A Parametric Approach to Efficient Implementation of Green Infrastructure in the Urban Field

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Abstract. Water availability has a key role in their process of occupation. However, accelerated urbanization had several detrimental impacts, increasing the vulnerability of urban communities. Because of the limitations of traditional planning, an alternative approach is emerging to respond to the constant changes in the landscape. Now, green infrastructure (GI), an ecosystem-based approach (EbA), is being used combined with traditional solutions to increase the resilience of the cities. In this paper, we proposed the use of an algorithm to determine the best place to implement GI. The algorithm used the inputs to develop a multi-criteria analysis capable of translating urban complexity. Results show that the GI solution can't be efficiently implemented without context evaluation. However, the algorithm has the potential to become an informative tool in the decision-making process of urban planning.

Keywords: Parametric Analysis, Bioretention, Sustainable Design, Green Infrastructure, Water Resources.

1 Introduction

The environment is a major factor in the formation of cities, and water availability has a key role in their process of occupation. Historically, cities started in the proximity of water sources, because without them, life in the cities could not be sustained. Hence, managing water wisely is a key prerequisite for the existence of cities. (Novotny et al., 2010) However, the accelerated growth and the urban soil degradation (caused by imperviousness, compaction, erosion, and contamination) had several detrimental impacts on welfare (Ferreira et al., 2018). The occupation of river beds and floodable areas instigates this degradation process, creating conflicting relationships between the urban area and the environmental systems. This made the local communities more vulnerable to natural hazards and the impacts of climate change, leading to inundations and floods becoming common in many urban areas across the world.

Currently, flood risk is dealt with through the improvement of drainage infrastructure to remove stormwater as fast as possible - within the Latin American context, most urban drainage interventions tend to be applied as punctual strategies (Horne et al., 2018). This is a characteristic of the ruling paradigm that treats the systems as isolated from each other, seeking its efficiency and optimization (Walker & Salt, 2006). Despite the technological advancements, the limitation of this current paradigm was perceived and, for the last two decades, professionals have seen a paradigm shift that requires them to respond to the dynamic characteristic of the landscape. Now, the landscape is understood as a complex temporal and constantly changing medium, composed of social and natural systems (Novotny et al., 2010; Steinitz, 2016).

Ecosystem-based adaptation (EbA) is a strategy defined as “the use of biodiversity and ecosystem services as part of an overall strategy to help people adapt to the adverse effects of climate change”. It is a people-centric approach, focused on reducing vulnerability and increasing resilience. In cities, it is commonly used to refer to green and blue infrastructure solutions as a way to adapt to climate change. These solutions consist of a network of natural or semi-natural areas that are combined with gray infrastructure (traditional infrastructure), to deliver a wide range of ecosystem services (benefits) at lower costs and to make the city more resilient (Browder et al., 2019; Capps et al., 2016; United Nations Environment Programme, 2021). However, the use of green infrastructure (GI) can only be effective within the context of a network of equipment, which allows for achieving the water performance needed to solve the problems of each city (Pereira et al., 2021).

In an era of such perspective change and with the increase of urban areas, it has become a challenge for researchers to find the best places for the application of GI. Given the problems of investment and the political, economic, and social issues this solution could hardly be applied extensively. The advance in technology and the development of mathematical and computational models have provided a new approach (Cantrell & Holzman, 2015) that combines graphics and data, making it possible for us to simulate options and adjust for possible outcomes, creating a more informed and easier to understand decision-making process strongly supported by information (Aminpour et al., 2022; Cantrell & Holzman, 2015; Eastman et al., 2008; Steinitz, 2016; Walker & Salt, 2006).

Based on this, the current work presents research on the development of a parametric algorithm capable of interrelating different data and urban aspects, to find out in which places the application of GI for stormwater management would be more efficient considering the complexity of the urban mesh. The impact of this study is to generate a parametric approach that helps in decision making, to favor the implantation of these types of facilities in the places where they are most needed, that is, to reallocate the urban green to the areas of the city in which it is more required. This impact will be reflected in a more strategic and viable approach to applying GI in the urban environment.

