Exploring the benefits of urban green roofs: a GIS approach applied to a Greek city

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Abstract

The loss of free and green spaces and their associated advantages for the urban population is a major threat for urban sustainability. The idea of planting roofs in order for them to act as natural filters within the urban tissue has been increasingly recognized as a technology that has the potential to diminish drastically the environmental problems of urban centers. In many countries, special laws are introduced which provide citizens with incentives or even involve an obligation to build green roofs. The objective of the research presented herein is to investigate and record the impact of the use of green roofs for the development of urban policies which aim at improving the quality of urban environment, using a combination of Geographical Information Systems (GIS) technology and specialized software. The developed methodological framework is applied to a real-world case study of a medium – sized Greek city. The use of a comprehensive GIS environment not only contributes to improving the quality of research but also offers the possibility of continuous updated information and monitoring of the factors that influence the development of green roof policies.

Keywords: green roofs, urban environment, GIS, urban sustainability, green spaces

Introduction

Cities have become extremely popular as places for residence and work; more than half of the world's population lives in urban areas (UN-HABITAT, 2013). In large urban agglomerations, buildings invade physical space, often aggressively, causing displacement, drainage, pollution and devastation. The loss of free and green spaces and their associated advantages for the urban population is a major threat for urban sustainability. The urgent need for more urban green space and for improving the energy and environmental performance of buildings under the objective of ameliorating the local microclimate and overall quality of life of urban dwellers, has led to a new tendency worldwide; to create new space on another "higher" level (Velázquez *et al*., 2018; Shafique

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et al., 2018, Mesimäki, 2018). This had as a result the establishment of another city “above the city”, by incorporating the natural aspect to the building itself (Aravantinos and Kosmaki, 1988).

The idea of planting roofs in order for them to act as natural filters within the urban tissue, meets wide acceptance recently, as it has been increasingly recognized as a technology that has the potential to diminish drastically the environmental problems of urban centers (Berardi *et al*., 2014). Green roofs have significant environmental, social and economic advantages and are considered able to replace, to a large extent, parks which are missing from modern cities. The total cost involved is not prohibited and the benefits are indisputable. In many countries, special laws are introduced which provide citizens with incentives or even involve an obligation to build green roofs.

For example, in Europe, Basel in Switzerland which has the largest area of green roofs per capita in the world, has promoted green roofs initially via investment in incentive programs, which provided subsidies for green roof installation. In 2002, an amendment to the City of Basel’s Building and Construction Law was passed, according to which all new and renovated flat roofs must be greened, following specific design guidelines (Climate Adapt, 2019). In the USA, San Francisco became the first city to require that certain new buildings should be built with a green roof. According to the law that went into effect beginning of 2017, between 15 to 30% of roof space on most new construction projects should incorporate solar, green roofs, or a combination of both (Snow, 2016).

A very useful tool in illustrating the available green roofs and mapping their positive environmental impact is Geographical Information Systems (GIS); GIS should be an indisputable part of any urban management approach, as it allows combining many different parameters such as societal, economic, environmental, spatial, land use and transport-related etc. in a dynamic environment. It uses an interactive environment, contributing to the effective management and visualization of spatial data.

This paper is part of a wider research still in progress and refers to an in depth analysis of the potential implementation of green strategies. The objective of the research presented herein is to investigate and record the impact of the use of green roofs for the development of urban policies which aim at improving the quality of urban environment, using a combination of Geographical Information Systems (GIS) technology and specialized software. The developed methodological framework is applied to a real-world case study of a medium – sized Greek city.

1. Background – Literature review

The green free spaces of a city can be divided into public (urban public gardens, urban forests, parks, and private spaces, traffic islands, squares, rows of trees, groves etc.) and private (courtyards, gardens, lawns, unbuilt sites etc.) The relationship between these two forms of green urban free spaces varies and depends on planning, functional, environmental, institutional and cultural factors. Protecting and securing private green spaces is of extreme importance but at the same time difficult due to the private interests linked to land exploitation (Belavilas and Vatavali, 2009). Public green spaces based on their location can be either urban or suburban. The existence of communication links between the two types is critical. Green roofs can play a key role in establishing this connection and support the easier movement of air masses, which can lead to improved air quality and ventilation of the city, as well as to the creation of a pleasant and healthy environment for the urban dwellers.

