SOLUTIONS AND CHALLENGES FOR SUSTAINABLE INTEGRATED MANAGEMENT OF STORMWATER IN URBANIZED AREAS OF ROMANIA

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Abstract. In this age of urbanization, sustainable development requires good sewerage concepts for the future - not only in growing cities, but also in rural areas. Efficient stormwater management has become an increasingly important national and international concern. Soil waterproofing is oriented to a large extent by land use planning decisions. Land use is a compromise between social, economic, and environmental needs, such as housing, transport infrastructure, energy production, agriculture, nature protection. Limiting soil waterproofing can be done by reducing land use, or by continuing soil waterproofing, but using land already occupied, for example, industrial sites, decommissioned. Keeping water in the city by allowing it to seep into the soil and accumulate in water bodies offers many benefits, including recreational space for people living in the area and creating a cooling effect during heat waves. The use of green infrastructure is a tested component of nature capitalization, to obtain environmental, economic, and social benefits. As an example, instead of building flood protection infrastructure, a green solution can be used to capitalize on the functions (services) of nature: restoring wetland to be able to take over excess water, protecting communities in the areas at risk of flooding. The best way to develop green infrastructure is to take a carefully integrated approach to land management and strategic land use planning. All land users and all policy sectors need to be involved early in the process of developing green infrastructure, with some of them taking responsibility. The purpose of this article is to present some effective measures for urban stormwater management that can be adopted both in cities and in rural areas, and secondly to present the importance of the concept of “Green Infrastructure” (G.I.). In this article is shown that just by simply reorganizing the territory by proposing vertically arranged parking lots and by proposing bioretention solutions, a series of benefits appear such as the cooling effect during heat waves, flood control, clean water and air, and attractive recreation areas, etc.

Keywords: urbanization, sustainable development, green infrastructure, bioretention cells.

Introduction

The most effective way to create green infrastructure is to take an integrated approach to land management [1]. This is best done through strategic planning of the spatial planning, which allows the investigation of spatial interactions between different land uses in a region or municipality [2]. Strategic planning is also a way to bring together different sectors so that they can decide together on local land use priorities in a transparent, integrated, and cooperative way. Spatial planning can guide the development of infrastructure outside sensitive sites, thus reducing the risk of further habitat fragmentation. Also, it can identify ways to spatially reconnect the remaining natural areas, for example by encouraging habitat restoration projects in strategically important areas or by integrating elements of ecological connectivity into new development schemes [3-6]. Green infrastructure describes all the network elements of connected green spaces that preserve the values and functions of natural ecosystems and benefit human communities. It consists of natural and anthropogenic elements, such as forested areas, green bridges, urban parks, grassy roofs and walls, high nature value agricultural land or high conservation value forests. According to Joachim Maes, by giving space to ecosystems, green infrastructure can preserve and create landscape features that guarantee that ecosystems will continue to provide services such as clean water, clean air, productive soils, and attractive recreation areas. Thus, it helps the economy and society and makes a vital contribution to natural mitigation and adaptation to climate change [7-12].

Case study

To highlight the effect that green infrastructure can have on surface runoff, it was considered as a case study of an unbuilt land located in an area of urban expansion, Figure 1. The location of the study area is entirely included in the agricultural circuit. The present documentation is elaborated having as the object the parcelling of some lands, in the surface of 45 900 m^2 to realize collective dwellings, as well as of some spaces for services and endowments of the neighbourhood. Accomplishment of the road and technical-urban works necessary for the creation of an adequate infrastructure is also foreseen. Current conditions of the land (unbuilt) were considered ideal for exemplifying how green infrastructures can significantly reduce the amount of rainwater leaking to the surface, if included in the

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planning and development phase. In this paper three spatial planning scenarios were analysed. The territorial balance of the studied area was prepared comparatively – the existing and proposed situations, Table 1.

Fig. 1. **Satelite image of the study area[13]**

Ratio of functions for all scenarios analysed is shown in Table1.

Table 1

Territorial balance

Type of surfaces	**Scenario 1 - ground level parking**		**Scenario 2 - semi-underground parking**		**Scenario 3 - multi-level car parking**	
	Surface	**%**	**Surface**	**%**	**Surface**	**%**
Agricultural land, m^2	-	-	-	-	-	-
Total traffic (streets, sidewalks), m^2	10 074	21.95	10 074	21.95	10 074	21.95
Agricultural land after the transfer of the road, m^2	-	-	-	-	-	-
Public facilities and services area, m^2	2 880	6.27	2 880	6.27	2 880	6.27
Collective housing area	21 281	46.36	21 281	46.36	21 281	46.36
Parking lots in the yard of the buildings (500 pieces), m^2	8 215	17.90	4 108	8.95	2 053	4.47
Recreational green spaces (playgrounds, squares), m^2	**3 450**	**7.52**	**7 557**	**16.47**	**9 612**	**20.95**
-	45 900	100	45 900	100	45 900	100

