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Green Drainage Infrastructure and the Architectural Design of Linear Parks: A Review

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Infraestruturas Verdes de Drenagem e o Projeto Arquitetônico de Parques Lineares: Uma revisão

RESUMO
Objetivo - O objetivo deste trabalho é analisar as infraestruturas verdes aplicadas à drenagem urbana sustentável, destacando sua contribuição para a mitigação de impactos urbanos como enchentes, inundações e ilhas de calor, e sua relação com o planejamento urbano e a gestão ambiental.
Metodologia - A pesquisa adota uma abordagem teórica baseada em revisão bibliográfica, explorando modelos internacionais e discutindo à relação entre urbanização e gestão ambiental, com foco na aplicação de soluções baseadas na natureza em cidades brasileiras.
Originalidade/relevância - O estudo preenche uma lacuna teórica ao explorar às soluções de drenagem urbana verde em cidades brasileiras, considerando as limitações atuais nas implementações dessas estratégias. Sua relevância acadêmica se destaca pela proposta de inovação no planejamento urbano sustentável.
Resultados - Os principais resultados indicam que a infraestrutura verde contribui significativamente para a infiltração da água, redução das enchentes e regulação do microclima urbano, promovendo resiliência climática e melhoria da qualidade ambiental nas cidades.
Contribuições teóricas/metodológicas - Este estudo oferece uma contribuição teórica ao integrar os conceitos de infraestrutura verde e drenagem urbana, além de propor abordagens metodológicas inovadoras para a aplicação prática desses conceitos no planejamento urbano.
Contribuições sociais e ambientais - As implicações sociais e ambientais, incluem a promoção de cidades mais resilientes, sustentáveis e com melhor qualidade de vida, além de maior conectividade ecológica, beneficiando as populações urbanas e o meio ambiente.

PALAVRAS-CHAVE: Drenagem sustentável. Soluções baseadas na natureza. Sustentabilidade urbana.

Green Infrastructures and the Architectural Design of Linear Parks: A Review

ABSTRACT
Objective - The objective of this work is to analyze green infrastructures applied to sustainable urban drainage, highlighting their contribution to mitigating urban impacts such as floods, inundations, and heat islands, and their relation to urban planning and environmental management.
Methodology - The research adopts a theoretical approach based on a literature review, exploring international models and discussing the relationship between urbanization and environmental management, focusing on the application of nature-based solutions in Brazilian cities.
Originality/Relevance - The study fills a theoretical gap by exploring green urban drainage solutions in Brazilian cities, considering the current limitations in the implementation of these strategies. Its academic relevance lies in proposing innovation in sustainable urban planning.
Results - The main results indicate that green infrastructure significantly contributes to water infiltration, flood reduction, and urban microclimate regulation, promoting climate resilience and environmental quality in cities.
Theoretical/Methodological Contributions - This study offers a theoretical contribution by integrating the concepts of green infrastructure and urban drainage, as well as proposing innovative methodological approaches for the practical application of these concepts in urban planning.
Social and Environmental Contributions - Social and environmental implications include promoting more resilient, sustainable cities with improved quality of life, as well as greater ecological connectivity, benefiting urban populations and the environment.

KEYWORDS: Sustainable drainage. Nature-based solutions. Urban sustainability.

Infraestructuras Verdes de Drenaje y el Diseño Arquitectónico de Parques Lineales: Una Revisión

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RESUMEN

Objetivo - El objetivo de este trabajo es analizar las infraestructuras verdes aplicadas al drenaje urbano sostenible, destacando su contribución a la mitigación de los impactos urbanos como inundaciones, anegamientos e islas de calor, y su relación con la planificación urbana y la gestión ambiental.

Metodología - La investigación adopta un enfoque teórico basado en una revisión bibliográfica, explorando modelos internacionales y discutiendo la relación entre urbanización y gestión ambiental, con un enfoque en la aplicación de soluciones basadas en la naturaleza en ciudades brasileñas.

Originalidad/Relevancia - El estudio llena un vacío teórico al explorar soluciones de drenaje urbano verde en ciudades brasileñas, considerando las limitaciones actuales en la implementación de estas estrategias. Su relevancia académica radica en la propuesta de innovación en la planificación urbana sostenible.