Green roofs are not based on a novel idea; their origin lies way back in time. From the Hanging Gardens of Babylon, one of the Seven Wonders of the Ancient Word, and Ziggurat, the planted scalable platforms on which Babylonians used to build temples to worship their gods in the area of Mesopotamia to the Celtic architecture examples of the Scottish Highlands during the Middle Age, the concept of creating green spaces above the ground was well-known to our antecedents. The period of Renaissance enhanced the interest in green roofs, stimulated by the revival of the classical culture and the trend of importing plants. Around 1400, Cosimo de' Medici, the founder of the House of Medici, created a green roof in his Villa in Florence, using a variety of imported plants. In the early 20th century, green roof gardens were considered an indication of high quality and luxury, and many leading architects of that time such as Antoni Gaudi, Le Corbusier, followed by Friedensreich Hundertwasser were strong supporters of their introduction (Lehmann, 2015; Magill *et al*., 2011).

Since then, a continuously increasing number of cities worldwide have adopted or/and attempted to promote the implementation of green roofs as a way to tackle many of the modern urban problems. Many countries have established a special legal framework which provides incentives for green roofs' creation. In Toronto, Canada, a 2009 bylaw made green roofs a requirement for new residential, commercial, institutional and industrial buildings with a minimum gross floor area of 2.000m2 (City of Toronto, 2016), while in Vancouver, developers can be exempt from developer permit fees if a green roof is planned (Plant Connection Inc., 2016). In North America, the green roof industry grew an estimated 18.5% in 2015, with Washington, D.C. being the leading city in green roof installations. Other cities in the USA with a large percentage of green roofs are: Chicago, New York, Denver, Baltimore, Seattle and Boston (GRHC, 2015). In Asia, many impressive examples of green roof design are met in Tokyo, Singapore, Shanghai and Beijing, while green roofs are also very popular in Australia. In Europe, according to a new French environmental legislation of 2015, rooftops in all new buildings in commercial zones across the country should either be partially covered in plants or solar panels. In London, the Greater London's Authority (GLA) "New London Plan" of 2008, included a part named "Living roofs and walls" which supported the introduction of green roofs in new development or the incorporation of them in existing buildings (Greater London Authority, 2008). Other European countries with a noteworthy (or increasing) number of green rooftops are: Germany, Norway, Denmark, Switzerland, the Netherlands, Spain and Italy (EFB, 2015). According to the EU Directive ((COM (2013) 249 final) "Green Infrastructure - Enhancing Europe’s Natural Capital", green roofs suggested as a tool which can contribute in achieving the sustainable development targets set in the context of Horizon 2020.

Green roofs can be divided into three broad types, namely intensive, extensive and semi – intensive (Mahdiyar *et al*., 2018). Intensive green roofs consist of a thick substrate layer (20 - 200cm) and are capable of accommodating a large variety of plants, including small trees and shrubs as well as human paths, water features, sitting spaces etc. As a result, they are usually associated with a high implementation and maintenance cost and taking care of them can be inherently complex and time consuming. Extensive green roofs are characterized by a thin substrate layer (< 15cm) and therefore only "light" vegetation can be planted successfully on them, such as grass, moss, and flowers. Their maintenance requirements, both in time and monetary terms, are limited; they are the preferable green roof type in cases when the rooftop is not easily accessible. The third type, semi - intensive green roofs, incorporates characteristics of both the aforementioned types; they are of moderate thick substrate layer and small herbaceous plants, grass and ground covers can be found on them. They need maintenance on a more frequent basis comparing to the extensive roofs, but still their requirements in this domain are lower than those of the intensive roofs (Vijayaraghavan, 2016).

Green roofs can have environmental, economic and social benefits. Among the main environmental benefits associated with the existence of green roofs are the improvement of urban air quality (Rowe, 2011), the mitigation of the "Urban Heat Island effect1" phenomenon (Getter and Rowe, 2006) and the retention of precipitation water (storm water management) (Berndtsson, 2010). Moreover, green roofs can serve as shelter for urban fauna and flora (Lundholm, 2006; Baumann, 2006) and as a way to reduce noise pollution within the city boundaries (Yang *et al*., 2010), provide additional insulation (Silva *et al*., 2015) and increase urban cultivation/farming (Hui, 2011). In addition to that, the composting of organic waste to fertilize green roofs can contribute in recycling and limiting the saturation of landfills (Delaney and Madigan, 2014).