The land is flat and does not require significant vertical systematization works. In scenario 1, all the parking lots are in the inner courtyards of the buildings. The area occupied by parking lots is in proportion of 17.9% from the total analysed area, as it can be seen in Figure 2 a) and Table 1. The chosen solution for scenario 2 considered to organize different parking from the interior yards, Figure 2, b). Semi-underground car parks are the best solution for crowded cities, offering the possibility to substantially increase the number of parking spaces without occupying public space through massive constructions, thus remaining free for projects beneficial to residents such as green areas, or relaxation areas.

Parking secures cars underground but brings nature and recreation spaces to the surface. The chosen solution for scenario 3 considered to create a parking construction having Ug + Gf + 4F, Figure 2, c). Vertical development of parking lots is an effective future solution that can solve the problem of parking spaces in cities. The quantities of rainwater for the study area are determined by the rational method which is based on the concept: rain of normal frequency will lead to maximum flow in a section of a basin when the rainfall time is equal to the maximum flow time from the farthest point to the section considered; on this basis for each section of calculation there will be single rain with a normal frequency of the territory from which the runoff flow results. Using the Romanian Standard 1846/2-2006, the runoff flow was calculated with equation 1:

$$Q_{pl} = m \cdot S \cdot \emptyset \cdot i \tag{1}$$

where m – dimensionless flow rate reduction coefficient, which considers the time storage capacity of the sewer and the duration of the calculation rain *t*; $m = 0.9$

S – area of the sewer basin, corresponding to the calculation section, in hectares;

$S = 4.59$ ha

Ø – average drain coefficient; Ø = 0.05 – for green surfaces, Ø = 0.9 – for mineral surfaces;

i – average rainfall $l \cdot s^{-1}$ ha, $i = 160\ l \cdot s^{-1}$ ha.

