Chapter 1

Urban Agglomeration and Supporting Capacity: The Role of Open Spaces within Urban Drainage Systems as a Structuring Condition for Urban Growth

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Additional information is available at the end of the chapter

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Abstract

Urbanisation greatly changes the natural environment—city growth may cause urban sprawl, increasing land consumption and infrastructure demands, with consequent built and natural environments degradation. To face this challenge, the supporting capacity of the natural environment needs to be addressed in the urban planning process. This chapter will particularly discuss urban drainage role in the planning context, integrating engineering, urbanism and landscaping in order to set the basic conditions towards a sustainable city development. Urban drainage systems (and the related urban rivers) play a crucial role in city planning, once it intermediates the needs of the built environment, providing safe areas free from flooding, and the demands of the natural environment, giving space and passage to floods. This particular feature gives to the drainage system a spatial structuring characteristic and it provides opportunities to revitalise city areas, improving biodiversity and recovering environmental values. On the other side, a city open spaces system is the main reserve of urban areas for sustainable urban drainage interventions. The adequate land use planning and consequent management of these open spaces shall be in the core discussion to produce integrated and functional solutions for built and natural environments.

Keywords: urban flooding, urban drainage, urban growth, supporting capacity, open spaces, multifunctional landscapes

1. Introduction

The process of city growth and the increase of urban population, during the twentieth century, led to a series of preoccupations with regards to the capacity of sustaining this growing process. There is a real threat of an environmental degradation. In 1968, the Club of Rome published a report where "limits of growth" were questioned [1] and highlighted the preoccupation with the existing economic models. In June 1972, the *Conference of the United Nations on the Human Environment* took place in Stockholm, Sweden, and brought together participants from 110 countries [2]. Starting from this meeting, known as the *Stockholm Conference*, the preoccupation with regards to environmental questions was voiced for the first time on a global scale. In 1987, the *Brundtland Report* called "*Our Common Future*" [3] elaborated by the World Commission on Environment and Development, created by the United Nations (UN), formalised the concept of sustainable development, foreseeing a more intelligent and rational production. The concept of sustainability, necessarily, needs to be seen within three basic pillars: social, economic and environmental. Sustainable urban solutions have to be able to attend the necessities of the society, preserving the environment and being economically viable as a whole and in the long run. Any disequilibrium of one of those pillars, which give support to the concept, can take to non-sustainable situations.

The proposal of a sustainable development was consolidated and widely disseminated after the *Conference of the United Nations on the Environment and Development*, known as *Rio 92* or *Eco 92*, realised in Rio de Janeiro in 1992 [4]. The elaboration of the *Agenda 21* [5] was perhaps the main result of this meeting. It defined objectives to promote sustainable development of human settlements, including: providing adequate housing for all; improving human settlements management; planning a sustainable management of land use; and promoting the provision of an integrated environmental infrastructure, targeting topics such as water, sewage, drainage and solid waste.

According to Lindholm [6], urban planning shows a utopic aspect that has to be complemented with a practical "here and present" perspective. To do this, it is necessary to identify what kind of spatial relations are being created intending to discuss and allow new future possibilities.

Today, we already fully understand that an urban planning cannot be separated from the environmental planning. Cities managed without integrated planning suffer with the loss of ecosystems and of its environmental and cultural values. Inundations, pollution, scarcity of water, shortcomings in public health, among many other grave problems, arise from this lack of integration.

Without intending to create an only definition for a so wide and complex topic, it is here understood that a sustainable city is the one which meets the social functions that are expected from it, through time, in a viable way and with a general positive balance, reaching an adequate quality of life for all its inhabitants, guaranteeing the distributed access to essential services and recourses, respecting the limits imposed by the natural system, being resilient and secure.

The definition of resilience [7–15] is a concept very much present in urban discussion nowadays [16, 17]. The resilience involves, generally (and with various interpretations, depending on the topic of the discussion), three main points: the capacity of a system to continue resisting, even if submitted to stressing conditions beyond those projected; the capacity of the system to recuperate functions in a fast way, continuing to offer its services; and the capacity of the system to recuperate structurally from suffered damages [18]. Meerow et al. [19] stated that resilience is a dynamic concept, recognising the importance of its temporal scale, where a systemic adaptability applies. This perception considers the urban system as a complex and adaptable system composed by socioecological and sociotechnical patterns that go through multiple spatial scales. In this way, the concept of resilience approaches the discussion about sustainability [20–23] as both concepts involve an integration through time, in which the systems must continue to function and provide adequate services today, as well as for future generations, submitted to future challenges.

McHarg [24] points to the necessity of considering landscaping as an ecological system, where the prime concern refers to the integration of social and environmental issues within the planning process. This author proposes a new perspective for a healthy relation between nature and the built environment, understanding the processes that shape landscape and using them as the basis for an efficient planning process. Rogers [25] poses that at the same time, the cities reunite and potentiate physical, intellectual and creative energies, they tend to damage natural environment configuring a threat to the very humanity itself. Today, cities are better known by their conflicts and problems than their potentialities. Harvey [26] highlights that the right to do (and redo) the cities (and ourselves), evolving towards a better place, is one of our most precious and neglected rights.

Various discussions are being motivated by the necessity of making the cities more sustainable [27–29]. Among these discussions, one that has been gaining space refers to the compact and diverse city concept [30–35], in which the networks of the infrastructure become less extensive and more efficient, less land is consumed and the reduced commuting consumes less energy. Burgess [36] defines the compact city as the one that results from a set of politics seeking to increase the constructed area and the demographic densities, to intensify the economic, social and cultural urban activities and manipulate the size, the form and the urban structure as well as the housing systems. This concept benefits from the environmental, social and global sustainability that derives from the concentration of urban activities. It is further believed that in more compact and diverse cities, social relations are intensified, increasing the process of democratisation. For Rogers [37], a city is sustainable when it is fair, pretty, creative, ecological, easy, compact, polycentric and diversified. Nevertheless, if extremely densified, cities that are more compact may lead to greater local negative ecological impacts, when compared with that resulting from less compact cities. There certainly is a limit for compaction, equalising the supporting capacity of the natural environment and the optimisation of the built environment. In this way, a balance shall be established between the built and the open spaces, defining the degree of city compaction affecting its sustainability. The idea is not creating an absolute rule, as all cities are cultural representations of huge magnitudes. However, a point of equilibrium for each city in its diversity must be found.

In this discussion about balancing built and open spaces, urban flooding arise as an element of disruption of urban services, of infrastructure networks, of housing and health systems. When urban rivers and drainage networks fail, leading to flooding, they produce urban negative consequences and, very often, irreparable socioenvironmental damages. However, although extensive flood control structures have been implemented in the recent years (e.g. dikes, dams, canals, pump stations, etc.), cities everywhere remain vulnerable to floods [38]. Ecologically, more sensitive mitigation approaches have appeared in recent years, encouraging flood hazard mitigation to work with nature [39]. Grizzetti et al. [40] remember that a territorial planning for urban water management is needed, and system multifunctionality has to be recognised as well as the benefits of approaching city and nature. Conceptually, urban drainage is an infrastructure system that occupies a key position interfacing natural demands (rainfall-runoff transformation and consequent discharges) and city needs (healthy neighbourhoods and city functions maintenance).

2. The supporting capacity as a limiting factor for urban planning

The capacity of the environment to support a human settlement can be defined as the maximum elasticity to which the environment can be subjected, without any irreversible degradation, to attend the urban necessities that will be developed systematically in this space.

The process of urbanisation, generally, demands multiple and continued efforts to satisfy the necessities of the population. However, this process, if not planned or barely conducted, causes harmful effects on the environment, resulting in a possible degradation of the natural environment as well as of the built environment. As the urban population increases, various problems related with the necessary infrastructure to attend this growing demand also increase. Many times the concept of supporting capacity is reduced to the capacity of the infrastructure to continue meeting the demands of the city development. However, from a systematic point of view, one must not overlook the wider concept of the supporting capacity and the perception that the built environment needs to respect the limits imposed by the natural environment.

As introduced earlier, the urban drainage system occupies a very specific position in this discussion. This system lies between the demands of the natural environment and the necessities of the built environment: the rain that falls on a watershed and needs to flow through the city is able to find its way within the drainage system, which offers, in turn, secure conditions for the city to occupy the natural space [41]. Therefore, the city may coexist with the natural watershed in a healthy combination [42]. Nevertheless, the very urbanisation modifies the natural space and the way in which this space responds to the water cycle, aggravating floods [43, 44]. In this way, environmental issues specifically linked to the urban drainage becomes more evident, once failures of the drainage system affect the functioning of the city, reflecting in vectors of environmental degradation. These are key questions for urban planners and decision makers, since they are structuring factors for planning the space and its sustainable occupation.

However, it is frequent that cities exceed the supporting capacity, consuming more than necessary (depleting natural recourses and expanding over the watershed space, modifying land use) and creating more and more waste (which the environment cannot absorb). The areas of a city which usually are exposed to more extreme conditions, with high densities of population, occupation and construction, with fewer open spaces and higher inundation risks, are also usually related with the more critical shortcomings of infrastructure and higher economic and social losses.

When modifying nature, without considering the supporting capacity of the environment, by means of unrestrictedly building and spreading urban growth, the population suffers with the reduction of environmental quality, which could directly and/or indirectly interfere in the quality of people's lives. Some consequences of this development, such as vegetal cover removal, erosion and/or silting-up of watercourses, lacking of open spaces, air and water pollution, inadequate deposition of garbage and sewage, among others, bear witness to the disequilibrium between the cities growth and the functional aspects of the natural environment.