A significant economic advantage of green roofs is energy savings; buildings which have a green rooftop are usually cooler during the warmest months of the year and have a higher inner temperature during winter, limiting this way the need for heating/air-conditioning. The amount of

[1] The "Urban Heat Island Effect" (UHI) is defined as the increase of air temperature in urban agglomerations of high density, due to the change of land use in built environments, characterized by the replacement of green spaces and vegetation with asphalt roads and surfaces made of concrete and similar materials. As a result, urban areas are essentially warmer than surrounding suburban and rural areas, especially during nighttime. The high air temperature in UHI increases the needs for air-conditioning and thus air pollutants' and greenhouse gas' emissions, while favoring the creation of smog (Gagliano *et al*., 2015).

savings is case specific and depends on many factors such as building's size, local climate and green roof's type (Blackhurst *et al*., 2010). By ameliorating the quality of life, public sectors' health costs' savings can be achieved (Clark *et al*., 2008) and in cases when urban farming is applied, the monetary amount dedicated to purchasing food can be diminished (Tomalty *et al*., 2010). The real estate value of a property also usually rises when the property (or the building where it is located) contains a green roof. This value increment varies but generally citizens consider properties which provide environmentally responsible features more attractive (Knepper, 2000).

Other less quantifiable advantages of green roofs include social benefits such as increased community space and improved livability of cities (Oberndorfer *et al*., 2007). Green roofs are related to the aesthetic upgrade of urban landscape and they can stimulate social interaction and enhance communication among citizens. At the same time, they contribute in reducing stress and anxiety which tend to characterize every aspect of modern urban life and thus in protecting urban dwellers' mental health. Furthermore, green roofs can be useful in promoting the environmental profile of public and /or private sector's organizations (Lee *et al*., 2014; Loder, 2014).

Despite their indisputable advantages, green roofs are related to certain negative consequences and challenges as well. The main factor that could impede the creation of a green roof is usually the high cost associated with its implementation and maintenance (Nurmi *et al*., 2016). In addition to that, return on investment cannot be easily estimated. Another drawback of green roofs, especially of those located in areas of drought climate, is the need for constant watering, fertilizing and investment of time. There is also the danger of causing structural damage to the building or the possibility that a water leakage occurs. What is more, fixing or/and replacing a green roof layer in case of damage is not a simple process and it usually requires an important amount of money (Claus and Rousseau, 2007; Vijayaraghavan, 2016).

Lately, the number of studies which attempt to approach the topic of green roofs and assess their effectiveness based on GIS technology and/or sophisticated modelling techniques have experienced a noteworthy increase. Examples include the following:

Karteris *et al*. (2016) examined the green roof potential and quantified its associated benefits with a focus on the city of Thessaloniki, Greece, utilizing a combination of satellite images, orthoimagery, GIS techniques and environmental modelling. Modelling techniques were also employed by Kokogiannakis *et al*. (2011) in order to create a database for the evaluation, in a user-friendly way, of the energy performance of green roofs with respect to different climate attributes in China. The impact of green roofs on urban microclimate was investigated by Saiz Alcazar *et al*. (2016), through the quantification of their contribution in adjusting the temperature of the environment during the warmest months of the year in areas of a Mediterranean - continental climate, with the aid of a three dimensional microclimate model. Virk *et al*. (2015), also using microclimate modelling, focused on London and evaluated the performance of green roofs in terms of decreasing energy use in office spaces, located in a Business Improvement District (BID) in the city centre. Seven green roof studies with a different geographical scope were compared and contrasted by Semaan and Pearce (2016), under the objective of identifying the advantages of green roofs in different type of climates as well as highlighting the differences which depend on location. Luo *et al*. (2011) designed an application system for urban green roof management based on GIS and Google Earth technology. A GIS analysis was performed by Berger (2013), aiming at the identification of buildings which have the highest green roof potential in New York City. Lamsal (2012) suggested a GIS - integrated cost - benefit analysis which takes into account the positive externalities, for investigating the implementation of green roofs in Atlanta region, USA.

