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Green Infrastructure And Sustainable Urban Planning: Innovating For Resilient Cities

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Abstract:
Background*: In the process of urban planning and management, there is a consensus on the difficulty of dismantling already implemented drainage systems, even when they are obsolete and inefficient. This justifies the relevance of studies and alternatives that enable the integration of innovative adaptation strategies, incorporating corrective and complementary measures to conventional systems. It becomes imperative that urban planning adopts new proposals to control stormwater, favoring a harmonious coexistence between humans and nature.*
Materials and Methods*: As a methodological procedure, a qualitative research on green infrastructure was adopted, taking the city of Tupã / SP as the space.*
Results*: The research found that the use of green infrastructure typologies as a multifunctional urban element for landscape structuring contributes to the management of stormwater, as well as to leisure, recreation, and the environmental quality of urban space.*
Conclusion: *Given the scenario presented, the importance of green infrastructure as a sustainable approach to guide the development of urban drainage plans becomes evident. In this sense, this study highlights the necessity to incorporate green infrastructure typologies as multifunctional urban elements in structuring the urban landscape. This approach not only contributes to proper stormwater management but also offers opportunities for leisure activities, recreation, and improving the environmental quality of urban spaces. This recommendation underscores the significance of considering integrated and sustainable solutions for the challenges faced by cities in stormwater management and in creating more resilient and pleasant urban environments for their inhabitants.*
Key Word*: Contemporary city, Environment, management.*

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I. Introduction

In the sphere of urban planning and management, the challenge of modernizing obsolete and ineffective drainage systems is widely recognized. This scenario underscores the critical need to research and develop alternatives that allow for the implementation of innovative strategies, capable of integrating corrections and complements to conventional drainage systems. Urban planning and environmental design emerge as powerful tools, promoting the fusion of concepts and techniques that adopt principles capable of effectively responding to the problems generated by outdated drainage systems, often causing floods in various cities. The management of urban drainage requires that urban planning seeks new approaches to stormwater management, emphasizing the harmonious coexistence between humans and the environment. In this line, the literature records various research that has supported fruitful discussions. Authors like Botelho (2011) argue in favor of developing new forms of urban occupation, materials, techniques, and legislations, that redefine the relationships of urban space use, recognizing that the idea of "deconstructing" cities is impractical and utopian in the face of the continuous need for construction and urban development, especially in the global south countries.

Thus, the relevance of adopting alternative mechanisms that favor hydrological processes of infiltration and percolation, such as buffering basins, infiltration, detention, retention, and porous pavements, is highlighted. Although these solutions do not represent recent technological innovations — since they were conceived in old hydraulic projects and, for various reasons, did not become popular in urban drainage applications — the novelty lies in the rescue of these practices and techniques by professionals from various areas. These are being reassessed as essential components of green infrastructure, considered alternative ecological approaches to urban drainage management, evidencing a movement towards more sustainable and resilient urbanization.

Herzog (2013, p. 111) highlights green infrastructure, or ecological infrastructure, as a rapidly evolving and expanding concept, founded on the principles of landscape ecology and urban ecology. This concept sees the city as an integrated socio-ecological system, promoting a holistic and systemic approach in urban planning. Ferreira and Machado (2010, p. 81) complement this view by explaining that green infrastructure, when applied in urban projects, not only incorporates, preserves, or restores the ecological structure of the intervened sites but also facilitates the harmonization between the "blue system" (water management) and the "green system" (biomass production), highlighting the interconnection and importance of both for urban sustainability.

The application of green infrastructure emerges as an innovative strategy to value and enhance the ecological structures inherent to local ecosystems. Its implementation in urbanistic projects, especially those aimed at urban drainage management, contributes significantly to the resilience of cities in the face of adverse climatic events, such as floods. This demonstrates how this approach can offer effective solutions to contemporary environmental challenges.

Thus, integrating green infrastructure into urban interventions means promoting a paradigmatic transformation towards the construction of sustainable and smart cities. These cities are designed to be multifunctional spaces that provide a wide range of benefits: from the improvement of urban drainage and the provision of environmental services to the promotion of balance and harmony with nature, including areas for leisure and recreation. This multifaceted approach aims, therefore, to elevate the quality of life and environmental well-being for all urban inhabitants, illustrating the transformative potential of green infrastructure in redefining urban landscapes for a more sustainable and resilient future.