Several studies have been realised and a series of efforts have been made to establish indicators for sustainable development. In 1996, for example, the Commission of the United Nations for Sustainable Development announced a project to evaluate and compare the degree of sustainable development for each country, generating indicators [45]. Since then, several indicators have been developed to evaluate the results of urban growth. Such indicators generally include social, economic, environmental and institutional categories. Among those, the "environmental" dimension ought to be the prime preoccupation in the pursuit of an environmentally healthy and sustainable development.

Kyushik et al. [46] discussed the urban carrying capacity as a determinant for the developing density and presented some authors who also discussed the supporting capacity concept. In this discussion, they firstly cite Chung [47], who stated that the ecologists generally consider the supporting capacity as the maximum number of individuals who can be supported by the environment in a given area, without compromising future generations living in this area. Planners generally define the supporting capacity as the capacity of a natural or artificial system to absorb the growth of the population or the physical development without considerable degradation or damage [48]. It is also defined as the level of human activities, growth of the population, land use and physical development, which could be sustained by the urban environment without causing serious degradation and irreversible damage [49]. This concept is based on the assumption that a certain environmental thresholds exists, which, when crossed, can cause serious and irreversible damages to the natural environment [50].

Considering the discussion developed and the definitions cited above, one can conclude that the limit of the supporting capacity of the environment is interlinked with the social environmental quality of the urban space. For this reason, the urban planning process and the discussion about socioeconomic, morphologic and functional aspects of the city have to incorporate the supporting capacity concept.

3. Open spaces system

The urban planning integrated with the environmental planning (or, simply, the urban environment planning), can provide an improvement in the quality of life in cities. However, this is only possible when some concepts and relations are understood linking environment, open spaces system and cultural landscapes.

Tuan [51] stated that "environment sustains us as creatures; landscapes display us as cultures". Schlee et al. [52] stressed that "the landscape is a product deeply impregnated with culture, which results in processes of continuous alterations, dictated by biophysical, social, economic and political factors, reflected in the forms of occupation and management of the territory".

Therefore, a landscape, and especially the urban landscape, is not only a cultural representation of a society but also a set of human actions in an environment which establishes itself in an integrated way, but not without conflicts during time. For Meining [53] "any landscape is so dense with evidence and so complex and cryptic that we can never be assured that we have read it all or read it right".

In this way, every urban landscape is distinct, but all of them consist of built spaces and non-built spaces—these last ones are the open spaces free of construction, either being public or private. Macedo and Queiroga [54] understand the open space system as "all the elements and the relationships that organise and structure the set of all open spaces of a determined urban area – from intra-urban to regional scale. It is basic in the existence of the city, because it is fundamental in the performance of the day to day life and in defining the urban form and the image of the city, reflecting its history and memory, participating in the public and private life spheres".

Rego et al. [55] define the open urban spaces system in: (1) environmental open spaces; (2) social interaction open spaces, such as parks, squares or gardens; (3) open spaces of infrastructure character, such as a strip of land protecting transmission lines; and (4) open spaces of mobility character, such as streets, roads and avenues.

Ironically, every city starts to be designed by its streets. These are the ways which connect the various parts and structured elements, leaving the first marks on the land which will define a human settlement. Therefore, the occupation/construction of a city is initiated by an element that afterwards will be named as an open space, which defines not only the border between what is public and private, but also where the largest part of the urban network infrastructure will be implemented.

It has to be pointed out that, at times, the open urban spaces are only apparently free of construction as the substratum is occupied by large structures such as metro, underground roads, garages or even canalised rivers.

In this way, it is understood that the open spaces system of a great number of consolidated cities is not the result of an environmental urban planning but the result of a process of hundreds or thousands of years which today, many times, is insufficient or inadequate to couple with the socioenvironmental demands.

Generally, the segmented organisation of a territory, without the proper preoccupation regarding its recourses, especially referring to open spaces, is one of the facts that characterises the urban sprawl of current metropolis. Urbanisation spreads without borders and without giving attention to the collective necessities, favouring a general disequilibrium [56]. A systematic and integrated vision is necessary, associating environmental questions and urban infrastructures. Public politics should be concerned in re-evaluating land use and the occupation, seeking to adopt more resilient and sustainable urban standards. The open spaces always present a great possibility to suffer and generate transformations (positives or negatives) in the landscape shaping (or re-shaping). Urban spaces are simultaneously the most promising and most fragile spaces, because they are subjected to inadequate or disorderly occupation, when their fundamental importance is not recognised [24].

This fact occurs in many cities in developing countries, from small town to metropolis, where open spaces, generally of environmental character, are ending up being occupied in

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an irregular manner by substandard dwellings of a population economically and socially less favoured, such as on hill sides, mangroves areas, the margins of rivers and lakes, following an accelerated population growth which is neither accompanied by a socioeconomic development, nor by an adequate infrastructure support.

A strategy to restrain the irregular occupation of those open spaces is to have them recognised as public structures with a social and patrimonial value, that is, spaces for congregating social groups, while appropriate for collective leisure.

Chiesura [57] argues that urban parks and open green spaces are of strategic importance for the quality of life of our increasingly urbanised society. Increasing evidences indicate that the presence of natural assets (i.e. urban parks and forests, green belts) and components (i.e. trees, water) in urban territories contributes to the quality of life in many ways. Besides, important environmental services such as air and water purification, wind and noise filtering, flood control or microclimate stabilisation, natural areas provide social and psychological services, which are of crucial significance for the liveability of modern cities and the well-being of urban dwellers.

Nevertheless, the lack of open spaces in consolidated cities is frequent, as it is frequent that such spaces are not adequately foreseen in still growing cities. To minimise the conflicts in the demand for space, the concept of multifunctional spaces could be the answer to optimise the landscape design, associating the open spaces with the urban occupation demands, without losing any functions already existing today.

A multifunctional space is an urban intervention which foresees more than just one use for the same place, guaranteeing a more rational use of the urban land. Different uses can target infrastructure aspects, such as urban drainage, as well as trying to overcome social privation, such as the absence of leisure areas.

It is necessary to densify cities into more compact arrangements, associating diverse and multiple uses to urban spaces, intending to optimise commuting and the several services offered, without eliminating open spaces. These spaces need to be preserved as a basic support for a city capable of meeting the environment, infrastructural and social needs, corroborating with the very concept of sustainability, also emphasising the well-being and the quality of life of the population.

In this way, the solutions for urban drainage problems should be able to integrate the response to urban demands regarding sanitation purposes with the supporting capacity of the urban watershed, using multifunctional spaces to reorganise the water cycle functions that were modified by urbanisation. Spirn [58] criticises superficial urban projects, created only to beautify the city with an artificial nature. For the author, radical changes are necessary, seeking to recognise and point out a series of damages, mainly in artificialized urban rivers, which do not respect the necessities of nature and do not consider the river as an essential strength that permeate the city. According to Naveh [59], one of the premises for a holistic concept of multifunctional landscapes is that these represent a complex interaction between nature and culture.

In this context, all the aggregated values of landscapes should be encouraged: their environmental aspects; their cultural, social and economical values; defending the environmental legislation as part of the regulation for a proper urban expansion, with the purpose of bringing the concept of supporting capacity to the discussion of urban and environmental planning.

4. Storm waters and cities

Water is probably the most essential natural resource and relates to diverse aspects of human settlements, from the beginning of the history, ranging from water supply, irrigation, transportation, territory defence, among others. From ancient times, man always looked for locations where the environment could give support for his survival. Great part of the first civilisations developed along river banks or near lakes.

Any city, however, tends to introduce modifications in the land use patterns, which induce a series of processes that change the environment, affecting the quality both of the natural and the constructed areas, and many of the supervening consequences are related to urban waters, in its wider sense.

Therefore, a paradox exists in the relationship between water and city [41]. Water is a fundamental resource, which is present in the history and in the origin of cities, but is also a problem in modern cities. Actually, for this reason, it is not unusual that cities turn their back to the rivers, which are degraded, polluted, frequently seen as sewage conveyors or buried and hidden. Most urban rivers are lost as landscape elements, impoverishing the urban biodiversity and degrading also the urban vicinity [41, 42].

The rivers, in general, can be considered as a synthesis of the territory to which they are connected [60]. Or rather, the actions which take place in the watershed reflect in the fluvial corridor. In this way, it can be said that artificial rivers, degraded, suffering from flooding and degrading the city, end up to be the product of the urban environment itself, which have dis-characterised the natural processes of their hydrographic basin.

The urbanisation process strongly alters the natural water cycle and the responses of the fluvial systems on the built environment. The removal of vegetation, the increasing imperviousness that follows this process, the regularisation of the surfaces and the introduction of an artificial drainage system modify significantly the superficial flow patterns, producing larger flow volumes and peak flows, reducing the base flow discharges and the time of the concentration of the basin. A frequent result of this process is the aggravation of flood problems observed in cities and the loss of fluvial ecosystems.

Urban flooding is strongly related with land use questions. Typical urban factors, such as housing shortage, for example, turn up as aggravating agents. The irregular occupation of riverine areas, which should be used as river space, increases flooded areas and flooding consequences. The floods, in turn, are responsible for the degradation of the urban built environment, interfering with various other urban systems. They generate damages to structures and urban equipment, devaluate areas subjected to inundation, induce losses associated to paralysed businesses and services, interrupt the circulation of pedestrians and transport systems. They spread water-borne diseases, affecting and being affected by the improper collection and disposal of urban sewage and solid waste. The system weakens as a whole, risks increase and a degradation cycle emerges [41]. In resume, the impacts of urbanisation are presented in **Figure 1**.