2. Case analysis

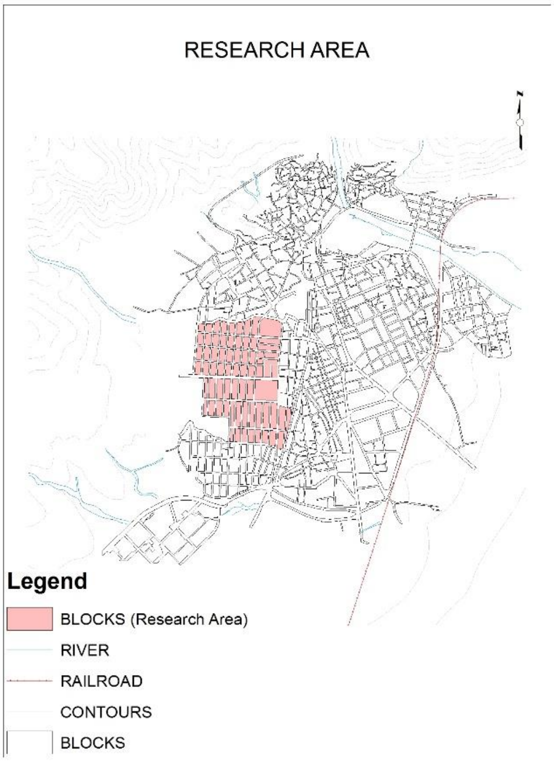
In Greek cities, a reduction in number and deterioration in quality of urban public green spaces is observed. These spaces, victims of rapid urbanization and over-estimation of land value after 1960, were briefly addressed only in the margins of urban planning and in their majority they were randomly created (Ioannou *et al*., 2004). This is in contrast with the common practice followed in Europe and worldwide, where green is an essential axis of urban organization and a main parameter of the urban area. Similar degradation characterizes many private green spaces, due the buildings' construction regulation, such as distances between buildings, land coverage ratio and buildings' density.

These phenomena have become more intense recently, leading often to stifling living conditions within the cities. It is worth mentioning that in 60% of Greek cities, green and water spaces cover less than 20% of their total area, while in the remaining 40%, it ranges between 20% and 29%, placing Greece in the penultimate position among European countries, after Hungary. An indication of the difficult current situation in Greece is given by the values of the index "urban green area per inhabitant" for the two largest Greek cities (2,55 for Athens and 2,73 for Thessaloniki) (EEA-JRC, 2013).

The paper focuses on Xanthi, a city of about 55,000 inhabitants (2011), situated in northern Greece. The city is located in an altitude of 60-145m. The large gradients have defined the form and development of the historic core and the flat zones have defined its modern extensions. The urban tissue consists of distinct sections with a particularly interesting variety in form and density, which is followed in general terms in its consecutive extensions: traditional parts with a coherent organic tissue, newer extensions with rectangular grid or normal geometries with great variety in the size of blocks (Giannopoulou *et al*., 2014) (Figure 1a).

The research area has been built at the beginning of the 20th century as a refugees' residential neighbourhood. It was planned using strict rectangular grid with elongated blocks, divided in small sites, with street width 8–10m. The residential units were located in pairs, having semi – basement and mezzanine. The reconstruction of the area began in 1970's, when ownership titles were given to the inhabitants. The process of consideration, which was the main building mechanism in combination with the failures of the General Construction Regulation (high densities, built – unbuilt space relationship) have led to the almost global domination of multi-storey buildings and in public and private open green space shrinkage (Giannopoulou *et al*., 2015) (Figure 1b).

Figure 1a. Xanthi and research area b. Research area – building coefficient



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3. Methodological framework

A Geographical Information System (GIS) was created, containing both spatial and descriptive information. All the spatial information regarding buildings, blocks, streets and green spaces was based on the digitalization of maps of the National Cadastre and Mapping Agency. The descriptive data that were used as input relied on detailed fieldwork recording. More precisely, information concerning buildings' height and size, building coefficient, construction age, roof type etc. was used. Focusing on green spaces, the boundaries of the areas they cover were designed and they were divided in spaces inside and outside blocks, public and private, while the location of trees was also specified. Moreover, data regarding each block's population (based on the most recent census of 2011 of the Hellenic Statistical Authority) were inserted to the GIS platform.

Next step was to define the suitability characteristics of buildings, excluding the ones where either for security or for structural reasons, the application of the green roof technology was unrealistic. In order to examine the suitability of buildings and identify potential restrictions, the existing legal/institutional framework was investigated. This is followed by the estimation of the green space that corresponds to every resident, before and after the aforementioned potential green roofs.