II. Green Infrastructure Typologies

Various authors, including Falcón (2007), Cormier and Pellegrino (2008), Franco (2010), Ferreira and Machado (2010), and Herzog (2013), among others, highlight a variety of constituent elements of green infrastructure. These elements encompass Permeable Green Spaces (such as gardens, parks, green corridors, and squares), Sedimentation Basins, Bioretention Basins (or Rain Gardens), Bioswales, Bioengineering techniques, Cleaning Biotope, Rain Gardens, Phytoremediation systems, Green Grids, Dry Lakes (or Detention Basins), Stormwater Ponds (or Retention Basins), Porous Pavements, Green Roofs, among others. These typologies are employed in urban environmental design to harmonize the green system (biomass), with the aim of managing the blue system (urban waters), through purification, detention, retention, transport, and infiltration processes.

Furthermore, green infrastructure plays a vital role in supporting native ecosystems and in the composition of the landscape, serving as ecological corridors that provide habitats for fauna and flora. It acts as a natural filter for air and water, as well as, performs social and cultural functions, by fostering an aesthetic and landscaped balance. This enriches the urban fabric by offering the community open spaces for recreation, leisure, and environmental education, as discussed by Ferreira and Machado (2010). Thus, the incorporation of green infrastructure into urban environments not only contributes to environmental sustainability but also significantly improves urban quality of life, promoting a more harmonious coexistence between the city and nature.

It is fundamental to recognize that the effectiveness of green infrastructure is significantly amplified when there is an integration with a continuous mesh of natural green spaces. This connection is essential for the preservation and enhancement of vital ecosystem services, such as air and water purification, climate regulation, and biodiversity promotion. Thus, the interconnection between green spaces constitutes a central pillar in maintaining ecological functionality in urban areas.

Before proceeding with any urban intervention, a careful assessment of the environmental challenges and opportunities present at the site of action is crucial. This preliminary analysis should aim at the effective integration of green infrastructure principles and techniques into urban planning. Identifying areas of high environmental vulnerability – those most susceptible to damage and, therefore, with priority for intervention – is a primary step to direct efforts and resources efficiently, maximizing the environmental and social benefits of the proposed actions.

In this context, there is an urgent need to rethink and reformulate traditional models of urban development and planning. The adoption of innovative approaches, which rely on alternative techniques supported by a solid environmental foundation, becomes imperative. These approaches should be designed to work in harmony with local natural cycles and ecosystems, aiming not only to mitigate the negative impacts of urbanization but also to promote lasting urban sustainability. Such strategies should range from sustainable stormwater management, using porous pavements and rain gardens, to the creation of green corridors that facilitate fauna movement and strengthen ecological connectivity. Therefore, transitioning to a planning paradigm that prioritizes green infrastructure and urban sustainability represents a promising path for the development of more resilient, healthy, and inclusive cities.

III. Benefits Of Green Infrastructure

Benedict and McMahon (2002) emphasize that green infrastructure plays a fundamental role in the natural protection and restoration of ecosystems. Such infrastructure is configured as an essential foundation for future development, promoting the benefits of biodiversity, social, and economic diversity. Moreover, it contributes to the maintenance of natural landscape processes, air and water purification, increased recreation opportunities, health promotion, and strengthening people's connection with nature and the sense of belonging to a place.

Herzog and Rosa (2010) list specific benefits of green infrastructure in the urban context, which include promoting the infiltration, detention, and retention of stormwater, filtering the first flush of rainwater contaminated by urban waste, creating habitats and connectivity for biodiversity, mitigating heat islands, encouraging sustainable mobility, reducing vehicle speed, and preventing landslides and erosion.

Connectivity emerges as a strategic concept for the conservation of urban greenery (Madureira, 2012). This principle, widely explored in landscape ecology, aims to combat the fragmentation of natural habitats, one of the main threats to biodiversity, by creating ecological corridors and structures that facilitate land use planning. Ribeiro (2010) complements this view by highlighting the importance of connectivity in maintaining ecosystems' capacity to absorb and resist changes, promoting balance and sustainability.

