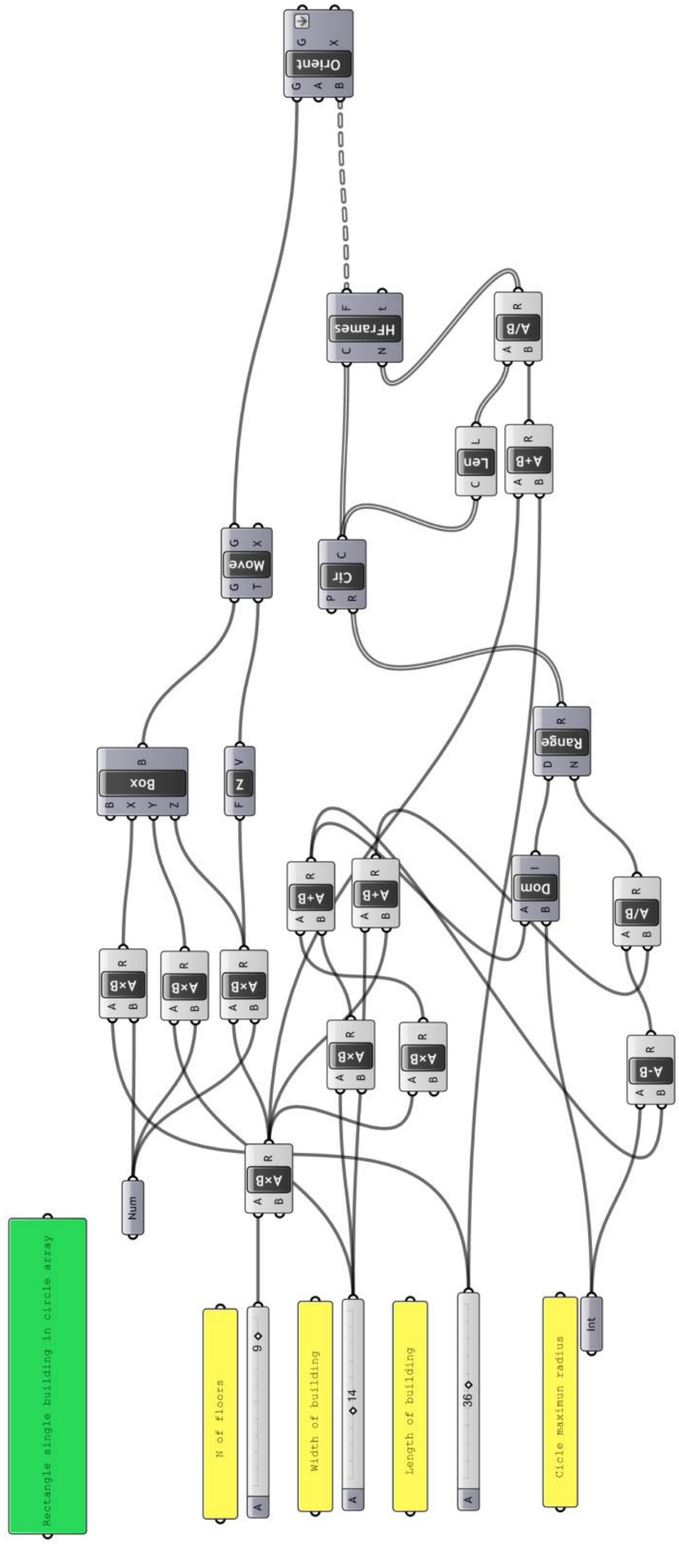

Factor
200
Factor
300
dimensions of the site
N of floors
Half of depth of building
Single unit square house
X
Pt
Move
Y
Ln
Move
Loft
Int
Srf
Divide
A×B
A×B
Height
Dim
A+B
Square plan dimensions
SubSrf
Neg
A/B
A/B
Area
Dom
Round
Round
Z
Rectangle
Extr
Cap


N of floors
Half of length of building
Half of depth of building
Single unit linear house
Dimensions of the site
Length
Width
Height
Divide
SubSrf
Area
Rectangle
Extr
Cap
Round
Round
Loft
Move
Move
Ln
Pt




Orient
HFrames
A/B
Len
A+B
Move
Cir
Box
Range
Dom
A×B
A-B
Num
Int
Tower building in circle array
N of floors
Width of building
Cicle maximun radius
9
14


Orient
HFrames
A/B
Len
A+B
Move
Cir
Range
Box
Z
A+B
A+B
Dom
A/B
A×B
A×B
A×B
A×B
A×B
A-B
A×B
Num
Int
Rectangle single building in circle array
N of floors
9
Width of building
14
Length of building
36
Cicle maximun radius


Orient
HFrames
A/B
Len
A+B
Move
Cir
Box
Z
Range
Dom
A×B
A-B
Num
Int
Rectangle single building in circle array
N of floors
9
Width of building
14
Length of building
36
Cicle maximun radius

ATTACHMENT E

CONFERENCE AND JOURNAL PUBLICATIONS

Urban Shape and Energy Performance: Evaluation of the Typical Urban Structures of Prague.

Ernest Shtepani, M.Sc (1), Anna Yunitsyna, PhD (2),

[1] *National Planning Sector, Ministry of Urban Development, Albania*

2 Department of Architecture, Epoka University, Albania

ABSTRACT

European cities had been developed historically as compact and dense structures, where the specific urban microclimate was achieved through the arrangement of the units of the urban pattern. The energy flows, such as transportation energy and the heating or cooling energy, were reduced. With the further development of the cities, the various urban morphologies came to place and the city energy demands grew. One of the ways of reduction of such demand is the creation of compact urban pattern, which is exposed to the maximum of solar radiation and potentially may reduce the heating demands of the buildings. The energy, which is received by building, is defined by its shape and orientation and the compacity depends on its geometrical properties, such as surface to volume ratio and the plot coverage. Within the study the various urban morphologies of Prague are tested in order to find the most energy efficient ones. The urban structures are selected according to their geometrical shape and include the urban blocks with different proportions, perimeters and site coverage ratio, dense medieval streets and minimalistic buildings of the socialist period. The computer simulation and analysis were performed using the models extracted from the virtual Google Earth model of Prague. During the process of evaluation of samples the relation between the urban morphology and such parameters as plot coverage, surface to volume ratio and the incident solar radiation was established and potentially higher energy efficient structures were indicated.

INTRODUCTION

Cities are constructed from the units of urban pattern, which vary by the shape, size and density. The arrangement and the geometry of units are the results of the multiple driving forces, such as economical efficiency, tradition, climate and culture. Within the traditional built structure there may be found the precedents, which lead to the climate responsive urbanism, such as management of the shape of the building, its orientation and compacity, provision of the corridors and courtyards for the intensive ventilation, regulation of the window size, provision of the wind and rain shelter [1]. There is the connection between the urban morphology and its energy demand. The compact and dense patterns, such as European urban block show better energy performance, then the scattered buildings [2]. The energy performance of the urban pattern may be optimized through the control of the energy gains and losses. Complex urban patterns with the bigger amount of small and medium-sized buildings demonstrate better energy performance, then the ones with the disperse distribution of the bigger volumes due to the intensive use of the building passive zones [3]. Urban geometry, which influences to the exposure of the building surface to the sunlight and therefore to the energy performance of the building is the factor, which can be evaluated using the computer simulation [4]. The factors of the building design quality, building systems efficiency and the occupants' behavior are the complex values, which are usually neglected in the idealized models.

Compacity of the units of the urban pattern declines the energy losses and minimizes the heating and cooling loads of the building. For the single building the better energy performance is registered for the bigger simple-shaped buildings in comparison with the complex structures and smaller buildings [5]. Complexity of geometrical shape and building proportions increase the surface to volume ratio of the building, which increases the heat loss or gain through the outer walls and roof [6]. Urban morphologies with higher urban density and compacity of the buildings demonstrate lower energy demands, which makes them more efficient [7].

Solar heat gains depend on the orientation of the building, density of the urban structure and site coverage ratio and on the available exposed building surface. Construction of the efficient urban pattern is specific for the climate conditions and may include the contrary solutions for the cold and hot, dry and wet climates. The solar potential of the urban structure is defined by building compacity, surface to column ratio and site coverage [8].

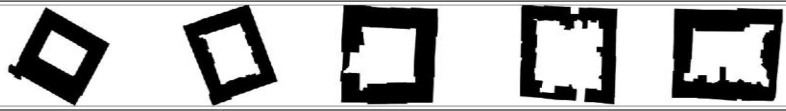
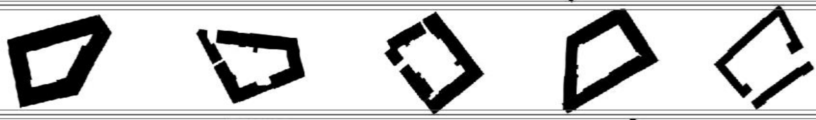
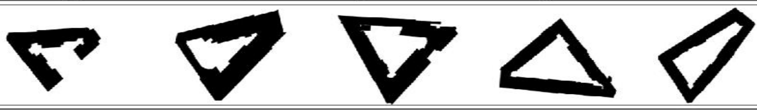
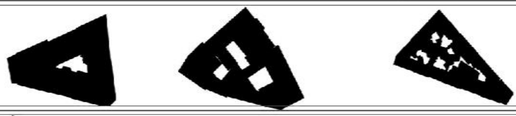
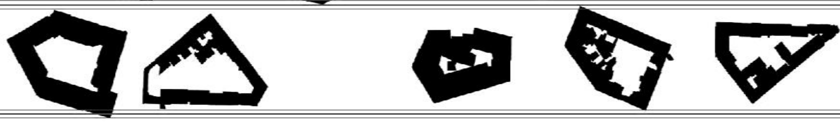
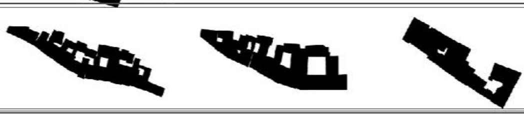
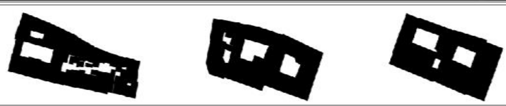
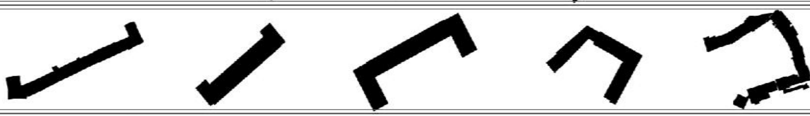
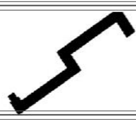
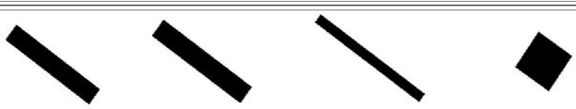
Within the study the connection between the urban morphology, building compacity, site coverage and the received solar energy is evaluated based on the evaluation of the parameters of 64 samples of different urban morphologies of Prague, Czech Republic subdivided in 16 groups. The computer based simulations of the solar access analysis in comparison with the geometrical properties of the structure aimed to select the cases with the highest energy performance, which is defined by higher solar gains and lower surface to volume ratio.