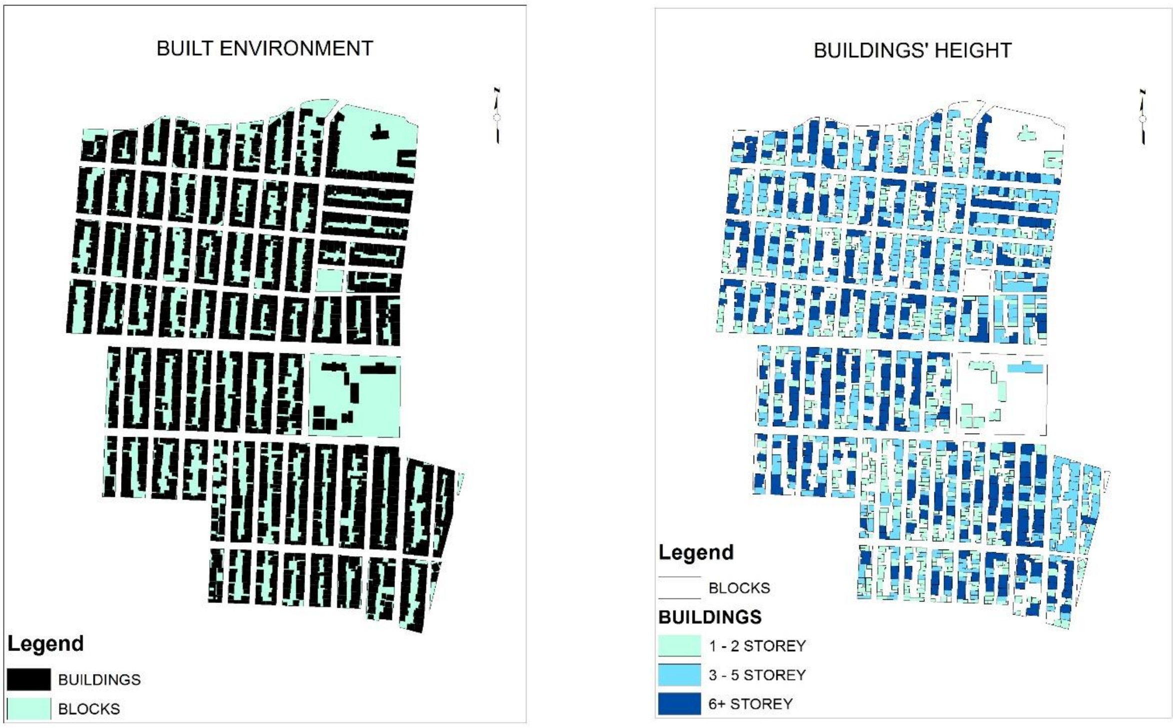
Finally, the environmental conditions of the area were modelled using Townscope software platform and the MRT (Mean Radiant Temperature) index before and after potential green roof implementation was calculated. Townscope is a software platform developed by LEMA (Local Environment Management & Analysis) Research Group of the University of Liege, Belgium, by Azar, Teller and Petillon during the European POLIS Project (1996 - 1998). Combining robust computational power and user-friendly graphical representation potential, it can be used to calculate the environmental conditions which influence the research area (EnergyCity, 2013; Teller and Azar, 2001). In this context, the software provides the opportunity to examine (and therefore assess) different alternative scenarios and policies regarding urban open spaces' shaping and configuration.

The MRT is among the most crucial factors affecting human thermal comfort in an open urban space (Huang *et al*., 2014). It is defined as the "uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure". It incorporates all short and long wave radiation fluxes (direct and reflected), to which the human body is exposed (Thorsson *et al*., 2007).

4. Results and Discussion

The cartographic representation through the production of thematic maps using GIS technology conducts a first approach of identifying the basic characteristics of the urban environment and achieving a complete overview of it. More precisely: The size and location of private open spaces is a factor which has greatly influenced the unique character of the research area. According to the existing building regulation which includes 45% of the research area's buildings, maximum 70% of a site's area can be covered, while the allocation of the unbuilt space is performed taking into account additional restrictions about the distances between buildings and streets or/and site's boundaries; therefore, leading to its fragmentation in the majority of cases. The previous building regulation which was applied until 1985 and also refers to 45% of the research area's buildings (the rest 10% includes the remaining refugees' old houses) suggested allocating the unbuilt part of the building just next to the back limit of each site and the built part on the front and edgeways part, enhancing this way the Urban Heat Island effect (Figure 2a).