Furthermore, Herzog and Rosa (2010) stress that green infrastructure is crucial for adapting urban areas to climate challenges, transforming monofunctional spaces into elements that replicate natural processes. This approach not only encompasses ecological issues but also enriches the urban fabric, promoting ordered open spaces such as parks and public gardens that serve multiple functions for the community. Therefore, green infrastructure represents a multidimensional strategy for urban planning, incorporating ecological principles to create more sustainable, resilient, and habitable cities.

The integration of an innovative approach in the planning and management of urban areas, as highlighted by Benedict and McMahon (2002), reveals the capacity of green infrastructure to enhance property values and reduce costs associated with urban infrastructure and public services. This perspective goes beyond mere real estate appreciation, indicating how green spaces can mitigate expenses related to flood control, water treatment, and stormwater management, among others.

Benedict and McMahon (2002) provide an in-depth analysis of the numerous benefits arising from the implementation of green infrastructure in the context of territorial planning. These authors argue that this approach not only meets human and environmental needs but also promotes a vital balance between economic development and ecological conservation. In a broad view, green infrastructure emerges as a means to develop a structure that harmonizes the rich diversity of natural resources with growth management practices, all within an ecosystemic and integrated approach.

This perspective allows for a better distribution of public green spaces, from the strategic location of green spaces, prioritizing critical ecological areas and ensuring the protection of the most vulnerable ecosystems before the start of urban growth and expansion. Additionally, it emphasizes identifying opportunities to restore and enhance the natural functionality of urban systems, establishing a cohesive and sustainable vision for the future of cities.

A key aspect of this approach is the strengthening of communities, by developing integrated systems that transcend the sum of their parts, thus providing predictability and security for all involved. This process encourages collaborative planning that seeks a balance between conservation and development, promoting urban development that is conscious of environmental needs and committed to ecological preservation.

In summary, Benedict and McMahon's (2002) vision of green infrastructure in territorial planning underscores the importance of urban development in harmony with the natural environment, offering a path to more sustainable, resilient, and habitable cities for future generations.