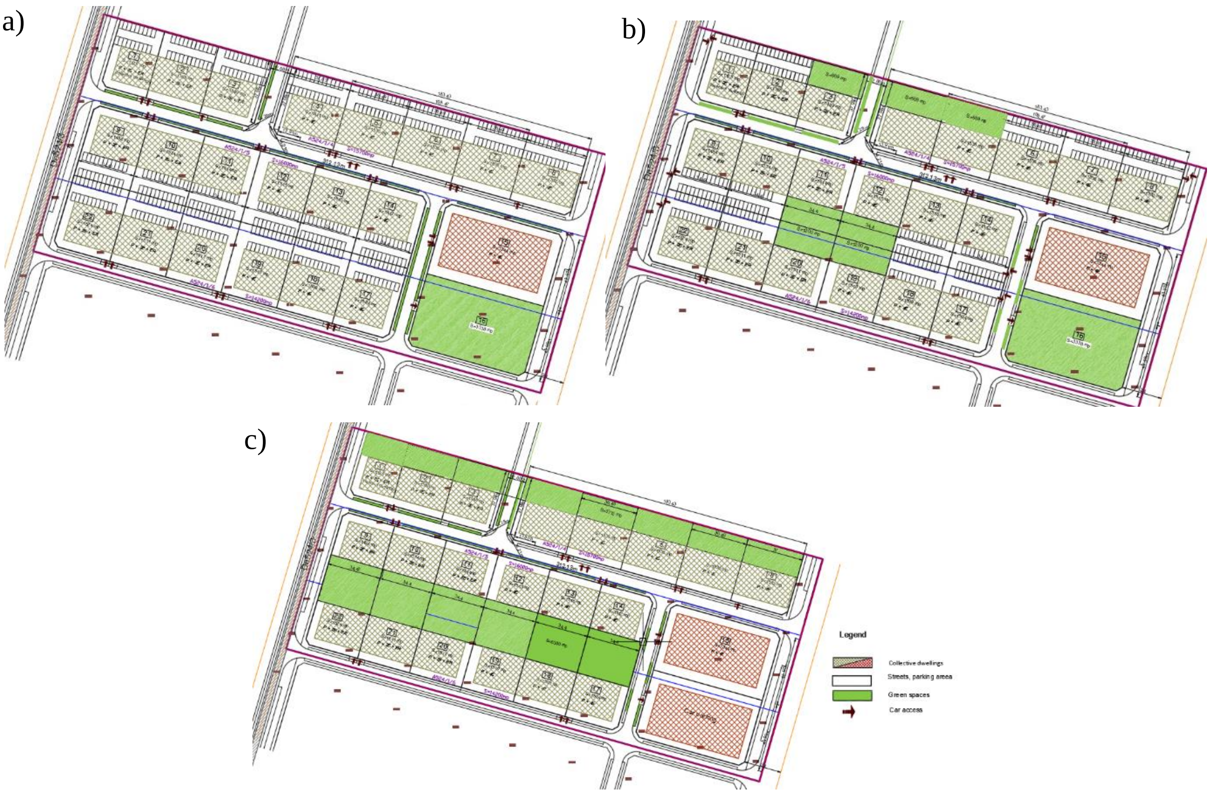

Fig. 2. **Urban development proposal and landscaping in three scenarios**

In Table 2 the runoff flow increases in scenario 1 with approximate 40 000 $m^3 \cdot day^{-1}$ compared to the current situation. Compared with scenario 1, in scenario 2 the runoff flow decreases by 9% and in scenario 3 by 13.6%.

Table 2

Runoff for the study area in all scenarios

Surfaces	**Current situation**			**Scenario 1-ground level parking**		
	m²	l·s⁻¹	**m³**·day⁻¹	**m²**	l·s⁻¹	**m³**·day⁻¹
Sealed surface	0	0	0	42 450	489.02	42 251.67
Green surface	45 900	29.38	2 538.09	3 450.00	2.21	190.77
TOTAL RUNOFF	-	**29.38**	**2 538.09**	-	**491.23**	**42 442.44**

Surfaces	**Scenario 2 -semi-underground parking**			**Scenario 3 -multi-storey car park**		
	m²	**l·s⁻¹**	**m³**·day⁻¹	**m²**	**l·s⁻¹**	**m³**·day⁻¹
Sealed surface	38 343	441.71	38 163.86	36 288	418.04	36 118.46
Green surface	7 557	4.84	417.87	9 612	6.15	531.51
TOTAL RUNOFF	-	**446.55**	**38 581.73**	-	**424.19**	**36 649.97**

Rainwater collection and infiltration solutions

To reduce the surface runoff that can be discharged into the sewer system, rainwater collection and infiltration solutions can be proposed at the place of rainfall. Rainfall/runoff collection and retention can be done using various types of low-impact development practices, such as bioretention cells, infiltration ditches, permeable or porous pavement, vegetative channels, and rain barrels. Green infrastructure ensures a certain amount of storage of precipitation/runoff and evaporation of stored water (except for rain barrels). Infiltration into native soil occurs in vegetative channels and can also occur in bio-retention cells, porous paving systems, and infiltration ditches if these systems do not use an optional waterproof bottom liner. Infiltration ditches and porous paving systems can be clogged. This reduces their hydraulic conductivity over time, in proportion to the cumulative hydraulic load on the ditch or pavement. For the study area bioretention basins and porous pavements were proposed, Figure 3. Bioretention cells -are covered with vegetation, they are shallow and use the interaction between plants, soil, and microorganisms to store, treat and reduce runoff volume and reduce flow rainwater runoff. They are generally designed for modified soils that allow rainwater to drain through soils. Rainwater can be between 15 and 30 cm high over the mulch layer and then filter quickly through the bed. The design characteristics of the bioretention cell are: the depth of the filter holder: 40-60 cm, recommended maximum: 90 cm; pond depth: 15-30 cm, The ratio between the length of the shortest flow path/length: 0.3, [4; 5]. The location constraints are also necessary: the depth: 60 cm to groundwater/bedrock; slopes: $< 20\%$ or terraced to slow down flow; environmental permeability: $\leq 0.01\ \mathrm{m \cdot h^{-1}}$ or need drainage; it requires use of a waterproof membrane and a lower drainage system, [6-8]. Maintenance is required to maintain performance and aesthetics. It is necessary to monitor the accumulation of sediments and their removal, if necessary, also a visual inspection of the access channel, repairs against surface erosion and finally the maintenance of vegetation. Bioretention cells can be of different sizes. Bioretention cells, also called rain gardens, can be applied to treat runoff from small areas, such as individual rooftops, driveways, and other on-lot features in single-family detached residential developments. Bioretention basins- these are structures of rainwater treatment coming from the commercial or institutional areas, namely from the parking lots and/or the roof. Urban bioretention- these are structures such as foundation planters located in ultra-urban developed areas, such as city streetscapes [9-12].

Fig. 3. **Urban development proposal with bioretention basins and porous pavements [12]**

Permeable or porous pavement- pervious asphalt, pervious concrete, and permeable pavers were proposed for pedestrian areas, residential driveways, and public sidewalks. Local jurisdictions may approve pervious asphalt and concrete for private streets and public roadways on a case-by-case basis. In Table 3 can be seen the advantages of each proposed scenario. It can be concluded that scenarios 2 and 3 have the most advantages. The benefits that humans obtain from environment in the form of goods and services provided by natural and semi-natural ecosystems are known under the generic name of ecosystem services [1; 2; 11]. Ecosystem services represent the totality of the benefits and advantages generated by the existence of a natural or a seminatural area. According to the Methodological guide for the quick evaluation of ecosystem services in protected areas in Romania, these benefits are classified into four major categories Namely: Production services, Adjustment services, Support services, Cultural services [3; 4].