2 Methodology

Within the context of climate change, EbA is a form of adaptation system to tackle the vulnerabilities of at-risk people, and GI is an important tool for the enhancement of urban hydrology (Pereira et al., 2021; Woroniecki et al., 2019). Once vulnerabilities are inside of a multifaceted context, solutions focused on place can help clarify important issues and identify potential values (Potschin & Haines-Young, 2013).

For this study, Bioretention cells (e.g. rain garden, bioswale, shallow dish) were the GI solutions selected to be implemented in the public areas of the study site (Figure 1). We chose these solutions due to the potential they have to be executed in small areas. As a benefit, they can help manage the volume of urban runoff through infiltration and temporary retention, treating it with bioremediation, and improving, thus, the overall quality of permeated water. This kind of solution, however, requires previous geography, pedology, and local climate examination. Therefore, a multicriteria analysis was made, using not only the local characteristics but also the best place conditions for Bioretention cells as parameters for the algorithm that was developed using Rhinoceros and Grasshopper software.

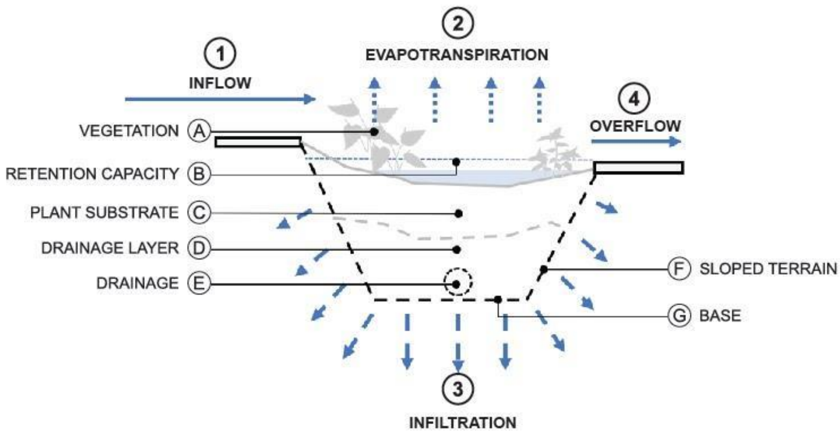

Figure 1. Simplified section of a generic Bioretention cell. Source: Pereira et al., 2021.

2.1 Algorithm Development

We composed computational reasoning to interrelate practical, measurable urban parameters that could be used on a collective database toward a traceable result. Understanding an algorithm as a sequence of steps was essential in the development of this study.

At first, we defined what would be the inputs - the necessary data - to identify the best locations for GI, based on their efficiency. We chose georeferenced data (shapefiles), collected from the city's database. These types of data contain related geometric and tabular information, allowing us to design a greater range of studies and manipulations. The shapefiles used as inputs were: topography, roads, lots, buildings, and blocks.

After the input definition, the algorithm was constructed using three phases: (1) initial analysis; (2) data processing, and (3) multicriteria analysis. In the end, we found a map that identified the most efficient places to implement GI according to the data provided (Figure 2).

