OPEN SPACE SYSTEMS AND URBAN DRAINAGE: AN EXAMPLE OF INTEGRATION BETWEEN SUSTAINABLE RAINWATER MANAGEMENT AND URBAN PLANNING

SISTEMAS DE ESPAÇOS LIVRES E DRENAGEM URBANA: UM EXEMPLO DE INTEGRAÇÃO ENTRE O MANEJO SUSTENTÁVEL DE ÁGUAS PLUVIAIS E O PLANEJAMENTO URBANO

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Abstract

In the last decades, the traditional view of urban drainage has been modified by an integrated approach of sustainable urban drainage management and urban planning. Open space systems appear as actors of environmental integration, providing opportunities to create multifunctional projects, combining drainage solutions with the urban growth and the union of fragmented areas. In this work, the object of study is Xavier de Brito Square, located in the Tijuca neighborhood, in the city of Rio de Janeiro. Considering its surroundings and the most affected areas by floods, this work proposes a route along the Maracanã River, to connect Xavier de Brito Square to other adjacent squares, seeking to improve the connection between the urban space and the river, integrating the existing open spaces. In addition, sustainable urban drainage measures were proposed, such as permeable pavements, rain gardens, and detention basins. With the aid of mathematical modeling, it was possible to analyze the effects of the proposed measures facing flood events.

Key-words: Open Space Systems. Sustainable Urban Drainage. Mangue Canal Watershed. Maracanã River.

Resumo

Nas últimas décadas, a visão tradicional do projeto de drenagem vem sendo modificada por uma abordagem integrada de manejo sustentável das águas pluviais e planejamento urbano. Os sistemas de espaços livres surgem como atores de integração do ambiente, configurando oportunidades de criação de projetos multifuncionais, por exemplo, acumulando funções para soluções de drenagem, organização do crescimento urbano e união de áreas fragmentadas. O presente trabalho tem como objeto de estudo a praça Xavier de Brito, localizada no bairro Tijuca, na cidade do Rio de Janeiro. Após reconhecimento do seu entorno e análise das áreas mais afetadas por inundações, optou-se por formalizar um percurso ao longo do Rio Maracanã, buscando melhorar a relação entre o espaço urbano e o rio, e estabelecer a integração dos espaços livres, conectando a praça Xavier de Brito às demais praças adjacentes. Além disso, foram propostas medidas de drenagem urbana sustentável ao longo do percurso escolhido, como a utilização de pavimentos permeáveis, jardins de chuva e bacias de detenção, por exemplo. A partir de modelagem matemática, foi analisada a resposta da região às inundações com a aplicação das medidas propostas.

Palavras-Chave: Sistemas de Espaços Livres. Drenagem Urbana Sustentável. Bacia do Canal do Mangue. Rio Maracanã.

http://dx.doi.org/10.11606/issn.2359-5361.v0i42p55-74

Introduction

At present, one of the main challenges cities face is the problem of urban floods, exacerbated by the process of urbanization itself. The damage done is countless, causing economic and social losses and interfering in transportation, sanitation, and public health sectors, for example. We can underline the damage to infrastructure and housing, the degradation of the natural environment and the devaluation of the built environment, the propagation of waterborne diseases, the impoverishment of the population with successive losses, among others, as emphasized by Miguez *et al.* (2016). The lack of a systemic view of macro drainage planning is the main factor behind the chaotic condition of flood control in Brazilian urban areas (CANHOLI, 2015).

Thus, as a way to mitigate the impacts of urban floods, the traditional view of the drainage project has been changed into an integrated approach of sustainable management of rainwater and urban space planning in recent decades. The perspective of incorporating concepts of environmental sustainability in the process of rethinking the city growth opens up an array of opportunities to be explored as integrated solutions in a multidisciplinary context. The combination of actions in urban areas, in the light of control of the urban land, and in the fluvial corridor, focusing on the watercourse as a synthesis of the territory, combines efforts to achieve a more sustainable construction for the operation of the cities, considering the drainage as the structural element of the landscape.

The open space systems emerge then as opportunities for the integration of urban space. As emphasized by Veról *et al.* (2018), open space systems can be used to support drainage solutions and to organize urban growth, allowing the conservation of green areas and providing structures for temporary storage of water. On the other hand, the watercourses that define the main drainage system can be coupled with the open space system, offering corridors that link fragmented green areas, keeping their ecological flows in an integrated environmental system.

In this context, the present work aims to stress the importance of open space systems as actors of the urban space integration, being an ally in the storage of urban flood volumes from a systemic analysis of the river basin. To this end, we aim to exemplify interventions of sustainable urban drainage and multifunctional projects in a river stretch.

Open Spaces System

Lynch (1960) considers open spaces as spaces outdoors, opposed to the enclosed spaces of buildings. Magnoli (1982), meanwhile, defines open urban spaces as spaces free of buildings, that is, backyards, public or private gardens, streets, avenues, squares, parks, rivers, forests, wetlands, and urban beaches or simple urban voids. Macedo *et al.* (2007) point out that open space systems present relationships of connectivity and complementarity, even if they have not been planned or implemented as such.