METHODOLOGY

The study is based on the evaluation of the geometrical parameters, such as surface to volume ratio and site coverage, and computer simulation in order to calculate the solar access of the 64 urban structures located in different districts of Prague, Czech Republic. The urban forms are selected according to their geometrical shape. Different types of the European urban block, such as square, rectangle, trapezoid, pentagon and triangle are presented by 43 cases. Within the geometrical groups the samples are subdivided according to the level of openness of the built structure and the estimated level of compacity. The building heights of urban blocks are ranged between 3 and 6 floors. The samples with high site coverage ratio are evaluated as filled urban blocks with additional structures built in the courtyard. The narrowness of the structure was estimated according to the ratio between the main dimensions of the courtyard and between the building heights. The 7 irregular organic structures of the medieval city are 3-4 floors high and subdivided according to the shape and the presence of courtyards. The last group of 14 cases is formed by the contemporary urban structures with the simple geometry, such as L-shapes, U-shapes, bars and towers. In this group the height of the building is usually bigger and reaches 8 floors for the typical buildings and 12 floors for the towers.

The footprints of the selected cases are shown at the table 1:

Table 1 Footprints of the selected samples of urban patterns

Typology	Footprint
Square Resctangle	
Narrow Resctangle	
Filled Resctangle	
Trapezoid	
Narrow Trapezoid	
Filled Trapezoid	
Triangle	
Filled Triangle	
Pentagon, Filled Pentagon	
Long Medieval Street	
Courtyard Medieval Street	
L - Shape	
U - Shape	
S - Shape	
Bar Shape	

The study proceeded with the extraction of the 3d models from the virtual model of Prague provided by Google Earth. The selected 3d models were elaborated in order to make them appropriate for the calculation of the geometrical properties and solar access using the Autodesk Ecotect simulation.

For every sample the following data was calculated:

- Surface to volume ratio – ratio between the sum of all surfaces of the sample and all volumes
- Building surface radiation – indicates the solar radiation of the built surface of the selected urban structure per year.
- Site coverage – ratio between the footprint of the building and site area.

ANALYSIS OF THE SELECTED PATTERNS

Surface to volume ratio

Surface to volume ratio of the structure is measured as the ratio between the sum of all surface of the building (including outer walls and roofs) and the volume of the building [9]. High surface to volume ratio, or the low compacity is an indicator of the potential heat losses though the external surfaces of the building and its low energy performance. For the sample cases the average value for every group of buildings is calculated.

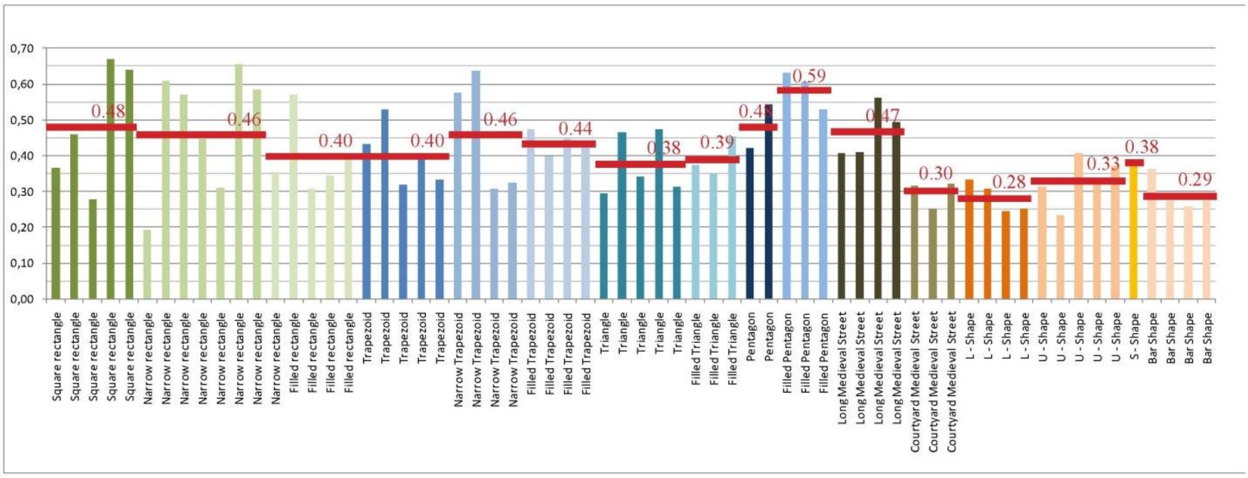


Figure 1 Surface to volume ratio and the average value for different samples of built structures, m^2/m^3

Simple-shaped contemporary build structures are characterized by the lowest ratio, which may be explained by the use of the compact volume with the simple geometry and lack of the building details. The energy losses of the buildings are minimized. The parameters of the variations of urban blocks, such as square, rectangle, triangle and trapezoid are similar, while the pentagon shape demonstrates higher surface to volume ratio. Triangular urban block may be considered as the most compact structure. Within each group the distance between the two buildings, which formed the courtyard, or the narrowness of the pattern, and the level of courtyard infilling, slightly influenced to overall performance. The long medieval street has performance equal to the urban block groups, while the courtyard medieval street is closer to the contemporary structures.

Building surface incident solar radiation

The computer based simulation was used in order to calculate the solar radiation, which is received by the all surfaces of the built elements of the building. The selected urban structures were evaluated using the Autodesk Ecotect Analysis. The weather conditions were applied for Prague, Czech Republic. The average value for every group of the built structures indicates the energy performance of the urban morphology.

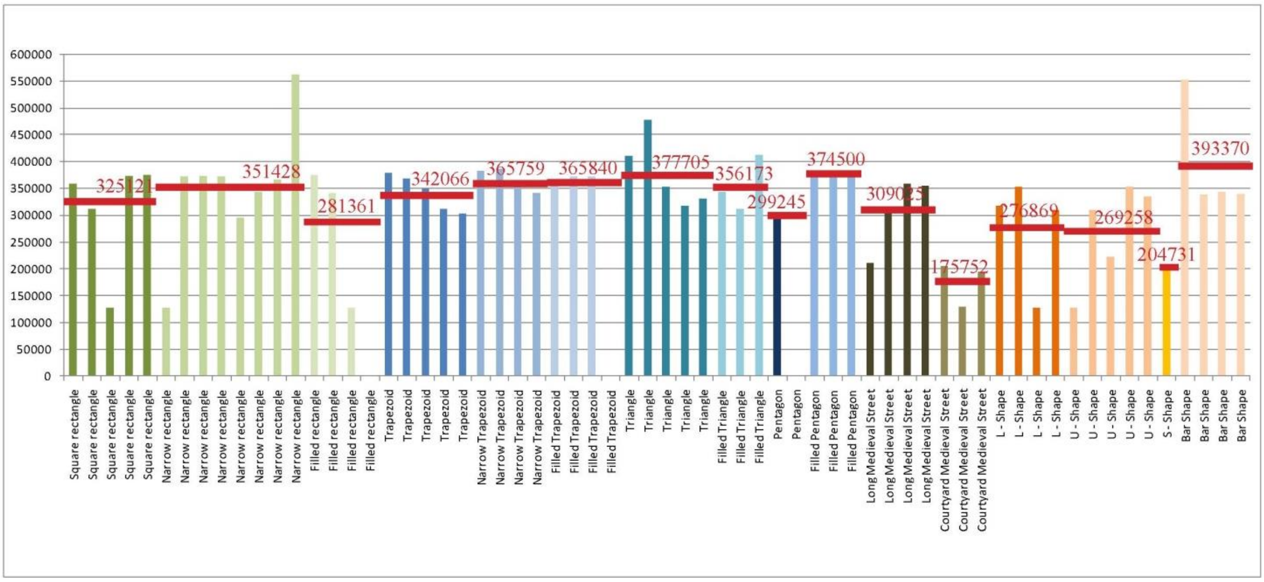


Figure 2 Incident solar radiation and the average value for different samples of built structures, KWt per year

The solar energy, which is received by different typologies of urban blocks is higher, then the one of the contemporary simple buildings. The medieval urban structures perform the worst. Among the morphologies of urban block, the filled structures have relatively smaller level of incident solar radiation. For the contemporary buildings the simple bar or tower-like building is more efficient, than L-shape or U-shape.

Site coverage

Site coverage represents the ratio of built-in land and may be evaluated as the relation between the building footprint to the land area [10]. Site coverage represents the intensity of the land use. The dimensions of the site are estimated according to the maximal dimensions of the sample building.