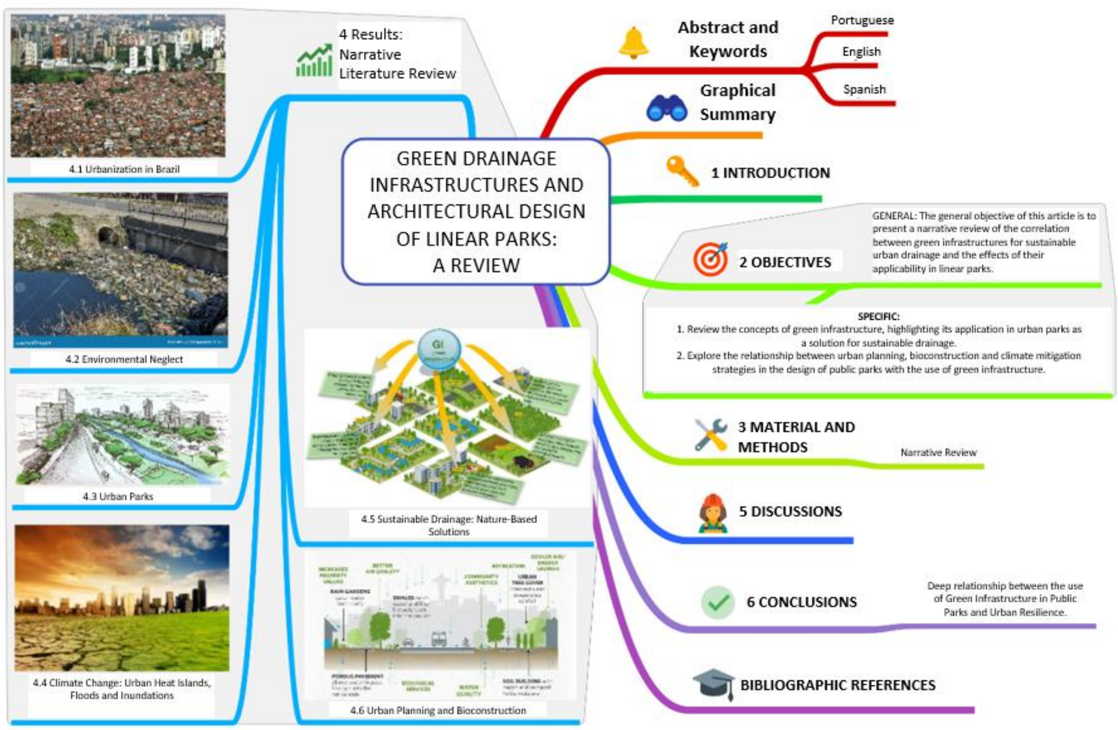
Resultados - Los principales resultados indican que la infraestructura verde contribuye significativamente a la infiltración del agua, reducción de inundaciones y regulación del microclima urbano, promoviendo la resiliencia climática y la mejora de la calidad ambiental en las ciudades.

Contribuciones Teóricas/Metodológicas - Este estudio ofrece una contribución teórica al integrar los conceptos de infraestructura verde y drenaje urbano, además de proponer enfoques metodológicos innovadores para la aplicación práctica de estos conceptos en la planificación urbana.

Contribuciones Sociales y Ambientales - Las implicaciones sociales y ambientales incluyen la promoción de ciudades más resilientes, sostenibles y con mejor calidad de vida, además de una mayor conectividad ecológica, beneficiando a las poblaciones urbanas y al medio ambiente.

PALABRAS CLAVE: Drenaje sostenible. Soluciones basadas en la naturaleza. Sostenibilidad urbana

GRAPHIC SUMMARY



1. INTRODUCTION

The accelerated urbanization of Brazilian cities, with their traditional planning, associated with environmental neglect and the impacts of climate change, has generated serious challenges in urban planning, especially regarding the management of rainwater and the creation of public spaces that promote sustainability. Traditional drainage solutions, predominantly applied in the Brazilian context, have proven to be limited in mitigating these impacts, intensifying problems such as soil impermeability and water contamination (Tucci, 2008).

In this context, green and blue infrastructures emerge as sustainable alternatives for urban stormwater management, promoting nature-based solutions (Sowińska-Świękosz; García, 2022).

This article aims to analyze the potential of these infrastructures, focusing on their application in linear parks, discussing how they can contribute to climate resilience and urban sustainability.

The literature review explores the impacts of urbanization on urban drainage and highlights innovative solutions based on green infrastructures. Disorganized urbanization has resulted in socio-spatial segregation and environmental degradation, making strategies that integrate urban planning and environmental management necessary (Ferreira, 2005; Santos; 1993). Furthermore, urban park planning can play a role in mitigating climate impacts by promoting leisure and biodiversity spaces (Farr, 2013; Sakata and Gonçalves, 2019). The study aims to contribute to the debate on integrated drainage and urban planning solutions, providing a conceptual basis for their implementation in Brazilian cities, with the aim of promoting a more sustainable and resilient urban environment to climate adversities.

2. OBJECTIVES

GENERAL OBJECTIVE

The general objective of this article is to present a narrative review of the correlation between sustainable urban drainage green infrastructures and the effects of their applicability in linear parks.

SPECIFIC OBJECTIVES

1. To review the concepts of green infrastructures, highlighting their application in urban parks as a solution for sustainable drainage.
2. To explore the relationship between urban planning, bioconstruction and climate mitigation strategies in the design of public parks with the use of green infrastructures.

3. MATERIAL AND METHODS

The methodology adopted in this work is a narrative bibliographic review, based on a current and pertinent theoretical framework that involves the analysis and synthesis of relevant academic sources on the topic in question. The research was conducted base d on the selection and study of scientific articles, review articles, books, specialized journals, conference proceedings and other publications that present significant contributions to the understanding of the subject. The sources were chosen based on the relevance and credibility of the authors.

4. RESULTS: NARRATIVE BIBLIOGRAPHIC REVIEW

4.1. Urbanization in Brazil

Urban development accelerated in the second half of the 20th century due to the concentration of the population in reduced spaces, generating competition for natural resources such as soil and water, resulting in the destruction of part of the natural biodiversity. The urban environment, composed of the natural environment and the population, is a living and dynamic system that generates a series of interconnected effects (Tucci, 2008).

Urbanization in Brazil has been an accelerated and generally disorderly process, with significant negative environmental and social consequences. The growth of Brazilian cities in the last century has resulted in urbanized areas with few permeable areas, the loss of green areas, the blocking of watercourses and the increase in problems such as flooding, pollution and heat islands. The urbanization process in the Brazilian context reveals the urgent need to rethink the urban development model, seeking alternatives that reconcile growth with sustainability. (Amorim, 2024; Ugeda Júnior, 2014; IBGE 2013; Ferreira 2005)

Milton Santos, in his book, “A Urbanização brasileira” (1993), analyzes Brazilian urbanization as a process deeply influenced by the characteristics of underdevelopment, highlighting the contradictions inherent to peripheral capitalism. The author argues that urban space in Brazil is marked by the reproduction of structural inequalities, in which the concentration of resources and opportunities benefits a few, while a large part of the population is excluded from full access to the city. This dynamic reflects the country's subordinate insertion in the international division of labor, which conditions urban growth to the needs of global capital (Santos, 1993).