The main gaps of integration between drainage design and urbanisation can be cited in a resumed way, as given in the following:

- When the increasing urban growth is not controlled, the exceeding soil sealing by impervious surfaces generate superficial flows surpassing the capacity of the drainage network, going beyond those discharges foreseen in the project horizon;
- lack of urban growth control in the total project area (mainly upstream), advancing towards areas which were originally natural, also increases discharges in the drainage network;
- unsuitable occupation of the bottom of valleys and riverine areas, which should be preserved as flood plains, directly exposes the communities installed there;
- lack of integration between drainage systems and the other basic sanitation systems, which need to be understood as complementary and not independent systems.

A series of reciprocal interferences can be mapped between the drainage system and the other urban systems, producing faults in cascades, as in a house of cards.

Gusmaroli et al. [61] proposed the adoption of an ecosystem approach to face river problems in urban areas, with the objective to amplify the concept of Waterfront Design, in which one seeks to improve the value of the contact line between city and water surface, reintroducing

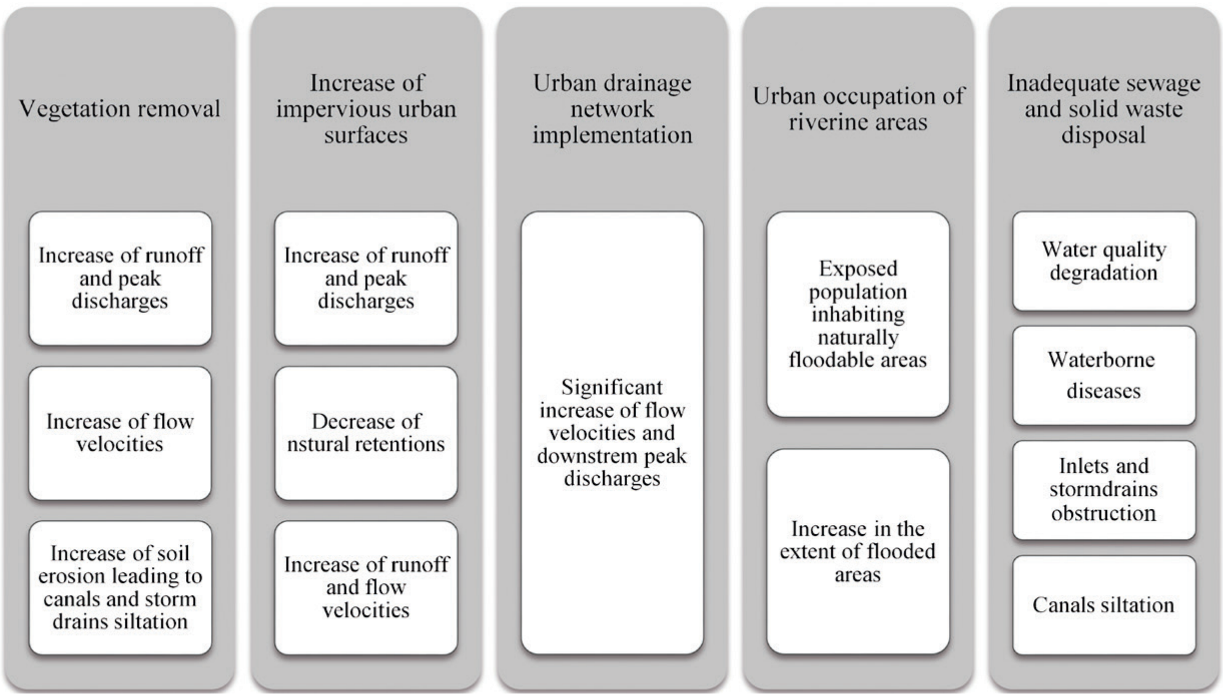

Figure 1. Impacts of urbanisation on inundations [41].

the watercourse in the city landscape. This approach widens the possibility of just using the presence of water as an aesthetic urban value, but also, and mainly, as an environmental asset, an element for connecting the city with nature. This possibility bring an opportunity to pursue the concept of fluvial restoration, from the point of view of an effective environmental improvement, looking at the city as a live organism in constant transformation and, due to this characteristic, capable to remodel and adapt itself (even if only partially, given all the modifications already suffered) to the demands of a more natural watercourse. The perspective to incorporate concepts of environmental sustainability into the process of rethinking the city growth opens a diversified set of opportunities to be explored as integrated solutions in a multidisciplinary context.

5. Urban drainage and open spaces

The traditional practices associated with drainage projects tend to focus on the problem of the resulting discharges in the storm drains and canals, equating them to these discharges. In this concept, the water needs to be rapidly conducted out of the watershed. This concept is very often responsible for transferring of flooding problems to downstream reaches situated in the lower river basin, without really solving the drainage problems.

Based on these questions, along the last decades, this traditional concept is being complemented or replaced by concepts which seek systematic solutions for the basin, with distributed interventions, looking to recover flow patterns similar to those existing before urbanisation. The new approach joins preoccupation of sustainable management of the urban rain waters, integrating those with urban space solutions. Measures for storing waters and incrementing the infiltration appear to be the alternative to treat the principal modifications introduced by the city growth on the water cycle [41]. These are called compensatory techniques [62], because they seek exactly to "compensate" the effects of urbanisation on the water cycle.

A resumed history of the conceptual evolution of urban drainage solutions since the Industrial Revolution is presented as follows:

- The necessity of urgent sanitation appeared as a primary concern in industrial cities. As they suffered from serious problems of epidemics, this fact led to the development of hygienist concepts in drainage projects, reflecting on the necessity to convey as fast as possible rain waters and sewage—storm drains and artificial canals were adopted as frequent solutions and the fluvial and sanitary systems worked together.
- The possibility of environmental degradation, the great rainfall intensities and the difficulty to treat diluted sewage led to the concept of separate sewer network at the beginning of the twentieth century.
- Until approximately the 1970s, the drainage focus was set on the increase of conveyance and the necessity to improve flow conditions to face the increase of run off generated by the cities growth.
- Since 1970, the traditional paradigms started to be broken.

- The vision that the traditional measures of canalisation tended to transfer problems became dominant.
- Compensatory techniques were adopted to control the distributed generated run off.
- On source controls to minimise run off were introduced.
- Quantity and quality of urban waters became integrated concerns.
- The concept of "sustainable drainage" was formalised, seeking to: minimise the transfer of flood problems in space (for other locations) and in time (for future generations); integrate drainage solutions with socioenvironmental aspects; increase the biodiversity in the built environment; revitalise the urban spaces and articulate with urban development plans.
- Rivers came to be seen as possible drivers for restructuring the urban landscape.
- Rain water started to be seen as a usable resource.

In this new approach, the objectives of an urban drainage system, in a wider context, can be defined as:

- The reduction of inundation of a given region of interest and the minimisation of damages to the community installed in the drained basin.
- Integration with the urban developing plan, both in what regards land use questions and the future urban growth.
- Preservation of riverine areas, as well as the integration of drainage solutions within urban landscapes, in multifunctional combinations.
- Integrated evaluation of questions regarding quality and quantity of the urban waters.
- A compromise between the drainage of the interest region and final destination in the receiving water body, without transferring problems downstream.

It is necessary to evaluate the points of conflict between the natural and the built environment, searching for means of convergence, equalising conflicts and potentialising synergies and positive results.

The search for sustainability need to be kept in the conjugation of the social, economic and environmental scales, with lasting results, as sustainability is a concept that directs the vision to the future. Therefore, a solution that intends to be sustainable needs to be able to stand and face future challenges. This characteristic converges to the concept of resilience. In this context, the sustainable development is capable to face future risks supported by the environmental resilience.

A set of premises is suggested here to direct the major drainage projects towards an effective solution for the urban flooding, considering an integrated vision for the river and the city, with a complementary (and not a competitive) approach regarding the natural and built environments. In this sense, the creation of "multifunctional spaces" allows that the open spaces remain in the urban cores already consolidated, associating hydrologic functions to the already existing socioenvironmental and economic functions.

The utilisation of these open spaces can permit:

- to control and reorganise flow discharges avoiding flooding;
- the introduction of fluvial parks, which may be used for leisure, landscaping and flood storage, besides helping the organisation of urban space and creating limits for the urban growth (preventing the city to advance over preservation areas);
- the increment of urban biodiversity;
- the use of green ways with the purpose of mobility and connection of the fragmented environmental areas;
- the valorisation of property in the neighbourhood;
- the eventual waterway transportation in specific cases.

Therefore, the creation of multifunctional spaces can (and should) be linked to a strategy that embodies the concepts of fluvial restoration. Such an action foresees the environmental recovery of the fluvial corridor, as an additional component of the sustainable urban drainage approach, which, in turn, offers a distributed action in the watershed, reorganising flow patterns and restoring water cycle functions, preventing flooding.

