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SUSTAINABILITY INDICATORS APPLIED TO URBAN DRAINAGE:
EVALUATION OF LOW IMPACT DEVELOPMENT (LID) TECHNIQUES BASED ON A LITERATURE REVIEW

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ABSTRACT – This article aims to configure a matrix to determine the selection of Low Impact Development (LID) techniques that enable the analysis of sustainable LID measures for sustainable urban drainage and environmental quality in cities. Aiming to achieve the objective, this article involved three steps: (1) the method of systematic literature review was used to identify the key attributes according to the sustainability measures found in the conceptual framework; (2) analysis of key attributes and performance of LID techniques, with a view to identifying possible techniques that present aspects that promote them to the category of sustainable applications to mitigate the impacts of impervious surfaces and urban flooding. And, finally, in the third stage (3) the research sought to evaluate the qualitative characteristics of LID techniques through their use in urbanized and consolidated areas in cities. Therefore, this research aims to support sustainable city applications by evaluating LIDs techniques effectiveness in urban planning, offering insights on its role in managing urban drainage.

Keywords: Urban sustainability; urban flooding; low impact development; sustainable indicators; urban impacts.

RESUMO – INDICADORES DE SUSTENTABILIDADE APLICADOS À DRENAGEM URBANA: AVALIAÇÃO DE TÉCNICAS DE DESENVOLVIMENTO DE BAIXO IMPACTO (LID) BASEADO NA REVISÃO DA LITERATURA. Este artigo tem como objetivo configurar uma matriz para determinar a seleção de técnicas de Desenvolvimento de Baixo Impacto (LID) que possibilitem a análise de medidas LID para drenagem urbana sustentável e a qualidade ambiental nas cidades. Visando atingir o objetivo, este artigo envolveu três etapas: (1) utilizou-se o método de revisão sistemática da literatura para identificar os atributos-chave de acordo com as medidas de sustentabilidade encontradas no quadro concetual; (2) analisaram-se os principais atributos e desempenho das técnicas LID, com o objetivo de identificar possíveis técnicas que apresentem aspectos que as promovam à categoria de aplicações sustentáveis para mitigar os impactos de superfícies impermeáveis e alagamentos urbanos. E por fim, na terceira etapa (3) a pesquisa procurou avaliar as características qualitativas das técnicas LID através da sua utilização em áreas urbanizadas e consolidadas nas cidades. Assim, esta pesquisa busca auxiliar aplicações em cidades sustentáveis, avaliando a eficácia das técnicas LIDs no planeamento urbano, oferecendo insights sobre seu papel na gestão da drenagem urbana.

Palavras-chave: Sustentabilidade urbana; alagamentos urbanos; desenvolvimento de baixo impacto; indicadores sustentáveis; impactos urbanos.

RESUMEN – INDICADORES DE SOSTENIBILIDAD APLICADOS AL DRENAJE URBANO: EVALUACIÓN DE TÉCNICAS DE DESARROLLO DE BAJO IMPACTO (LID) BASADO EN LA DE LA REVISIÓN DE LA LITERATURA. Este artículo tiene como objetivo configurar una matriz para determinar la selección de técnicas de Desarrollo de Bajo Impacto (LID) que permitan el análisis de medidas LID sostenibles para el drenaje urbano sostenible y la calidad ambiental en las ciudades. Para lograr el objetivo, este artículo involucró tres pasos: (1) se utilizó el método de revisión sistemática de la literatura para identificar los atributos clave según las medidas de sostenibilidad encontradas en el marco conceptual; (2) se analizaron los principales atributos y desempeño de las técnicas LID, con el objetivo de identificar posibles técnicas que presenten aspectos que las promuevan a la categoría de aplicaciones sustentables para para mitigar los impactos de las superficies impermeables y las inundaciones urbanas. Y finalmente, en la tercera etapa (3) la investigación buscó evaluar las características cualitativas de las técnicas LID a través de su uso en áreas urbanizadas y consolidadas de las ciudades. Por lo tanto, esta investigación busca ayudar a las aplicaciones en ciudades sostenibles, evaluando la efectividad de las técnicas de LID en la planificación urbana, ofreciendo información sobre su papel en la gestión del drenaje urbano.

Palavras clave: Sostenibilidad urbana; inundaciones urbanas; desarrollo de bajo impacto; indicadores sostenibles; impactos urbanos.

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I. INTRODUCTION

The challenges of urban flooding in contemporary cities emphasize the necessity of introducing innovative solutions for sustainable urban drainage and environmental preservation. The control of concentrated loads in urban drainage remains ineffective, with projects in river basins traditionally prioritizing effluent control to ensure improvements in urban drainage within the city. The global expansion of urbanization and the repercussions of urban stormwater on both human populations and aquatic ecosystems underscore the critical significance of addressing the management of urban drainage in this scientific research context (Chocat *et al.*, 2001; Fletcher *et al.*, 2013).

One of the main challenges that the drainage system faces are the large floods that occur in cities and the qualitative and quantitative control of surface water runoff. In their assessment, Fletcher *et al.* (2014) mentions that urbanization impacts the physical properties of urban soils, resulting in changes in water dynamics and the ability of soils to manage water flow, intensifying environmental challenges. This affects the soil´s ability to act as a natural filter, intensifying environmental challenges. Furthermore, in recent years, many urban areas have suffered frequent flooding as a result of climate change and urban sprawl (Jemberie & Melesse, 2021; Marostica, 2023).