Open spaces can be classified into different categories. According to the classification used by the Open Space Systems (SEL / RJ) research group of the Graduate Program in Architecture of UFRJ (PROARQ-FAU / UFRJ), open spaces can be, for example, of an environmental character, such as environmental protection areas and national parks; character of permanence like squares, parks and gardens and character of circulation, such as roads, sidewalks and bicycle paths.

As pointed out by Schlee *et al.* (2009), urban open spaces constitute a complex system, interrelated with other urban systems that can be juxtaposed with the open spaces system or overlap, totally or partially, as systems of actions. As examples of the diversity of roles are urban circulation and drainage, leisure activities, comfort, preservation, conservation, and environmental requalification. Moreover, it is important to underline that open spaces present themselves as instruments to stimulate a greater appropriation of the public space by the population. Magnoli (2006), for example, reflects on these spaces as socially integrating elements. Macedo *et al.* (2012) stress that open spaces are one of the main existing urban infrastructures, considering that a large part of daily life takes place in them and for them, being the principal venues where societal conflicts and agreements happen.

Sustainable Urban Drainage

Over the years, the hygienist concept of urban drainage, which established the capture, conduction, and discharge of rainwater, has been replaced by the concept of sustainable urban drainage, which adds the actions of storage and infiltration, when possible. According to Pompêo (2000), the perspective of sustainability associated with urban drainage introduces a new approach to actions, based on the recognition of the complexity of the relationships between natural ecosystems, the artificial urban system, and the society.

From this approach, the problem of urban floods is then evaluated in a more systemic way. The search for restoring some characteristics close to natural runoff becomes a more important issue. As examples of actions introducing storage and infiltration functions, we can mention, among others, the detention basins, the rain gardens, and the permeable pavements, which will be described below (ZHOU, 2014; WANG *et al.*, 2017). Such measures can also integrate the urban space harmoniously, setting up recreation areas to be used in dry weather and thus bearing multifunctional characteristics, with the bonus of improving the environment in which it is inserted (Miguez *et al.*, 2016).

Permeable pavements

The use of permeable pavements (Figure 1) allows the infiltration through a permeable surface to a reservoir placed under the surface of the ground before the actual infiltration in the soil takes place (Urbonas and Stahre, 1993). Because permeable pavements are not tough enough to withstand heavy traffic (DUARTE, 2003), their implementation is more common in parking lots and streets with low traffic (JHA *et al.*, 2012). Permeable covers come up, then, as an alternative to the use of traditional waterproof surfaces, such as asphalt and concrete used in sidewalks, parking lots, sports fields and even inside the subdivisions. As these surfaces take up much of the urban areas, the use of permeable pavements helps in the infiltration of rainwater and, consequently, acts in the reduction of floods (Miguez *et al.,* 2016).

According to Urbonas and Stahre (1993) and Araújo *et al.* (2000), permeable pavements can be porous asphalt, porous concrete or hollow concrete blocks filled with granular material. It is important to mention that the use of these pavements is restricted, depending on the groundwater level, soil type, and maintenance.

Detention Basins

According to Miguez *et al.* (2016), the detention basins are short-period storage reservoirs, which reduce the peak flows of flood hydrographs, increasing their base time. Generally, they do not reduce the volume of the direct flow, only redistribute the flows for a longer period of time, thus forming a temporary, useful volume, with part of the direct flow. They can be used to control the maximum flow, volume control or even solid material control. From a constructive point of view, the detention basins can be created by damming a river or canal, digging a basin in the existing soil or by a combination of excavation and dam.

The detention basins allow integrated solutions with urban planning, thus creating multifunctional projects. A common example is the design of lowered recreational squares and courts, which in dry weather provide areas for leisure and permanence, whereas in periods of rain, they work as temporary storage of flood volumes. Some examples can be seen in Figure 2.

Rain Gardens/Bioretention Systems

The rain gardens, also known as bioretention systems, are gardened areas with a lowered surface in relation to the

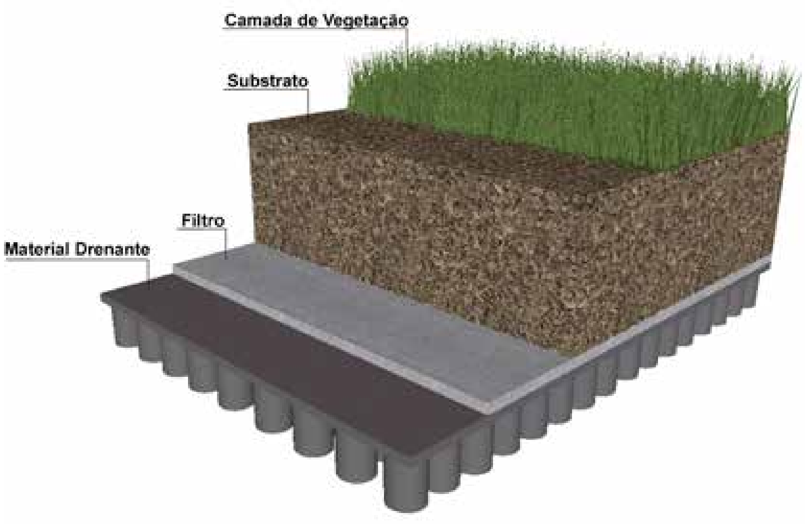


Figure 1: Typical Model – Permeable Pavement
Source: Miguez *et al.*, 2018.

surrounding areas and where the soil is prepared with more permeable materials, such as sand. This measure retains the accumulated rainwater in the reservoirs formed by the lowering of these areas, favoring infiltration (Figure 3). Upon reaching its storage capacity, the surplus volume sheds onto the net, following its traditional course (Miguez *et al.*, 2016).