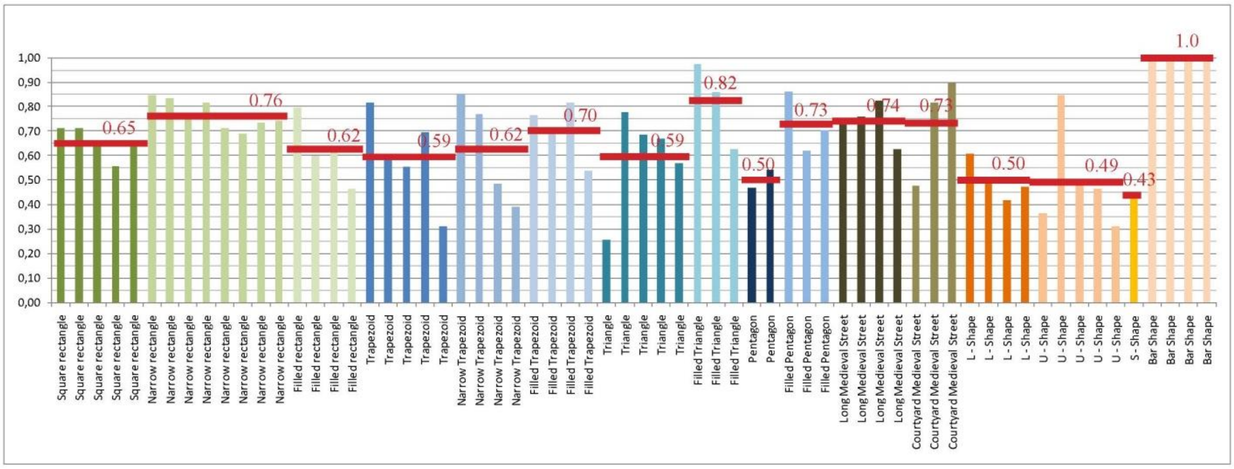


Figure 3 Site coverage and the average value for different samples of built structures, %

The average value of site coverage reaches the maximum value for the bar or tower-shape buildings since there no closed or semi-closed courtyard available. For all typologies urban blocks coverage ratio is the highest for the filled structures and for the urban morphologies with narrow units. The two groups of the medieval streets have high value of site coverage.

Comparison between the three parameters

Given below diagram allows to evaluate the relation between the type of urban pattern and site coverage, surface to volume ratio and incident solar radiation. The most energy efficient urban pattern is characterized by low surface to volume ratio and high level of received solar radiation. The site coverage is the parameter, which is established usually in the urban standards. According to the way of estimation of the site area for the sample cases, the lower site coverage is preferable. The optimal value at figure 4 represents the combination between the three parameters.

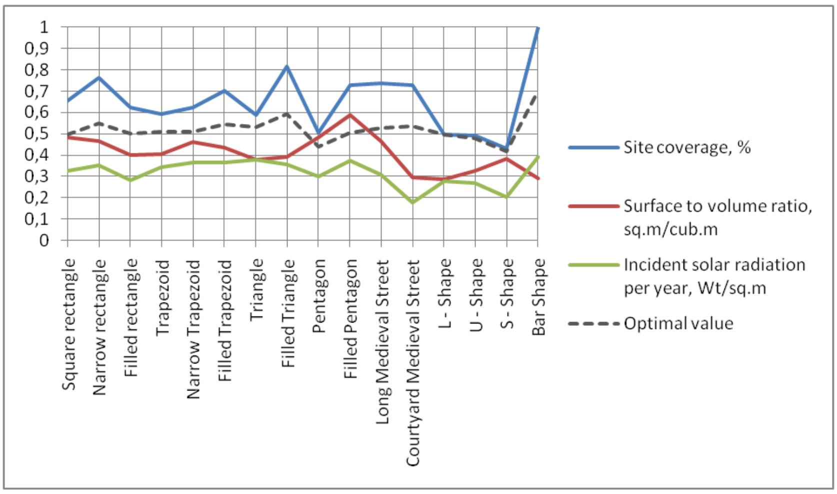


Figure 4 The relation between the average values of the site coverage, surface to volume ratio and incident solar radiation for different samples of built structures

According to the analysis the energy performance of the urban blocks is higher, then the one of simple-shaped buildings. Among the urban block morphologies the ones with irregular orientation of sides, such as triangle blocks and trapezoids are more preferable. The urban block with smaller number of sides has higher potential, then the one with bigger one, such as pentagon. The parameters of the medieval street are comparable to the ones of rectangular urban block.

CONCLUSION

Within the study the energy performance of different built structures, which represent the typical units of various urban morphologies of Prague was evaluated. The analysis preceded from the evaluation of the three parameters, such as surface to volume ratio, site coverage and incident solar radiation to the finding of the parameter, which will characterize their optimal relation.

From the three main subcategories of the urban morphologies the European urban block had shown the higher solar access, then the medieval street and the simple shape units. Within the four geometrical shapes of the urban block, the highest performance is character for the triangle – the structure with the lowest number of sides. There is a connection between the physical shape of the unit and its solar potential. The blocks based on the use of the inclined grid are more preferable, then the rectangular ones. The bar and tower buildings demonstrate the highest compacity, or the lowest surface to volume ratio and the highest site coverage.

The study is based on the evaluation of the virtual model of Prague, which leads to some limitations, based primarily with the quality of the building models, which are provided. The computer simulations are conducted for the individual built units, and the influence of the real urban environment, such as trees and other buildings is neglected. The amount of the solar radiation, which is absorbed by building, depends on the physical properties of the walls, such as used materials and the number and character of the openings. Evaluation of the potential of the building shape for gain of the solar radiation and energy losses is an approach towards the reduction of the building energy demands together with the quality of the building design and systems and the environmentally aware behavior of the inhabitants.

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URBAN PATTERN GEOMETRY AND ITS POTENTIAL ENERGY EFFICIENCY

Ernest SHTEPANI, M. Arch; Anna YUNITSYNA, PhD*,

Head of National Planning Sector
Ministry of Urban Development
Address: Rruga A.Toptani, nr. 1, 1001 Tirana/Albania
E-mail: shtepani.ernest@gmail.com

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

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 (Williams 2014). 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 (Cheng 2009). 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 (Cheng 2009). 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 (Vicky Cheng, Koen Steemers, Marylene Montavon, Raphaël Compagnon 2006).

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 (Michael Doherty, Hitomi Nakanishi, Xuemei Bai, Jacqui Meyers 2009). Urban structures with higher density tend to be more energy efficient than the ones with lover density (Philipp Rode, Christian Keim, Guido Robazza, Pablo Viejo, James Schofield 2014). 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 (Adolphe 2001). 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 (Philip Steadman, Stephen Evans, Michael Batty 2009). 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 (Curdes 2010).

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 (Mani 2012).

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. The width of the building is fixed at 14m.

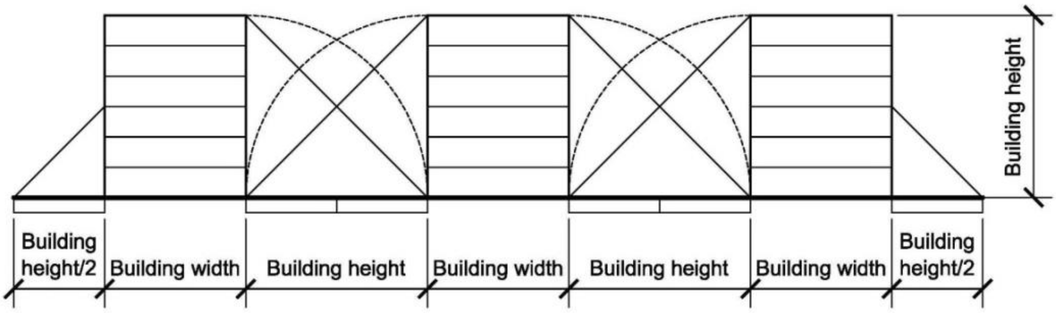

Figure 1. Sample section of the generated model with indication of the distances between buildings

As the result, 60 urban models were generated. 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.

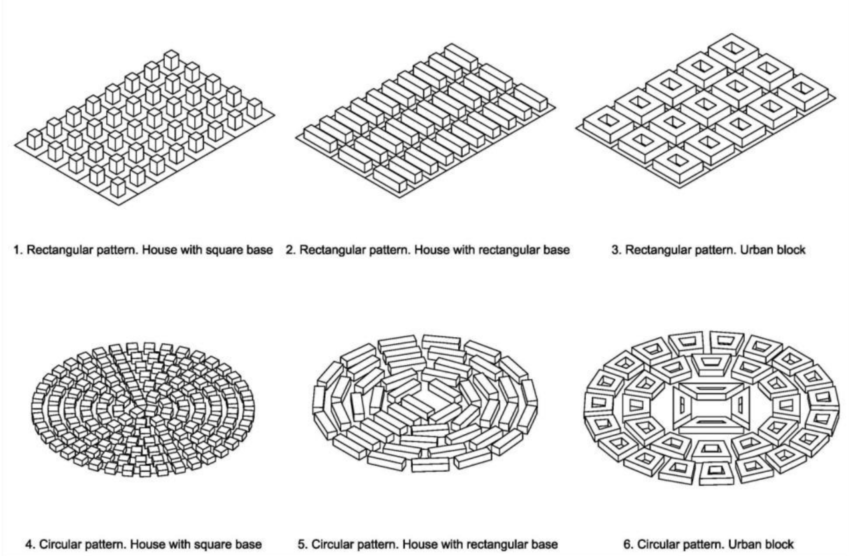

Figure 2. Samples of the six urban patterns

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
- 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. 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 behavior 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.

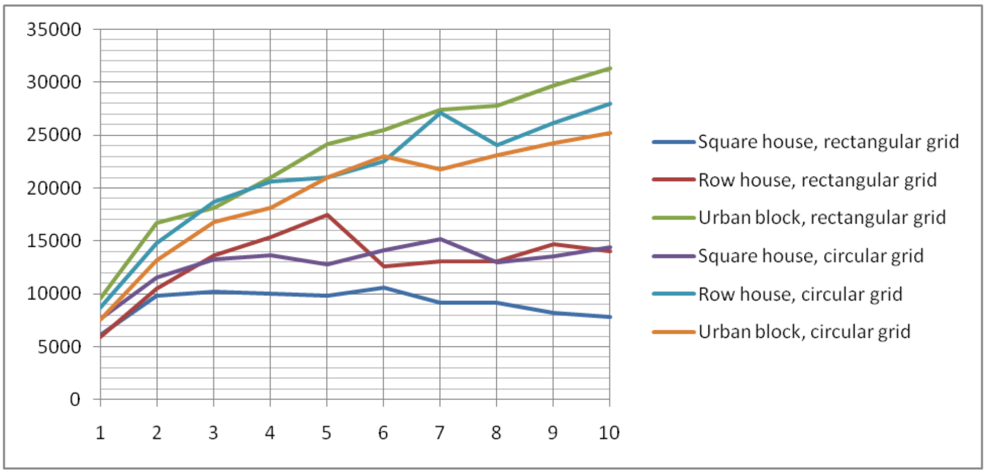

Figure 3. Building density and the number of floors for different urban patterns, sq.m/ha

3.2 Number of the buildings.

Since the generated patterns require two different sites – rectangular and circular – it is possible 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.