As these problems generated by urban runoff increase, strategies that use engineered solutions, especially impermeable hydraulic networks and underground pipes that emphasize rapid removal of runoff from cities to protect citizens, are becoming the conventional standard for stormwater management (Roy *et al*., 2008). Furthermore, given the urbanization of river basins in developing countries, the phenomenon of urbanization, according to Silveira (2002a), generates surface waterproofing, which prevents infiltration of rainwater into the soil, producing more water for drainage. These problems constitute one of the major hydrological calamities to which the population has been subjected due to impermeable surface coverings and occur as a result of the inadequate occupation of streambeds and urbanization of cities.

In this sense, aiming to obtain a greater understanding of urban water management, the traditional solutions used by municipal management have been questioned by many scholars, for example, Kourtis *et al*. (2017), Silveira (2002b) and Zhou (2014), as they lack more comprehensive and flexible approaches that include sustainable drainage and infrastructure. As these traditional strategies have proven inadequate, often worsening existing problems, an alternative urban stormwater management approach known as LID "Low Impact Development" has evolved in New Zealand and North America, in countries such as Canada and the United States. Refers to LID – a landscape-based strategy to maintain and replicate the nature of urban locations with the aim of minimizing the impacts of stormwater runoff and pollution on watershed ecosystems (Roy *et al*., 2008).

According to the literature, LID is a sustainable stormwater management strategy that is rapidly gaining acceptance in several countries around the world (Babaei *et al*., 2018; Chang *et al*., 2018). In terms of using sustainable technology around the world, researchers consider LID as a stormwater runoff and management approach that facilitates water cycle system recovery based on increasing infiltration rate and decreasing runoff coefficient (Ferguson, 1991).

In this case, in the development of these low impact technologies, the dissemination of their results to the institutions and bodies responsible for future urbanization in the city would have technological potential to build more sustainable environments. Implementing low impact technologies involves diverse approaches like retaining, detaining, collecting, infiltrating, and filtering runoff near its source as a valuable resource (Coffman, 2002). There are many elements in the LID toolkit, including rain gardens, bioretention basins, bioswales, green roofs, rain barrels, permeable pavements, riparian buffers, and wetlands.

Studies in the area of Low Impact Development demonstrate that LID techniques reduce the risk of urban flooding by slowing stormwater runoff, providing thermal benefits by reducing heat island effects, and providing habitat for wildlife (Berndtsson, 2010). Furthermore, the techniques are capable of creating floating wetland systems (Chua *et al*., 2012), providing bioretention cells, rainwater harvesting and green roofs, and permeable concrete pavement systems (Nemirovsky, 2011). Therefore, all of these aforementioned practices have been used as LID techniques in cities (e.g., Brown *et al*., 2013; Jemberie & Melesse, 2021; Marostica, 2023; Palermo *et al*., 2020; Trinh & Chui, 2013; Trowsdale & Simcok, 2011; Walsh *et al*., 2014).

Based on the identified knowledge gap, this research focuses on urban flooding issues and enhancing city drainage using LID technologies, evaluating their sustainable attributes and the positive and negative impacts of these techniques on urban drainage in cities. Therefore, this article aims to configure a matrix to determine the selection of LID techniques, enabling the assessment of sustainable practices with a focus on their potential for sustainable urban drainage and environmental quality to mitigate the impacts of impermeable surfaces on cities and emphasizing the efficacy of LID techniques.

II. MATERIALS AND METHODS

Aiming to achieve the objectives of this article, the methodology adopted was divided into three stages of the research development process: the first stage (1) used the systematic literature review method to identify the key attributes according to the measures of sustainability found in the conceptual framework.

Based on this premise, the identifications of the articles consulted were through the databases: *Periodic CAPES* (Ministry of Education); *Web of Science* (Clarivate Analytics) and *Scopus* (Elsevier B.V.), selected with a time frame of approximately 20 years in the period 2002-2023. The time frame of the years chosen for the database was defined according to the possibilities of finding studies to deal with urban flooding in cities in a sustainable way and through LID techniques.

After selecting the databases, the studies were selected as search keywords to find studies related to the research. In this way, four keyword terms in english-portuguese were used: ("urban flood" OR "*enchente urbana")* AND ("low impact development" OR "*desenvolvimento de baixo impacto"*), ("lid tools" OR "*ferramentas lid") AND (* "urban drainage" OR "*drenagem urbana")*.

The results found in the *CAPES* database were 2125 results, *Web of Science* with 4792 results and Scopus with 542 available results. Due to the high volume of identified data, it was necessary to apply search refinement filters for the search to occur with the expected volume of results. Using selection filters available in databases such as "Runoff", "Water Resources", "Environmental Science" and "Stormwater Management", a smaller volume of data was obtained for the research.

After applying the search terms in the selected sources, a set of studies was selected for further use. The high number of documents constituted an evaluation process that sought to identify relevant studies. The searching for studies stage included the search for relevant papers. In the first round, 621 papers were selected by title review. Among the records removed before screening, 27 articles were identified as duplicated by Zotero.

In the screening stage, 394 papers were selected for abstract review. Some studies had to be excluded because it was not possible to access the full texts due to limitations in scientific databases with paid and restrictive versions. On the other hand, the 78 studies that were considered relevant for the review (final extraction) were archived for use in the first stage.

In the second stage (2), the analysis focused on the key attributes and performance of LID techniques, aiming to identify potential strategies that present aspects that promote them to the category of sustainable applications for urban flooding. And finally, in the third stage (3), the research sought to evaluate the qualitative characteristics of LID techniques by referencing relevant authors.

This evaluation encompassed their application in urbanized and established areas within cities, assessing their efficacy in addressing environmental impacts. Furthermore, the examination considered the integration of these techniques with urban planning initiatives and their role in advancing sustainable development within the urban drainage systems of cities.