In short, it was in the 20th century that Brazil underwent an intense social and spatial transformation, marked by the industrialization process that intensified after the 1950s. Until then, the country was predominantly rural, with 68.76% of the population living in rural areas in 1940 and only 31.24% living in urban areas. This scenario changed in 1960, when the rural exodus intensified due to agricultural modernization and migration to cities in search of better living and working conditions. During this period, the urban population represented 44.67%, while the rural population still corresponded to 55.33%. The definitive reversal occurred in the 1970s, when for the first time Brazil recorded most of the population living in urban areas, with 55.92%, in contrast to 44.08% in rural areas. This phenomenon consolidated the country's urbanization process and reflected profound changes in the way of life and spatial organization of the Brazilian territory (IBGE, 2013).

This trend continued in the following decades, resulting in an increasingly dominant urban reality. In 2010, 84.36% of the Brazilian population already lived in urban areas, while only 15.64% remained in rural areas. This picture illustrates the magnitude of the transformation that occurred over the last century, with a significant population concentration in cities, redefining the country's social, economic and environmental challenges (IBGE, 2013).

Santos (1993) points out that the coexistence of modernity and archaism is a central characteristic of Brazilian cities. This phenomenon manifests itself in the adoption of technological and scientific innovations, which coexist with traditional forms of social and economic organization. This coexistence does not eliminate disparities but rather intensifies them by creating fragmented and unequal urban spaces. City centers often concentrate the advances of modernity, while the outskirts remain marked by precariousness and the lack of adequate infrastructure.

Santos (1993) also highlights the relationship between urban space and public policies; state interventions often favor the interests of the real estate market and large economic groups, to the detriment of social demands, and urbanization, in this context, is instrumentalized as a way of expanding control and accumulation of capital, generating social exclusion and spatial segregation. Thus, Brazilian urban planning tends to reproduce and intensify the structural inequalities of society.

Ferreira (2005) also points out how the instruments of the City Statute (2001) seek to democratize urban space through regulatory policies, confronting historical privileges of the elites. However, the implementation of these instruments faces challenges, such as the lack of political will and the fragmentation of public policies in municipal master plans, which often ignore the needs of the peripheries.

The Master Plan is an essential instrument for urban planning, guiding the sustainable development of cities and guaranteeing the social function of property. According to the *Guia para Elaboração e Revisão de Planos Diretores* (*Guide for the Preparation and Review of Master Plans,* Ministry of Regional Development, 2022), a product resulting from technical cooperation between the Brazilian and German governments, based on the ANDUS Project – Support for the National Agenda for Sustainable Urban Development in Brazil, it establishes guidelines for territorial organization, considering economic, social and environmental aspects. In addition to regulating land use and occupation, it promotes access to decent housing, infrastructure and urban services, ensuring a better quality of life for the population. Its formulation must involve social participation, strengthening democratic governance and allowing the population to actively contribute to building the city they want. Sustainable urban development occurs when the growth of cities balances social inclusion, environmental preservation and economic efficiency. (MDR, 2022).

This approach is aligned with several targets of the Sustainable Development Goals (ODSs), such as SDG 6 (water quality), SDG 11 (sustainable and affordable urbanization) and ODS 13 (climate resilience and adaptation) (MDR, 2022). The implementation of these strategies in the Master Plan aims at more sustainable urban planning adapted to the climate and social needs of municipalities. (MDR, 2022).

4.2. Environmental Neglect

The lack of efficient public policies for environmental conservation, combined with a focus on economic development without considering the preservation of natural resources, has intensified problems such as flooding, air pollution and degradation of water bodies. Over the last few decades, we have seen irreversible damage to Brazilian urban and natural ecosystems. It is known that the interaction between man, watercourses and nature played a fundamental role in its evolution, directly influencing the historical and geographical organization of urban space. In the past, this relationship was more harmonious and integrated with nature. However, with the advancement of technology, social progress and economic growth, bodies of water began to be seen as obstacles to urban development. As a result, there was a distancing from this natural element, which has currently caused numerous socio-environmental problems, highlighting an increasingly less sustainable development model. (MDR, 2022; Romeiro, 2012; Castro, 2022)

The preservation of natural resources, flora and fauna in Brazil depends on a set of agencies and regulations that operate at different levels of government. Chronologically, it was in 1934, during the government of Getúlio Vargas, through Decree 23.793/34, that Brazil enacted the first Brazilian Forest Code. Its main objective was to regulate logging in the country, giving rise to the concept of protective forests. It was only in 1965, under Law 4,771/65, that the term Permanent Preservation Area (APP) emerged, replacing the concept of protective forests with this concept and four other typologies that should be preserved: national park, national forest and legal reserve. However, this regulation did not apply to the urban context, only with Law 6,766/79, which began to provide for a *non aedificanti* strip of 15 meters along each bank of watercourses. In 2001, the Statute of Cities, Law 10,257/2001, was approved, providing for *public order and social interest standards that regulate the use of urban property in favor of [...] environmental balance*. It was from this moment that urban problems began to receive greater attention from governments. In 2012, the Forest Code was revised, and the New Forest Code was enacted, Law 12.651/2012.