6. Case study and discussion

Dona Eugênia River Basin (coordinates 22° 46′ 55″ S, 43° 25′ 44″ O) drains a watershed of 18 km^2 situated in the Rio de Janeiro metropolitan area, crossing two cities of a lowland region called Baixada Fluminense: Nova Iguaçu and Mesquita. Dona Eugênia River is about 10 km long. The first 4 km are located in Nova Iguaçu inside an environmental preservation area called Gericinó/Mendanha. The subsequent 6 km run through the city of Mesquita, crossing a dense urban area until its outfall at Sarapuí River. The preserved upstream area contrasts with the degradation found in the lower urban area, just a few kilometres downstream, and is a reference for restoration goals. The climate is hot and humid with a summer rainy season (Aw in the Koppen climate classification). It has an average annual temperature of 22°C and an average annual rainfall of 1700 mm [63]. Mesquita has approximately 170,000 inhabitants, according to the 2010 Brazilian Census [64] and the Human Development Index calculated for the city and reported by the United Nations Development Programme in 2010, is 0.737, which places Mesquita at the 850th on the list of Brazilian municipalities.

The city has many infrastructure problems. According to Ref. [42], in the most populated areas of the city, there are numerous shantytowns built illegally, without considering environmental risk factors, both in flat flood prone areas and on steep hillsides. Even in areas regularly occupied, urban growth was not controlled, urban occupation sprawled, open areas are few and infrastructure was not adequately provided. The main problems of this city can be summarised as follows:

- Intense and irregular informal settlements on riverine areas;
- Lack of vegetation in the urban reaches of the river;
- Urban settlements in risk areas, including dwellings on river banks, where the houses act as dikes, "canalising" the river;
- Parts of the main river run canalised underground;
- Recurrent problem of flooding, which affects about 80% of the city population;
- Sedimentation at various points of the river;
- Discharge of sewage and solid waste into the river, with visible environmental degradation and health hazards;
- Scarce infrastructure;
- Degradation of the urban environment.

In the recent past, the municipality has canalised Dona Eugênia River towards its upstream reaches in an artificialisation process that is stressing the environmental protection area, while configuring a loss of opportunity to integrate the river as an environmental asset in the urban landscape. The consequences are clear: less biodiversity, fewer open green areas, less leisure opportunities, greater environmental fragmentation (with consequent degradation) and worse floods downstream.

In the context of the discussion developed in the previous sections of this chapter, this case has motivated a research joining the necessity to find a flood control alternative, the aspiration to revitalise the degraded urban areas and the goal to improve environmental conditions. The main part of this research is concerned with the reorganisation of the open spaces system, providing a storage capacity to the urban drainage system, while using the river path as a corridor to integrate environment fragmented areas among them and with the upstream protected forest.

A mathematical hydrodynamic model—MODCEL—developed in the Federal University of Rio de Janeiro (UFRJ) was used to produce flood maps and then evaluate flood conditions. Due to the limited availability of data, the model calibration used the results of a previous study as reference. This study was, carried out by the Rio de Janeiro state government, in the revision of the *Water Resources Master Plan of the Iguaçu-Sarapuí River Basin* [63]. The catchment's outlet was one of the control points adopted for calibration purposes. At this point, the target discharge was 40 m^3/s, and the modelled value reached 41 m^3/s. To ensure a greater reliability, the calibration process also reproduced critical flooding points, based on historic events and population memories.

The diagnosis of the current situation considered as a design storm event with a 25-year return period, as recommended by the Ministry of the Cities, in Brazil. **Figure 2** shows the flood map obtained for this situation, confirming the criticality of the flooding problem in

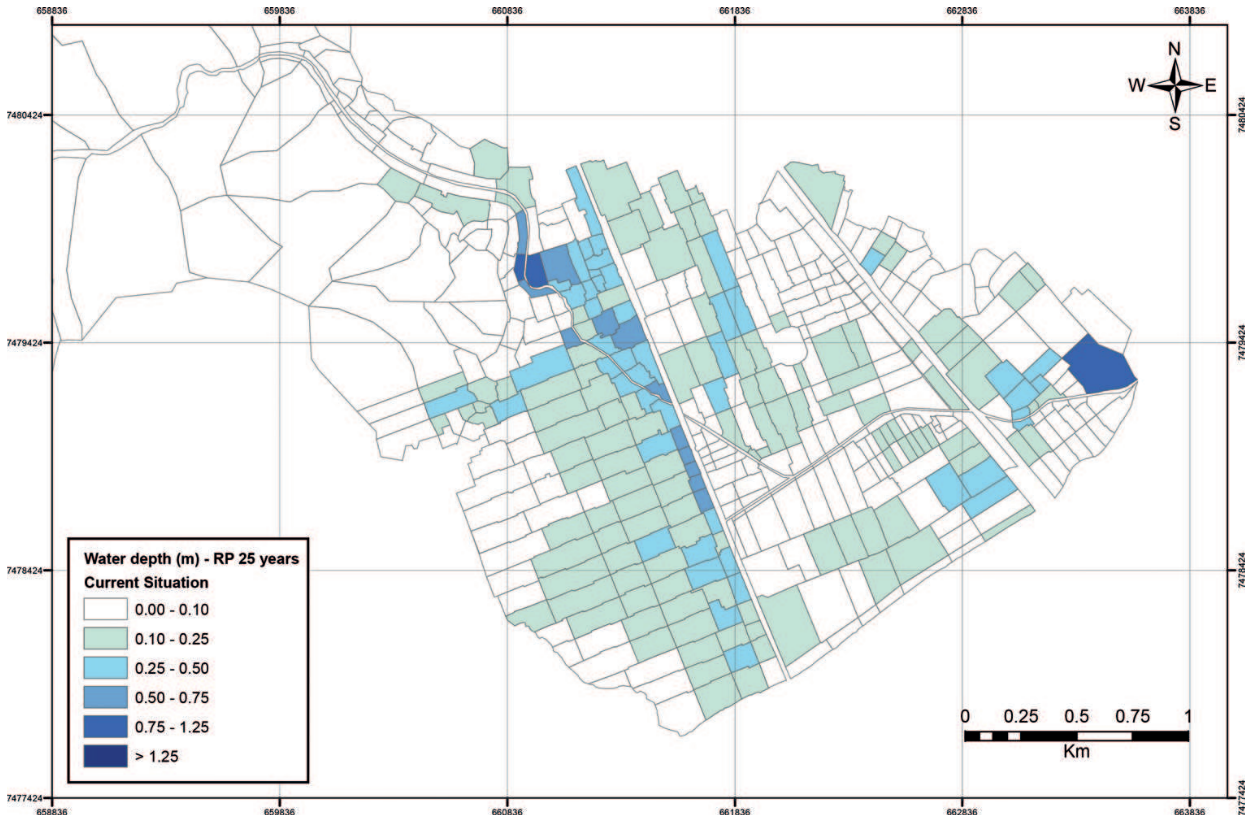

Figure 2. Current situation—flood map—recurrence period 25 years (Source: see Ref. [42]).

Mesquita. The mathematical modelling showed areas with inundation levels reaching more than 0.75 m in some places. The critical points are associated with the city centre region and in riparian areas with informal settlements. This antagonistic situation shows that both formal and informal urban areas suffer from significant flooding. The region located upstream the railway line is also critical, once the railway walls act as a barrier to runoff and urban storm drains are insufficient.

It is important to note that some flooding observed in the current situation is due to the lack of minor drainage in the basin. Thus, floods are retained in the plains and cannot reach the river rapidly. The city centre is greatly affected: both major and the minor drainage system fail. The plains near the river, at the city centre and a natural wetland downstream (where some informal settlements appear) show the highest flooding levels.

An interesting observation related to a past situation helps to illustrate the discussion. In the beginning of 1970 decade, only the area upstream the railway was urbanised (**Figure 3**).

Mesquita population, according to IBGE census for 1970 [65], was 93,678. Considering that soil imperviousness is proportional to the population density, it was possible to simulate floods in 1970. Taking the same rainfall event of 25 years of recurrence period, flood maps simulated for 1970 were compared with the ones obtained for 2010 (**Figure 4**). Two main observations arise from comparing these maps:

- In the downstream areas, where no urbanisation took place, there were no flooding problems.

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• In the upstream area, although with fewer people and less imperviousness, floods were already significant (even if less important than today). This means that the space that should be occupied by flood flows was inadvertently occupied by the built environment.

Flood control is a matter of allocating spaces. Flood flows need space and the open spaces system of a city can be used to fulfil this aim.

After completing the flooding diagnosis, an alternative has been studied to solve this problem, with the expectation of avoiding river overflows and organising major drainage demands,