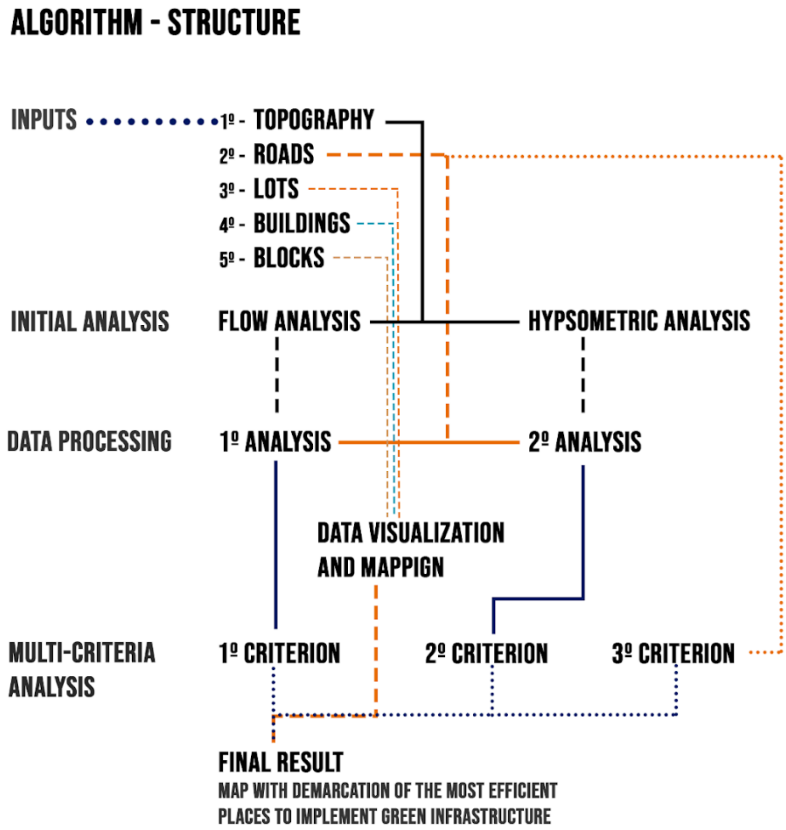

Figure 2. Algorithm structure/workflow process. Source: Authors, 2022.

In the first phase, the topography datum was the elementary input for the algorithm, and with it, we made two initial analyses. Initially, we made water flow analysis using the “Groundhog” plugin developed by Philip Belesky, Landscape Architecture professor at RMIT University in Melbourne, Australia (Figure 3). This helped us to understand its runoff behavior in the area, identifying where it is greater and where the water potentially accumulates. Then, we did a hypsometric analysis (Figure 4) to map the higher and lower-level heights of the land.

Figure 3. Water flow analysis map. Source: Authors, 2022.

Figure 4. Hypsometric analysis map. Source: Authors, 2022.

The second phase comprised crossing data, adding road information to the results found in the first phase. Starting from it, we made our first analysis: we determined the number of intersections between water runoff lines and road lines. This aimed to create retention potential criteria through the identification of the water flow behavior. So, we made an average intersection index - a mathematical evaluation necessary because the roads have different dimensions - calculated by the number of total runoff intersections divided by the extension of the respective road.

The second analysis of this phase was the data processing between hypsometric and roads through their geometric projection. This investigation pointed to mapping the average level heights of each road so we could classify them in origin, middle, or bottom areas. The classification considered the average height level across the road, qualifying the execution potential. For this criterion, we consider the roads on middle-level heights (yellow colors) would be the most appropriate locations for the setting of GI. This occurred because since the middle areas receive water from the origin areas, they have the potential of functioning as interruptions to the natural water runoff, preventing flooding in the bottom areas, where the water and its washed pollutants concentrate

The two initial phases allowed us to identify two different criteria for the choice of the best place for GI. To make the multi-criteria analysis more practical, we created a third parameter, based on the road hierarchy. We considered that an arterial road, for example, has more possible intervention areas for GI than a local road. Therefore, we determined a score for each road hierarchy, valuing with higher scores the ones that had more capacity of having Bioretention cells.

The established three criteria were used to develop a variable score system that aimed to search different scenarios. The criteria function as variables that can be modified and manipulated in different ways. The resulting map is a demarcation of the roads that got the best score, the demarcation works from a gradation of colors for the visual identification of the GI execution potential: red for roads with higher potential; yellow for roads with intermediary potential, and blue for roads with low potential (Figure 5).