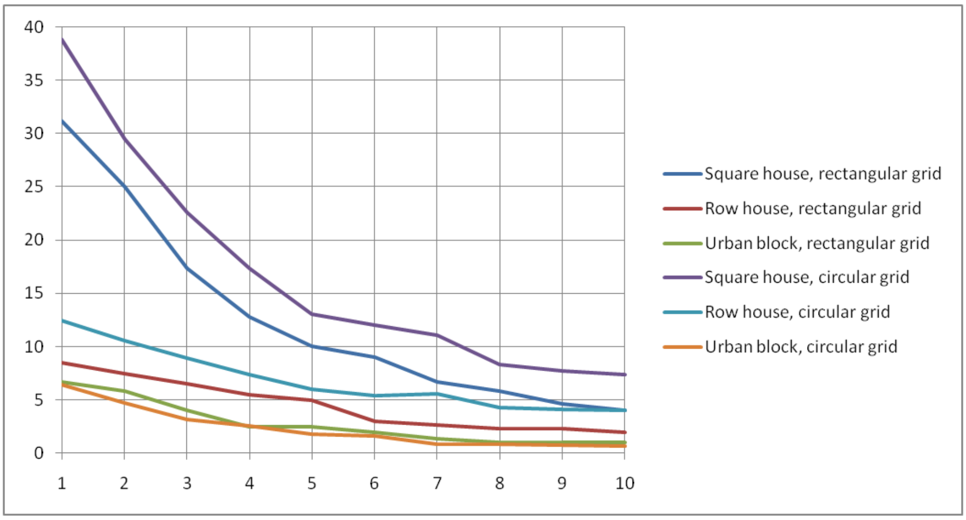

Figure 4. Number of buildings and the number of floors for different urban patterns, unit per ha

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.

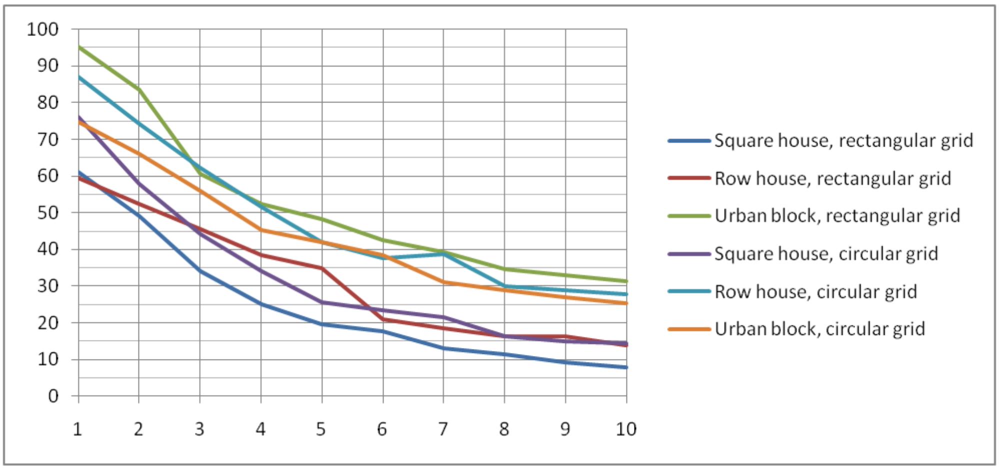

Figure 5. Site coverage and the number of floors for different urban patterns, %

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 ratio.

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.

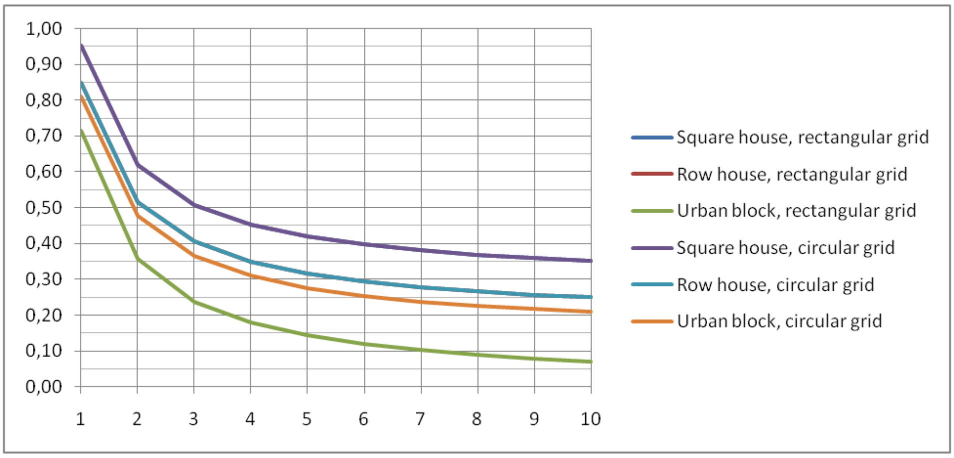

Figure 6. Surface to volume ratio and the number of floors for different urban patterns, sq.m/cub.m

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. 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.

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.

According to the results of simulation 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.

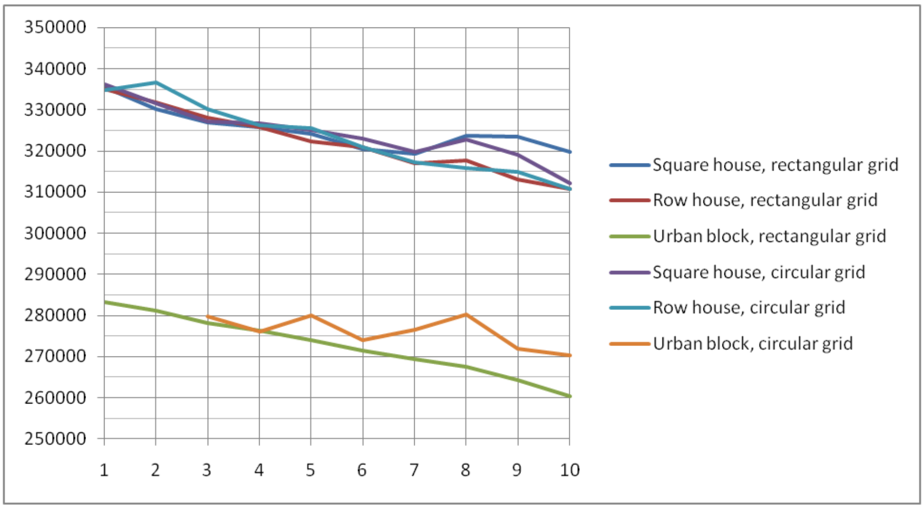

Figure 7. Incident solar radiation and the number of floors for different urban patterns, KWt per year

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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Optimization of the Urban Pattern Using the Galapagos Evolutionary Solver

Ernest Shtepani(1); Anna Yunitsyna (2)

1. *National Planning Sector, Ministry of Urban Development, Tirana, Albania*
2. *Department of Architecture, Epoka University, Tirana, Albania*

Corresponding author: Ernest Shtepani (shtepani.ernest@gmail.com)

Abstract: Urban morphology is a result of the interconnection of various factors, such as climate, economy, traditions and culture. Urban districts had been developed in order to find the most efficient structure, to establish the optimal street network and to provide the high level of land use. The spatial organization of urban districts as well as the geometrical shape of the buildings has direct connection with the urban microclimate and with the energy consumption of the district. Compact urban structures with low surface to volume ratio have big potential to minimize the cooling and heating loads of the buildings. Urban patterns with high density provide the maximal economical efficiency with the reduction of the resources spent for the provision of the transport, energy, water and wastewater infrastructure. Within the research the relation between the building density and the surface to volume of the urban pattern were studied in order to generate the optimized solution. The six parametric models of the different urban morphologies were established. Within the algorithms the geometrical properties of the buildings, such as height, width and length could be changed, but the plot remained fixed. The Galapagos Evolutionary Solver was used as a tool in order to find the set of parameters, which brings to the urban pattern the optimal combination of density and surface to volume ratio. Among all tested patterns the rectangular and the trapezoidal urban blocks with relatively small dimensions of the base and bigger number of floors had demonstrated the highest economical and energy performance.

Key words: Algorithmic urban pattern, building density, surface to volume ratio, urban morphology, urban pattern optimization.

1. Introduction

Urban forms can be found at all planning levels, starting from macro to intermediate scale of development. Urban forms may include region, city, district, neighborhood, street or urban block. Each of them has its specific physical characteristics such as shape, size and configuration of the units [1]. The energy efficiency of urban morphology is associated currently with the efficiency of the cooling and heating systems of each of its buildings and with the properties of the insulation materials [2]. Within the present research the level of the urban district, neighborhood or the combination of several urban blocks is selected in order to evaluate the properties of the urban morphology as a single object. The generated algorithmic models of the urban forms are defined by the specific pattern of the square based tower buildings, or row houses, or by the grid of urban blocks and by the main dimensions of the buildings. Urban pattern influences to all sectors of infrastructure. The resources, which are needed to establish and supply the energy, transport, water supply and wastewater, solid waste and social infrastructures may be reduced by provision of the compact urban morphology with higher density. Within the generated idealized model it is possible to evaluate the density in terms of the total provided habitable area rather than residential or occupancy density. The building density is a ratio between the sum of all habitable areas and the site area. Application of different urban morphologies, which vary by the height and the shape of the buildings may provide the similar density. In this case it is important to establish the additional factors, which may help to evaluate the efficiency of the urban solution. The maximal site coverage, which characterizes the amount of built-in land, is provided usually by the urban planning standards. The other parameter is the minimal solar obstruction angle is requiring the lower site coverage and lower density with the growth of the building height [3]. Decrease of the site coverage results with the increase of the amount of sky, which may be observed from the ground. The sky view factor is one of the parameters, which influence to the phenomena of urban heat island [4].

Urban form and morphology and the density of urban affect the energy consumption of the district. The length of the transport network and the costs, which are associated with it are reduced in the cities with the higher density. The social networks and community interactions in the cities may be stimulated by the higher density [5]. Higher density makes the urban district to tend to be more energy efficient than the one with lover density [6]. The outdoor microclimate is defined by the character of urban pattern, which influences at the energy consumption of the buildings as well. Building compacity may affect to the energy losses of the building and consequently to the heating and cooling loads. Bigger buildings and buildings with the simple footprint demonstrate better energy performance in comparison with the smaller ones and the ones with the complicated plan shapes [7]. The ratio between surface and volume of the buildingis a parameter,which depends on the complexity and proportions of the geometrical influences to its heat loss or gain through the outer walls and roof [8]. The lower energy demands as well as the lower cost for the establishment and supply of the road system are character for the patterns with higher urban density and compacity of the buildings, which makes them more economically efficient [9].