Para Borges *et al.* (2011):

> APPs are directly linked to environmental functions, through the provision of fundamental goods and services for the entire population. These goods and services are related to flow regulation, sediment retention, soil conservation, groundwater recharge, ecotourism, biodiversity, and, ultimately, a multitude of benefits (Borges et al., 2011, p. 1203).

In its Article 4 of Law No. 12,651/2012, it is established that APPs in urban areas must, for watercourses less than 10 meters wide, provide a strip with a minimum width of 30 meters. Such strips must be preserved and implemented under *any perennial and intermittent natural watercourse, excluding ephemeral ones* (Brazil, 2012). Even with all this legal apparatus, several environmental irregularities are observed, either due to a lack of oversight by the responsible entities or the lack of adequate environmental management. Law No. 14,285/2021 amends Law

12,651, allowing the regularization of buildings on the banks of watercourses and bodies of water in consolidated urban areas.

Tucci (2007) points out that poor environmental management associated with disorderly urban development has created a critical factor in the degradation of ecosystems and water resources in urban areas. The increase in soil impermeability reduces water infiltration, compromising the supply of aquifers and reducing river flow during dry periods. Another significant impact is the contamination of rainwater and aquifers, intensified by the transport of polluting substances aggregated to sediments. During floods, waste from street washing and polluted drainage systems increases the load of suspended materials, impairing water quality.

In Brazil, although most sewage systems are separate, the indiscriminate infiltration of contaminated water and the presence of inadequate landfills aggravate aquifer contamination. Tucci (2007) warns that sustainable urban management, including the expansion of permeable areas, is essential to mitigate these impacts and promote more effective environmental management.

4.3. Urban Parks

From the perspective of urbanism, Cullen (2008) defines the urban landscape as the art of the environment, by associating the relationship between streets, buildings and the space between them, considering human perception.

In geography, Bertrand (2004) presents a perspective that emphasizes the role of scale as an inseparable element in the study of landscapes.

The space between buildings highlighted by Cullen (2008) and the portion of space highlighted by Bertrand (2004) unfold into several concepts and ideas, one of which is linked to the natural form of space, which Serra (1993, 45) considers to be "the form determined not only by the natural "roughness" of the relief and hydrography, but by all other aspects such as the subsoil, soil, climate, vegetation and fauna".

For Santos (1982), the landscape is understood as a set of geographic objects, distributed over a territory in its geographic or spatial configuration, apprehended in its visible continuity, where social processes give life to these objects. Gorski (2008) summarizes the idea of landscape as a dynamic element, with interactions between ecosystem components (biotic and abiotic) and socioeconomic and cultural components, producing the perception of a whole, including aesthetic and emotional valuation.

The composition of the urban landscape involves several essential components, among which open spaces stand out. According to Sanchotene (2004), open spaces are the non-built areas in a city, belonging to the public authorities or private owners, regardless of their specific use. When these spaces are intended for the preservation of vegetation or for the leisure of the population, they are classified as green areas, encompassing squares, parks, public gardens and urban afforestation, with vegetation that can be either natural or cultivated.

Urban parks, whether publicly or privately managed, are key elements in the landscape and environmental configuration of cities, making up a system of open spaces. They play an essential role in promoting quality of life in urban areas, offering places for leisure, active recreation and coexistence with nature. In addition to promoting psychological and social well-being, urban parks play an important role as areas of ecological resilience, helping to absorb pollutants, mitigating the effects of urban heat and contributing to climate balance. In the context of green and blue infrastructures, urban parks are essential instruments for integrating ecological solutions that aim at sustainability and the adaptability of cities to climate change (Farr, 2013).

The origin of urban parks in Brazil dates back to the 18th century, when the Portuguese crown's interest in the territory's natural resources encouraged the creation of gardens and public walkways to protect certain areas (Melo; Lopes; Sampaio, 2017). Over the course of two centuries, urban parks have accompanied the urban transformations of cities, reflecting the social and cultural values of urban populations. Despite this, unlike European parks, which emerged to meet the needs of the urban masses in the 19th century, Brazilian parks were aimed at emerging elites, who sought to build an urban landscape compatible with international standards (Macedo; Sakata, 2002).

Over time, urban parks in Brazil began to perform functions that go beyond aesthetics, incorporating social and ecological roles. Currently, they promote leisure and quality of life, while adapting to the challenges of urbanization and urban planning, contributing to better environmental quality (Melo; Lopes; Sampaio, 2017). In the 20th century, most parks served the leisure of higher urban classes, located in central areas. However, in the 21st century, new projects began to prioritize environmental conservation, with locations in peripheral neighborhoods and functions that include combating heat islands and maintaining the microclimate (Sakata; Gonçalves, 2019).

Sakata and Gonçalves (2019) highlight that, since the beginning of the 21st century, parks have been conceived primarily as sustainability tools. Described as “sustainable parks”, they have permeable and wooded areas that assist in urban drainage and mitigation of adverse climate effects. In addition, even parks aimed at leisure in deprived areas are presented as environmental actions. This movement consolidated a new category of urban parks, such as fenced forests and linear parks, which integrate environmental conservation and recreational functions (Sakata; Gonçalves, 2019).

Furthermore, Lorca (1989) highlights the aesthetic and educational relevance of parks, which beautify cities and provide opportunities for environmental education. These spaces encourage awareness of nature and its impact on human life, promoting integration between urban life and the environment. Therefore, urban parks become indispensable for the quality of life in urbanized areas.