Figure 2a. Built environment b. Buildings' height



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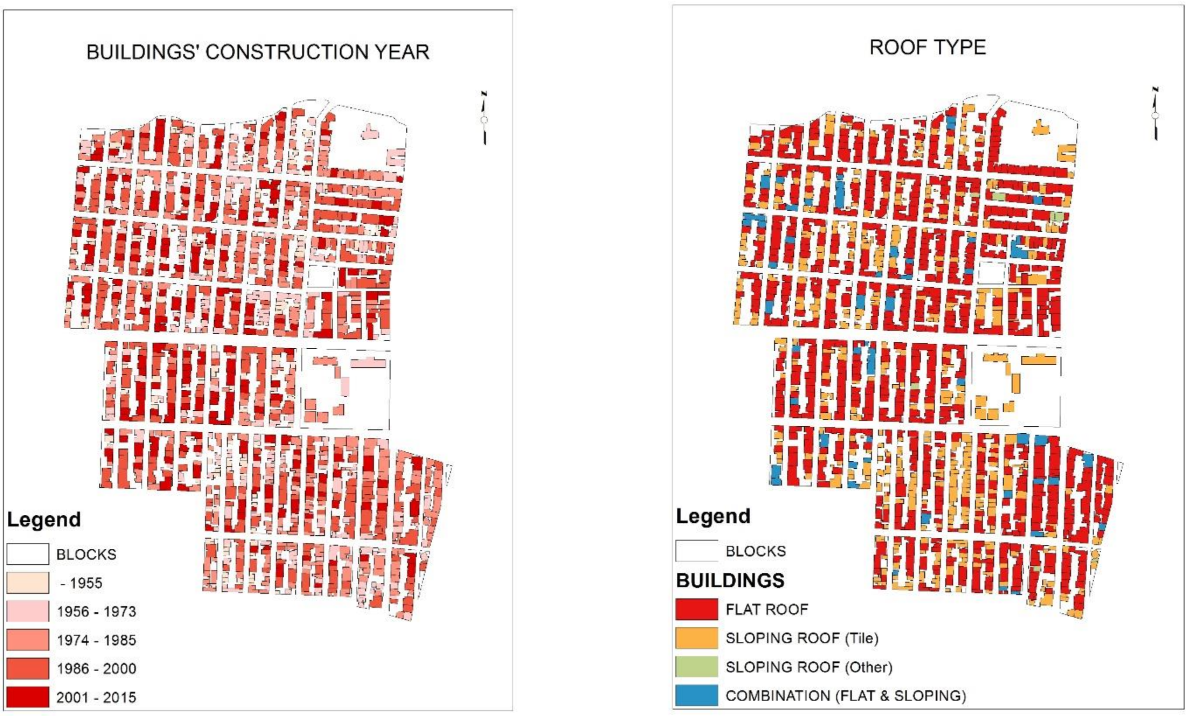
The building stock mainly consists of residential multi-family buildings which have three storeys or more, 19% of which have mixed use (shops or offices, on the ground floor and apartments on the other floors) (Figure 2b). A basic classification according to their year of construction is illustrated in Figure 3a. The age criterion is very important due to the fact that additional information concerning the building's energy behaviour, such as typology, materials, elements, and construction practices applied can be retrieved with the aid of it (Theodoridou *at al.*, 2011). The majority of buildings have flat roofs, with typical stairwell and elevator shafts as well as penthouse's terrace areas. Slopped roofs are characteristic for single-family houses, of 1-2 storeys (Figure 3b).