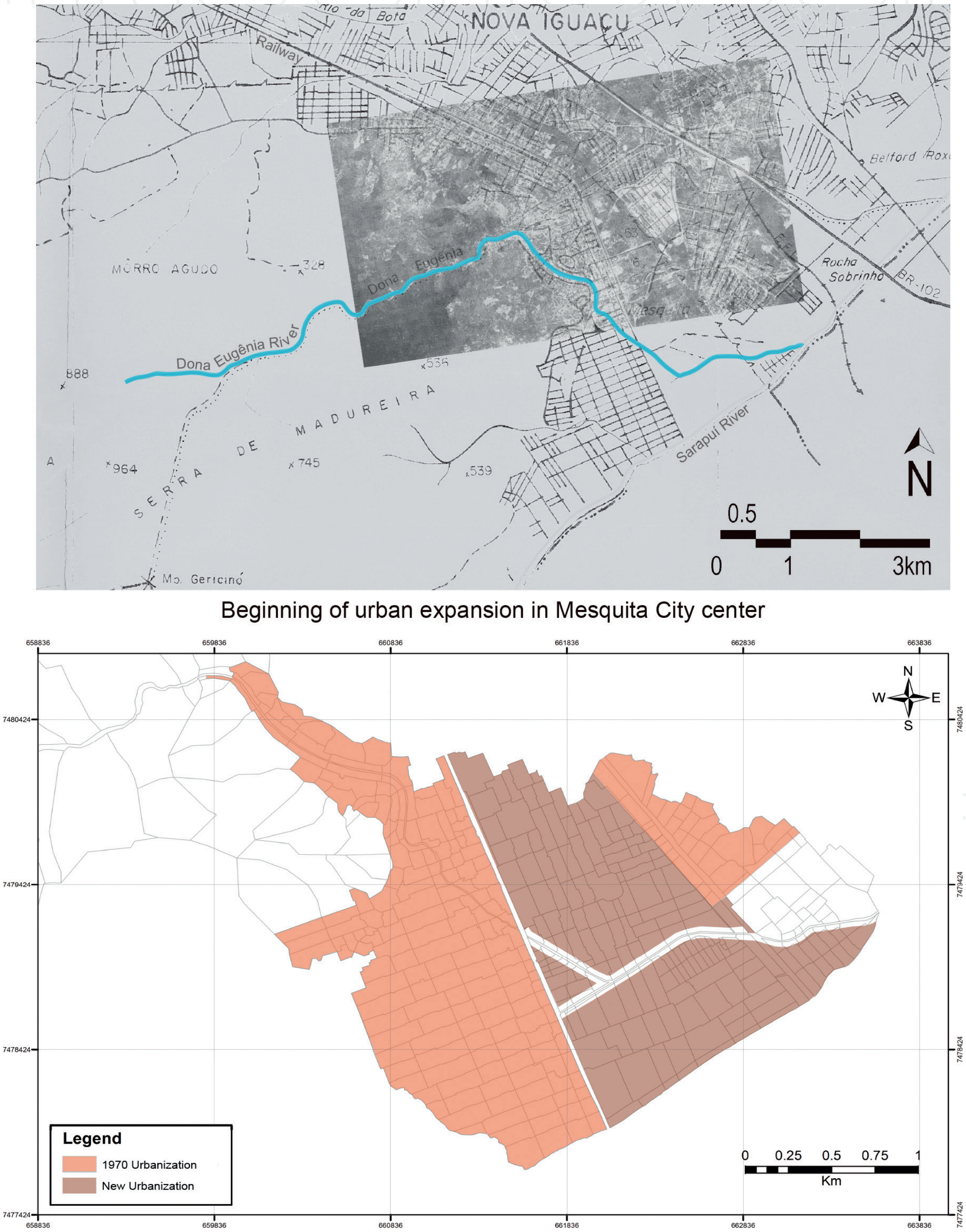

Figure 3. Past situation (1970) (Source: see Ref. [42]).

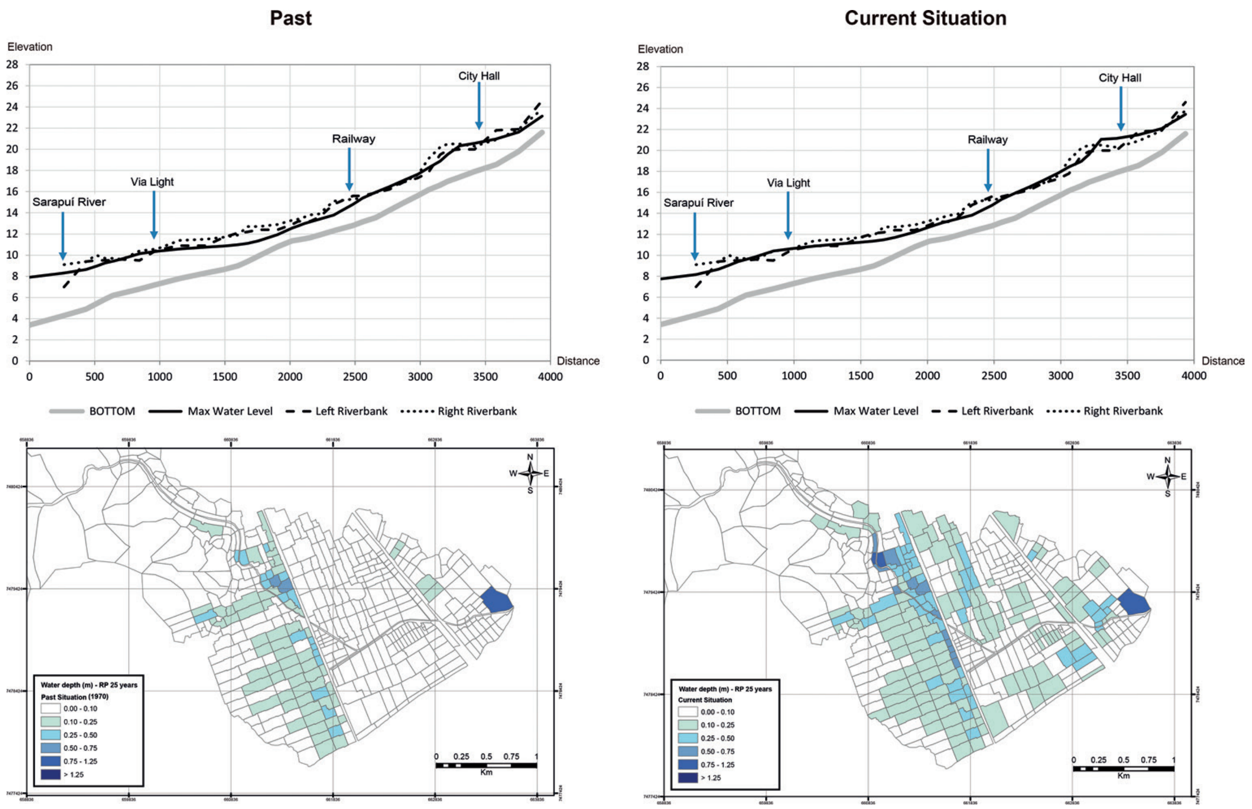

Figure 4. Current and past (1970) situation—flood maps—recurrence period 25 years (Source: see Ref. [42]).

using the open space system to reorganise flow patterns, but also providing river improvement and urban revitalisation, increasing both natural and built environment values. This alternative combined River Restoration (RR) solutions and Sustainable Drainage (SD) techniques, acting through the spaces provided by the open spaces system. In this alternative (RR + SD), the river was analysed and divided in three stretches in the urban area, identified as different landscape units: an upper reach near the natural protected area (area 1—upstream); a central area in the core of the city (area 2—middle reach); and a wetland in the river outfall (area 3—downstream), as schematically shown in **Figure 5**.

All the three areas suffer from informal settlements, substandard habitations and flood risks. Taking into account that it is a consolidated urban watershed, the open spaces shall be considered with multifunctional characteristics (landscaping, recreation, biodiversity and flood control, for example).

The design project proposals are listed in **Table 1** and **Figures 6–9** show the concepts supporting the proposals. The total storage volume offered by the three areas, in the combined RR + SD alternative, sums approximately 270,000 m^3, with additional contribution of infiltration measures and on-site detentions (adding 106,000 m^3).

Figure 10 shows the flood map for the alternative proposed. It is noticeable that flooding levels reduce all over the basin. The modelling system did not represent minor drainage, what

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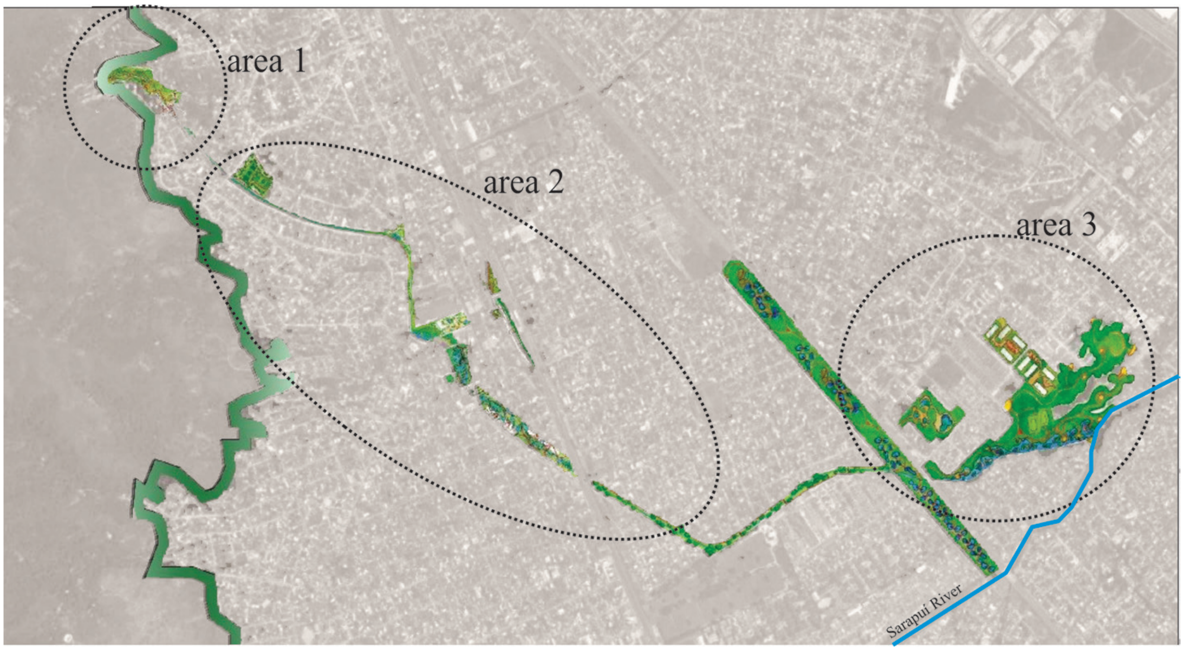

Figure 5. RR + SD alternative (Source: see Ref. [66]).

is probably the explanation to the remaining flooding areas. These water depths are low and the river does not overflow anymore. Additionally, the city of Mesquita currently marked by a grey landscape has the opportunity to revitalise degraded urban areas, also improving environmental connections.