As emphasized by Righetto (2009), bioretention systems have the advantage of integrating the natural landscape of the region, being recommendable in areas with high waterproofing index, like parking lots, for instance. The vegetation, which can be of different species and sizes, is a fundamental component in this system, being responsible for the removal of water and pollutants.

Case Study

The present work has as its object of study Xavier de Brito Square, located in Tijuca neighborhood, in the North Zone of the city of Rio de Janeiro (Figure 4), and inserted in the watershed of the Mangue Canal (Figure 5). This basin has a drainage area equal to 45.4 km^2 and drains Tijuca, Grajaú, Vila Isabel, São Cristóvão, Rio Comprido, Maracanã, Santo Cristo and Cidade Nova neighborhoods.

The main watercourses of the Mangue watershed are the Maracanã, Joana, Trapicheiros, Comprido and Papa-Couve Rivers, which have their springs in the Tijuca massif or the Engenho Novo mountain range and flow into the Mangue Canal which, in turn, runs into Guanabara Bay.

The land relief of the Mangue Canal basin presents marked drops in the West and Southwest regions, where the Tijuca massif is located (Figure 6). From this region on, the topography is less rugged, where the urbanized area of the basin begins with totally flat areas. This topographic configuration hinders the flow into the macro drainage canals (RIO DE JANEIRO CITY HALL, 2015).

The Mangue Canal basin has suffered the effects of floods since the 18th century. With the increase of urbanization, floods became more frequent and damaging during the 20th and 21st centuries. All these events have fostered the demand for traditional structural interventions based on plumbing concepts to reduce flood risks. However, the number of great floods kept growing over time, even with the undertaken interventions. Currently, this basin is the target area of great floods control work, with an original project of five large reservoirs, as well as a tunnel to restore the course of the Joana River to its natural mouth. The original project has been modified and, at the moment, three reservoirs (Bandeira Square, Niterói Square, and Varnhargen Square) have already been put into operation. Figure 7 shows the flood map of the Mangue Canal basin for a 25-year return period, as recommended by the Ministry of Cities for macro drainage projects, in a situation prior to the cited project.

(a) Detention basin coupled with landscape techniques and leisure use in Santiago, Chile

(b) Detention basin with Sports Purposes in Porto Alegre - RS

Figure 2: Detention Basins - Examples of multifunctional landscapes
Source: AQUAFLUXUS, 2011.

(a) Example of a rain garden on a street

(b) Example of a rain Garden on a sidewalk

Figure 3: Examples of rain gardens
Source: ABCP and FCTH, 2013.

Figure 4: Location of Xavier de Brito Square – Tijuca nei-ghborhood
Source: Map produced on Google Earth Image, 2017, by Bruna Battemarco, 2017.

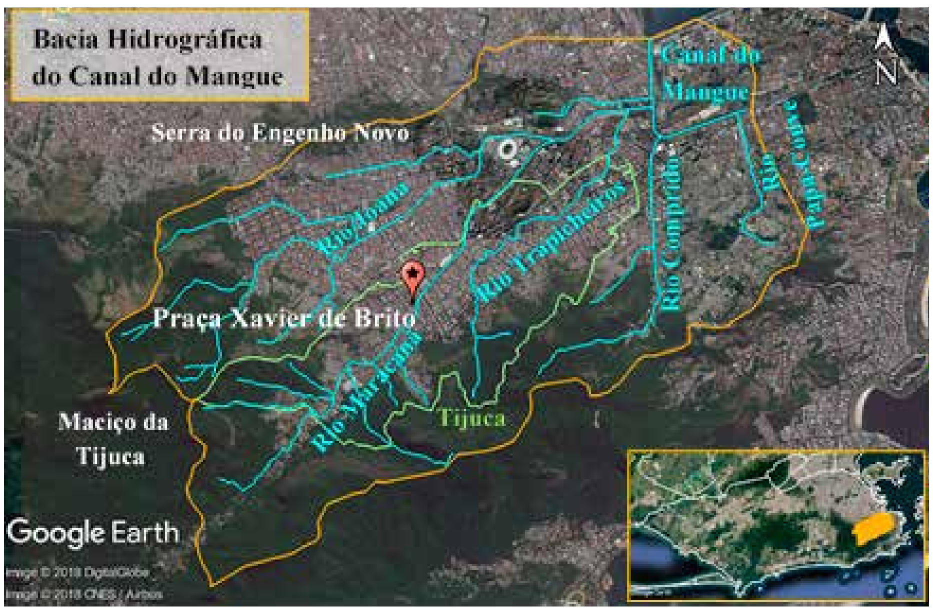


Figure 5: Location of Xavier de Brito Square - Mangue Canal Basin and Hydrography
Source: Map produced on Google Earth Image, 2017, by Bruna Battemarco, 2017.