Figure 3a. Buildings' construction year b. Roof type



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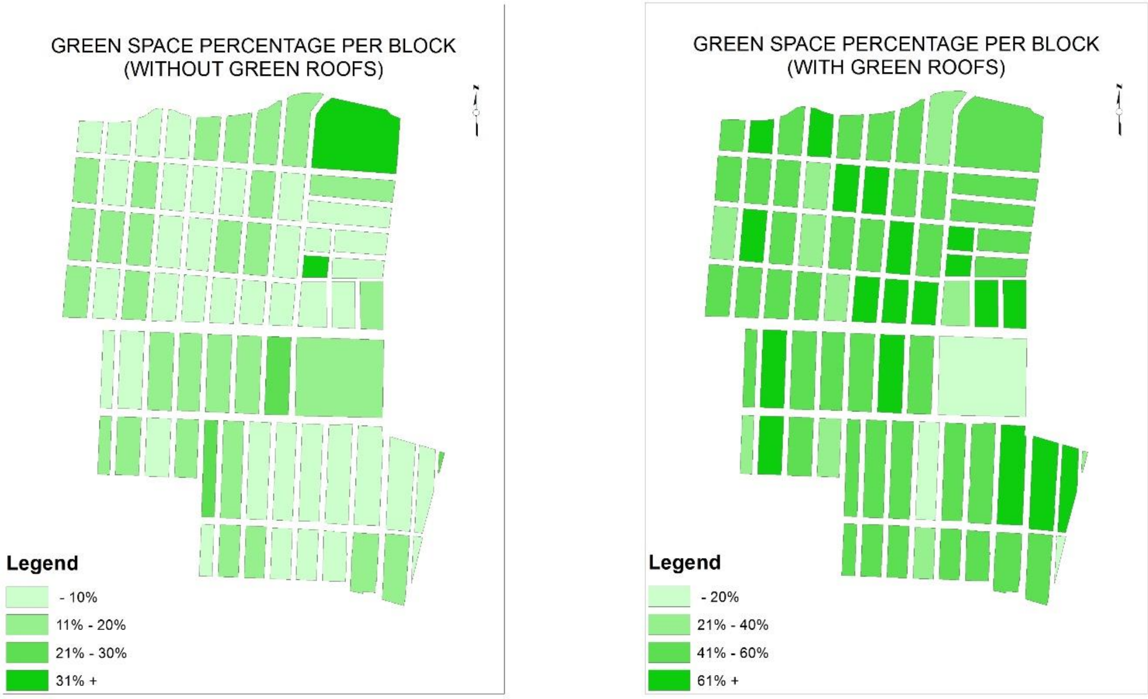
Two criteria were applied to evaluate the buildings' suitability for the green roof applications. The first criterion concerned excluding buildings with sloping roofs and those with combined roofs (flat and sloping). The fact that most of the buildings within the research area contain flat roofs is a parameter which encourages green roof installations. The actual available green roof area of all the flat roofs was obtained by subtracting the surfaces of the staircase and elevator shafts, the perimeter parapets and other roof elements like penthouse terraces, on which green roofs cannot be applied according to the present construction regulations. The second criterion concerned their maximum permissible static loads, based on the first actually strict National Antiseismic Regulation in 1985.

Figure 4a. Green spaces b. Research area - 3D Representation (Buildings and Urban Green)

Source: own representation

Figure 5. Green space percentage per block a. without green roofs b. with green roofs



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Within this context, the buildings dated before 1985 and after 1985 were examined separately and simulated with extensive and semi-intensive green roofs respectively. From a total of 1100 buildings of the area, 700 were found to be suitable according to the two aforementioned criteria (Figure 6a).

Green in urban open spaces is extremely limited and is gathered mostly in a small park in the north-eastern part of the area. According to the current legal framework, private open spaces should contain natural areas with trees and plants covering at least 2/3 of the unbuilt space of each site. Nevertheless, illegal interpretation of the urban planning law and covering all the available unbuilt space using tough elements and forms that modify the topography of the ground are common phenomena. The existing urban planning practice appears to be tolerant in such interventions and law violations, leading to general deterioration of the quality of the urban environment. The percentage of green spaces per block has increased drastically after the implementation of green roofs (Figure 5a, 5b).

The 3D file of the research area (Figure 4b) was created using Autocad2016 and then it was used after adaptations as input to Townscope software platform, in which the essential parameters for the analysis were defined. May 15th was selected as the base day for the calculations. The parameters for which values were set in this stage are: humidity, climate type, air turbidity, average temperature and air speed, as well as clothing. For the average temperature and air speed, the last 10 years' average was calculated, based on measurements that have taken place at the local meteorological station (25^{o}C and 4m/s respectively).

Following that, the reflection and emissivity properties of the most common materials of the external surfaces of the area were defined, the recognition of which was made through a land field survey. The simulation procedure included semi-intensive green roofs for buildings constructed after 1980 as well as extensive roofs for buildings constructed before 1980. The results of the simulation are presented in the maps of Figures 6b, 7a and 7b.

Figure 6b simulates the current situation of the research area; MRT index takes a minimum value of 29.71^{o}C and a maximum of 31.05^{o}C. The minimum value appears at the block where school buildings are located, while the maximum ones at the unbuilt spaces within the blocks which are situated in the north-northwestern and south-southeastern part of the area. Figure 7a which illustrates the simulation results after the green roof implementation, MRT index is lower (between 29.3^{o}C and 30.9^{o}C). Maximum values in this case are met at the streets' network, while values at the unbuilt spaces within the blocks are rather uniform.