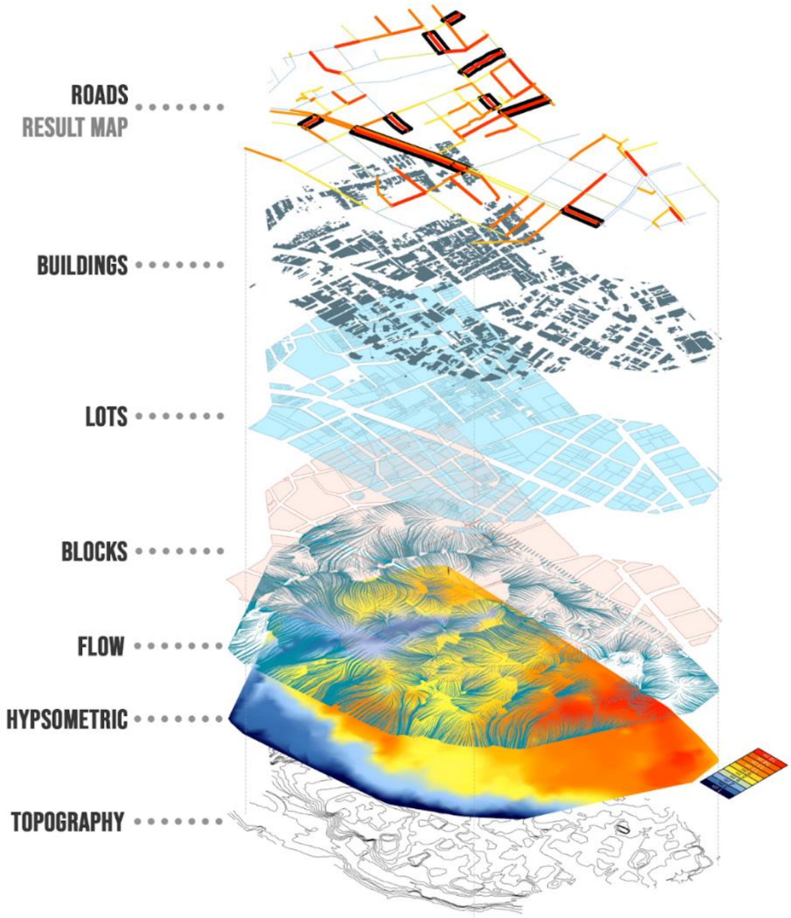

Figure 7. Superposition of the generated maps and information. Source: Authors, 2022.

3 Results

We built the map through a visual approach that used the inputs as data for the graphics. That allows the reader a better understanding of the area and facilitates the comprehension of the behavior of water in a complex urban mesh. The focus is that we have enough information to make a more oriented decision.

Results show that a road has different classifications throughout its extension. Hence, the same solution will have different performances when used without considering the context. This emphasizes the need for previous analysis.

On both maps, results show that, with the input used, the higher potential areas are scarce, but the number of road sections with intermediary potential is very high. Comparing the two maps, however, we can see that there are areas that remain with the same potential classification, besides the change in criteria score. This occurs because of the good operation on all three criteria.

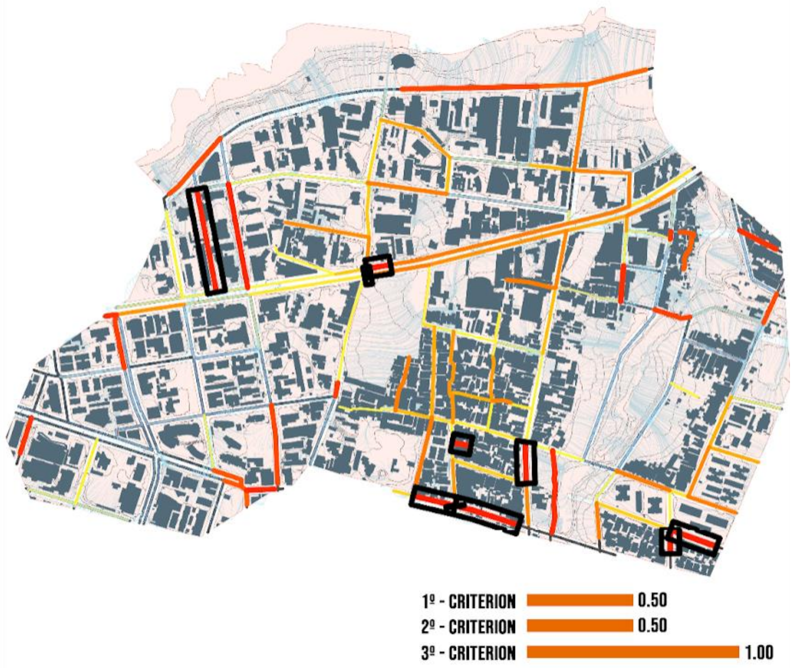

Figure 6. Result map with emphasis on road hierarchy (3rd criterion). Source: Authors, 2022.

