Landscape Information Modeling for vulnerable landscape recovery: the case of Bom Jardim in Fortaleza, Ceará, Brazil.

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Abstract. Even with the difficulty of implementing NBS for EbA as a solution due to the inconsistent documentation of past experiences and heavy dependence on local, ecological and social conditions, would it be possible to implement NBS that incorporate the needs of each place? This paper shows the experience of the implementation of a NBS in an urban area, in the context of "Present City Project", using parametric modeling to simulate outcomes during the planning process. The algorithm used inputs to develop a multi-criteria analysis capable of translating urban complexity. The result of this process is a comprehensive map identifying the most efficient locations for implementing GI based on the provided data and the streets suitable for interventions with NBS as well as their water absorption capacity. Throughout the process of submitting the "Present City Project," the algorithm played a pivotal role as an essential tool for raising public awareness.

Keywords: Parametric Analysis, Nature Based Solutions, Landscape Information Modeling, Sustainable Design, Water Resources.

1 Introduction

Traditional drainage infrastructures (gray infrastructures) are not prepared for 21st century challenges. The established status for centralized, optimized and efficient functioning on which they are planned considers that the changes that occur will all be incremental. As a result, the solutions adopted are not resilient, i.e., they are not able to "absorb disturbance and still retain its basic function and structure" (Walker & Salt, 2060; Novotny et al., 2010). This flaw has a great impact on the environment, especially in cities. The rapid increase of population in urban areas (more than half of the global population lives in cities, and more than 70% are to do so by 2050), makes them more vulnerable to the impacts of climate change (Wijesiri et al., 2020; Nerini et al., 2017). Thus, resilience is a feature that is perceived as the one to be developed to maintain the life and socioeconomic activities in cities (Jaramillo & Nazemi, 2018) by a process of continuous adaptation (Woroniecki et al., 2019).

Ecosystem-based Adaptation (EbA) are the use of biodiversity and ecosystem services to help people adapt to the adverse impacts of climate change (CDB 2009 apud Chong, 2014). They are a subset of Nature-Based Solutions (NBS) an umbrella term that involves “Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.” (Cohen-Shacham et al., 2016). Both concepts have a critical role in the development of resilience in cities, focusing on reducing vulnerabilities, protecting ecosystems, and being more resource and energy efficient (URBiNAT, 2021). By incorporating elements that mimic “natural” environmental processes, cities can move away from opposing nature and instead embrace the understanding that they are an integral part of it (Spirn, 2010).

In the last years, NBS for EbA were promoted by several institutions (e.g., the World Bank, the United Nations and the European Commission), with the publication of manuals and reports that offer many examples and options for planners. However, the main difficulty of implementing these solutions lies in the inconsistent documentation of past experiences. Also, its heavy dependence on local, ecological and social conditions (Browder et al., 2019), makes it difficult to find the appropriate tool capable of considering a great number of different parameters for the choice and implementation of the solutions.

So, would it be possible to implement NBS that incorporate the particular needs of each place? This paper shows the experience of the implementation of a NBS in an urban area. This research was conducted within the framework of a public call for Brazilian municipalities that took place in March 2023. The "Present City Project " called for cities to submit ideas for the implementation of demonstrative projects focused on integrated and people-centered urban development (Ministério das Cidades, 2023). This initiative is a partnership between the Brazilian Ministry of Cities and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, with funding from the German Federal Ministry for Economic Cooperation and Development (BMZ). The project itself strongly aligns with the "leave no one behind" principle of the 2030 United Nations Agenda (ONU, 2023) and aims to promote the right to sustainable cities in Brazilian urban development policy. The conducted study builds upon previous case studies carried out in other regions (Moura & Carvalho, 2020; Guedes et al., 2022). In this one, the research team utilized Landscape Information Modeling (LIM) tools as crucial instruments for the implementation of NBS not only for project development but also to raise awareness among public actors.

The complexity of urban landscapes finds a more suitable approach in parametric modeling to simulate various outcomes during the planning process (Moura et al., 2018). LIM is a powerful tool for engaging various stakeholders, as landscape planning often involves individuals from diverse disciplines and backgrounds. This case study utilized and perfected an algorithm to develop a NBS implementation system, complemented by 3D visualization, with the primary aim of assisting designers and planners (Carvalho et al., 2023).