III. RESULTS OF STAGES AND DISCUSSION

This section delineates the three stages of analyzing the research findings. The subsequent in-depth analysis facilitated the identification of significant LID techniques in controlling urban flooding and improving urban drainage in cities. In this context, the ensuing discussion encompasses analysis and reflections on LID sustainability measures and the theoretical knowledge discovered. This dialogue among the results promises to contribute to the advancement of the utilization of LID techniques in cities with impermeable surfaces, promoting the development of sustainable urban drainage.

1. Sustainability Measures Matrix

The measures identified in the systematic literature review were analyzed together, based on a matrix, thus creating a total of 19 sustainability LID measures cited by the authors; with this, a grouping was made considering its nature and proximity to the subject (table I).

Sustainable measures encompass distinct actions and strategies implemented to foster sustainable development, thus generating key attributes as a way of uniquely identifying the sustainability LID measures that were associated for each group related to the mentioned authors. These tangible initiatives are designed to mitigate adverse impacts on both the environment and society, concurrently maximizing enduring benefits.

Table I – Grouping of Sustainability Measures.

Quadro I – Agrupamento das Medidas de Sustentabilidade.

Group and Key Attributes	Sustainability LID Measures	Acknowledged Theoretical Attributes	Referenced Authors of the Systematic Literature Review
1. Runoff and Storm Drainage for Flooding	1. Protection or restoration of the stream's morphology; 2. Identify the flows that must be avoided in streams; 3. Implementation of stormwater retention basins with smaller, multi-level intakes to reduce flows above erosion limits; 4. Multiple benefits of stormwater control measures; 5. Reduce the impact of flooding in engineering works.	✓Impact on the flow of waters; ✓System of drainage that capture problems caused by surface runoff; ✓Plan and control the distribution of superficial flow.	• Chocat *et al.* (2001) • Fletcher *et al.* (2014) • Jemberie & Melesse (2021) • Kourtis *et al.* (2020) • Vietz *et al.* (2014a) • Roy *et al.* (2008) • Silveira (2002b) • Trinh & Chui (2013) • Zhou (2012, 2013, 2014)
2. Environmental quality and Socio-Environmental Changes	6. Rainwater control measures that reduce the volume of excessive rainwater runoff into streams, providing adequate water quality; 7. Preservation of riverside space; 8. Draw public planning attention to the benefits of ecologically healthy streams in sustainable cities; 9. Encourage planning and approval processes on a catchment scale; 10. Public perception of streams through sustainable projects focused on social objectives; 11. Changes in policy and legislation to protect and restore streams through changing values and attitudes.	✓Social and institutional impediments; ✓Management and Public institutions.	• Burton *et al.* (2018) • Trinh & Chui (2013) • Vietz *et al.* (2014a, 2014b) • Walsh *et al.* (2005, 2012)
3. Performance of LID Combinations	12. Sustainable mitigation measures for flooding; 13. Reduction of economic and environmental impacts associated with heavy rain events; 14. Maintains the water balance of landscapes; 15. Low-impact practices and sustainable approaches; 16. Water storage capture in a designated area of the landscape; 17. Use of LID applied in the city that contribute to soil retention and infiltration. 18. LID techniques absorb pollutants in rainwater runoff and release clean air into the environment; 19. Hydraulic advantages and sustainable environmental effects when applying these low-impact control measures.	✓Modern techniques that seek to imitate pre-development environmental conditions; ✓Application of practices that seek to imitate the hydrological regime and water balance.	• Fletcher *et al.* (2013, 2014) • Kourtis *et al.* (2020) • Marostica (2023) • Trowsdale & Simcock (2011) • Vietz *et al.* (2014a) • Vrban (2019) • Zhou *et al.* (2013)

In this way, it was possible to define three groups based on a key attribute term as a definition for the group of sustainability LID measures identified in the systematic literature review. In relation to group 1, the key attributes were defined by the theme of Runoff and Rainwater for Flooding and its dynamics with the natural flow of streams, avoiding urban problems in the management of rainwater.

In group 2, Environmental Quality and Socio-Environmental Changes, emphasis is placed on public perception of streams through sustainable projects, changes and legislation aiming to restore sustainability values in urban cultures. Addressing water quality, soil, vegetation and bioclimatic factors facilitates local environments adaptation, mitigating urbanization's environmental impact.

In group 3, Performance of LID Combinations, modern techniques are included that seek to imitate the pre-development of environmental conditions and water balance of urban landscapes, reduce economic and environmental impacts related to rain events and urban flooding, in addition to bringing to cities applications of infiltration and capture of urban soils.

2. Analysis of Key Attributes and Performance of LID Techniques

Based on the analysis of the key attributes groups, a second matrix was created to identify possible performances of LID techniques that would promote them to the category of applications with sustainable solutions for urban flooding.

For this proposal, another grouping was accomplished, with the purpose of finding the possible performance of LID structures produced by sustainability initiatives proves successful in urban environments mentioned by the authors. The authors examined groups of key attributes, thereby conducting an analysis of the performance of LID Structures in urban areas based on the findings of these studies, in accordance with the conceptual framework shown previously. The characteristics observed during the analysis were divided into the three key attributes, so that a greater focus can be found on the performance of each LID technique in urban areas. The group and attribute-key were investigated, identifying seven techniques. Among the LID applications cited area: (1) Green roofs, (2) Permeable Paving, (3) Bioretention Systems, (4) Green Areas and Landscaping, (5) Rain Gardens, (6) Grass Strips / Plant Filter Strips and (7) Infiltration Trenches, recognized by the reference authors.

Based on the combinations of LID Techniques in each key attribute, according to the table presented, we sought to understand each of the three groups mentioned and their sustainable performance. The groups were investigated for understanding based on the cited authors, in addition, the authors address issues related to the benefits and disadvantages of LID techniques and their performance in the urban landscape and in urbanized areas.