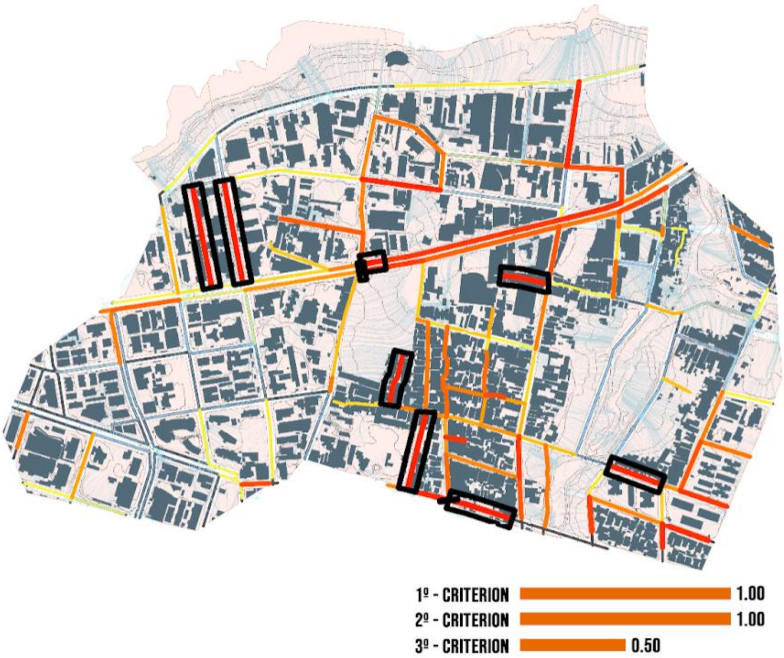

Figure 7. Result map with emphasis on water runoff and road lines intersection (1st criterion) and middle-level heights (2nd criterion) Source: Authors, 2022.

4 Discussion

4.1 Quotes

Quotes must be in italics.

Our analysis explored the use of an algorithm to determine the best places for the execution of GI in an area of a city. The algorithm was based on local data and considered three criteria that were used as a scoring system to evaluate each road section, serving as a tool for better visualization of urban complexity. This kind of visualization creates a new way of intervention in the landscape, based on a greater complexity of systems connecting and operating on different scales (Cantrell & Holzman, 2015; Walker & Salt, 2006).

The different scenarios produced showed us how important each criterion was. Their variations exemplified the impact of different approaches. With it, we could anticipate the sites with better potential for solutions and a range of alternatives, making more informed urban interventions for the future. However, our inputs were limited, considering aspects of urban morphology. This might be problematic from a socio-economic perspective. The lack of this information disregards the local citizens' benefits and the potential cultural impact of the interventions. Also, we didn't incorporate the different Bioretention cells. This was a reflex of our choice for testing the viability of the tool in generating generic scenarios.

This research has proposed a novel way of approaching a multi-criteria analysis for the best place to implement GI. For that, we tested a tool that integrated morphology aspects with the water dynamics, integrating different knowledge and giving the water a key role, leaving the background in urban decisions. Our research represents a step further for the development of a tool that helps in decision making, by the use of physical, behavioral, and geometric inputs. However, there is a complex context of social and cultural needs that influence the choice of these decisions, as there are other variables that are subjective to the urban planner's perception that wasn't considered for this study that must always be taken into consideration in the planning process. In this way, it is not only performance and efficiency that must determine the intervention sites, but an in-depth study of the area. The algorithm works as a qualitative analysis to validate and assist in this process, opening new possibilities to explore the GI elements within the urban environment.

The results obtained were an innovative way of relating different data, by using georeferenced files, which facilitates the selection and direction of the algorithm's workflow. Therefore, using the Rhinoceros and Grasshopper software was an assertive choice to visualize the data and generate different overlapping geometric analyses (Figure 8). The great advantage of working with a parametric approach is that its structure is the same, so the input data modification will generate a new analysis. The algorithm will work using the same method, generating a standardized dynamic and interactive scenario analysis. Thus, it could be used as a tool for adaptive planning.

For the near future, the present work seeks to incorporate more city variables to create a more complete form of analysis that can fit within the limitations of urban databases, incorporating new criteria to validate potential areas, so we can elaborate a more context-specific parametrization utilizing optimization systems and data managing.

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