2 Case Study

The Brazilian urban population has been historically neglected when it comes to decent and quality housing. Fortaleza (Fig. 1), the capital of the state of Ceará, has undergone a staggering population growth over the past six decades, expanding nearly fivefold from 514,000 residents in 1960 to approximately 2.4 million in 2010 (IBGE, 2010). As the fifth-largest city in Brazil, it also holds the distinction of being the fifth most unequal city globally (Un-Habitat, 2011). The ramifications of this rapid expansion are felt in low-income informal settlements, which currently house over 40% of the city's population (Fortaleza, 2016).

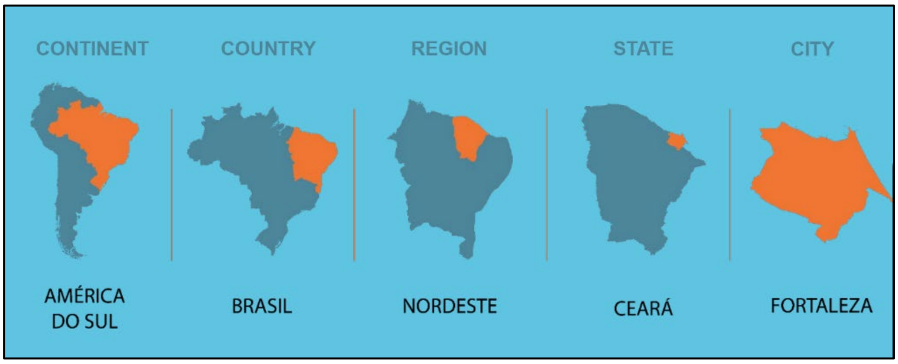

Figure 1. Fortaleza location. Source: Authors, 2023 (“Present City Project” team).

The city also faces the escalating challenge of rising temperatures throughout the 21st century, a direct consequence of increasing greenhouse gas emissions, according to PBMC (2016). Future projections indicate an even more pronounced escalation in temperature levels. Consequently, Fortaleza is regarded as a city highly susceptible to the impacts of climate change by PBMC (2016). This vulnerability is particularly magnified in the context of informal settlements, exacerbating the risks faced by their inhabitants.

The research built for the "Present City Project," focused on a region southeast of Fortaleza city - the district of Grande Bom Jardim. Bom Jardim is in the city region with the lowest Human Development Index (HDI) in Fortaleza, making it an area with inadequate urban infrastructure services and significant social and environmental challenges (IBGE, 2010). During the past six decades, Grande Bom Jardim experienced rapid growth due to the influx of a low-income population. The government did not provide sufficient support to accommodate this growth adequately, resulting in various issues, particularly concerning housing problems. Therefore, the region faces socioeconomic disparities, with below-average income levels and literacy rates compared to the city's overall average. Additionally, the population growth rates in this area exceed those of regions with better infrastructure and urban services (IBGE, 2010).

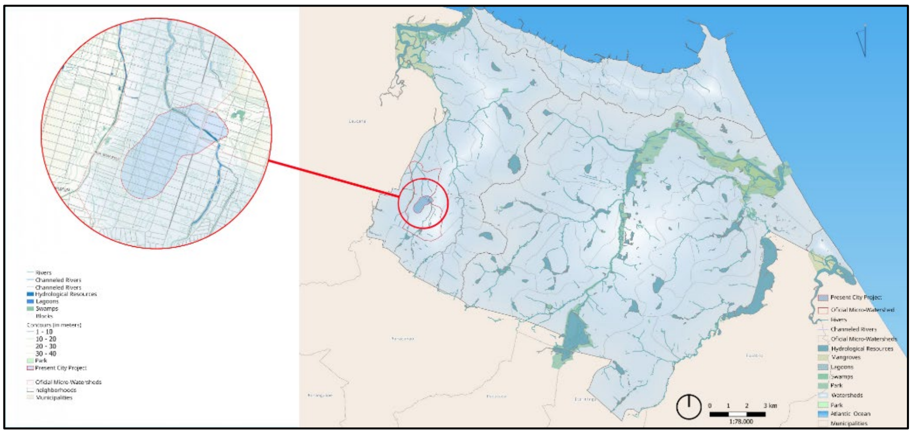

Figure 2. Urban Context: ecological dimension. Source: Authors, 2023 (“Present City Project” team).

However, amidst these challenges, Grande Bom Jardim is home to one of the most proactive and engaged social groups, persistently striving for an improved quality of life. In Fortaleza, there is a notable surge in social entrepreneurship movements, with a specific focus on bolstering investments in housing and mixed-use complexes, particularly in Grande Bom Jardim. Given the active community engagement, high levels of participation, and the untapped potential of the local creative economy, the group viewed the opportunity to work with Grande Bom Jardim as a means to address the region's environmental vulnerability and enhance the living conditions of its population.