2.1.1. Group 1 – Runoff and Storm Drainage for Flooding

Storm-induced urban flooding results in the loss of life and property. To mitigate these risks, various methods, both structural and non-structural, are adopted (table II). Examples include changing the land use structure, upgrading the sewer system and establishing an early warning system. As an effective response to stormwater management challenges, LID techniques emerge as on-site design alternatives. These techniques utilize natural, engineered infiltration and storage techniques to control rainwater (Mijin *et al*., 2017).

However, LID techniques are often localized and sparsely distributed in areas where increased runoff and pollutants may be of concern (Trinh & Chui, 2013). Subsequently, only parts of storm drainage systems benefit from LID techniques unless the techniques are installed in all basins, including along culverts, to replace lost riparian environments. Furthermore, for highly urbanized watersheds in cities where space is limited, low-impact stormwater control distribution could offer an effective retrofit to address flooding issues as demonstrated by Morsy *et al*. (2016), while Trinh and Chui (2013) also demonstrated that a relatively large coverage of green roofs (14%) and bioretention systems (5%) would produce significant effects on channel flow, highlighting the importance of planning headwater area rehabilitation near the receiving ends of watersheds.

Examples of such large-scale canal rehabilitations in heavily urbanized environments include the once canalized Kallang River in Singapore (fig. 1), which was restored to improve its ecological health by manipulating the river's morphology and flow regimes (Marostica & Miron, 2022). In this case, the project aimed to improve the capacity of the Kallang water channels (fig. 2), transforming the channelized stream into a renaturalized river (American Society of Landscapes Architects [ASLA], 2016) with regard to the treatment of the receivers of the water flow. The open space above the channels (i.e. the top width) should also be considered as a space in which LID techniques can be installed so that the surface flow is treated immediately before entering the channels.

Table II – Performance of LID Structures with Key Attributes.
Quadro II – Desempenho de estruturas LID com atributos-chave.

Group and Attribute - Key	Performance of LID Structures in Urban Areas	Reference Authors
1. Runoff and Storm Drainage for flooding	 **LID Combinations:** Green Roofs, Permeable Paving, Bioretention Systems, Green Areas and Landscape, Rain Gardens.	· Ahiablame *et al.* (2016) · Barbaro *et al.* (2021) · Berndtsson (2010) · Chaffin & Gunderson (2016) · Chang (2010) · Chua *et al.* (2012) · Damadaram *et al.* (2010) · Davis & Threlfall (2009) · Fileni *et al.* (2019) · Fletcher *et al.* (2013) · Gallo *et al.* (2012) · Jia *et al.* (2011) · Lee *et al.* (2012) · Jemberie & Melesse (2021) · Liang *et al.* (2020) · Luan *et al.* (2017) · Marostica & Miron (2022) · Mijin *et al.* (2017) · Mitchell (2008) · Onema *et al.* (2020) · Tirpak *et al.* (2021) · Trinh & Chui (2013)
2. Environmental Quality and Socio-Environmental Changes	 **LID Combinations:** Green Roofs, Bioretention Systems, Green Areas and Landscape, Rain Gardens, Grass Strips/Vegetable Filter Strips.	· Brown (2005) · Chaffin & Gunderson (2016) · Fletcher *et al.* (2014) · Karamouz & Nazif (2013) · Marostica (2023) · Morsy *et al.* (2016) · Palermo *et al.* (2020) · Vijayaraghavan *et al.* (2012) · Wang *et al.* (2016, 2019)
3. Performance of LID Combinations	 **LID Combinations:** Green Roofs, Permeable Paving, Bioretention Systems, Green Areas and Landscape, Rain Gardens, Grass Strips/Vegetable Filter Strips, Infiltration trenches.	· Babaei *et al.* (2018) · Chang *et al.* (2018) · Berndtsson (2010) · Ferguson (1991) · Jemberie & Melesse (2021) · Li *et al.* (2019) · Marostica (2023) · Poole & Berman (2001) · Qin *et al.* (2013) · Samouei & Özger (2020) · Tirpak *et al.* (2021) · Trowsdale & Simcock (2011)

Fig. 1 – The canalized Kallang River (2008). Colour figure available online.

Fig. 1 – O Rio Kallang canalizado (2008). Figura a cores disponível online.

Source: Ying (2014)

Fig. 2 – The renaturalized Kallang River (2016). Colour figure available online.

Fig. 2 – O Rio Kallang renaturalizado. Figura a cores disponível online.

Source: ASLA (2016)

Furthermore, research based on field observation and modelling has indicated that LID approaches cannot completely replace conventional urban drainage systems to control stormwater runoff (Fletcher *et al.*, 2013) and must be incorporated into the conventional drainage system to provide control solutions for a full spectrum of storm and rainfall events (Damadaram *et al*., 2010).

Liang *et al*. (2020) studied the performance of five project scenarios with different spatial distributions, but with the similar hydraulic dimensioning of discharge structures of LID controls, at the urban catchment scale, and the results confirmed that the hydrological performance was notable for the rainfall intensity. Lee *et al*. (2012) investigated the use of LID facilities in a demonstration district in Asan Tangjung New Town located in South Korea, and found that these facilities can reduce peak flood discharges in the return period of 50 to 100 years. The reduction in peak flood discharge by each storm return period has been estimated to be about 7 to 15% on a broader catchment scale. Furthermore, Luan *et al*. (2017) revealed that LID techniques are more effective in reducing flooding during stronger periods and shorter storms in some regions.