Figure 6a. Buildings' suitability for green roof implementation b. MRT - Current Situation

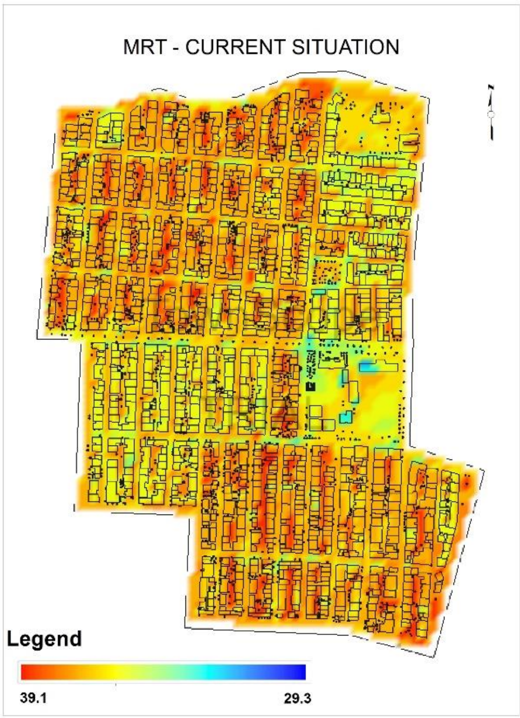

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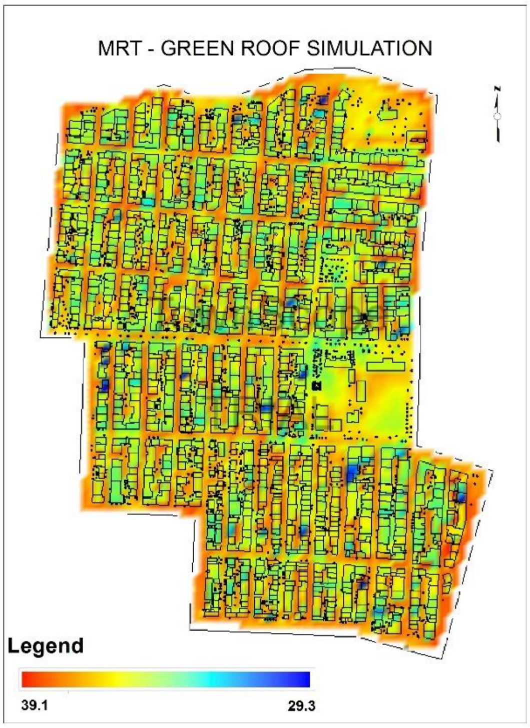
Figure 7a. MRT - Green roof simulation b. MRT - Simulation vs current situation



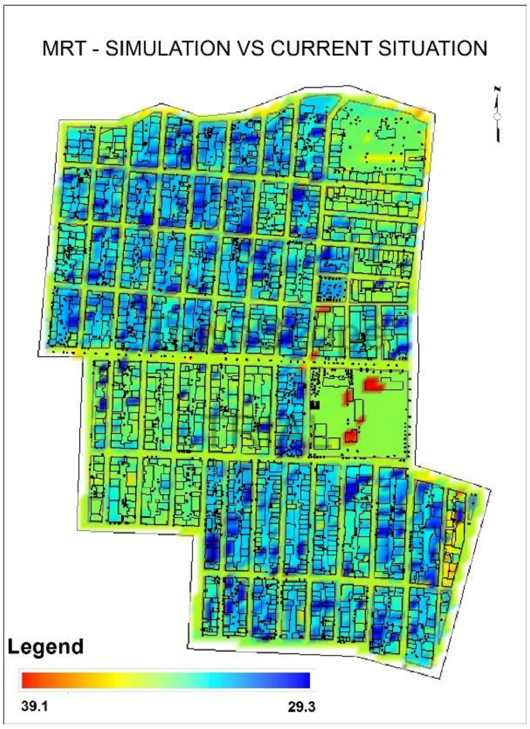


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Figure 7b illustrates the differences between the current situation and the potential future scenario after green roofs' implementation. The maximum reduction of the MRT index observed is 1.15ºC. The increase of the MRT index by 0.5ºC occurs in the school block which are not suitable for green roof implementation. The average reduction of the index is approximately 10% and takes places in those areas where MRT, according to Figure 6b, has currently its highest values.

Conclusions - Perspectives

The fruitful results of the methodological approach suggested herein are expected to facilitate decision – making and communication between the multiple actors involved in the process, as well as foster social understanding of the green roof concepts, towards the principles of sustainable and smart city development. The use of a comprehensive GIS environment not only contributes to improving the quality of research but also offers the possibility of continuous updated information and monitoring of the factors that influence development of green roof policies. In addition to that, the collaboration with specialized software would facilitate the thorough examination, analysis and correlation of parameters involved, towards the principles of sustainable and smart city development.

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