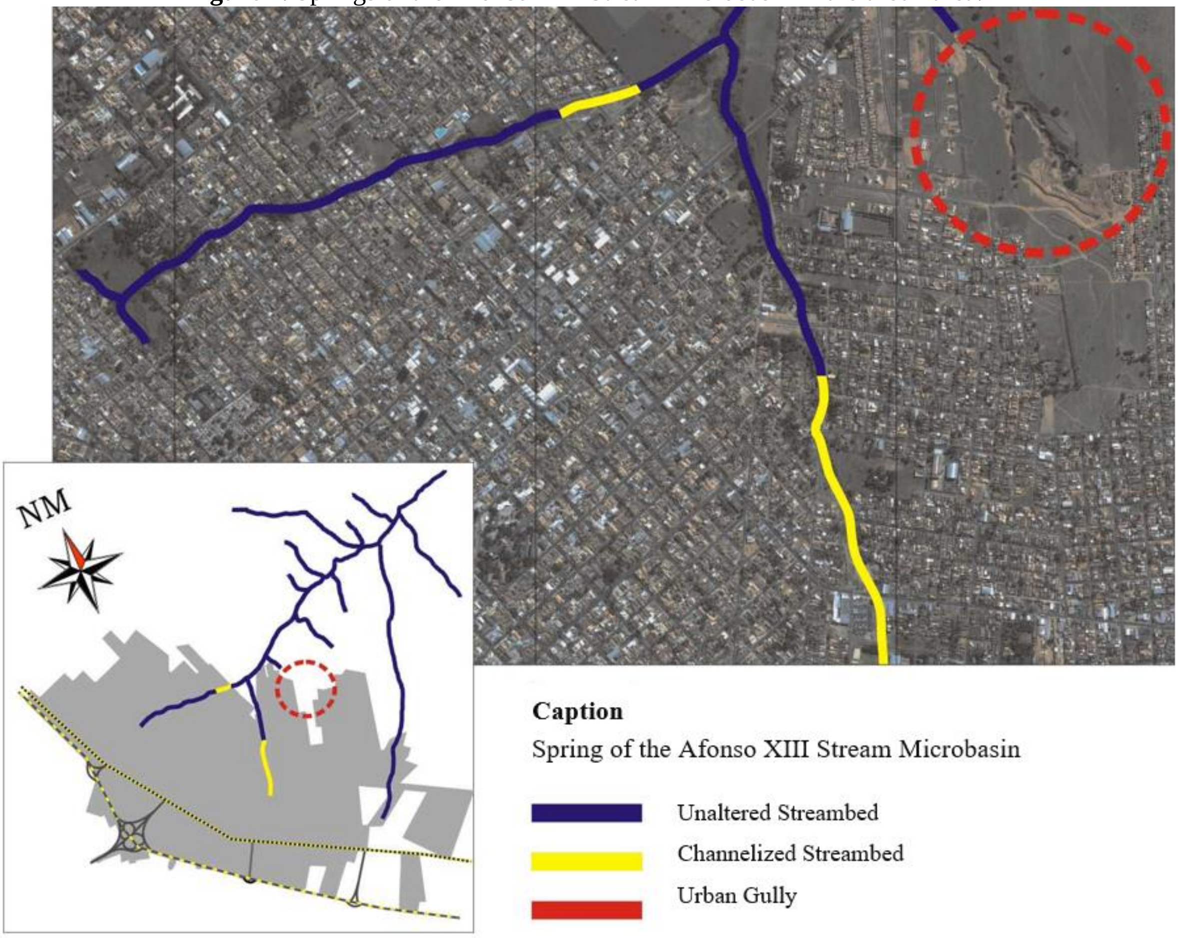
IV. Case Study

The focus of this study is the city of Tupã, located in the southwest of the State of São Paulo. As is the case with many cities in São Paulo, Tupã was initially planned following a grid pattern, commonly referred to as a chessboard model, which determined the city's original spatial arrangement. However, with uncontrolled growth and urban expansion, this initial planning was gradually altered. New areas were added to the urban fabric without proper consideration of urban and environmental guidelines, resulting in a fragmented and disconnected spatial configuration.

This disorderly urban expansion is marked by irregular and impactful occupation of the valley bottoms of the Ribeirão Afonso XIII, in addition to encroachment on peripheral areas. Due to its geographical location, Tupã is situated on the watershed divide between the Peixe and Aguapeí Rivers. The water bodies to the north of the municipality flow into the Aguapeí River, while those to the south head towards the Peixe River. This places Tupã in a unique position, encompassing two important Water Resources Management Units: the Aguapeí river basin (UGRHI 20) and the Peixe river basin (UGRHI 21).

This geographical and hydrographical peculiarity of Tupã adds a layer of complexity to the challenge of managing urban development in a sustainable and integrated manner, highlighting the importance of considering environmental and urban guidelines in the city's expansion.

Figure 1. Springs of the Afonso XIII Stream Microbasin in the urban area.



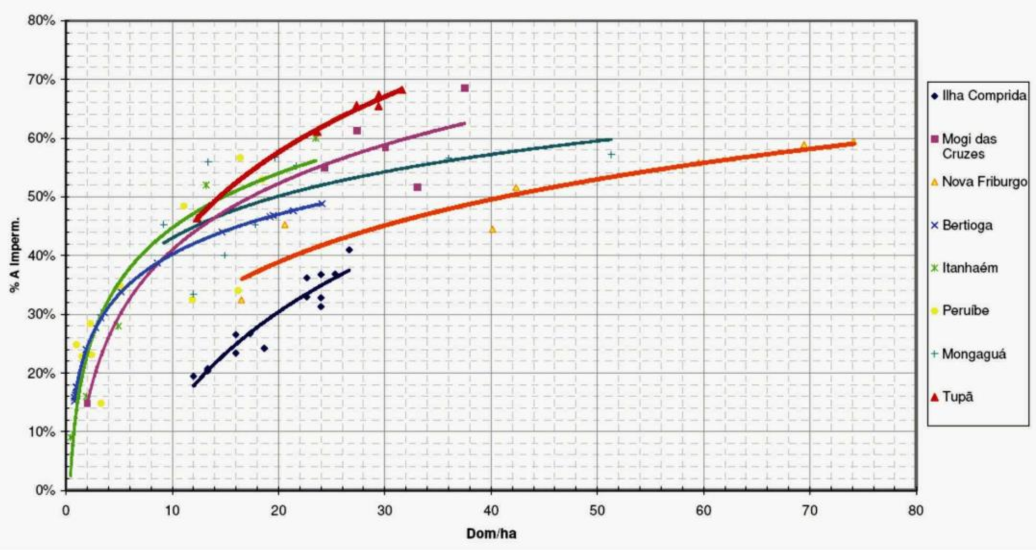
Source. SEPLIN - Tupã, image taken by the QuickBird Satellite, 2006.