Urban green spaces (UGS) are essential for the well-being of populations, offering benefits to physical and mental health. According to Zhang and Qian (2024), areas such as parks and community gardens allow people to connect with nature, reducing stress and anxiety, in addition to strengthening the sense of community. These spaces also improve air quality and reduce the heat island effect, creating healthier environments. In regions of social vulnerability, access to quality UGS is essential to improve health and quality of life, promoting more inclusive and sustainable cities.

4.4. Climate Change: Urban Heat Islands, Floods and Inundations

The increase in temperatures on planet Earth has visible and perceptible repercussions in cities, whether through intense thermal discomfort on hotter days, in the Brazilian reality, or through the intensification of flooding, inundations, floods and landslides, we can understand these elements as one of the main effects of climate change in Brazilian cities. The growth of impermeable areas, urban deforestation and the lack of planning for rainwater drainage directly contribute to these problems. This subtheme reviews the main factors that aggravate urban heat and flooding, discussing how traditional gray drainage, based on runoff systems and rigid infrastructure, fails to deal with the challenges imposed by climate change. (Santos, 1993, Amorim, 2009; Amorim, 2004; Guo, Mingfu and Yu, 2021)

Cities are always undergoing constant transformations, whether social or territorial, and their landscape reflects these actions, such as demographic growth, which is more intense in medium and large cities, as well as the dynamics of land occupation and use. In this context, the urban landscape is configured as a key element for understanding the interactions between the built environment and local environmental and climatic phenomena (Santos, 1993; Cullen 2008). Therefore, understanding the process of urban and rural land use and use is intrinsically related to the study of the landscape, an element that integrates, spatially and temporally, the relationships between society and nature in the environment.

For Santos (1982), the landscape is understood as a set of geographic objects, distributed over a territory in its geographic or spatial configuration, apprehended in its visible continuity, where social processes give life to these objects. Gorski (2008) summarizes the idea of landscape as a dynamic element, with interactions between ecosystem components (biotic and abiotic) and socioeconomic and cultural components, producing the perception of a whole, including aesthetic and emotional valuation.

Mascaró and Mascaró (2009) state that in order to understand the urban climate, it is necessary to observe the topography of the site, the urban morphology and the size of the city to be analyzed.

One of these climatic elements that have a great impact on the health of the population are heat islands, one of the phenomena present in the urban climate. Amorim et al. (2009) define:

> The urban heat island (ICU) is essentially defined by the difference in temperature between the central area of the city and the rural environment or peripheral areas with low density of buildings [...] (Amorim et al., p.2, 2009).

Heat islands, in turn, can cause thermal discomfort to humans, which comes from the study of thermal comfort. Thermal comfort refers to the feeling of well-being in relation to the thermal conditions of the environment. This concept is influenced by factors such as air temperature, relative humidity and ventilation (Gomes; Amorim, 2003). In urban areas, thermal comfort is directly related to the perception of climate conditions by residents and the balance between the ambient temperature and the human body's ability to maintain a stable internal temperature. In cities, built surfaces and population density interfere with natural ventilation and increase heat retention, which contributes to discomfort. The urban climate, characterized by high temperatures and low air circulation, generates thermal stress, which affects productivity and well-being (Rodrigues; Marques; Mendonça, 2012).

The phenomenon of heat islands has direct implications for the health of urban populations. Pagnossin, Buriol and Graciolli, (2016) point out that the perception of thermal comfort is subjective, varying according to individual preferences, the activity performed and clothing.

However, Brazilian cities do not only witness changes in temperature and thermal sensation throughout the year. The lack of strategic and adequate urban planning means that the severe weather, which has intensified in recent years, causes environmental, social and economic disasters with greater impacts.

Kron et al. (2012) point out that natural disasters have 6 classifications:

Kron et al. (2012) pontuam que os desastres naturais possuem 6 classificações:

> 1. Geophysical and geological events (earthquake; volcanic eruption; tsunami; [...]);
> 2. Meteorological events (cyclones; [...] hailstorm; and local wind; [...]);
> 3. Hydrological events (flood; storm; [...] landslides)
> 4. Climatological events (heat wave; drought; fires; cold wave; frost; [...])
> 5. Biological events [...];
> 6. Extraterrestrial events (asteroids) (Kron et. al, 2012, p. 536, 537, our translation).

Among these impacts, on the urban scale and in this work, climatic and hydrological events, especially heat waves and floods, could be mitigated if adequate and sustainable urban planning were put into practice.

Floods, downpours and inundations are distinct phenomena, although related to hydrological dynamics. Piroli (2022) conceptualizes the 3 phenomena. For the author, floods refer to the cyclical process of increasing the volume of water in the beds of rivers and streams, being directly influenced by the physical characteristics of the basin and the intensity of rainfall. Floods, in turn, result from concentrated rainfall or the rupture of retention structures, and can be intensified by soil impermeability in urban areas, which increases the risk of material damage and human losses. Finally, floods differ from other processes because they involve the overflow of water into historically non-flooded areas, directly affecting populations, infrastructure and economic activities, and are often associated with changes in land use in river basins. Although related, these processes have specific causes and impacts that require distinct management and prevention strategies.

Based on Piroli (2022), Tucci (1993) points out that floods result from climatic events in which precipitation is more intense than expected and the amount of water that reaches the watercourse exceeds its drainage capacity. In urban areas, floods mainly result from disorderly occupation and soil impermeability, which alters the natural hydrological cycle and intensifies surface runoff.