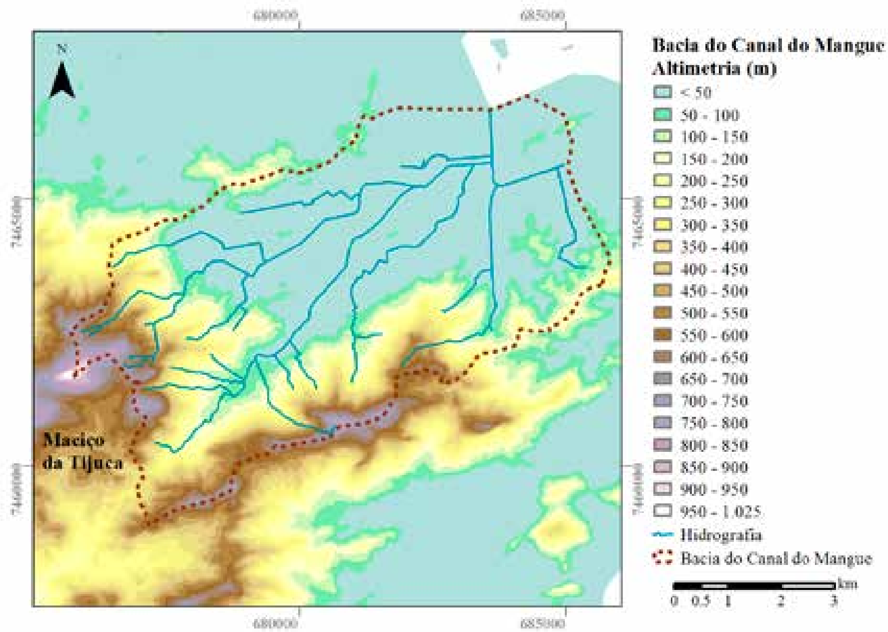


Figure 6: Altimetry map of the Mangue Canal Basin
Source: Map produced with data from Instituto Pereira Passos, by Lilian Yamamoto, 2018

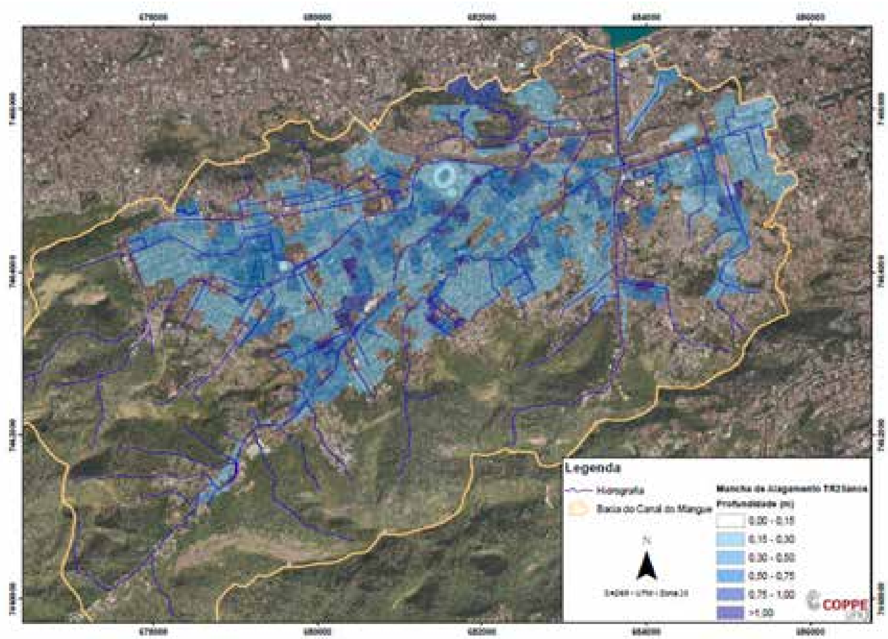


Figure 7: Flood map – 25-year return period – No interventions in the basin
Source: Rezende, 2018.

Methodology

The methodological process of the present work consisted of the steps presented below:

Study of the open spaces of environmental character, character of permanence and character of circulation to understand the characteristics of the surroundings in different scales;

Analysis of the flood map of the watershed which contains the selected study area in order to recognize the affected areas and the most critical points;

Recognition of the surroundings of the selected case study through site visits;

Analysis of the obtained data to choose the pilot route, seeking to improve the relationship between the urban space and the river, as well as devising systemic solutions to enhance the effectiveness of local urban drainage;

Proposing measures for sustainable urban drainage;

Mathematical modeling with the use of the MODCEL[1] tool (MASCARENHAS and MIGUEZ, 2002; MASCARENHAS *et al.*, 2005; MIGUEZ *et al.*, 2017) to analyze the response of the watershed to the proposed measures.