The following benefits were analysed in the study case as it can be seen in the table below: Regulation services - are represented by the ability of ecosystems to influence and regulate natural processes: regulation of climate, water quality and quantity, protection against wind, stabilization of landslides, flood control, etc. Support services - represent all those indirect benefits that derive from the fact that ecosystems provide the necessary conditions for the manifestation of other benefits: the provision of substrate for biological diversity, adequate space for human activities, ensuring abiotic heterogeneity, etc. In table 4 the high ecosystem services are offered by scenario 3, but also scenario 2 has good ecosystem benefits.

Table 3

Comparative analysis for proposed solutions – strengths

Scenario 1 – ground level parking	**Scenario 2 - semi-underground parking**	**Scenario 3 – Multi- level car park**
Minimum investment costs	Minimum investment costs	-
Minimum maintenance costs	Minimum maintenance costs	-
Parking lots in the immediate vicinity of homes	Parking lots in the immediate vicinity of homes	-
Green area 3 450 m^2	Green area 7 557 m^2	Green area 9 612 m^2
Public mineral surface 42 450 m^2	Public mineral surface 38 343 m^2	Public mineral surface 36 288 m^2
Rainwater surface runoff 42 442.44 $m^3 \cdot day^{-1}$	Rainwater surface runoff is 38 581.73 $m^3 \cdot day^{-1}$ decreasing compared to scenario 1 in percentage of 9%, through landscaping solutions for soil unsealing	Rainwater surface runoff is 36 649.97 $m^3 \cdot day^{-1}$ decreasing compared to scenario 1 in percentage of 13.64% through landscaping solutions for soil unsealing
-	Recreation areas (playgrounds, sports, green spaces) in each yard	Recreation areas (playgrounds, sports, green spaces) in each yard
-	Small number of vehicles that occupy the public space on the ground - at the level of the entire studied area	Small number of vehicles that occupy the public space on the ground - at the level of the entire studied area
-	Reduces the average urban temperature and prevents the formation of urban heat islands	Reduces the average urban temperature and prevents the formation of urban heat islands
-	Ensures complementarity between a higher number of parking spaces and the need to provide space for community activities	Ensures complementarity between a higher number of parking spaces and the need to provide space for community activities
-	Solutions for efficient rainwater management are proposed through bioretention arrangements, resulting in a functional and at the same time aesthetic landscape	Solutions for efficient rainwater management are proposed through bioretention arrangements, resulting in a functional and at the same time aesthetic landscape

Table 4

Ecosystem services [5;10]

Types of ecosystem services for the district		**Scenario 1**	**Scenario 2**	**Scenario 3**
REGULATING	Air-quality regulation;	low	medium	high
	Climate regulation;	low	medium	high
	Water regulation;	Low	medium	medium
	Natural hazard regulation	low	medium	high
SUPPORTING	Soil formation and retention	low	medium	high
	Water cycling	low	medium	high
	Provision of habitat	low	medium	high
	Pollinators	low	medium	high
	Recreation	low	medium	high

Conclusions

1. Through this study case the importance of using green infrastructure to reduce the risk of floods is shown and the advantages generated for existence of a natural or a seminatural area. At the same time, it is well known that in the already constructed areas difficulties have been observed to install these green infrastructures, which is why it is necessary to take these infrastructures into account in the urban development planning. Thus, it is possible to achieve, on the one hand, the maximum efficiency of the equipment and, on the other hand, the flood risk can be considerably reduced.
2. Green infrastructure can be a profitable option for new development, urban modernization, and redevelopment projects as a stormwater management tool.
3. As it can be seen in the case study, just by simply reorganizing the territory by proposing vertically arranged parking lots and by proposing bioretention solutions, a series of benefits appear such as the cooling effect during heat waves, flood control, clean water and air, and attractive recreation areas, etc.
4. In scenarios 2 and 3, where a vertical reorganization of the parking lots was proposed, compared to scenario 1, where the parking lots remained arranged on the ground, the surface runoff decreases by approximately 9%, respectively 13.6%.
5. The two solutions for reorganization of parking lots, proposed in scenario 2 and 3, offer good ecosystem services for humans.

Author contributions

Conceptualization, A.G.; methodology, C.G. and C.S.; validation, C.G. and A.G.; writing – original draft preparation, A.G.; writing – review and editing, A.G. and C.S. All authors have read and agreed to the published version of the manuscript.

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