According to Piroli (2022), disorderly urbanization and inadequate occupation of environmentally sensitive areas, such as riverbanks and hillsides, have aggravated the effects of floods in Brazilian cities. Soil impermeability, a characteristic of urban areas, reduces the infiltration capacity of rainwater, increasing surface runoff and concentrating large volumes of water in natural courses, which are often altered, blocked or obstructed, contributing to the occurrence of floods and other associated problems, resulting in significant social and environmental damage.

According to Tucci (2007), like floods, floods resulting from urbanization arise from the construction of impermeable surfaces, such as streets and roofs, which contribute to reducing infiltration and increasing the volume and speed of rainwater runoff. This process requires greater capacity of the drainage sections, which can generate localized flooding due to design errors, river strangulation and accumulation of sediment and waste.

Flooding in medium-sized cities is directly related to the process of disorderly urbanization and the lack of integrated urban drainage planning. According to Tucci (2007), urbanization in small and medium river basins intensifies surface runoff due to soil sealing, overloading both secondary drainage and macrodrainage systems, and urban expansion in these cities tends to occur from downstream to upstream, increasing the impact of new occupations on older areas located downstream, generating greater risks of flooding and economic and social losses.

The replacement of native formations by anthropic uses, without considering the limits of environmental resilience, directly interferes with the hydrological cycle, as it reduces the soil's capacity to retain water, making it difficult to replenish the water table and compromising the supply of springs (Piroli, 2022).

For the author:

> In urban areas, water that fails to infiltrate, prevented by roofs, concrete and asphalt, in addition to not contributing to the recharge of aquifers, runs off concentrated, in considerable volumes, which in some cases can drag vehicles and people and destroy structures. When it reaches the lowest points of the relief, this water that did not infiltrate and was not temporarily retained along the way causes floods that affect public roads and also a wide range of activities, in addition to putting the health and lives of people and animals at risk (Piroli 2022, p.28).

Regarding floods, according to The Emergency Events Database (EM-DAT), a portal developed in partnership with the Center for Research in Disaster Epidemiology (CRED) and the World Health Organization (WHO), in 2022, the world recorded 387 occurrences of natural disasters, 12 of which were concentrated in Brazil and, on average, between 2001 and 2021 the number of environmental disasters was 370. This year, Brazil occupied one of the positions in the Top 10 mortality - 2022, recording a total of 272 deaths due to flooding in the country, in this period the world recorded 7954 deaths due to flooding occurrences against the average of 5195 deaths between the periods 2002-2021. This indicates that this type of environmental disaster has intensified throughout the world (EM-DAT, 2023).

Guo, Mingfu and Yu (2021) discuss floods as a frequent natural hazard with major socioeconomic and environmental impacts worldwide. The risk is especially high in urban areas due to changes in land use and hydrological processes altered by human activities. Pluvial floods result from the overloading of urban drainage systems during heavy rainfall and have historically received less attention in risk management compared to river and coastal floods. However, these events can be equally devastating. The losses are direct and indirect, such as the destruction of critical infrastructure, and there are also indirect impacts, such as the loss of productivity and economic opportunities. Due to climate change, the frequency and severity of these floods tend to increase.

In Brazil, a traditional urban stormwater drainage system is still widely used, essential to prevent floods, inundations, flooding and environmental degradation. According to Tucci (2008), Brazil is in a stage of water development called the "hygienist phase". This phase dates back to the 1970s, when the focus was on eliminating diseases through the supply of drinking water and sewage collection, without proper treatment of effluents and with inadequate management of urban drainage. Many Brazilian cities still lack an effective sewage treatment system, resulting in a scenario of water pollution and increased vulnerability to natural disasters such as floods. In the 21st century, the country still has an obsolete infrastructure, with storm drainage not designed to deal with atypical and extreme weather events, with serious social and environmental consequences.

Some urban disasters are attributed to a traditional storm drainage model, which is not designed to deal with atypical and extreme weather events. This system, which generally uses storm drains and canals, is widely used to control rainwater runoff. However, these methods have considerable limitations. Soil waterproofing, for example, reduces the natural infiltration capacity of water, which increases surface runoff and, consequently, increases the risk of flooding and contamination of water bodies. Furthermore, exclusive reliance on gray infrastructure (such as canals and galleries) generates high maintenance costs and makes the system less resilient to extreme weather events, compromising the effectiveness of urban drainage (Tucci, 2008).

In short, by creating cities that promote the replacement of green areas with buildings and paved roads, the processes of energy, heat and humidity exchange are modified, resulting in characteristic phenomena such as heat islands and thermal inversion. These phenomena are intensified by the presence of large population clusters, the reduction of vegetation and the increase in impermeable surfaces, which together alter atmospheric circulation and air quality, making the environment more hostile and influencing the quality of life in cities (Rodrigues, Marques and Mendonça, 2012).

4.5. Sustainable Drainage: Nature-Based Solutions

Analyzing the reality in which the planet we inhabit finds itself, it is necessary to review how we plan our cities and how we promote the management of the natural environment effectively, promoting the applicability of a model that incorporates nature-based solutions and promotes sustainability in cities is essential.

Sustainable drainage emerges as an effective alternative to traditional drainage, offering solutions that integrate natural processes into urban planning. Aiming to contribute to the reduction of flooding, the improvement of water quality and the promotion of a more resilient city, this sustainable solution is based on natural processes for a more sustainable city in balance with nature.