Fileni *et al*. (2019) identify that using permeable paving techniques and rainwater basins, more than 40% of the flooding volume could be reduced with LID applications (Fileni *et al*., 2019; Luan *et al*., 2017). Furthermore, Ahiablame *et al*. (2016) highlight those different levels of implementation of LID practices reduced runoff when studying the river basin by up to 47%. Jemberie and Melesse (2021), in a study on optimizing urban land use, employed LID techniques in Ethiopia, to show that combined LID techniques have a significant impact on reducing urban flooding by up to 75% (Jemberie & Melesse, 2021).

In a comprehensive study conducted by Wang *et al*. (2016), it was found that urbanization and climate cause changes, generating adverse and significant effects on existing stormwater management systems. The influence of climate can severely affect the functionality of LID systems. Furthermore, another study evaluated by Wang *et al*. (2016), mentions that LID design parameters must include a degree of adaptation and resilience against rainfall outbreaks and urbanized site conditions, such as increased impermeability to provide resilience to potential outbreaks in rainfall intensity and increases in site tightness, that refers to the degree of spatial constraint or compactness exhibited by a specific location or environment.

Thus, as the increasing frequency and intensity of precipitation events existing as a modern-day reality, LID design needs to incorporate functionality within the domain of changing climatic conditions and the anthropogenic effects of urban areas (Chang, 2018), through rooftops, greens (Jia *et al*., 2012), rain gardens (Berndtsson, 2010), and bioretention systems (Tirpak *et al*., 2021). For implementations of LID flood prevention techniques specifically, the most prevalent urban barriers are: overlapping land, property and boundaries, lack of funding, low political priority for stormwater, management, lack of government leadership, and dominance of gray infrastructure, leading to a lack of interdisciplinary expertise, and gray skew patterns related to water management (Brown *et al.*, 2013; Chaffin & Gunderson, 2016).

The use of LID for stormwater management has been proven to slow the rate of runoff to receiving bodies of water as well as reduce the volume of water that is received by gray infrastructure in a storm event (Chaffin & Gunderson, 2016). This presents a unique challenge for landscape architects to reshape the narrative about ecological and environmental design and development (Marostica, 2023).

However, there are several LID techniques such as Bio-Retention Cell, Rain Garden, Green Roof, Permeable Pavement and Vegetative Swale (Davis & Therelfall, 2009; Onema *et al*., 2020) that can be used to control runoff. Thus, various studies accomplish around the world have demonstrated that the implementation of LID practices has a significant influence on reducing runoff and flooding in the urban environment.

The LID techniques have a series of principles to be considered when implementing the scenario, such as the physical characteristics of the area, width, slope, type of soil and impermeability, and precisely because of this, there is integration between the different spatial circumstances found in each local. Its association with the application and promotion of policies that involve the community appears to be an essential factor in the success of its implementation in urbanized spaces in cities. LID technology aims to control runoff at the source through structural and non-structural measures (Barbaro *et al*., 2021). Among them, non-structural techniques (vegetated and natural areas) are based, for example, on establishing protection and quality of green spaces through the reduction of impermeable surfaces and using structural techniques (technical systems) such as the mandatory installation of equipment that allows infiltration into the soil (Palermo *et al*., 2020). In the United States, several implemented practices of urbanization concepts are based on theoretical and practical principles such as incorporation of sustainable planning policies and implementation of green areas and efficient use of urban space.

In the United States again, certain urbanization concepts implemented practices are ground in both theoretical and practical principles, including the integration of sustainable planning policies and the establishment of green spaces coupled with efficient utilization of urban areas (Mitchell & The Oregonian, 2008). These initiatives acknowledge the formation of space through a networked system, connecting spatial fragments within the city. The aim is to prevent dispersed occupation and address the needs of the inhabitants effectively. Furthermore, the cities of Portland (fig. 3) and Seattle have become a reference for the applicability of sustainable structures in urbanized areas of the city due to their use for small and large rain events, in addition to being associated with non-structural measures, which involve municipal administrations and the community, through encouraging the construction of a functional and pleasant landscape.

The city of Portland has successfully integrated sustainability into its effective urban planning programs (Mitchell & The Oregonian, 2008). Portland is capable of achieving its climate action plan goals efficiently, from building new developments to collecting and disposing of waste, based on sustainable application programs in the city's urban spaces.

These sustainable applications allow for the establishment of standards aimed at less dense occupations, enabling accessibility to transport; stimulating community participation and creating a pleasant urban landscape. These low impact structures, such as infiltration ditches, trenches, rain gardens and bioretention cells, seek to capture rainwater to conserve, clean, detain and subsequently conveyance of stormwater (Gallo *et al*., 2012). Furthermore, these techniques expand the permeable area, infiltrate water into the soil and contribute to reducing surface runoff of rainwater (Marostica *et al.*, 2022).

Fig. 3 – Tanner Springs Park, Oregon, Portland with LIDs applied. Colour figure available online.

Fig. 3 – Tanner Springs Park, Oregon, Portland com aplicação de LIDs. Figura a cores disponível. online.

Source: Dreiseitl consulting (2010)

In an analysis implemented in China by Jia *et al*. (2012), in the Beijing Olympic Village, scenarios were considered to verify the results obtained on land where LID techniques were implemented. In the scenario results, the improvement of the urban landscape was considered, through the use of spaces, green roofs and reduction of paved areas; in addition to considering the principles of LID, such as rerouting rainwater, using bioretention cells and increasing the detention time of rainwater. As a final result of the tests in the Olympic Village, it was verified that the volumes and flows drained were lower where LID practices were used. In conclusion, the LID techniques applied in urbanized spaces have as practice issues involving urban drainage and sustainability, urban control measures that aim to compensate for the excessive waterproofing of areas.