Laszlo and Rocha (2014) provide a detailed description of the Aguapeí and Peixe Watershed, noting that its main rivers exhibit typical meandering characteristics in their alluvial areas, while their sources and upper sections tend to be more entrenched and subject to erosion. This natural scenario begins to undergo significant transformations with the advancement of urbanization, especially evident in the Afonso XIII Stream microbasin.

The urban expansion in Tupã had direct consequences on this microbasin, with the occupation of the springs and surrounding areas resulting in a series of serious environmental impacts. The removal of riparian vegetation, urbanization of valley bottoms, discharge of effluents from industrial, commercial, and residential origins, as well as the improper disposal of urban solid waste, which ends up being transported by drainage networks, are some of the problems observed. These human actions not only compromise environmental quality but also exacerbate the area's vulnerability to erosive processes and pollution.

A study conducted by the Hydraulic Technology Center Foundation of the Polytechnic School of Engineering at the University of São Paulo (CTH) illustrates the impact of urbanization on soil permeability in Tupã. Comparing the urban density and soil sealing of this city with other localities, a remarkably high soil sealing index was identified in Tupã. This data points to the critical challenge of managing urban growth sustainably, mitigating adverse effects on the natural hydrological cycle, and preserving the integrity of local ecosystems. The situation in Tupã serves as a warning about the need to adopt urban planning and management practices that respect the limits and regenerative capacity of natural environments.

Figure 2. Comparison of Dwellings/Inhabitants Curves X % Impermeable.



Source. Hydraulic Technology Center Foundation, 2008a.

Based on the analyses conducted, the research group from the Hydraulic Technology Center (CTH) developed future projections for the level of soil sealing in the city of Tupã (presented in Table 02). These projections highlight the urgency of adopting effective measures to mitigate or even reverse the adverse impacts resulting from the rapid urbanization process. The increasing trend of soil sealing underscores the importance of implementing sustainable urban planning strategies that can balance development with environmental preservation, ensuring the sustainability of water resources and the health of local ecosystems for future generations.

Table 1. Projection of Soil Sealing in the City of Tupã/SP

YEAR	HOUSEHOLDS	URBAN AREA	HOUSEHOLD / URBAN AREA	% SOIL SEALING
2005	19.680	1.633,09	12,05	45,8
2007	20.312	1.637,57	12,40	46,4
2025	26.038	1.677,90	15,52	51,7

Source. Hydraulic Technology Center Foundation, 2008a. Adapted by Benini, 2009.

As illustrated in Table 1 - Projection of Soil Sealing in the City of Tupã, the percentage of sealed areas is expected to increase by 5.9% from 2007 to 2025. Given the severity of the impacts observed, the last decades have marked the beginning of a critical review and the subsequent reformulation of the technical procedures used in urban drainage management. This reassessment culminated in the formulation of the Urban Macrodrainage Studies of the Tourist Resort of Tupã, which includes an Immediate Action Plan and a Continued Action Plan.

According to the Hydraulic Technology Center (2008), the implementation of this plan aims significantly to improve the quality of life for the inhabitants of Tupã "in the current scenario," involving investments of around R$ 69,000,000.00 until 2027. The partnership established in 2010 with the Federal Government, through the Growth Acceleration Program (PAC) Sanitation, marked the beginning of the Macrodrainage Plan's works, with the first phase budgeted at 24.5 million reais, distributed among non-reimbursable funds, financing approved by Caixa Econômica Federal, and municipal counterparty.