The Maracanã River Course: From Professor Pinheiro Guimarães Square to lamartine Babo Square

From the study carried out on basic cartography (open spaces of environmental character, character of permanence and character of circulation), we sought to formalize the route along the Maracanã River having its center on Xavier de Brito Square. By bringing it into focus, it is possible to see in the map of Figure 7 the presence of more accentuated flooding in its vicinity and the extent of this behavior along the river. Due to its proximity, this river plays a fundamental role in the drainage of the square, as well as being the protagonist in the drainage of the basin as a whole, since it receives much of its flow.

Therefore, the Maracanã River was adopted as the guiding principle of the project in order to establish the integration of the open spaces, connecting Xavier de Brito Square to the other adjacent squares, thus formalizing the route along this river. Such a proposal seeks to improve the relationship between the urban space and the river, besides devising systemic solutions to enhance the effectiveness of local urban drainage. However, it is important to highlight that this is a pilot project that must be replicated in other rivers in the Mangue Canal basin to guarantee the effectiveness of reducing the water depth.

At first, we decided to start the route at Professor Pinheiro Guimarães Square (first open space of permanence upstream) and to finish it at São Charbel Square (first open space of permanence downstream). However, due to its small size and little opportunity for intervention, it was decided to extend the route to Lamartine Babo Square. By doing that, the chosen route, shown in Figure 8, has a total length of approximately 2.2 km, with a starting point on Professor Pinheiro Guimarães Square and an arrival point on Lamartine Babo Square, following the course of the Maracanã River (fully piped) along Maracanã Avenue. The route has four stopping points - Professor Pinheiro Guimarães Square, Xavier de Brito Square, São Charbel Square, and Lamartine Babo Square - whose main characteristics are shown in Table 1, and three stretches of walk (detailed in Table 2). A right-of-way was also defined for interventions along the route. To define its width, we opted to use the current legislation of the State of Rio de Janeiro for the definition of marginal protection bands (FMPs). Thus, as the Maracanã River basin meets the requirements of Decree No. 42.356 of March 16th, 2010 (State of Rio de Janeiro, 2010) to reduce the minimum limits

1 Hydrodynamic model, *quasi*-two-dimensional, that simulates the flow pattern from the division of the urban landscape into homogeneous cells, which interact with each other through one-dimensional hydraulic relations. As a result of the modeling, it is possible to obtain the flood map of the basin under study, thus offering support for the design decisions.

Figure 8: Total route selected
Source: Map produced by Bruna Battemarco (2017) about Google Earth image, 2017.

TABLE 1: CHARACTERISTICS OF STOPPING POINTS – SQUARESS

General information	Potential	Vulnerability
Professor Pinheiro Guimarães Square		
Area: 3.540 m^2 Scope: Local No fitness equipment Expansive space	Square with slope towards the canal. 30% of the total permeable area. Location juxtaposed to the canal	Partial access by stairs, jeopardizing accessibility. Obstacle to flow on one side of the canal.
Xavier de Brito Square		
Area: 10.700 m^2 Scope: Neighborhood Square with leisure / fitness equipment Pickup area	Located near the canal (approx. 20 m). 80% of the total permeable area. Access ramps, favoring accessibility.	-
São Charbel Square		
Area: 670 m^2 Scope: Local No leisure/fitness equipment Claustrophobic space	Located near the canal (approx. 10 m). Access ramps, favoring accessibility	Semipermeable: Permeable area without maintenance. Elevation of the square in relation to the level of the street (approx. 30 cm) – Not friendly to pedestrians.
Lamartine Babo Square		
Area: 1.390 m^2 Scope: Local No leisure /fitness equipment Expansive space	Semipermeable Located near the canal (approx. 15 m).	-

Source: Author.

Table 2: Description of the route stretches.

Location – Stretch (Source: Map produced on Google Earth Image, 2017, by Bruna Battemarco, 2017)	Characteristics
	• Beginning: Professor Pinheiro Guimarães Square; • End: Xavier de Brito Square; • Length: 1.100 m; • Sections with right margin confined by residences; • Presence of obstacles in communication between river and plain; • Stretches with a narrow sidewalk along the left bank; • Presence of critical stretch – river confined between the back of the built spaces; • Presence of stretches with no access of the population to the banks of the river.
	• Beginning: Xavier de Brito Square; • End: São Charbel Square; • Length: 486 m; • Stretch with no access of the population to the banks of the river; • Wide sidewalks, approximately 2.0 m wide, and impermeable.
	• Beginning: São Charbel Square; • End: Lamartine Babo Square; • Length: 607 m; • Stretch without the population access to the banks of the river; • Wide sidewalks, approximately 2.0m wide, and impermeable

Source: Author.

determined by the Forest Code (Brazil, 2012) in the definition of FMP, a right-of-way of 15 m from each bank of the Maracanã River along the route was defined.

Proposed Solutions: Sustainable Urban Drainage on the Route

After analyzing the route and recognizing the existing vulnerability regarding local urban drainage, some solutions to sustainable urban drainage were proposed. Among the proposed measures, permeable pavements, detention basins and rain gardens can be cited. Besides these, we also tried to propose solutions aimed at improvements to pedestrians and users of the squares. The proposed measures are presented below.