The intervention was chosen to be carried out in the Granja Portugal neighborhood, inserted in the district of Grande Bom Jardim. The stretch of the stream where the physical intervention of the project will be located is located in a watershed of the Maranguapinho River (Fig. 2).

In addition to our research group, the initiative involved key partners, including the Fortaleza City Hall, Fortaleza Planning Institute (IPLANFOR), Municipal Infrastructure Secretariat (SEINF), and Regional Executive Secretariat V (Fig. 2). In April, it was announced that Fortaleza was selected as one of the 12 projects out of a total of 170 proposals.

3 Methodology

Design Science Research (DSR) has been selected as the methodological approach for this study due to its capacity to design practical solutions for identified problems, thus contributing to related research, evaluating diverse designs, and effectively communicating the conclusions to the relevant audience (Peffers et al., 2007).

According to Peffers et al. (2015), the DSR process model comprises 10 steps, which are as follows (Fig. 3):

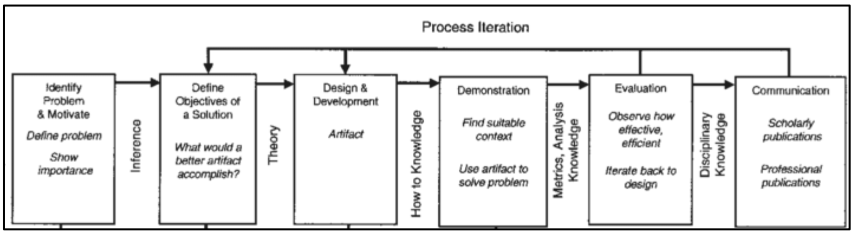

Figure 3. Design Science Research Methodology. Source: Peffers et al., 2007.

3.1 The Artifact

The selected framework for developing the algorithm centers on the interaction between two software applications, Rhinoceros and Grasshopper. Rhinoceros 3D stands as a CAD platform solution. Moreover, it incorporates Grasshopper, a complimentary plugin that offers a visual programming interface.

We chose to utilize georeferenced data presented as shapefiles, sourced from the city's database. These shapefiles encompass both geometric and tabular data, empowering the algorithm to conduct a diverse range of analyses and manipulations. The shapefiles used as inputs encompassed topography, roadways, and hydrology (Guedes et al., 2022; Moura et al., 2018).

With the input parameters established, the algorithm was developed in three phases: (1) initial assessment, (2) data manipulation, (3) multicriteria evaluation. The culmination of this process resulted in a comprehensive map identifying prime locations for implementing GI based on the provided data. Additionally, the algorithm determined suitable streets for intervention and the capacity of NBSs for water absorption (Fig. 4).

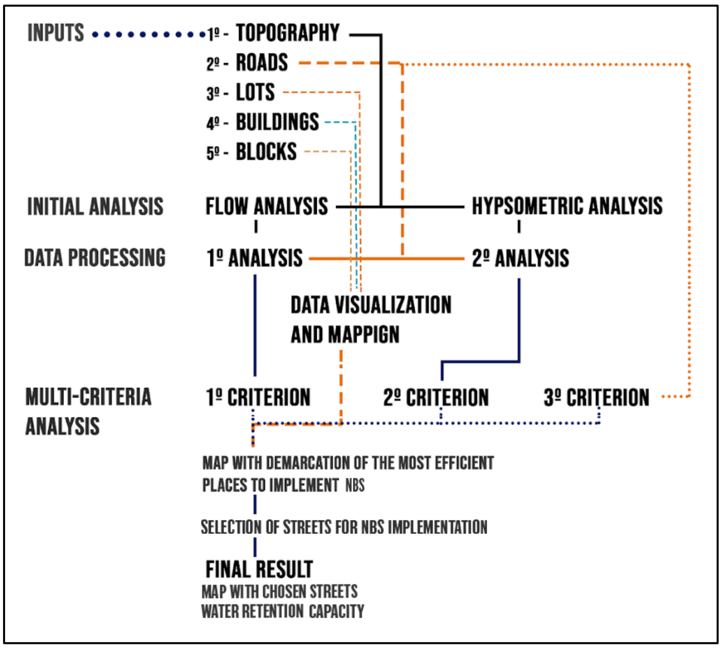

Figure 4. Algorithm structure. Source: Authors, 2023.