2.1.2. Group 2 – Environmental Quality / Socio-environmental Changes

In a study regarding water quality in urban spaces, Vijayaraghavan *et al*. (2012) also confirmed that pollutant discharge through sustainable techniques such as green roof systems was largely based on soil depth and rainfall volume; they found that during the onset of rains, pollutant concentrations were highest but decreased considerably during subsequent rains.

By implementing a floating wetland system for nutrient removal in Singapore, Chua *et al*. (2012), concluded that the size of the floating system must be increased. Its nutrient removal performance exemplified LID techniques in treating urban runoff.

Financing barriers are often seen in urban areas with impervious surfaces, hindering ecological design and environmental development. This is particularly evident when assessing land for potential development, where measuring the return on investment for ecological design becomes essential. However, comparing this assessment with a project´s ROI (Return on Investment), as discussed by Chaffin and Gunderson (2016), can be a challenging due to the differing metrics used to evaluate project profitability.

Thus, rather than looking at ecological design solutions separate from development, considering that these ideas together can offer multi-functional benefits, for example, using interactive ecological design to fill the percentage of green space needed for new urban developments. However, ecological design and environmental infrastructure still face barriers that need to be understood in large cities. These barriers can, in turn, create a lack of acceptance for LID strategies. Compared to existing gray infrastructure adoption rates, LID strategies have been shown to be a viable alternative to stormwater management implementation rates, although still limited (Brown *et al.*, 2013).

The literature has presented the main barriers that currently exist for the implementation of LID (e.g., Brown *et al.*, 2013; Chaffin & Gunderson, 2016; Marostica, 2023). LID implementations need to fit into environmental and social systems, which sometimes requires a retrofit project. In this sense, the "retrofitting" system (fig. 4) is the act of installing new systems designed for high energy efficiency and low energy consumption in previously constructed buildings. This can range from small activities such as installing energy-efficient light bulbs to installing state-of-the-art sustainable systems in buildings. A more efficient building will be cheaper to operate and have less impact on the environment and with a better sustainable rating, it can increase the value of the property and the neighborhood in which it is located.

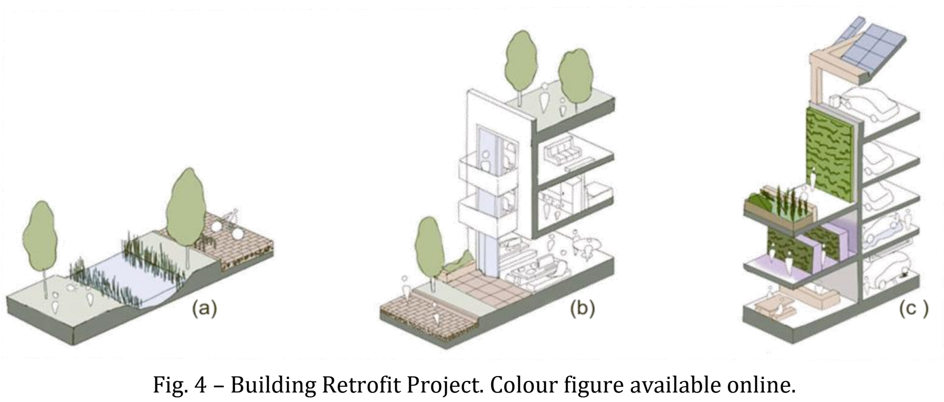

Fig. 4 – Building Retrofit Project. Colour figure available online.

Fig. 4 – Projeto de Retrofit em edifício. Figura a cores disponível online.

Source: Adapted from 3DReid (2022)

The image above (fig. 4) demonstrates a building retrofit process: in the location (a) existed the natural environment without human intervention; and after the construction of the building in the image (b), there was an overload built in the urban environment, thus, image (c) shows the retrofit accomplish in the building with the optimization of LID practices (rain gardens, landscapes, green roof and photovoltaic panels, drainage paving), covering various aspects of ecological design and evaluating the effectiveness of sustainable practices within an urban environment under engineering and architectural changes. Furthermore, the authors Karamouz and Nazif (2013) evaluated the impacts of climate change, identifying through storm drainage modelling, such as the image shown, that there may be an optimization of sustainable functions in urbanized cities through urban retrofit projects.

Thus, countries have been developing research on environmental quality for several decades, as well as control strategies such as the use of best management practices, LID and green infrastructure, all focused on the use of engineering practices to get better improved aspects of groundwater, water quality and natural channel flow (Marostica & Miron, 2022).

2.1.3. Group 3 – Performance of LID Infrastructures

One of the reasons for the use and application of LID techniques are the increase in impervious surfaces on urbanized land, which reduces space for riverside areas and the banks of rivers and streams, as the space is generally converted into impermeable roads for cars and pedestrians. Furthermore, considering the importance of the stream's temperature, restoring the riparian forest is not sufficient (Poole & Berman, 2001). For the restoration of these large consolidated urbanizations, complementary measures are necessary and must be adopted, as well as the possibility of drainage paving for open concrete channels in urban basins, plant grass filters and green and landscape areas. Thus, in response to the growing urbanization of cities and the limitation of consolidated space, connectivity between urban areas and the performance of LID techniques are reestablished.

Samouei and Özger (2020) investigated the hydrological response of the basin after replacing proportions of impervious surfaces with combinations of LID practices in urbanizations, and the results showed that implementing 5-20% of LIDs has a notable impact on water flow peak runoff and reduced rainfall volume, especially in storm events with shorter return periods.

A study by Trowsdale and Simcock (2011) reported that approximately 14 to 100% of an urban area's inflow was drained through a green roof system, with the lowest percentage referring to large rainfall events and vice versa, in a light industrial basin in New Zealand. In this way, green roofs delay a fraction of the rain before it reaches storm drainage systems, while rain gardens treat water that runs off the surface of the earth. Berndtsson (2010) suggested that in highly developed urbanized areas, LID may only be effective in handling small storms. In addition, green roofs delay a fraction of the rain before it reaches storm drainage systems, while rain gardens treat water that runs off the surface of the earth.