According to Porto et al. (1993), urban drainage is defined as a set of strategies and actions aimed at mitigating the risks of flooding, reducing the damage caused by these events and allowing urban growth in a balanced and sustainable manner. The concept of urban drainage goes beyond the simple execution of structural works, also encompassing legal, institutional, technical and social aspects. To achieve effective solutions, it is essential to have integrated planning that includes specific public policies for the sector, adequate management of land use and the implementation of both short- and long-term measures. This process requires the action of responsible entities that have the necessary technology and can apply standards, carry out works and promote the participation of society, ensuring efficient and sustainable management of urban drainage.

Stormwater management incorporates one of the essential elements of infrastructure in urban drainage planning. As already noted, in Brazil the traditional drainage methodology is still used, and it is still in a hygienic phase, seeking efficient sewage treatment. In developing countries, cities vary in the stages of development of urban water. In developed countries, most of the problems have been solved with regard to water supply, sewage treatment and quantitative control of urban drainage (Tucci, 2002).

The author also states that the way we manage urban drainage in Brazilian cities does not encourage the prevention of problematic situations, such as floods, with public management proposing to declare a public calamity whenever situations of this level occur. Tucci (2002) points out, with the aim of improving urban drainage management, that in order to avoid greater harm to the population and the environment, substantial changes in management are necessary, with professionals working to change the reality of the cities they manage in coordinated action with the spheres of public power. This solution is proposed through sustainable urban drainage, with non-structural and structural measures.

To promote a nature-based solution, sustainable urban drainage must respect the characteristics of the hydrological cycle, enabling its maintenance, in time, space and with regard to water quality. Pompeo (2000) defines urban drainage as the set of actions to control the runoff of rainwater and mitigate flooding in urban areas. Traditionally, priority has been given to the rapid evacuation of water through storm drains, transferring the problems to other regions. More recent approaches emphasize sustainable solutions, such as infiltration areas and containment reservoirs, integrating drainage into urban planning. Therefore, sustainable urban drainage seeks to balance development and the environment, ensuring the resilience of cities.

For Alencar (2017), sustainable urban drainage is a system that prioritizes the use of devices capable of delaying the arrival of water to water bodies, resulting in a reduction in peak flow, preventing flooding and protecting areas adjacent to water bodies. This is because the devices contribute to reducing the excess water volume resulting from urbanization and soil waterproofing processes, also helping to control pollutants from surface runoff, since some microdrainage components filter the water, showing greater effectiveness in controlling the water quality of water bodies when compared to the treatment carried out in the macrodrainage system (Alencar, 2017).

Other authors argue that, in the context of sustainable urban drainage, it is essential to respect the characteristics of the hydrological cycle, ensuring its maintenance over time, in space and in relation to water quality. This approach aims to avoid the problems generated by conventional drainage, in addition to reducing the environmental impacts resulting from the urbanization process (Ripol e Silva; Pinheiro; Dias Lopes, 2013).

In order to promote more efficient management of rainwater, nature-based solutions are presented. Classified as green and blue infrastructures, where green refers to natural or semi-natural systems that facilitate the infiltration and retention of rainwater, reducing the overload on conventional drainage systems and reducing the risk of flooding, and blue refers to natural drainage systems that contribute to the regulation of the hydrological cycle and the preservation of aquatic ecosystems Davies et al. (2015).

Sowińska-Świerkosz and García (2022) present the conceptualization of Nature-Based Solutions (SBN). In short, the term emerges as an innovative alternative for managing natural systems, balancing the benefits for nature and society. They are defined as actions that simultaneously address environmental, social and economic challenges, inspired or supported by nature.

The concept of Solutions Based on Green Infrastructure (BGI) has gained prominence in recent decades as an effective alternative for the management of urban rainwater, they help control rainwater, promoting environmental sustainability, proposed in two categories, large and small scale. In large-scale BGI, nature-based solutions are ponds and retention basins, while small-scale solutions such as green roofs, permeable pavements, bioretention systems, among others, are used. Small-scale BGI are more applicable in urban areas with high building density, as they are elements that facilitate water infiltration into the soil and help reduce the impact of stormwater runoff (Moghanlo; Raimondi, 2025).

Addo-Bankas et al. (2024) present a timeline illustrating the significant milestones in the development and implementation of Green Infrastructure over the past 50 years:

- 1970s: The creation of the EPA (US Environmental Protection Agency).
- 1980s: In 1987, the National Green Networks was created in the United States.
- 1990s: In 1991, New Zealand adopted the revised Low Impact Design Manual as part of the Resource Management Act.
- 2000s: The European Commission launched the European Green Capital Award (EGCA) in 2008 to recognize cities that have implemented GI practices.
- 2010s: In 2014, the Chinese government implemented the "Sponge City Initiative," managing stormwater and flooding in urban areas through green infrastructure-based solutions.
- Present: The Sponge City Initiative has resulted in projects implemented in 30 pilot cities in China. (Addo-Bankas et al., 2024, p. 5, our translation)

According to Gong and Hu (2017), stormwater green infrastructure:

> [..] is defined as a stormwater management approach that simulates natural hydrology processes at the site and building scale, i.e. Green Stormwater Infrastructure, which refers to various ecological measures for stormwater management. GSI is different from the traditional municipal piping network, which includes a series of stormwater

> management elements consisting of plant, soil and rain-related grey infrastructure (Gong and Hu, 2017, p. 220, our translation).

In this perspective, Green Infrastructure is an innovative solution to address water management challenges in cities by combining natural resources and sustainable technologies to reduce flooding and improve water quality. In addition to helping with water conservation and storage, Green Infrastructure also brings benefits such as the purification of pollutants, the creation of greener urban spaces and the promotion of biodiversity. For the authors, it is essential to invest in this approach as it means making cities more resilient, ensuring clean water and a healthier environment for future generations (Addo-Bankas *et al.,* 2024; He et al., 2021; Maes et al., 2019).