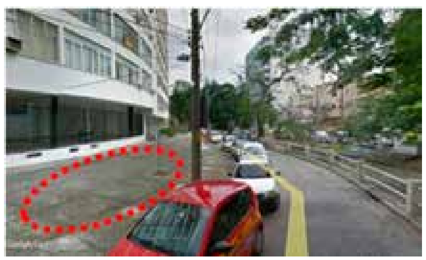
Permeable Pavement

It is proposed the replacement of the existing cover with permeable paving on the sidewalks of Professor Pinheiro Guimarães Square; in some areas of Xavier de Brito Square, as the coating of the fountain and the sidewalks of the surroundings, on Lamartine Babo Square; in the large parking lot on the critical

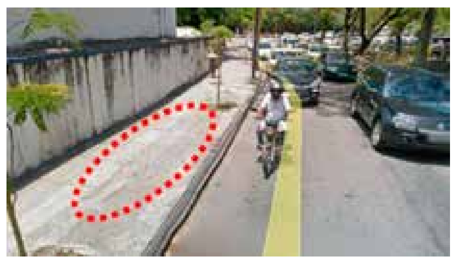
(a) Professor Pinheiro Guimarães Square

(b) Fountain on Xavier de Brito Square

(c) Parking lot on critical stretch



(d) Sidewalk on Stretch 1



(e) Sidewalk on Stretch 2

(f) Lamartine Babo Square

Figure 9: Examples of selected areas for the use of permeable pavement.
Source: Google Earth Images, 2017..

stretch located on Stretch 1 and on the sidewalks of Stretches 1, 2 and 3. The photos in Figure 9 show the selected areas for the use of permeable pavement.

Detention Basins

It is proposed the configuration of detention basins on Xavier de Brito Square, from the lowering of the area designed for dogs (0.80 m) and the gardens at the back of the square (0.60 m), a stair-step pattern of the existing fountain (0,40m), and on São Charbel Square, from the lowering of its internal area (0.50 m). The photos in Figure 10 show the selected areas to set up detention basins.

Rain Gardens / Bioretention Systems

It is proposed the configuration of rain gardens in some areas of São Charbel Square and Lamartine Babo Square (surroundings). Rain gardens are also proposed on the existing wider sidewalks (approximately 2.0 m) on the stretches. The photos in Figure 11 show some selected areas for the adoption of the proposal.

(a) Area designed for dogs – Xavier de Brito Square

(b) Gardens at the back of Xavier de Brito Square

(c) Fountain on Xavier de Brito Square

(d) São Charbel Squarel

Figure 10: Selected areas to set up detention basins
Source: Authors, 2017.

Improvement in the communication between river and plain

During the visit to the site and also during the analyses performed via Street View of Google Earth, obstacles that interfere in the communication between the river and its plain were observed. It is proposed, then, the withdrawal of such obstacles, exemplified in Figure 12.

Improvement to pedestrian circulation

Aiming to improve the circulation of pedestrians, we propose the expansion of sidewalks and/or the consolidation of spaces of permanence, with the insertion of some benches, for example, on Professor Pinheiro Guimarães Square and in some specific areas along Stretch 1. The photos in Figure 13 show some selected areas for the adoption of the proposal. It's also proposed the revitalization of Lamartine Babo Square, with the implementation of leisure/fitness equipment and the creation of covered spaces for permanence (with tables and benches).

Results and Discussions

In order to exemplify the combination of the proposed measures for sidewalks, Figure 14 and Figure 15 are presented. In Figure 14, an example of a plan view for the wider sidewalks, with more than 2.0 m wide existing on stretches 2 and 3, with the use of permeable pavements and the establishment of the rain gardens can be visualized. In Figure 15, in turn, a three-dimensional model of the proposed solution to the sidewalks is presented.

In order to evaluate the response of the watershed to flooding with the proposed measures, mathematical modeling was done, and the results are presented in Figure 16 and Figure 17. In comparison with the flood map in Figure 16, it's possible to conclude that, in the basin scale, the measurements did not

(a) Gardens on São Charbel Square
Source: Authors, 2017.

(b) Surroundings of Lamartine Babo Square
Source: Google Earth Image, 2017..

(c) Wide sidewalks – Stretch 2
Source: Authors, 2017.

Figure 11: Examples of selected areas for the configuration of rain gardens

(a) Obstacle on Professor Pinheiro Guimarães Square
Source: Google Earth Image, 2017

(b) Existing wall on Stretch 1
Source: Authors, 2017

(c) Obstacle on Stretch 1
Fonte: Google Earth Image, 2017

Figure 12: Examples of selected areas to intervene to improve the communication between the river and its plain

Professor Pinheiro Guimarães Square

Example selected on Stretch 1

Figure 13: Examples of selected areas to intervene to improve the circulation of pedestrians
Source: Google Earth Image, 2017

influence in reducing the water depth, as expected. Only when the scale of the route is observed (Figure 17), in turn, it is possible to notice a difference, even if very subtle, in the flood map, in the regions highlighted in red. Although it is not noticeable on the maps due to the value bands used, the water depth had a slight reduction along the route (an average of 4 cm).