3.2 Initial Analysis

The study's rainfall analysis plays a crucial role in defining the boundaries of the basin affected by rainfall, thereby identifying the region contributing to flooding events (flood impact area). This area may or may not extend beyond the officially planned zones. To achieve this, modeling techniques are employed, involving a geometric simulation algorithm that accounts for water behavior on the terrain using contour lines. The result is a comprehensive graphical representation of rainfall patterns and the spatial distribution of vulnerability gradients.

After confirming the rainfall accumulation area (the river), a subsequent set of simulations was conducted to further refine the impact analysis. This step involved a detailed examination of water flow, aiming to extract precise numerical and spatial data to enhance decision-making. Notably, the maximum distance recorded is approximately 930m. Another insight provided by the simulations is the identification of areas prone to water accumulation along the path from the point of rainfall to the watercourses.

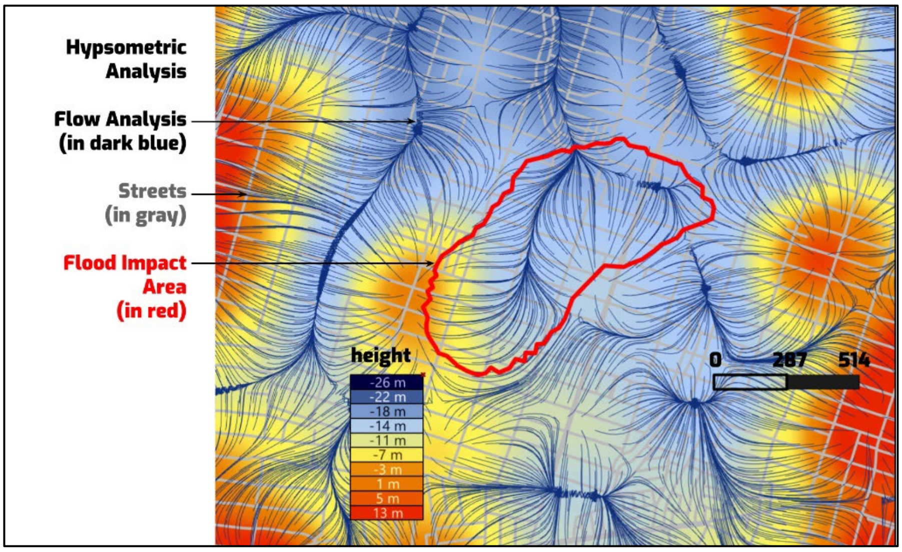

Figure 5. Algorithm flow visualization. Source: Authors, 2023.

3.3 Data Processing

The modeling also generates the empirical equation for the calculation of surface runoff in the studied impact area. The equation allows the calculation of the volume of demand for reservoir or absorption of this water by the infrastructure equipment and results in a value in liters per hour (Silva et al., 2013). The impact area is about 0.46 km2. The runoff rate (f) was defined for a return period of 100 years, i.e. 100 years is the average interval in which precipitation greater than or equal to 95.6mm/h is expected to occur (in the case of Fortaleza) (Silva et al., 2013). The result obtained is 279,479.58 L/h, this value will be used as an ideal goal for the absorption capacity of NBS.

$$R = (A * \alpha * f) / \Delta t \quad (1)$$

3.4 Multi Criteria Analysis

Figure 6. Multi Criteria Analysis. Source: Authors, 2023.

In addition, an algorithm was utilized to assess the potential for implementing NBS along each road, street, or avenue within the study area, considering its water retention capacity as a crucial criterion. This algorithm harnessed data and inputs to conduct a multi-criteria analysis, enabling a comprehensive understanding of the intricate spatial aspects of the urban network, as shown in Figure 6.

The results are depicted on the map, using a color-coded system. Roads marked in red are identified as the most suitable for accommodating NBS, taking into account the topographic and morphological characteristics of the city. Roads in yellow represent intermediate potential, while those in green exhibit lower efficiency in terms of NBS implementation (Guedes et al., 2022).

4 Results

In this context, a number of roads were chosen as key for intervention due to their size, length and distribution along the rainfall impact area, making them ideal for the implementation of bio-swales and green gardens (Fig.7).

The final step of the algorithm shows the amount of water that will be retained by the chosen intervention, in this case it was retained approximately 975,000 L/h and the goal of 279,479.58 L/h, has been overcome. It is important to clarify that this value is decided by the researcher in use of the algorithm, for example, the return period in the surface runoff calculation can be set for 50 years instead of 100 and the researcher is also free to choose between different street choices by analyzing different outcomes.