Watershed Reaches	Characteristics	Vocation	Proposal
Area 1 (upstream)	This area is the most upstream urban reach. Urban growth is spreading and forcing the occupation of the valley that leads to environmental protection area. Substandard houses, poverty and an informal growth mark this area. Natural and built environment degradation is spreading. Floods are not observed in this area	This area may act as a transition from the city to the upstream protected areas, working as the entrance door linking the city with the upper green park. It is possible to use the hills and the steeper slopes to propose a dam for temporary flood storage purposes.	• Control urban occupation, diminishing urban density; • Avoid increasing imperviousness; • Escalate a set of different park typologies to allow a smooth transition between the city and the upstream green areas. This way, the park set in the sequence of the controlled urban growth area should begin with urban equipment, then becoming green, possibly exploring fruticulture (as an economic possibility for the local population), until reaching the protected environmental area. • A fluvial park, along the river course is also proposed. This park will begin here, connecting the upper forest to the city, and it will continue throughout the watercourse, crossing the city from one end to another.

Watershed Reaches	Characteristics	Vocation	Proposal
Area 2 (middle reach)	This area is the most floodable one. It is also the densest occupied area. The Major hall is here, in the city centre, near the river. There are also a line of houses, stacked on both riverbanks, strangling the river, discharging their sewage and hiding the river from urban landscape.	This area should provide space for flood storage. However, multifunctionality here is a key concept, once free space is rare.	• Continue with fluvial park, opening space where possible or necessary • Relocation of the houses that are directly settled on the riverbanks, giving space to the river. New housing typologies must be explored, using multi-floor buildings on stilts or pilotis. • Fluvial parks store temporary floods. • A number of soccer fields, public squares and free open areas near the river shall be incorporated in the blue-green way that is being created. These areas will also assume multifunctional characteristics, helping in the flood control.
Area 3 (downstream)	This is the lowest area, near the outfall on the Sarapuí River. It is a floodable area, and there are slums spreading fast. It is also a swampy area.	This area can be used as a humid park, also contributing in improving water quality. Urban occupation should be avoided	• The fluvial park finishes in a constructed wetland. • The houses settled in a very low elevation should be relocated.

Table 1. Characteristics of the design areas and proposal.

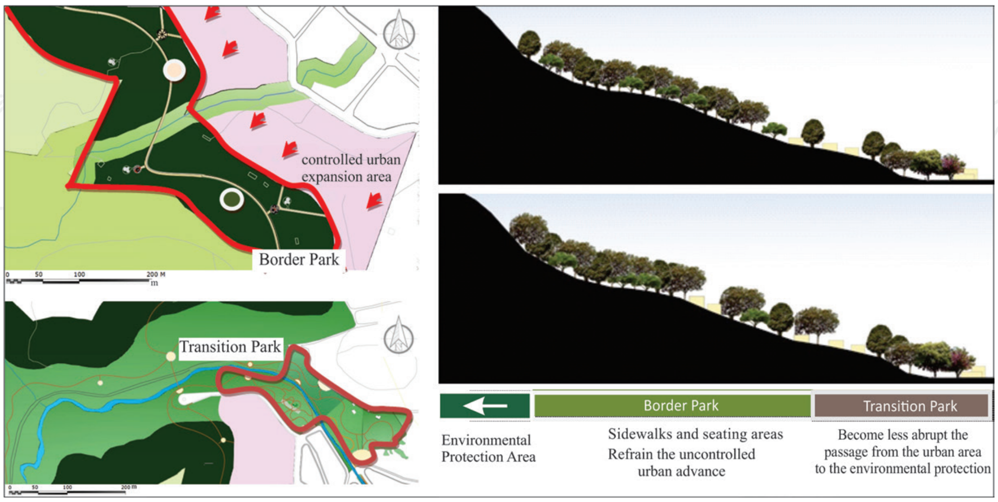

Figure 6. RR + SD alternative – area 1 (upstream) proposals (Source: see Ref. [66]).

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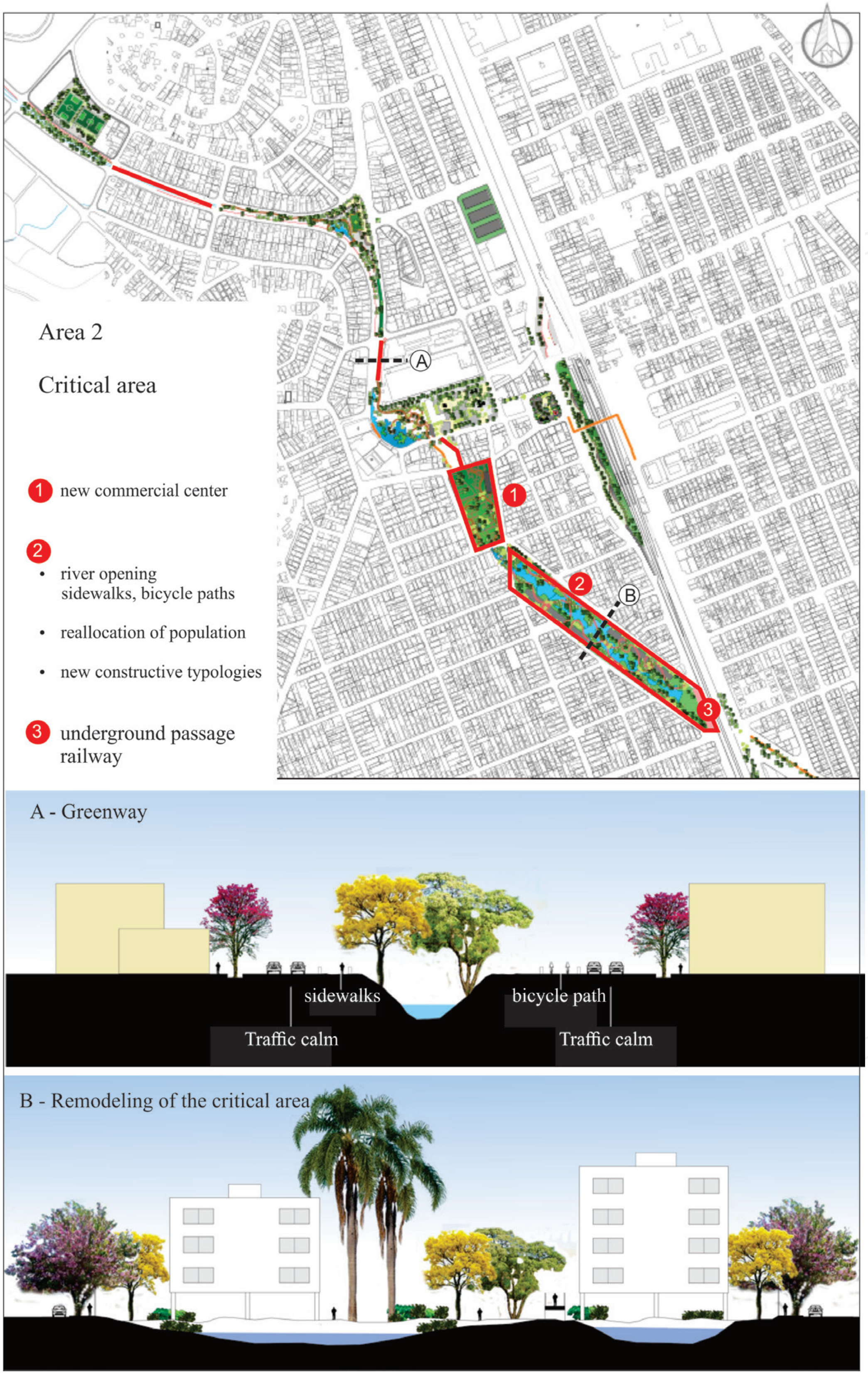

Figure 7. RR + SD alternative – area 2 (middle reach) proposals (Source: see Ref. [66]).