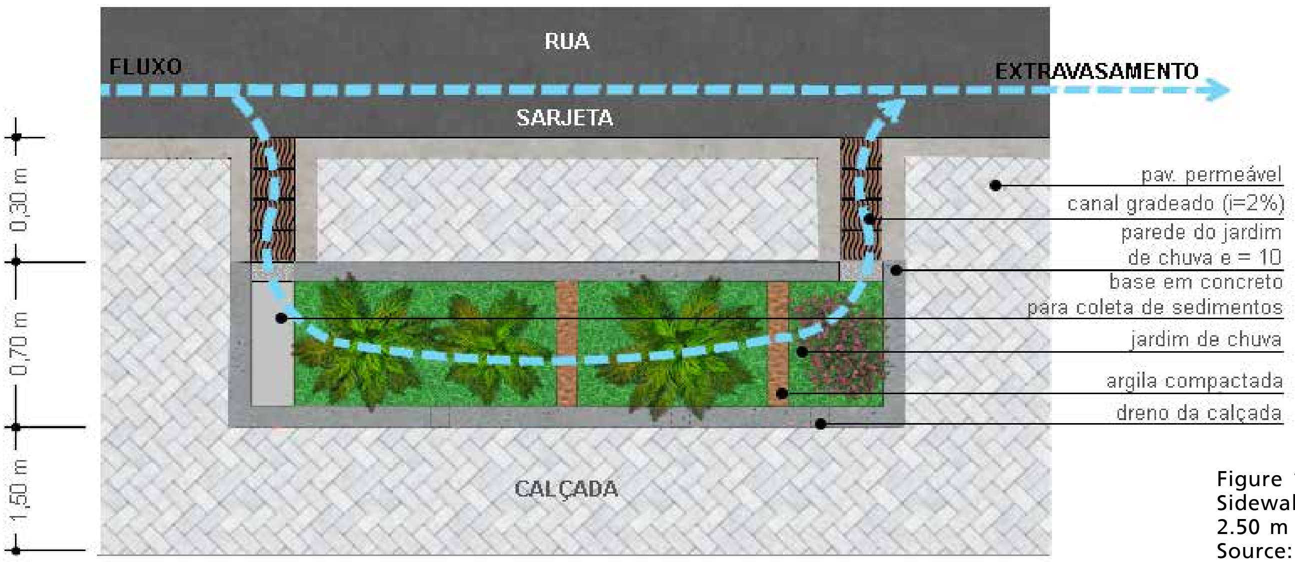


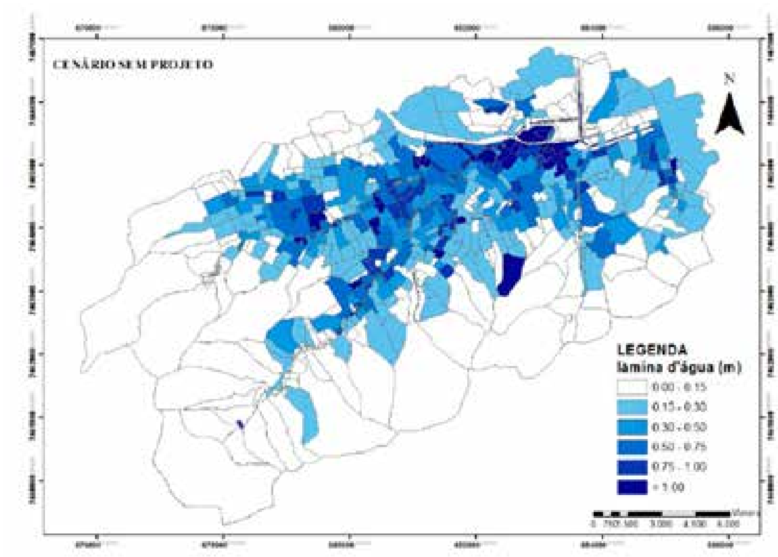
Figure 14: Project Model for Extending Sidewalks 2 and 3 - Example for sidewalks 2.50 m wide
Source: Adapted from ABCP and FCTH, 2013.

Figure 15: Three-dimensional model of the operation of a rain garden on the sidewalk
Source: Adapted from Philadelphia Water Department, 2014.