Marostica (2023) analyzed the impacts of the urbanization of an urban sub-basin with consolidated buildings that suffer from urban flooding and frequent rains. In general, the application of the scenarios with the performance of LID techniques in this area had a reduction in the simulated values. Therefore, it was concluded that flood control can be maximized with LID techniques if they are used in joint performance.

Jemberie and Melesse (2021) analyzed the impacts of urbanization and climate change on the magnitude of flooding generated, using the Storm Water Management Model (SWMM) and the LID sustainable land use optimization technique, and identify that combined LID techniques have an impact significant in reducing urban flooding by up to 75%. The studies also indicated that LID installations present different performance in controlling runoff under rainfall with different characteristics. Qin *et al*. (2013) found that bioswales perform best during a storm event with an early peak, permeable pavements perform best with an intermediate peak, and green roofs perform best with a late peak. Tirpak *et al*. (2021) identify that the combined effects of the bioretention cell and permeable pavement led to significant mitigation of parking lot runoff, reducing runoff depths and water flow rates.

In a study in China on the performance of LID techniques in an urban context, Li *et al*. (2019) demonstrated that LID practices, based on bioretention, grass filters, and permeable pavement, indicated good performance in mitigating urban storms at the watershed scale under different rainfall scenarios. In fact, different types of LID practices have been widely adopted by researchers, especially bioswales (rain barrel) and permeable pavement techniques.

In general, LID techniques rely on distributed runoff management measures that seek to control stormwater by reducing impermeability and retaining, infiltrating and reusing stormwater at the development site where it is generated. Many studies have recommended the performance of LID techniques as a suitable solution for stormwater management (Berndtsson, 2010; Jemberie & Melesse, 2021; Li *et al*., 2019; Qin *et al*., 2013; Samouei & Özger, 2020; Tirpak *et al*., 2021; Trowsdale & Simcock, 2011). LID installations such as grass strips, vegetative filter strips and green areas, vegetative ditches, rain gardens, permeable paving and bioretention have been widely used to control surface flow urbanization in many already urbanized areas, and in this study, different LID techniques were presented with joint performance to demonstrate improvements in urban storm drainage in the places where they were built.

3. Qualitative Analysis of LID Techniques

Based on the mapping analysis of the performance of LID techniques identified in the literature to deal with the problems of flooding and urban drainage, we intend to present as a result of the sustainable aspects of these techniques mentioned regarding qualitative analysis in the urban environment.

With the three key attributes identified (Runoff and Storm Drainage for flooding, Environmental Quality and Socio-Environmental Changes and Performance of LID combinations) in urbanized areas, it was possible to identify seven techniques according to the relevant projects referenced by the authors. This assessment covered its application in urbanized and established areas in cities, evaluating its effectiveness in addressing environmental impacts. Furthermore, the examination considered the integration of these techniques with urban planning initiatives and their role in advancing sustainable development in cities' urban drainage systems.

Next, the techniques found in the performance of LID structures according to the key attributes were investigated based on the synthesis of this work, thus identifying seven techniques that were applied in urban drainage projects according to the citations of the referenced authors. Among the LID applications that were cited are: (1) Green Roofs, (2) Permeable Paving, (3) Bioretention Systems, (4) Green Areas and Landscaping, (5) Rain Gardens, (6) Grass Strips / Plant Filter Strips, and (7) Infiltration Trenches.

Based on the qualitative analysis of low impact sustainable techniques, the aim is to identify possible positive and negative impacts of LID techniques through the characteristics of each technique through the authors referenced according to table III.

Table III – Performance of LID Techniques analyzed.

Quadro III – Desempenho das estruturas LID analisadas.

LID Techniques cited by Authors Description	Positive Impacts of LID Techniques	Negative Impacts of LID Techniques	Reference Authors
 (1) Green Roofs Coverage of buildings for planting undergrowth, grass, flowers and trees.	✓ Reductions in the volume of rainwater contribute to the microclimate and solar radiation; ✓ Improvements in the thermal performance of buildings; ✓ Increase in the proportion of green areas in cities; ✓ Impact on landscaping and restoration of the natural ecosystem.	✓ The retained volumes of microdrainage depend on project characteristics such as roof slope, type of vegetation, substrate and soil moisture.	· Trinh & Chui 2013 · Davis & Therelfall 2009 · Onema *et al.* 2020 · Gallo *et al.* 2012 · Marostica 2023 · Vijayaraghavan *et al.* 2012
 (2) Permeable Paving Installation of flooring on private and public roads that allow rainwater to infiltrate into the ground.	✓ Control of water quantity: percolation through the permeable pavement to the underground soil and storage of gravel, followed by infiltration into the native soil or removed by a drain; ✓ Water quality control: pollutants filtered through underground soil and storage of gravel and/or soil during infiltration	✓ The hard, impermeable surface area (e.g. road, parking area or sidewalks) that prevents or slows the infiltration of water into the ground.	· Silveira (2002) · Fileni *et al.* (2019) · Li *et al.* (2019)

Table III – Performance of LID Techniques analyzed (continuation).

Quadro III – Desempenho das estruturas LID analisadas (continuação).