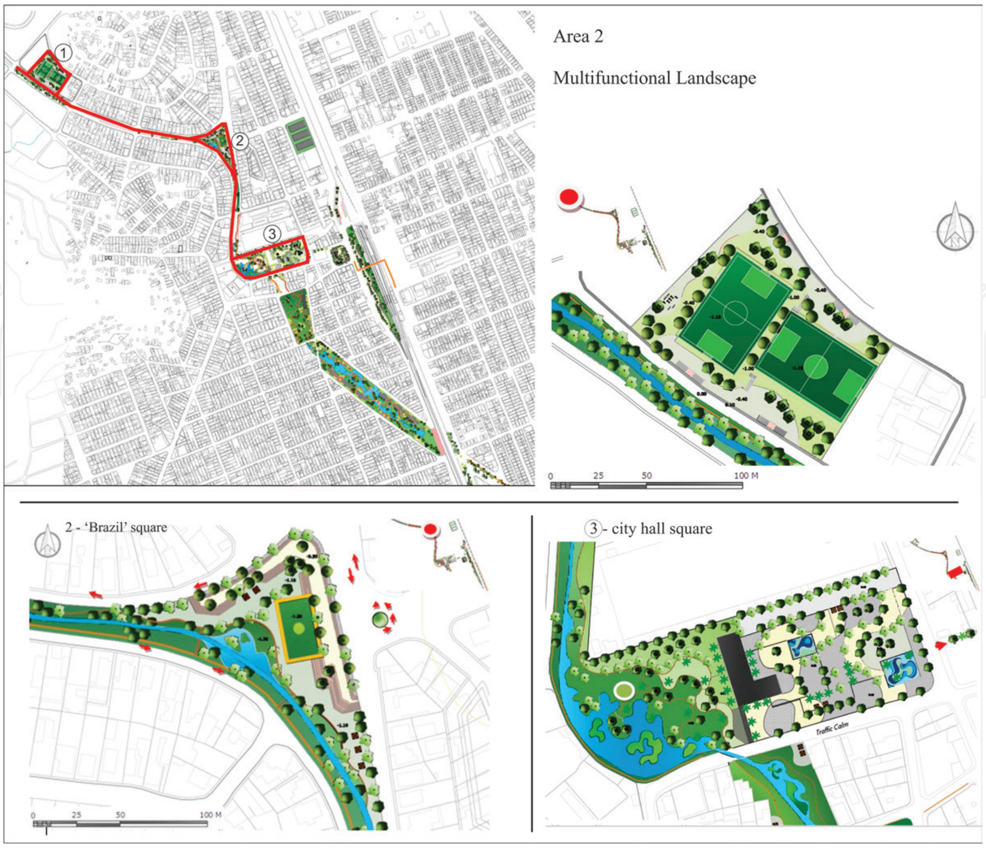

Figure 8. RR + SD alternative – area 2 (middle reach) – details (Source: see Ref. [66]).

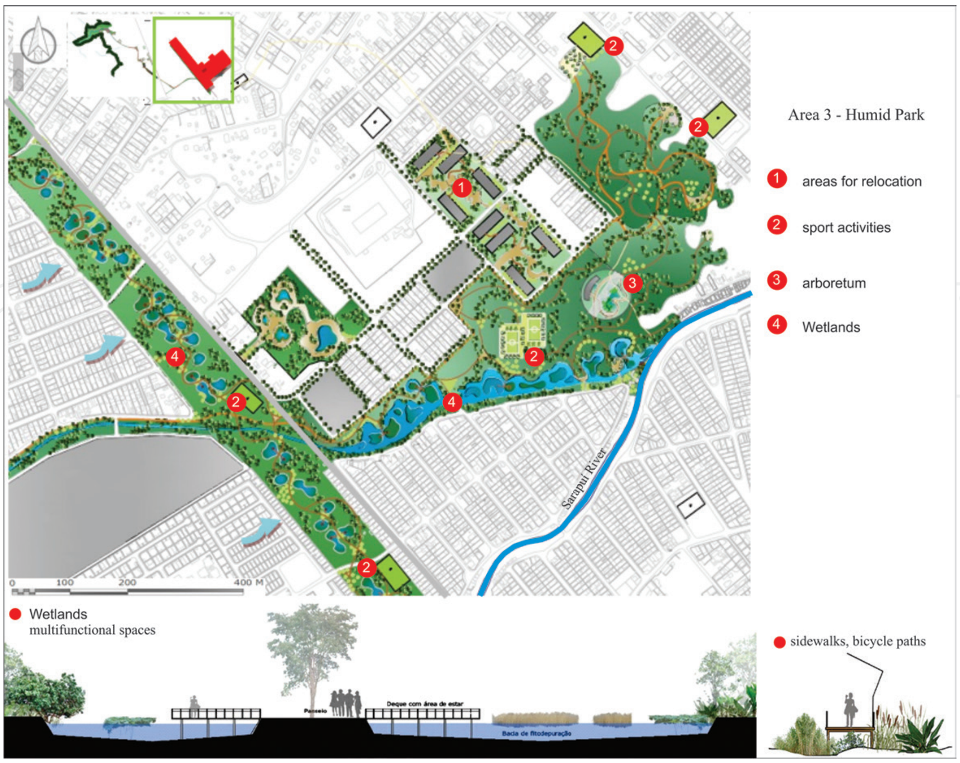

Figure 9. RR + SD alternative – area 3 (downstream) proposals (Source: see Ref. [66]).

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Figure 10. RR + SD alternative – flood map – recurrence period 25 years (Source: see Ref. [42]).

7. Concluding remarks

The urban flooding problem can be seen as problem of space allocation. In using areas that should be preserved for inundation purposes and encouraging a land use that generates a major quantity of runoff, the process of urbanisation must foresee new and alternative spaces to temporarily store floods. In this way, the drainage system may continue working, and, consequently, the whole city may preserve its functions.

Therefore, one is aware of the necessity of utilising open spaces as fundamental pieces for mitigating floods in the cities. By doing this, the limited discharge capacity of the traditional drainage system, whose result is converted into a flooding volume spread throughout the city, can be resolved when the open spaces are considered as a possible reservoir to store exceeding volumes of the drainage system. In this approach, open spaces act as multifunctional landscapes. In this sense, the creation of multifunctional spaces can permit that the remaining open spaces in the already consolidated urban centres incorporate hydrologic functions to their original purposes.

It needs to be pointed out, nevertheless, that the city growth, in an uncontrolled form, leads to urban sprawl, on the one side, and the discussion of sustainability considering the concept of compact cities, on the other side, can both lead to a suppression of open spaces. Therefore, the urban and environmental planning, taking into consideration the supporting capacity of the natural environment in which the city is inserted, make it possible to improve the quality of life in cities.

The set of actions in the urban tissue, utilising open spaces to support drainage solutions, acting in the fluvial corridor and combining efforts to revitalise the urban environment, poses a sustainable approach for facing urban floods within an agglomeration trend.

The case study chosen to illustrate this discussion, and shown in the previous section, confirms the proposed concepts, collaborating for an urban sustainable development, through a model of interventions capable to embrace environmental, economic and social aspects.

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References

[1] The Club of Rome. About the Club of Rome. 1968. Available from: http://www.clubofrome.org [Accessed: Aug 25, 2017]

[2] UNEP – United Nations Environment Programme. Stockholm, 1972. Report of the United Nations Conference on the Human Environment. 1972. Available from: http://www.unep.org [Accessed: Jun 25, 2012]

[3] United Nations. Our Common Future-Brundtland Report. Oxford, UK: Oxford University Press; 1987. p. 204

[4] UNCDE – United Nations Conference on Environment and Development. Earth Summit. 1992. Available from: http://www.un.org/geninfo/bp/enviro.html [Accessed: Jul 25, 2017]

[5] UN – United Nations. Agenda 21: Earth Summit – The United Nations Programme of Action from Rio. Rio de Janeiro: United Nations, Department of Public Information; 1993

[6] Lindholm G. 'Visible gestures': On urban landscape perspectives in planning. Planning Theory. Swedish University of Agricultural Sciences, Sweden. 2011;**11**(1):5-19

[7] Johannessen Å, Wamsler C. What does resilience mean for urban water services? Ecology and Society. 2017;**22**(1):1. DOI: https://doi.org/10.5751/ES-08870-220101

[8] Andoh RY, Iwugo KO. Sustainable urban drainage systems: A UK perspective. In: Global Solutions for Urban Drainage. Portland, Oregon, United States: American Society of Civil Engineers; 2002. pp. 1-16

[9] Sayers P et al. Flood Risk Management – A Strategic Approach, Part of a Series on Strategic Water Management. Paris: Asian Development Bank, GIWP, UNESCO, and WWF-UK; 2013

[10] UNDP-United Nations Development Programme. Human Development Report 2014–Sustaining Human Progress: Reducing Vulnerabilities and Building Resilience. New York, USA. 2014

[11] European Commission. The EU Approach to Resilience – Learning from Food Crises, COM(2012) 586 final, Communication from the Commission to the European Parliament and the Council. Brussels, Belgium. 2012

[12] IPCC. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M, Midgley PM, editors. Cambridge, UK, and New York, NY, USA: Cambridge University Press; 2012. 582 pp

[13] McBain W, Wilkes D, Retter M. Flood Resilience and Resistance for Critical Infrastructure. Publication C688. CIRIA, London, UK; 2010

[14] UNISDR. UNISDR Terminology on Disaster Risk Reduction. Geneva, Switzerland: United Nations International Strategy for Disaster Reduction; 2009

[15] Brown R, Keath N, Wong T. Transitioning to water sensitive cities: Historical, current and future transition states. 11th International Conference on Urban Drainage. IAHR/IWA, Edinburgh, Scotland, UK; 2008

[16] Abhas KJ, Miner TW, Stanton-Ge Z. Building Urban Resilience – Principles, Tools and Practice. Washington DC: International Bank for Reconstruction and Development/The World Bank: 2013

[17] UNISDR. Making Cities Resilent: My City is Getting Ready. 2012. [Online] Available from: http://www.unisdr.org/campaign/resilientcities [Accessed: Aug 19, 2017]

[18] Miguez MG, Veról AP. A catchment scale integrated flood resilience index to support decision making in urban flood control design. Environment and Planning B: Urban Analytics and City Science. 2016;**44**(5):925-946. DOI: 10.1177/0265813516655799

[19] Meerow S, Newell JP, Stults M. Defining urban resilience: A review. Landscape and Urban Planning. Mar 2016;**147**:38-49

[20] Xu L, Marinova D, Guo X. Resilience thinking: a renewed system approach for sustainability science. Sustainability Science. 2015;**10**(1):123-138. DOI: https://doi.org/10.1007/s11625-014-0274-4