The solar radiation, which is received by the urban pattern, depends on the shape, compacity, the character of surface of the buildings and the distance between them. The solar access is decreasing with the increasing of the density of the urban structure, which may increase the building energy demand for heating [10].

Within the study the relation between the urban pattern, density and compacity of the buildings is established based on the finding of the optimal parameters for the higher economical and energy efficiency of the algorithmic models of six different urban morphologies. The evolutionary algorithms are applied in order to find the urban model with the highest building density and lowest surface to volume ratio.

2. Description

Within the study the algorithms describing the six common urban patterns were developed. The typical buildings, such as square based tower, row house and urban block were arranged in a rectangular and circular array. The algorithms were designed using Grasshopper plug-in for Rhinoceros software. For the generation of models the two sites (rectangular and circular) with fixed dimensions were used. For each pattern the height of the building could range between 1 and 10 floors and the length and the width of the built units could vary, which gave the possibility to generate numerous variations of urban patterns. The distance between the buildings and from the site border to the building was defined by the minimal solar obstruction angle of 45 degrees. Fig. 1 shows the sample section of the generated urban pattern. According to the settings of Grasshopper definitions the number of the buildings, which could fit on site and the density of the pattern directly depend on the height of the building and the dimensions of the base.

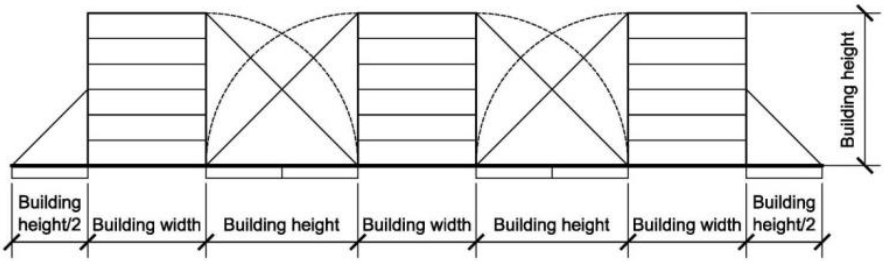

Fig.1 Sample section of the generated model with indication of the distances between buildings.

The problem of finding the urban pattern with the optimal combination of the high building density and low surface to volume ratio was examined with the use of the Galapagos Evolutionary Solver, which is a part of Grasshopper plug-in. Evolutionary computation can be used for solving of the optimization problems due to the simplicity of the approach, flexibility, applicability to the wide variety of problems and the self-optimization ability [11]. Evolutionary algorithms need the specification of the target, or fitness function, which can be expressed through the parameter, or through the combination of parameters to be optimized [12]. The Galapagos Evolutionary Solver requires variables or genes, which are allowed to change. The Generation Zero of the model is based on the random selection of the variables combinations, but with the further generations the preferred genomes are selected. The higher the number of generations is performed, the more probable is the opportunity to find the combination with better fitness [13]. During the process of computation the multiple models of urban morphologies were generated in order to find the optimal solution first independently for the building density and surface to volume ratio and further for the combination of the two parameters. For each typology the two variables, or genes were defining-the number of floors and the shape of the building base.

The six models of the generated urban patterns are shown in the Fig. 2.

For the square based house (tower) the side could be selected within the range between 10 and 20m. The sample row house has fixed width of 14 m and thelength could be between 20-50m. The side of the urban block was between 50 and 200m. In the circular array this rule was applied to the smallest side of the trapezoidal block. For each case 25 generations were performed and top 25% of the best fitting solutions were selected and analyzed.

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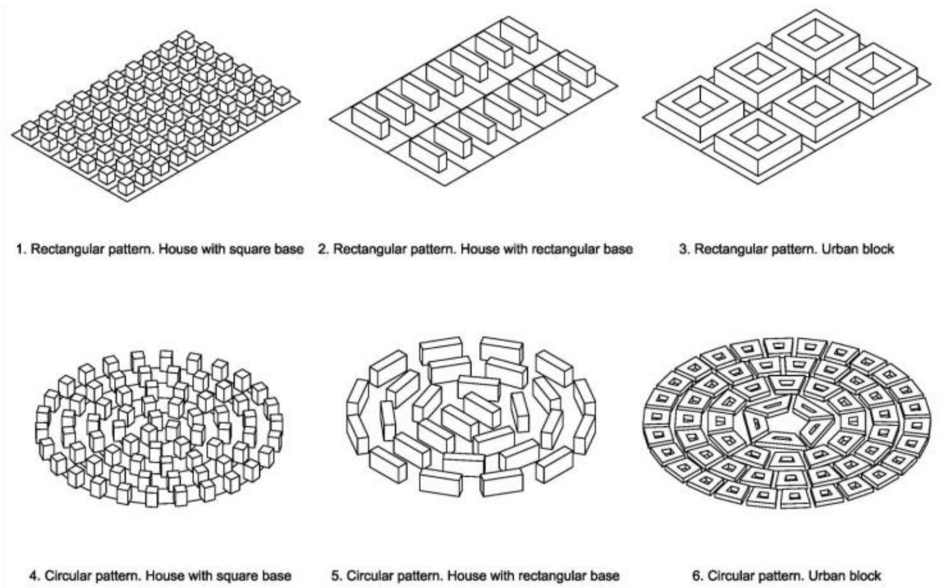

Fig.2Samples of the six urban patterns.

The evaluation of the urban patterns is based on the following parameters:

1. Surface to volume ratio-ratio between the sum of all surfaces of the buildings and all volumes. For the urban pattern with lower energy losses this coefficient should be minimized;

2. Building density-ratio between the total habitable area of all buildings and the site area. For the efficient use of the land plot the building density should be maximized;

3. The third fitness value-the coefficient indicating the maximal density and minimal surface to volume ratio.

3. Results and Discussion

3.1Rectangular Pattern: Tower House with Square Base

The urban pattern is based on the population of the units with the square base and variable length of the building side. The height of the building is ranged from 1 to 10 floors. The distance between the buildings was calculated to be not less, then the height of the building. Since the site border was limited the amount of buildings, which could be placed on side and the building density were changing with the growth of height. For the pattern, which is based on the repetition of the similar units surface to volume ratio is the same for every building. Within 25 generations there were selected 31 patterns, which represent the top 25% of the best fitting solutions. The coefficient is ranged between 0.267-0.364 m^2m^{-3}. The lower coefficient characterizes the higher and wider buildings. Within the selection the side of the building was ranged between 20 and 14 m and the height-between 10 and 6 floors. The surface to volume ratio is directly connected with the dimensions of the building and gets the lowest value with the maximum dimensions of the building base and height. The building density was examined for the 24 patterns and was ranged between 16,000 and 11,127 m^2ha^{-1}. The width of the building is ranged between 15 and 20 meters, the height-between 10 and 3 floors. The connection between the density and the building dimensions is not linear-the high level of density is demonstrated by the patterns of 5-7 floors buildings.

The Evolutionary Solver generated 37 patterns with the highest fitness value. The selected patterns were optimized in order to have the lowest surface to volume ratio and the highest density. The building side ranged between 20 to 14 meters, the height-between 10 and 4 floors. The graphical distribution of the fitness value of patterns is presented at the Fig. 3.

The best values belong to the series of patterns with buildings of 6-10 floors with the side of 19-20 m.

3.2 Rectangular Pattern: House with Rectangular Base (Row House)

For the row house pattern the width of the building was fixed at 14m and the length and height were changeable. The surface to volume ratio was calculated

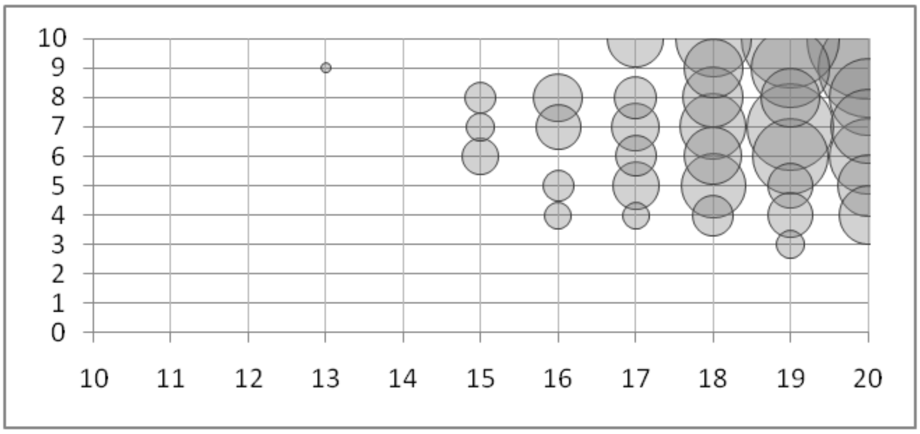

Fig.3The distribution of the parameters of rectangular pattern with square based buildings based on the maximal fitness value, number of floors/building side, m.

for 76 patterns and ranged between 0.25 and 0.311 m^2 m^{-3}. There were selected the patterns with buildings with all variety of lengths from 22 to 50 m and from 10 to six floors high. The minimalcoefficient is recorded for the set of 10 floors buildings with long building side of 40-50 meters. The building density was calculated for 57 patterns and ranged between 18144-13104 m^2 ha^{-1}. The maximal values are demonstrated by the patterns with 5-7 floor buildings with length of 45-50m. The overall distribution of lengths ranged between 21 and 50 m, of heights-between 10 to 3 floors. The high density is noted for the two families of patterns: one with buildings with length from 38 to 50 mand height from 5 to 9 floors, second-with length 28 to 37 m and 5-6 floors.

The fitness value was calculated for 87 patterns. The highest coefficient belongs to patterns with 9 and 7 floors with the building lengths of 39 and 45 meters consequently.

According to the Fig. 4 the high coefficient is character for the three families of patterns: first and the biggest-buildings with length from 30 to 50 m and height from 6 to 9 floors, second, 44 to 50 m and 9 floors, third, 24 to 35 m and 5-6 floors.