It is important to note that the allocation of public resources to this project implies direct responsibilities for public managers, who can be held accountable for any failures or omissions affecting the plan's execution. The Hydraulic Technology Center (2008) emphasizes that structural interventions must be complemented by compensatory and non-structural measures, many of which are institutional in nature, that will be part of the PAC and should be implemented by 2028. These measures are essential to ensure the sustainability of the Urban Macrodrainage Studies in Tupã, requiring effective implementation and compliance by the municipal public authority, in addition to persistence and continuous oversight.

Thus, the execution of the Macrodrainage Plan requires a joint effort of oversight by the public administration, control bodies, Public Prosecutor's Office, and civil society, emphasizing the importance of rigorous monitoring. Regarding the Continued Action Plan, scheduled for execution from 2014 to 2027, observations during this research indicated that some actions had already been carried out in 2012, demonstrating proactive progress in the planned measures.

The sustainability plan in Tupã includes a series of structural measures aimed at improving the city's environmental management. Among these measures, the creation of a Linear Park at the meeting of the right and left branches of the Afonso XIII Stream stands out, providing leisure areas and promoting local biodiversity. Moreover, the requirement of microdrainage systems in all new subdivisions aims to ensure efficient stormwater management, mitigating potential environmental impacts.

Other structural actions encompass extensive and compensatory initiatives, such as increasing the urban soil's permeability through green infrastructure, like permeable pavements and dry detention basins. These measures aim not only to improve rainwater absorption but also to strengthen the connectivity between green spaces, in addition to controlling erosion, especially in areas susceptible to gully formation.

Besides structural measures, Tupã has adopted non-structural measures to promote urban sustainability. This includes regulating land use through the Sustainable Development Master Plan, implementing a Soil Permeability Rate, conserving urban green areas, and regularly maintaining urban cleaning services and drainage systems. The revegetation of the riparian forest of the Afonso XIII Stream's left branch and the requirement of minimum permeability rates in residential, commercial, and industrial projects complement these actions, demonstrating Tupã's commitment to promoting a more sustainable and resilient urban environment.

Overall, both the implementation of the Immediate Action Plan and the anticipation of the Continued Action Plan's measures have shown significant benefits in improving environmental quality and the quality of life of the population, as evidenced by institutional results and consolidated actions arising from the Macrodrainage Plan. Regarding green infrastructure, the implementation of some typologies has been observed, such as detention reservoirs and increasing soil permeability through the creation of parks, squares, and gardens, in addition to the use of permeable pavements. Notably, these initiatives, including those anticipated in relation to the schedule outlined in the Continued Action Plan, are contributing to the city's environmental quality by expanding the permeable area and providing new community use spaces for the residents of Tupã.

V. Final Considerations

The city of Tupã, like many other urban areas across the country, faces challenges arising from the fragility of its drainage infrastructure in the face of intense rainfall, exacerbated by the increasing urban soil sealing and the lack of adequate stormwater galleries, along with a significant deficit of green areas. These factors contribute to the occurrence and worsening of flooding events. The development and implementation of the Macrodrainage Plan, comprising the Immediate Action Plan and the Continued Action Plan, represent a commendable initiative in the context of Tupã's urban management. Even in the execution phase, this plan demonstrates the local government's commitment to integrating planning into its management practices, aiming to improve the quality of life for the municipality's citizens. This example can serve as inspiration for other cities, showing that despite urban challenges, suitable solutions can be sought with political determination.

Considering the scenario presented, the importance of green infrastructure as a sustainable approach to guide the development of urban drainage plans becomes evident. In this sense, this study emphasizes the need to incorporate green infrastructure typologies as multifunctional urban elements in structuring the urban landscape. This approach not only contributes to proper stormwater management but also offers opportunities for leisure, recreation, and environmental quality improvement in urban spaces. This recommendation highlights the importance of considering integrated and sustainable solutions to the challenges faced by cities in stormwater management and in creating more resilient and pleasant urban environments for their inhabitants.

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