[21] Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T, Rockström J. Resilience thinking: Integrating resilience, adaptability and transformability. Ecology and Society. 2010;**15**(4):20. DOI: https://doi.org/10.5751/ES-03610-150420

[22] Turner BL. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? Global Environmental Change. 2010;**20**(4):570-576. DOI: https://doi.org/10.1016/j.gloenvcha.2010.07.003

[23] Lélé S. Resilience, sustainability environmentalism. Environment and Development Economics. 1998;**3**(2):221-262. DOI: https://doi.org/10.1017/S1355770X98260128

[24] Mcharg IL. Design with Nature. New York: Natural History Press; 1969

[25] Rogers R. Cidades Para um Pequeno Planeta, Barcelona: GGili; 2001

[26] Harvey D. The Right to the City. New Left Review 53, London, UK. September-October 2008

[27] Forest Stewardship Council (FSC). Sustainable Cities. Sustainable Development for Urban Infrastructures. 2010. pp. 1-38. Available from: www.siemens.com/cities

[28] Allen A. Sustainable cities or sustainable urbanisation? Journal of Sustainable Cities. 2009;**34**(10):1667-1691. DOI: https://doi.org/10.1080/0042098975394

[29] Zetter R, Butina Watson G. Designing sustainable cities. In: Zetter R, Butina Watson G, editors. Designing Sustainable Cities in the Developing World. Hamphire: Routledge Taylor & Francis Group; 2006. pp. 3-18

[30] Shi L, Gao L, Yang S. Effects of a compact city on urban resources and environment. Journal of Urban Planning and Development. 2016;**142**(2014):1-9. DOI: https://doi.org/10.1061/(ASCE)UP.1943-5444.0000324

[31] Seya H, Yamagata Y, Nakamichi K. Creation of future compact urban form scenarios of Tokyo in combination with adaptation policies. In: Energy Procedia. Vol. 61. Amsterdam, Netherlands: Elsevier Ltd; 2014. pp. 357-360. DOI: https://doi.org/10.1016/j.egypro.2014.11.1124

[32] Woodcock K, Dovey S, Wollan I, Robertson I. Urban policy and research. Speculation and Resistance: Constraintson Compact City Policy Implementationin Melbourne. 2011;**29**(4):343-362

[33] Catalán B, Saurí D, Serra P. Urban sprawl in the Mediterranean?. Patterns of growth and change in the Barcelona Metropolitan Region 1993-2000. Landscape and Urban Planning. 2008;**85**(3-4):174-184. DOI: https://doi.org/10.1016/j.landurbplan.2007.11.004

[34] Dieleman F, Wegener M. Compact city and urban sprawl. Built Environment (1978–). 2004;**30**(4):308-323. DOI: https://doi.org/10.2307/24026084

[35] de Roo G. Environmental planning and the compact city a dutch perspective. Studies in Environmental Science. 1998;**72**(C):1027-1042. DOI: https://doi.org/10.1016/S0166-1116(98)80061-7

[36] Burgess R, editor. Compact Cities: Sustainable Urban Forms for Developing Countries. London and New York: Spon Press; 2001

[37] Rogers R. Cidades para um pequeno planeta. Barcelona: Gustavo Gilli; 2005

[38] Andersen TK, Shepherd JM. Floods in a changing climate. Geography Compass. 2013;**7**(2):95-115

[39] Barbedo J, Miguez M, Van Der Horst D, Marins M. Enhancing ecosystem services for flood mitigation: A conservation strategy for peri-urban landscapes. Ecology and Society. 2014;**19**(2):54. DOI: http://dx.doi.org/10.5751/ES-06482-190254

[40] Grizzetti B, Lanzanova D, Liquete CA. Assessing water ecosystem services for water resource management Reynaud, A.C. Cardoso European Commission Joint Research Centre (JRC), I-21027 (VA). Italy Environmental Science & Policy. 2016;**61**:194-203

[41] Miguez MG, Veról AP, Rezende OM. Drenagem Urbana: do Projeto Tradicional à Sustentabilidade. Rio de Janeiro: Elsevier; 2015

[42] Veról AP. Requalificação Fluvial Integrada ao Manejo de Águas Urbanas para Cidades mais Resilientes. Tese de Doutorado: COPPE/UFRJ, RJ; 2013

[43] Miguez MG, Rezende OM, Veról AP. City growth and urban drainage alternatives: Sustainability challenge. Journal of Urban Planning and Development. 2015;**141**(3): 04014026-1-04014026-10

[44] Miguez MG, Veról AP, de Sousa MM, Rezende OM. Urban floods in lowlands—Levee systems, unplanned urban growth and river restoration alternative: A case study in Brazil. Sustainability. 2015;**7**:11068-11097

[45] Comissão das Nações Unidas para o Desenvolvimento Sustentável. COMISSÃO EUROPEIA. Cidades europeias sustentáveis. Bruxelas, 1996. Available from: ec.europa.eu/environment/urban/pdf/rport-pt.pdf. [Accessed: Sep 10, 2017]

[46] Kyushik O, Yeunwoo J, Dongkun L, Wangkey L, Jaeyong C. Determining development density using the Urban Carrying Capacity Assessment System. Landscape and Urban Planning. 15 August 2005;**73**(1):1-15. DOI: https://doi.org/10.1016/j.landurbplan.2004.06.002

[47] Chung S. A conceptual model for regional environmental planning centered on carrying capacity measures. Korean J. Region. Sci. 1988;**4**(2):117-128

[48] Schneider DM, Godschalk DR, Axler N. The Carrying Capacity Concept as a Planning Tool. Planning Advisory Service Report 338. Chicago: American Planning Association; 1978

[49] Oh K, Jeong Y, Lee D, Lee W. An integrated framework for the assessment of urban carrying capacity. Journal of Korea Planners Association 2002;**37**(5);7-26

[50] Kozlowski JM. Sustainable development in professional planning: A potential contribution of the EIA and UET concepts. Landscape Urban Plan. 1990;**19**(4):307-332

[51] Tuan YF. Espaço e lugar. São Paulo: DIFGL; 1979

[52] Schlee MB, Nunes MJ, Rego AQ, et al. Sistemas de espaços livres nas cidades brasileiras – um debate conceitual. In: Tângari VR, Andrade R, Schlee MB. (org.). Sistemas de Espaços Livres – o cotidiano, apropriações e ausências. Rio de Janeiro: PROARQ; 2009

[53] Meining DW, (org.). The Interpretation of Ordinary Landscapes – Geographical Essays. Oxford: Oxford University Press; 1979

[54] Macedo S, Queiroga EF, et al., (org). Sistemas de espaços livres – conceitos, conflitos e paisagens. São Paulo: Laboratório QUAPÁ-SEL; 2011

[55] Rego AQ, Tângari VR, Gomes RB. Paisagem e Planejamento do Sistema de Espaços Livres sob a Influência do Arco Metropolitano do Rio de Janeiro: Magé. Anais do VI Colóquio QUAPÁ-SEL. São Paulo: FAUUSP; 2011

[56] Tardin RH. Espaços Livres: Sistema e Projeto Territorial. Ed. 7 Letras, Rio de Janeiro, Brazil. 2008

[57] Chiesura A. The role of urban parks for the sustainable city. Department of Leisure, Tourism and Environment, Wageningen University General Foulkseweg. Landscape and Urban Planning. 2004;**68**(2004):129-138

[58] Spirn AW. O Jardim de Granito. São Paulo: EDUSP; 1995

[59] Naveh Z. Ten major premises for a holistic conception of multifunctional landscapes landscape and urban planning 57. In: Naveh Z, editor. Transdisciplinary Challenges in Landscape Ecology and Restoration Ecology.Org.por, Holanda, Netherlands: Springer; 2001. pp. 269-284

[60] CIRF – Centro Italiano per la Riqualificazione Fluviale. In: Nardini A, Sansoni G, editors. La riqualificazione fluviale in Italia: linee guida, strumenti ed esperienze per gestire i corsi d'a cqua e il territorio. 1st ed. Venezia: Mazzanti; 2006

[61] Gusmaroli G, Bizzi S, Lafratta R. 2011. L'approccio della Riqualificazione Fluviale in Ambito Urbano: Esperienze e Opportunittà. In: Acqua e Città – 4° Convegno Nazionale di Idraulica Urbana, Venezia, Italia. June 2011

[62] Batista M, Nascimento N, Barraud S. Técnicas Compensatórias em Drenagem Urbana. Porto Alegre, Brazil: ABRH; 2005

[63] COPPETEC. Plano Diretor de Recursos Hídricos, Recuperação Ambiental e Controle de Inundações da Bacia do Rio Iguaçu-Sarapuí, Laboratório de Hidrologia e Estudos do Meio Ambiente. Rio de Janeiro: COPPE/UFRJ; 2009

[64] IBGE–Instituto Brasileiro de Geografia e Estatística. Censo Demográfico, Brazil. 2010. Available from: https://censo2010.ibge.gov.br/resultados.html

[65] IBGE–Instituto Brasileiro de Geografia e Estatística. Censo Demográfico, Brazil. 1970. Available from: https://biblioteca.ibge.gov.br/visualizacao/periodicos/69/cd_1970_v1_t16_rj.pdf

[66] Bigate I. Rios Urbanos e Paisagens Multifuncionais: O Projeto Paisagístico Como Instrumento de Requalificação Urbana e Ambiental. Dissertação de Mestrado. Rio de Janeiro: PROURB/FAU/UFRJ, RJ; 2013