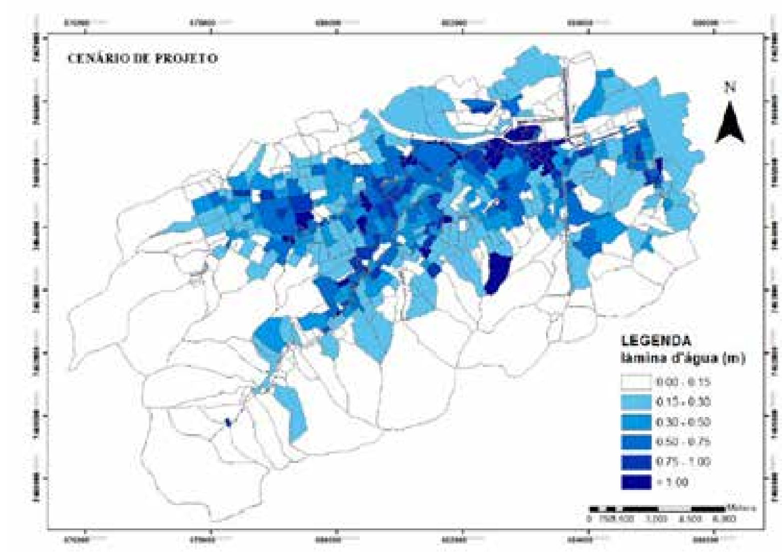
Final Considerations

This work aimed at emphasizing the importance of integrating open space systems with sustainable urban drainage solutions. In cities, with high levels of waterproofing and little opportunity for storage of flood volumes, the open spaces emerge as essential allies in the application of measures distributed in the watershed to reduce water depth and look for characteristics closest to the natural hydrologic cycle.

From the definition of a route along the Maracanã River, we sought to exemplify the application of measures of sustainable urban drainage in the existing open space system. As expected, the application of the specific measures, on the scale of the route, does not interfere in the response of the basin to the floods as a whole. Even on the scale of the route, the measurements brought a very subtle improvement in the water depth, with a reduction of a few centimeters. This highlights the importance of proposals for sustainable urban drainage to be distributed in the scale of the watershed and the same being used as a planning unit.

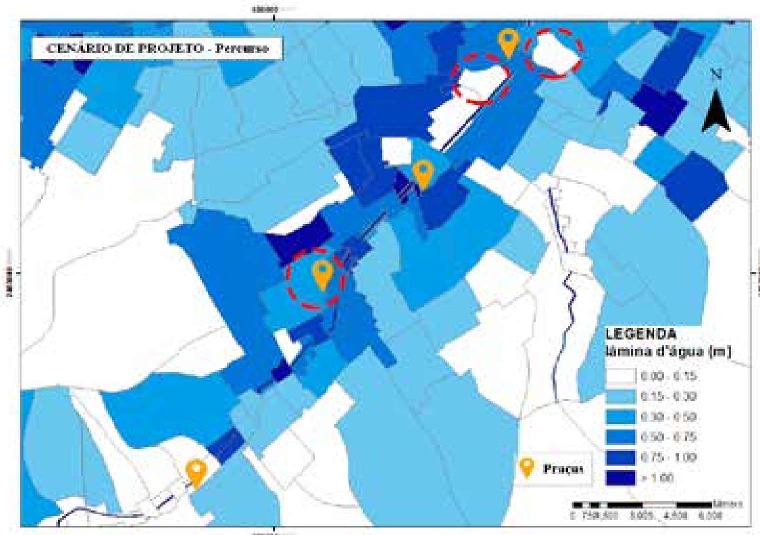


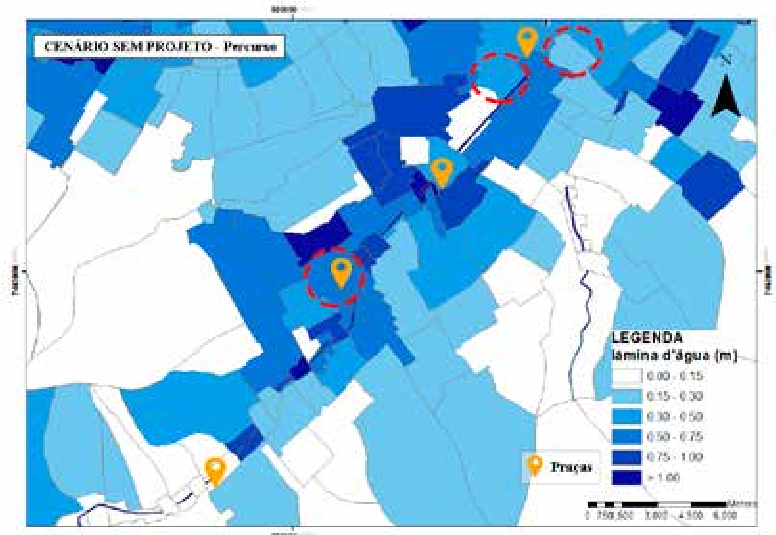
(a) Scenario without Project - Basin



(b) Project Scenario - Basin

Figure 16: Flood Map – Basin Scale





(a) Scenario without Project – Route

(b) Project Scenario - Route

Figure 17: Flood Map – Route Scale

It is also important to highlight that the basin response to an event with a 25-year return period was verified, as indicated by the Ministry of Cities for macro drainage projects. However, better results are expected with the application of the measures proposed for more frequent events, with a 10-year return period, for example, indicated by Rio Águas for micro drainage projects in the city of Rio de Janeiro.

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Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior- Brasil (CAPES) - Finance Code 001 and Process 1681776, as well as by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) - Process 303240/2017-2.

The authors would like to thank Gustavo Lennon da Silva, undergraduate student of Architecture and Urbanism at the Federal University of Rio de Janeiro, for the adaptation of some images presented in this manuscript.

Editor's note:
Translation: Kátia Arigone
Submission: 11/04/2018
Acceptance: 04/02/2019