3.3Rectangular Pattern:Urban Block

Urban block is defined by the length and the height of the building with the fixed width of 14m. During the generation it was appeared, that the site could be populated by one, two or six buildings with various dimensions due to the site limitation. The surface to volume ratio was calculated for the 16 patterns and ranged between 0.209 to 0.309 m^2 m^{-3}. The recorded dimensions are between 54 and 273m and 4 to 10 floors. The highest values belong to two patterns with

70×70 and 120×170m bases and 10 floors high. The ratio was directly connected with the height of the building, but the correlation with the building base was not established due to the complex shape of plan. The density value ranged between 31360 and 18293 m^2ha^{-1} for the 13 patterns. The maximal density is character for the small-sized urban block with the side of 51-79m and 8-10 floors high.

As it is shown in Fig. 5, there is an evident division of patterns in the three groups by the fitness value. The most efficient are the small scale units with 70-80m side. The second group has the side of 130-170m, the third-of 170-270m.

3.4Circular Pattern: Tower House with Square Base

The circular pattern is based on the repetition and rotation of the same building unit, as in rectangular pattern, therefore results for the surface to volume ratiowhich characterizes only the geometrical property of the unit are the same, as in rectangular pattern. The building density was calculated for 32 patterns and ranged between 24,851 and 15,915 m^2ha^{-1}. The side of the building ranged between 15 to 20 m, the height-between 3 and 10 floors. The highestdensity was noted for the buildings with bigger side with the optimal height of 9 floors.

Within the examined 44 patterns the highest fitness value in registered for the widest building with 9 floors. The overall distribution of values is between 11 and 20 m for the building side and 2 to 10 floors. Fig. 6 shows the fitness value for the generated patterns.

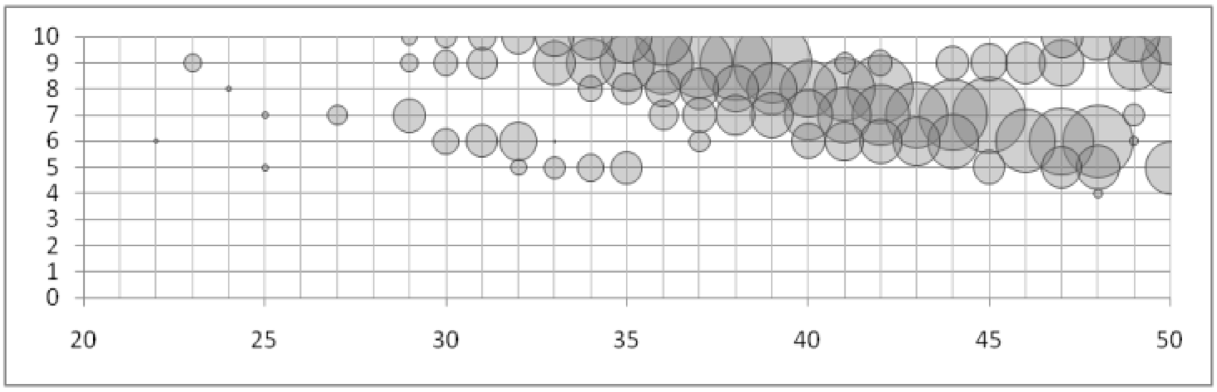

Fig.4 The distribution of the parameters of rectangular pattern with rectangular based buildings based on the maximal fitness value, number of floors/building side, m.

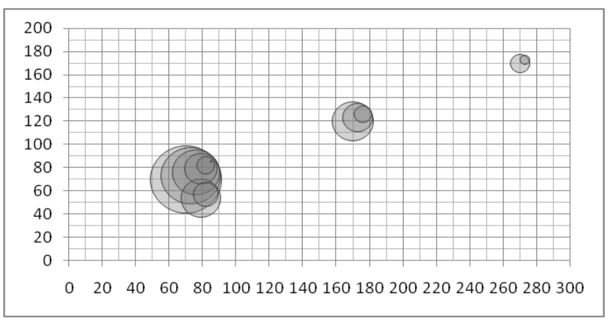

Fig.5 The distribution of the parameters of rectangular pattern with urban block based on the maximal fitness value, block length/block width, m.

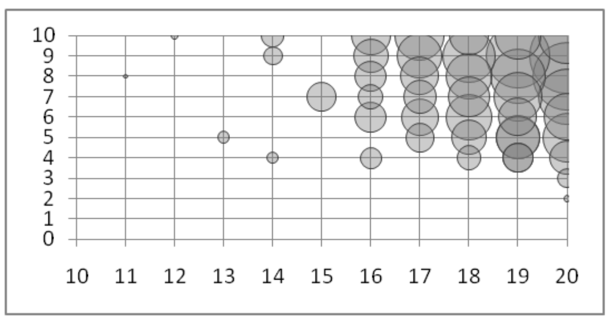

Fig.6 The distribution of the parameters of circular pattern with square based buildings based on the maximal fitness value, number of floors/building side, m.

The preferred patterns have the building side of 18-20m and the height of 7-9 floors.

3.5 Circular Pattern: House with Rectangular Base (Row House)

The surface to volume ratio for the circular pattern with row houses is identical to the one of the rectangular pattern. The building density for the 64 cases was ranged between 27,938 and 19,818 m^2ha^{-1}. The length of the building is registered to be between 50 and 25 m, the height-between 10 and 5 floors. As it is shown in Fig. 7, the best results are demonstrated by the units with the biggest length and height, but within the data the two main groups of patterns can be evidenced: the group based on the use of 10 floor buildings with the length of 37-50m and 7 floor buildings with the length of 31-50m.

The best fitness value is noted for the bigger buildings of 10 floors height and 45-50m length. Among the 76 cases the height parameters are 6-10 floors and the length 22-50m.

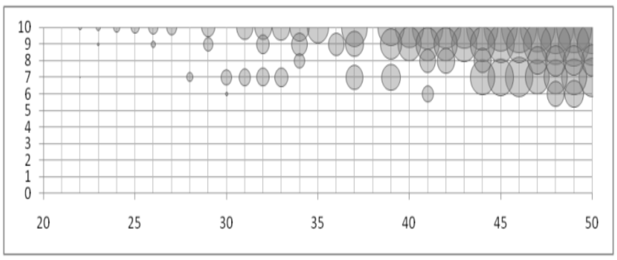

Fig.7 The distribution of the parameters of rectangular pattern with circular based buildings based on the maximal fitness value, number of floors/building side, m.

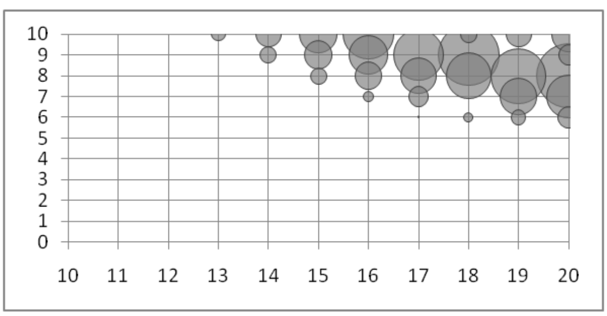

Fig.8 The distribution of the parameters of circular pattern with urban blocks based on the maximal fitness value, number of floors/building width, m.

3.6Circular Pattern: Urban Block

In circular pattern each block has trapezoidal shape, where the size of the smallest side is defined as the sum double width and height of the building. The dimension of each block are different, therefore the surface to volume ratio is calculated for the overall pattern. Within the 37 best cases there are included the patterns of 6-10 floors height and 11-20m wide. The coefficient ranged between 0.166 and 0.25 m^2 m^{-3}. The higher values are registered for the wider buildings of 8-10 floors height. The building density for the 33 patterns is between 29454 and 22043 m^2 ha^{-1}. Among the patterns of buildings with 4-10 floors high and 12-20m width, the highest density is considered for the high and wide buildings with 7-9 floors and gets maximum for 7 floors building of 16m width.

As it is shown in Fig. 8, the fitness value was calculated for 29 patterns within the range of 6 to 10 floors and 13 to 20 width of the building. The maximal values are character for the patterns of 8-9 floors and 17-20m width.

3.7 Discussion

Within the paper it was observed the relation between the urban morphology and the dimensions of its units and its potential for the economical and energy efficiency based on the evaluation of such parameters, as building density and compacity, and the optimized solutions for the urban patterns were proposed. The summary of findings is presented at the Table 1.

The surface to volume ratio is identical for the row house and towers house rectangular and circular patterns consequently. The ratio of the urban block is the lowest, which shows its potential in minimization of the head and cooling losses of buildings. The ratio is evidently decreasing with the growth of the physical dimensions of the buildings. The maximal ratio belongs to the patterns with tower units, which shows the lowest efficiency of such type of urban development.

The connection between the physical dimensions of the built units and the density is more complex due to the application of the algorithm to the site with fixed dimensions. The highest building density is recorded for the two urban block patterns, the lowest-for the tower pattern.

The high level of density does not mean the population of site by the widest and tallest units. The optimal density can be achieved by the use of the 6, 7or 9 floor buildings; the width of the units may vary as well. Calculation of the building density does not show the results, which are applicable to every urban structure due to the use of the specific site, but it allows evaluating the overall tendency.

Table 1 The main parameters of the generated urban morphologies.

		Rectangular pattern			Circular pattern		
Parameter		Tower house	Row house	Urban block	Tower house	Row house	Urban block
Surface to volume ratio	Number of generations	25	76	16	25	76	37
	Value range, m^2m^{-3}	0.267-0.364	0.25-0.311	0.209-0.309	0.267-0.364	0.25-0.311	0.166-0.25
	Number of floors, generation	10-6	10-6	10-4	10-6	10-6	10-6
	Optimal number of floors	10	10	10	10	10	10
	Building side/width, m, generation	20-14	50-22	54-273	20-14	50-22	20-11
	Optimal building side, m	20	50	70x70, 120x 170	20	50	20
Building density	Number of generations	24	57	13	32	64	33
	Value range, m^2 ha^{-1}	16000-11127	27938-19818	31360-18293	24851-15915	27938-19818	29454-22043
	Number of floors, generation	10-3	10-3	10-6	10-3	10-5	10-4
	Optimal number of floors	10	6	10	9	10	7
	Building side/width, m, generation	20-15	50-21	179-51	20-15	50-25	20-12
	Optimal building side, m	20	48	70x70	20	50	16

Fitness value: Minimal surface to volume ratio, maximal building density	Number of generations	37	87	13	44	76	29
	Number of floors, generation	10-4	10-5	10-5	10-2	10-6	10-6
	Optimal number of floors	10	9	10	9	10	8
	Building side/width, m, generation	20-14	50-22	273-54	20-11	50-22	20-13
	Optimal building side, m	20	39	70x70	20	50	20

The best fitness value is demonstrated by the urban block patterns. The optimal dimensions of the urban block are relatively small: 70×70m for the rectangular unit and 64×69 for the trapezoid. The optimal height of the block is 10 and 8 floors consequently. The dimensions on the units of tower and row house patterns tend to be maximal, but the use of the specific site provides the different solutions with the best fitness value.