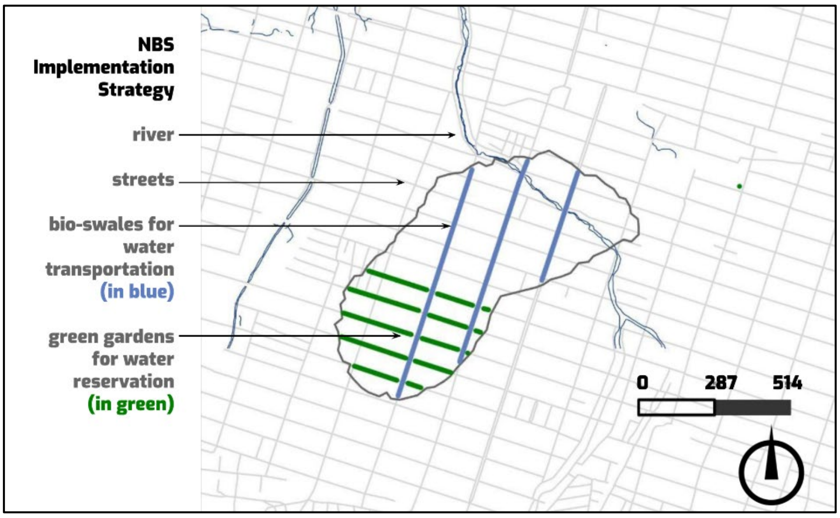

Figure 7. Multi Criteria Analysis. Source: Authors, 2023.

5 Discussion

Following the initial acceptance of Fortaleza’s proposal in the "Present City Project," the working group received guidance from the project's counselors, who aimed to secure funding for its implementation. During this process, it became evident that the group's initial research goal did not align with the municipality's financial constraints and objectives. Thus, a shift in perspective occurred, leading the group to redefine its ambitions. Instead of aiming for the original ideal goal, the project was reformulated as an "experiment," focusing on a small stretch of track and river to receive intervention. The revised objective acknowledged the financial limitations while aiming to set an example with a fully transformed street and river stretch, serving as a model for future sustainable interventions within the city (Fig. 8).

One of the key advantages of working with LIM is gaining a deep awareness of our limitations and possibilities, grounded in factual data. This emphasis on factual understanding has been instrumental in shaping our approach to sustainable practices. As a final outcome of the project, we must acknowledge, as a limitation, that the project's final proposed changes might not have an immediate and significant practical impact on the city's drainage. However, we remain hopeful that this endeavor will set a positive example to be followed by others.

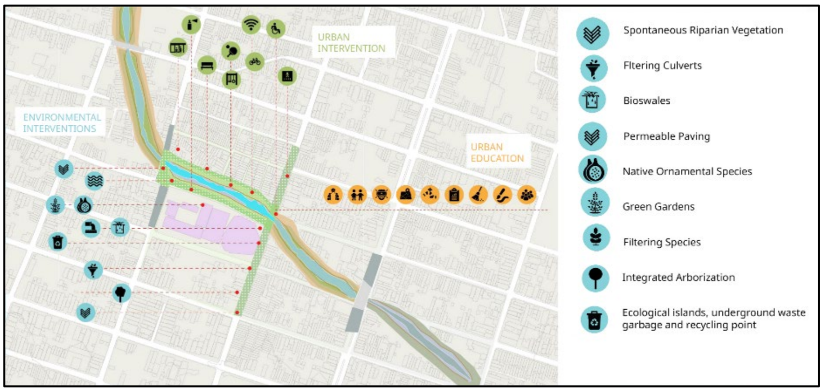

Figure 8. Final “Present City Project” Proposal. Source: Authors, 2023 (“Present City Project” team).

Throughout the process of submitting for the "Present City Project," the algorithm played a pivotal role as an essential tool for raising public awareness. It allowed us to engage in discussions with professionals outside the confines of the laboratories where the algorithm was originally conceived. This interaction proved invaluable in refining and perfecting the algorithm. As a result, the Fortaleza proposal was strengthened by its foundation in factual data, while also being mindful of the social and economic aspects of the challenge at hand. With that said, the research objective was grasped: implementing NBSs in an urban area while being attentive to its unique social and environmental issues. This was made possible mainly due to the collaborative nature of the project. Looking ahead to future applications, we recognize that working with public actors is crucial to proposing a more concrete intervention.

Besides that, we understand there is a technical gap in the algorithm, as it was developed by a team of landscape architects. While it is highly visual and focused on the general understanding of how urban hydrology behaves and affects city drainage, it lacks technical refinement since no hydrological engineer has contributed to its development until this moment. We look forward to diminishing this gap so that, in the future, this tool can become even more reliable to users.

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