Other authors point out that Green Infrastructure is a multidisciplinary concept that integrates urban development with sustainable environmental solutions, aiming to minimize the impacts of urbanization on natural resources. In the context of water management, Green Infrastructure encompasses several strategies and interventions, such as rain gardens, bioswales, green roofs and permeable pavements, which assist in the infiltration and control of the quality and quantity of rainwater (Ying *et al.*, 2022; Zhang, Chui, 2019; Oijstaeijen, Passel, Cools, 2020).

4.6. Urban Planning and Bioconstruction

Urban planning plays an essential role in shaping cities, as the lack of adequate infrastructure and limited access to essential services can intensify the vulnerability of communities. In many cases, the lack of adequate planning results in areas with climate vulnerability, causing discomfort to those who use this space. (Costa, 2024;).

For urban planning to be aligned with sustainability and its consequences, the implementation of urban sustainability policies is necessary. With a complex nature, due to its interdependence with elements that shape the urban environment, economy, culture, infrastructure, natural resources, social and environmental challenges, an integration of these systems is required so that decisions can be made at different scales and forms of governance (Kalantari *et al.*, 2019).

Following the concept of green infrastructure, for this to be implemented it is appropriate to use sustainable techniques and materials. In this sense, bioconstruction is a sustainable alternative within civil construction, prioritizing the use of materials with low environmental impact, adaptation to the local climate and efficient waste management. According to Francisco, Santos and Silva (2023), this approach seeks to minimize environmental impacts from planning to the use of the building, integrating sustainable techniques that value regional materials, such as soil, reducing production costs and providing greater thermal comfort.

Although bioconstruction uses mostly natural and recyclable materials, it does not exclude the application of industrial and technological products. According to Cantarino (2006), this construction model integrates the use of natural or recycled raw materials available on site, the use of rainwater, renewable energy and waste recycling. Bioconstruction presents itself as a viable strategy to make architecture and civil engineering more aligned with sustainability and the well-being of communities.

Okimoto (2021) states that bioconstruction deals with, in addition to better construction materials and fewer negative impacts, urban sanitation, transport and mobility infrastructures must also be bioconstructed, aligned with existing natural processes.

5. DISCUSSIONS

The review presented highlights that intense urbanization and soil sealing have aggravated problems such as flooding and heat islands, requiring sustainable alternatives in urban drainage management (Tucci, 2007; Piroli, 2022). Traditional gray infrastructure, based on channeling rainwater, has shown limitations in its ability to deal with extreme weather events and conserve water resources (Tucci, 2008; Porto et al., 1993). In contrast, nature-based solutions, such as bioswales, green roofs and permeable pavements, have demonstrated efficiency in reducing surface runoff and improving water quality (Moghanlo and Raimondi, 2025; Addo-Bankas et al., 2024).

The analysis also highlights the importance of urban parks in the environmental management of cities. Parks are essential for mitigating heat islands and retaining rainwater, in addition to promoting leisure and biodiversity spaces (Farr, 2013; Zhang and Qian, 2024). The implementation of green infrastructure in urban parks enables the integration of sustainable drainage and urban planning strategies (Sakata and Gonçalves, 2019). However, challenges persist, such as the need for investment in public policies and awareness of the relevance of these solutions for urban quality of life. In the context of sustainable urban drainage and green infrastructure, urban planning focused on bioconstruction can create innovative architectural and urban solutions, contributing to environmental regeneration and mitigating the effects of climate change.

6. CONCLUSIONS

This work demonstrated that urban drainage green infrastructure represents an effective alternative for mitigating the impacts of climate change and its effects on urban environments, with regard to stormwater management. Implementing nature-based solutions integrated with sustainable drainage can significantly contribute to climate resilience and improving the quality of life in cities. To move forward in this direction, it is essential to strengthen public policies and encourage the adoption of these mechanisms, promoting more efficient and sustainable urban planning.

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STATEMENTS

CONTRIBUTION OF EACH AUTHOR

The conception and study design were jointly developed by the graduate student (Fernanda Nascimento Rigolo) and the advisor (Fernando Sergio Okimoto), with the latter responsible for defining the objectives and methodology, guiding the development of each stage of the study. Data curation was performed by the graduate student under the advisor's supervision, ensuring the quality and organization of the collected information. Formal data analysis was conducted by the graduate student, with methodological support from the advisor for applying the necessary methods.

Data collection was carried out by the graduate student under the advisor's guidance, who assisted in defining the approach and applied methodologies. The study methodology was adjusted and refined through collaboration between both, with the advisor providing direction for method development. The initial draft was written by the graduate student, following the advisor's instructions for structuring the manuscript.

Critical revision of the text was performed by both authors, with the advisor responsible for the final review to ensure clarity and coherence. The final manuscript revision was conducted by the graduate student, with adjustments made to comply with journal guidelines under the advisor's supervision. The work was coordinated by the advisor, who ensured the overall study quality and provided continuous guidance throughout the process.

We, **Fernanda Nascimento Rigolo and Fernando Sergio Okimoto**, declare that the manuscript entitled "**Green Drainage Infrastructures and the Architectural Design of Linear Parks: A Review**":

1. **Financial Ties**: Has no financial ties that could influence the results or interpretation of the work.
2. **Professional Relationships**: Has no professional relationships that could impact the analysis, interpretation, or presentation of the results.
3. **Personal Conflicts**: Has no personal conflicts of interest related to the manuscript's content.