4. Conclusion

Within the research the multiple variation of the six urban patterns were generated based on the use of the parametric algorithms. In order to find the optimized urban pattern with the highest energy and economical efficiency the Evolutionary Solver was applied. The three parameters, such as building density, surface to volume ratio and the fitness value are compared for the different urban patterns.

The use of the urban block in the city development is more preferable according the results of comparison between the different urban patterns. The dimensions of the building base are relatively low, but the height is maximized. Application of the compact urban pattern may reduce the overall energy demands of the urban district and make the urban development more sustainable.

The findings of the study are based on the computer simulation, which required to apply some limitations. There were selected the patterns with the most common building dimensions and heights, the average solar obstruction angle, the dimensions of site were limited. Establishment of the different ranges of the main parameters, change of the site borders or use of the built units with the complicated geometrical shape or with the prevailing vertical dimension may affect to the results of the study.

Evaluation of the economical and energy efficiency of the urban morphology was based on the finding of optimal combination of the surface to volume ratio and building density. For the future research the more parameters, which may influence on the overall energy performance of the urban pattern, can be applied. The more complex research may include the different approaches of the sustainable design, such as evaluation of the solar radiation, which can be received by the built units, finding of the preferable orientation of them, checking of the available space for the installation of solar panels and calculation of the passive zones.

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Energy Efficiency in the Urban Scale: Case Study – Prague, Czech Republic

Ernest Shtepani[1], Anna Yunitsyna[2]
[1] National Planning Sector, Ministry of Urban Development, Rruga Abdi Toptani 1, Tirana, Albania
[2] Department of Architecture, Epoka University, Rruga Tiranë-Rinas, Km 12, 1039, Tirana, Albania
E-mail: shtepani.ernest@gmail.com, ayunitsyna@epoka.edu.al

Abstract. *Cities are a complex mass of morphological properties of many city fragments, which play a major role in energy consumption. Urban form, urban patterns, or city fragments can also be seen as defined by algorithms or form generators. Cities are designed taking into account infrastructure, city standards and land use regulations. Energy efficiency of the urban form may be understood as the balance between gains and losses of energy, which may depend on a set of parameters mostly defined by the geometrical shape of the buildings and the distance between them. The study starts from the development and analysis of 60 hypothetical models in order to evaluate their energy efficiency potential. The Galapagos Evolutionary Solver is used as a tool in order to find the set of parameters, which brings to the morphological properties the optimal combination of density and surface-to-volume ratio. At the final stage morphological properties of 64 Prague's patterns were selected. Computer simulation and analysis is performed using the models extracted from the virtual Google Earth model of Prague. During the process of evaluation of the samples, the relationship between the urban form and such parameters as plot coverage, surface-to-volume ratio and the incident solar radiation was established and potentially higher energy efficient structures were indicated. As the result of analysis the interrelation between urban form and energy efficiency was established, which allowed to identify the urban patterns with the higher potential of energy efficiency.*

Key Words: algorithmic modeling, digital city, parameters of energy efficiency, morphological properties, urban pattern, Prague.

Introduction

Parametric urbanism can be interpreted in various ways, and for the study of the energy efficient cities the focus is on the display and interpretation of parameters influencing the possible energy gains and losses of the built structures. Centrally-planned urbanism addresses to a big-picture view, and misses all the local details that significantly affect the solution. This centralized approach invariably works through large-scale destruction of existing structures (either man-made or natural), followed by the construction of lifeless non-adaptive solutions (Salingaros, 2011). Parametric urbanism is about development of strategy and channeling of information, analyzing the data before drawing conclusions. It results as a city, where social, economic, environmental and spatial equations are resolved in favor of construction of the most sustainable and efficient urban morphology (Hindi, 2013). Application of algorithms could help city modeling adapt to different measures using algorithmic simulations (Leach, 2009). DeLanda (2004) draws some connections between what he calls self-organizations and genetic algorithms of applied scripting patterns.

Fortier states, that the urbanist nowadays deals with management, logic on the things, reflect on the harmony of the space, dissonance and difference, doing things more comprehensible. The objectives of the profession are different from the 16th century Palladio or 19th Century Urbanism (Fortier, 2003). Owens (1986) explains, that spatial configurations of the city for evaluation are selected with varying degrees of subjectivity and the majority of them is ruled out by non-energy considerations. Salat emphasizes the importance of city density, which is a major contributor to energy efficiency, especially in relationship to transportation (Salat et al., 2012). High density cities increase the social networks development and community interactions (Doherty et al., 2009). Lower density structures demonstrate the lower level of energy efficiency (Rode et al., 2014). There is a common agreement among researchers about the efficiency of compact cities (Große et al., 2016), there are other important issues, such as passive solar radiation and the ventilation factor. With the increase of compactness, the possibility to use natural resources like passive solar energy is decreasing since the tall building may cast shadows and block the natural light and solar heat and reduce the efficiency of passive cooling (Littlefair, 1998).

Buildings are the major agents of energy consumption. Energy efficiency of housing is very difficult to tackle because of its very complex properties related to lighting requirements, construction, privacy requirements and urban regulations. The energy efficient properties should meet at the same time social, physical and economic criteria. Research on surface-to-volume ratio is addressed to find the building typology with the minimal surface area and consequently the minimal potential energy losses, and the maximal built volume. March (1971) suggested, that the most efficient building would be "a half Cube or half sphere". This statement is actually based on surface-to-volume ratio, where a more energy efficient structure is actually less exposed to the outer environment. Compact, cube-like building actually has the minimum of heat gains and losses, but the large part of the central floor area is not accessible for natural daylight (Behsh, 2002). Outer surface is a major medium of temperature exchange that follows a linear law by which for the same volume the more surface means more energy spent for keeping the same temperature. A low surface-area-to-volume ratio is optimal for a passive, low-carbon building (Thorpe, 2014). Curdes compares the index of surface to volume of different typologies where very obviously modernist high-rise buildings seem to have a good ratio. Poor performance is evident in individual housing, medieval and traditional European urban block structures are identified as energy efficient (Curdes, 2010). Increase of building compacity, which is higher for the structures with the simple footprint and clear undivided volume, reduces the heating and cooling loads of the building (Adolphe, 2001).

Solar radiation has a tremendous effect on energy efficiency, especially through passive solar gains, which is in fact the amount of solar energy that is absorbed by the thermal mass of the building. Exposure of the building or south facing orientation is one of the most fundamental principles which increase solar energy gains. The total gain from solar radiation is defined as the incident solar radiation during the selected period on the facades of a building (Rode et al., 2014).

Wind pressure has a major effect on temperature exchange. The relationship is linear: the more pressure, the higher the rate of temperature exchanges. In winter the wind movement in the outdoor environment affects heat loss of the building, while in summer the change of wind direction and speed in the outdoor environment affects the ventilation and indoor air circulation. (Huifen et al., 2014)

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Methodology

This study aims to find the relationship of morphological properties of urban pattern, such as shape and dimensions of the built units, and its energy efficiency, testing the criteria of density, site coverage, available solar radiation, wind flow and surface-to-volume ratio.
The research is performed by the following steps:

- Definition of the set of measurable parameters which influence the energy efficiency of the urban pattern
- Generation of a variety of 3dimensional models, which could be used for computer analysis
- Analysis of energy efficiency of the urban patterns according to the selected criteria
- Optimization of the dimensions of the main six typologies with the use of genetic algorithms
- Analysis of energy efficiency of morphological properties of city fragments of Prague

In order to find the influence of the geometrical parameters of the urban patterns on its energy efficiency, the study starts by generating of a set of hypothetical models or archetypes of urban pattern which may create possibilities for further testing or computer simulations. 60 generated patterns vary from 1 to 10 stories and include Square house, Row house and Urban block typologies arranged with the use of rectangular and circular grid. The Grasshopper definitions (urban morphology algorithms) are designed in a way, that the number of the buildings and dimensions of the built units (the length and the width) are adjusted in the fixed site according to the building height. Samples of the generated models are presented in Figure 1. At this stage, some other properties which work independently from urban geometry, such as occupant behavior, thermo-insulating materials or human feeling of the temperature are omitted. Energy efficiency of urban morphology is analyzed through comparison of its performance by different criteria such as density and site coverage, surface-to-volume ratio, annual solar radiation, wind sheltering factor, building dimensions and geometry.
The second part of research is based on an investigation of possibilities to find the geometrical properties and the way of spatial arrangement of the most energy efficient urban morphology. The problem of finding the urban pattern with the optimal combination of the high building density and low surface-to-volume ratio was examined with the use of the Galapagos Evolutionary Solver. The Evolutionary Solver requires variables or genes (the height and the width of the generated building), which are allowed to change (Rutten, 2010). Evolutionary algorithms are applied to the pattern definitions in order to optimize the morphologic properties of building blocks in relationship to minimal surface-to-volume ratio and maximal density.
At the final stage the performance of theoretical generated urban morphologies is compared with the behavior of the groups of buildings, which are extracted from the existing city. Prague is very rich in urban forms with different layers of urban patterns, starting from the European City Block to prefabricated row-houses of the communist era buildings, to postmodern typologies, thus it is an exemplary site for the experiment. The 3D model of Prague is available in Google Earth since 2009 (Mellen, 2009) and the selected parts of it were exported for the further analysis (Figure 2). Different urban morphologies in Prague, including urban patterns of different shapes and models from triangular patterns to hexagons, and from row housing to towers and urban blocks are compared through the tri-fold properties of energy efficiency – surface to volume ratio, incident solar radiation and building density.

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Measurement and analysis

- **Density and Site Coverage**

Density is one of the most important qualities of urban morphology, which is connected with its energy efficiency potential. The highest efficiency is usually associated with the highest density, which means at the same time reduction of the urban road network, the network of energy supply and rational organization of the urban space. There is no direct connection between the density and the height of the building. At it is seen after the comparison of 60 generated patterns from 1 to 10 floors, for the square- and rectangle-based building, density is increasing only up to 5 floors with the growth of the floor number. For rectangular and trapezoidal urban blocks density is growing proportionally with the increase of the building height. At this stage it is important to understand that the building height can't grow without limits. Tall buildings are negatively perceived by inhabitants. An increase in height requires the increase of the space between buildings and the existence of wide streets.
For every generated urban pattern site coverage ratio is decreasing with the increase of the height of the building. The highest values are noticed for the rectangular and trapezoidal urban blocks, and the lowest values characterize the patterns generated by square-based buildings. Site coverage is restricted by the urban regulations, and for all the low-rise and especially single floor building patterns, it is at least 60%, which is not permitted by the urban regulations.
The task of finding the variety of urban patterns with the maximal density is investigated at the second stage of the research. The dimensions of the same six generated morphologies were set as flexible. With the application of genetic algorithm, the set of the most optimal solutions for the given site was found. The statement, that the highest density is typical for the rectangular and trapezoidal urban block patterns, is proven by the results of optimization. The optimal density is achieved by the application of the 6, 7 or 9 floor buildings; the width of the units may vary slightly. According to this statement, there is no need to use the buildings with maximal height in order to achieve maximal density.
For Prague models calculation of the density was complicated by the fact, that real buildings could have different heights of floors and floor plans configurations at different levels. Therefore, in this case the site coverage is a value, which is more objective. The average value of site coverage reaches the maximum for the bar or tower-shape buildings, since there are no closed or semi-closed courtyard available. It is at the same time an indicator of the lack of private space, which is associated with the specific building. For rectangular, triangular and trapezoidal urban blocks, site coverage ratio is the highest for the filled structures and for the urban morphologies with narrow units. In this case it may be observed, that the inner courtyard of the built unit is filled by one or two floors of uninhabited structures, which reduce the private open space. The two groups of the medieval streets have the highest value of site coverage.
High level of density for the urban pattern is associated primarily with the economy of resources and energy. For the real urban situation the connection is not straight. The statement, that higher density may minimize energy losses, is valid only for the generated abstract models, where the distance between buildings is set to provide the minimal solar obstruction angle of 45 degrees. In this case the building receives the maximal solar radiation. In the real city the distances are smaller in many cases, and buildings may cast shadows one to another. The balance between energy gains and losses can be different.

- **Surface-to-volume ratio**

Buildings with the higher surface exposure have more intensive temperature exchange and higher energy losses. High surface-to-volume ratio shows the potential heat losses though the external surfaces of the building. The more compact is the outer envelope of the building, the smaller is the surface-to-volume ratio and the better is its energy performance.

60 generated models of the six basic typologies are designed in a way that the built unit has a simple box-like shape, or in case of the urban block – the perimetral, trapezoidal or rectangular building with open courtyard. At this stage it is easy to conclude, that the surface-to-volume ratio and, therefore, the potential energy losses of urban block are higher than the compact building due to the presence of void. The performance of the urban block pattern based on the use of rectangular grid is better than the one with the circular grid. For the tower and row house patterns the surface-to-volume ratio does not depend of the type of the spatial arrangement – rectangular or circular. The highest surface-to-volume ratio is found for the low-raised buildings, which makes this typology less energy efficient. The ratio is decreasing with the growth of the physical dimensions of the buildings, which shows the bigger and taller buildings are more efficient. Pattern with tower built units has the maximal ratio, which shows the lowest efficiency of such type of urban development.

Minimal surface-to-volume ratio was used as a parameter for the optimization of generated morphology with the use of a genetic algorithm. The lowest ratio, the lowest potential energy losses and consequently the better energy performance was demonstrated by the urban block patterns. The optimal dimensions of the urban block in application to the given site are relatively small: 70x70m for the rectangular unit and 64x69 for the trapezoid and the optimal height - 10 and 8 floors consequently. This correlates with the conclusion from the previous phase that it is not necessary to apply maximal dimensions to the buildings in order to achieve density and minimize the energy losses. For the units of tower and row house patterns dimensions tend to be maximal, but the use of the specific site provides multiple solutions with the best fitness value.

In the case of Prague the minimal surface-to-volume ratio is registered for the simple-shaped contemporary structures. These buildings are characterized by the use of the compact volume with a simple geometry, flat roof and lack of the building details. The parameters of the variations of urban blocks, such as square, rectangle, triangle and trapezoid are similar. Examining the variations between the geometries of urban block, the pentagon shape demonstrates higher surface-to-volume ratio, making it less efficient. The triangular urban block may be considered as the most compact structure with minimal energy losses. The specificities of the real morphologies, such as the distance between the two buildings which formed the courtyard, or the narrowness of the pattern and the level of courtyard infilling, slightly influenced the overall performance. The long medieval street has performance equal to the urban block groups, while the courtyard medieval street is closer to the contemporary structures.

It is important to note that the surface-to-volume ratio cannot be observed as the only parameter which affects the energy efficiency of the urban patterns. It indicates the potential energy losses, but there are also potential energy gains of solar radiation. In this case it may be predicted that the perimetral urban block will always cast a shadow on to one of its walls, which will reduce the possible energy gains.

- **Annual Solar Radiation**

Solar radiation indicates the energy which is received by all the walls and roofs of the built units of the urban pattern. The higher level of received solar radiation indicates the pattern with higher energy gains, which gives to it the potential to be more efficient. The computer simulation was conducted for the 60 generated urban patters and for the 64 samples from Prague. At the first stage of research by results of simulation the urban block performs worse in comparison to the other generated patterns. Both circular and rectangular urban block patterns receive less solar radiation, which can be explained by the complex shape of the building with the courtyard, which causes an extra shading of the walls. Incident solar radiation increases with the decrease 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 the 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.
In the case of the Prague examples, the solar energy which is received by different typologies of urban blocks is higher than the one of the contemporary simple buildings. The blocks with the irregular orientation of sides, such as triangular or trapezoidal are more preferable than rectangular. The structures with an open courtyard gain more radiation than the ones with the filled one. The medieval street structures perform the worst. For the contemporary buildings the simple bar or tower-like building is more efficient than the L-shape or U-shape.

- **Wind Sheltering Factor**

Simulation of the virtual wind tunnel was conducted for an analysis of wind performance of 60 generated urban patterns. The acceleration of wind speed is connected with the decreasing of the air temperature and therefore with potential energy losses. The study was based on the presupposition that in conditions of central Europe it is more preferable to create the wind shadow and therefore to prevent the cooling of building surface by the air flow.
In both rectangular and circular form, low storey buildings create a wind shadow for the whole examined area. Up to the 5-6 floors the wind speed is still lower than the average, but for the high-rise buildings, it is significantly higher, resulting in the appearance of wind tunnels between the buildings. The wind speed accelerates more than average along the perimeter of the morphologies, indicating the necessity of additional thermal insulation and wind protecting membranes of the building facades. In the circular pattern this phenomenon is more evident.

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Conclusion

The study is based on the search of the balance between the energy losses and energy gains of the morphological properties of urban patterns. In some cases, the requirement which may enforce one of the elements of this equation, will contradict the other. Nevertheless, it is possible to draw the general set of rules, which may be applicable for different urban solutions.
Low energy losses are character for the compact urban structures with high density. For the simple-shaped box-like buildings, the highest reasonable level of density is achieved for the built units of 5 floors. The same height is the best solution for the wind sheltering. Simple-shaped buildings have low surface-to-volume ratio which decreases with the increase of height and perimeter of the building. In this case it is important to note that building dimensions cannot increase endlessly; building height is usually controlled by the urban regulations and building width is accepted according to the necessity of direct lightening of the rooms. Potential energy gains of the simple-shaped buildings are higher. Incident solar radiation decreases with the increase of the building height, but it may be noticed that it remains stable from 5 to 7 floors.
The urban block demonstrates the increase of the density with the increase of the building height. Application of the genetic algorithm allowed to identify its optimal dimensions. In order to minimize the energy losses the side of the urban block should be about 60-70m. Urban block demonstrated the best results in its ability to create a wind shelter. The courtyard remains protected with the use of the building of any height. Meanwhile, in order to create a comfortable flow through the streets, the height of the built unit should not be more than 6-7 floors. The energy gains of the urban block are smaller than of a similar pattern which is combined by the simple-shaped buildings.
The study had been developed based on the climate conditions of Central Europe with the condition of maximization of energy gains and minimization of energy losses. In order to apply the theory to a different place, the balance between these two factors should be changed

according to actual climate conditions. Thus, in severe north conditions where the issue of minimal energy losses dominates, compact building shapes and creation of the wind shelter prevails over the potential gains of solar radiation, since the intensity of northern sun is very low. In moderate climates, the issue of wind protection may be less important, but in wet climates the natural ventilation should be encouraged. In hot climates the situation is reversed and the built form should be designed in order to maximize the energy losses and maximize the shading. The building shape in this case becomes less compact and more porous.

Selection of the type of urban form depends in every case not only on the requirements of energy efficiency, but on the urban context, climate, tradition and other factors. Different typologies from the individual houses, row houses to the residential towers can be applied within the borders of one city, but the factor of selection of the morphology with the correct balance between the energy gains and losses can advance the urban planning towards more sustainable solutions.

The algorithms or form generators could be used in designing the cities of the future or scanning and analyzing existing cities. The concept further advances the ideas of parametric urbanism in an era where information technology could be used as a tool to improve cities and urban form based on the use of algorithms. The generated optimized city could be more energy efficient and socially and economically viable in the threshold between open space and built form.

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Illustrations and tables

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ERNEST SHTEPANI

BRIEF

Ernest Shtepani graduated in 2007 at the Politechnic University in Tirana, with a diploma in architecture. He received his Master Degree at Anhalt Univesity of Applied Sciences in Bauhaus-Dessau Germany in 2010. Ernest Shtepani has worked as a full time lecturer at Polis University in Tirana, and since 2014 is working as a part time lecturer at Epoka University. Since 2012 is conducting his research at Czech Technical University in Prague in the topic of Energy Efficency. Between 2013 and 2017 has worked in the Ministry of Urban Development focusing on the Territorial Development Sector. Ernest Shtepani has writen a number of articles on "Energy Efficency in the Urban Scale" published in various scientific conferences in Albania, Montenegro, USA, Spain etc.