LID Techniques cited by Authors Description	✓ **Positive Impacts of LID Techniques**	✓ **Negative Impacts of LID Techniques**	· **Reference Authors**
 (3) Bioretention Systems Bioretention features are excavated surface depressions that contain vegetation grown in a soil-mulch mixture placed above a gravel drainage bed.	✓ Control of the amount of water: retention on the surface or in underground storage, total or partial infiltration into the native soil and evapotranspiration; ✓ Water quality control: pollutants are filtered through mulch/manipulated soil and absorption by plant roots.	✓ This system can cause clogging, which allows pollutants to pass through and is also prone to water stagnation in the bioswale, therefore this type of system requires maintenance.	· Silveira (2002) · Trinh & Chui (2013) · Davis & Therelfall (2009) · Onema *et al.* (2020) · Gallo *et al.* (2012) · Jia *et al.* (2011) · Tirpak *et al.* (2021) · Li *et al.* (2019)
 (4) Green Areas and Landscape The area of land covered by lawn or mowed grass and often evenly sloped and planted trees covering the landscape.	✓ Provides beautiful landscapes in cities and environmental well-being for society; ✓ Reduction of heat islands and global warming in cities; ✓ Among the green areas are areas that increase the proportion of permeable green areas and improve the quality of life, such as green paths or green ways, considered unpaved green roads for pedestrians and cyclists.	✓ Not found in the literature.	· Marostica *et al.* (2022) · Poole & Berman (2001)
 (5) Rain Gardens It is a type of bioretention cell that consists of the concentrated soil layer with no gravel bed beneath it.	✓ Control of the amount of water: storage in surface depressions, infiltration and evapotranspiration; ✓ Water quality control: for filtered water, filtration through soil and absorption of pollutants by plants.	✓ Among the disadvantages are the problems that may arise during operation, mainly resulting from design or implementation errors, inconveniences during the implementation of these solutions.	· Berndtsson (2010) · Davis & Therelfall (2009) · Onema *et al.* (2020) · Marostica (2023) · Trowsdale & Simcock (2011) · Berndtsson (2010)
 (6) Grass Strips / Vegetable Filter Strips Vegetated filter strips that provide additional infiltration for flows leaving a storm catchment.	✓ Vegetation strips are used to reduce velocities while providing infiltration; ✓ Vegetation is maintained to reduce erosion risks and help prevent surface runoff from concentrating; ✓ Reduction of heat islands and global warming in cities.	✓ Not found in the literature.	· Silveira (2002a) · Li *et al.* (2019)

In the presented table, the seven techniques (green roofs, permeable paving, bioretention systems, green areas and landscapes, rain gardens, grass strips/plant filter strips and infiltration trenches) have more characteristics with positive impacts for cities, such as: (i) the reduction in the volume of rainwater; (ii) contribute to improving the microclimate and reducing solar radiation from urbanizations; (iii) impacting landscaping and restoring the natural ecosystem; (iv) controlling the quantity and quality of rainwater; and, (v) reducing heat islands and global warming of cities. However, it cannot be forgotten that LID techniques also have negative characteristics, as: (i) the maintenance of the areas in which the techniques were applied in cities; (ii) terrain where the relief can be very uneven; and, (iii) areas of hard surfaces or volumes retained by the areas of the terrain that can delay soil infiltration.

Based on the above, the mapping of LID techniques found in the literature has a vast set of sustainable characteristics for the control of rainwater runoff in urbanized areas affected with impermeable surfaces, which tends to contribute to the better adaptation and consideration of these techniques in spatial analysis and, even more suitable for sustainable urban drainage in cities, as cited according to the studies referenced by the authors of this research.

IV. CONCLUSION

In this study, the documentary survey and selection of LID techniques were discussed. From the comparative analysis of the groups of key attributes comparative to the performance of LID system, the aim was to identify possible performances of low impact techniques (LID) with positive and negative attributes that could contribute to (i) runoff and storm management for flooding; (ii) potential for sustainable urban drainage and environmental quality; (iii) mitigating the impacts of impermeable surfaces on cities; and, (iv) emphasizing the efficacy of LID techniques.

Concurrently with this stage, the sustainable aspects of the LID mentioned regarding their quality in the urban environment were presented. Thus, the method found in the performance of LID structures according to the key attributes cited by the authors of the literature were investigated based on seven sustainable techniques: (1) Green Roofs, (2) Permeable Paving, (3) Bioretention Systems, (4) Green Areas and Landscape, (5) Rain Gardens, (6) Grass Strips and Plant Filter Strips, and (7) Infiltration Trenches, which were explained in accordance with the referenced authors.

Furthermore, the research was guided by a justification to identify and qualify the researched techniques for sustainable application for promoting the development of sustainable urban drainage in urbanized cities with impermeable surfaces. Seeking to assess the collaborative potential of LID techniques with municipal authorities, it can be inferred that the implementation of these techniques indicates enhanced development and implementation in public management and urban drainage. Moreover, it contributes to the advancement urban projects in cities, aiming at the potential of the techniques presented and which can therefore be used in other urban contexts and realities.

This was facilitated by a broad search of studies with national and international authors demonstrating different structures and solutions for already consolidated urbanized areas. Considering that this research contributes to the development of sustainable applications for cities, and the results can enhance the development of urbanizations, it is understood that the approach to analyzing and evaluating the performance of LID from the perspective of literature seeks through this research to provide information on the use of these sustainable techniques for urban planning and drainage in cities and on the relevance and usefulness of LID techniques for controlling urban flooding. In contrast, the proposed solutions may not be generalized to all urban areas due to variations in environmental, social, and political conditions, which can limit their practical viability. These limitations underscore the importance of future research and methodological improvements in the field.

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AUTHOR CONTRIBUTIONS

Sara Desiree Marostica: Conceptualization; Methodology; Software; Validation; Formal analysis; Investigation; Resources; Data curation; Writing – original draft preparation; Writing – review and editing; Visualization; Supervision; Project administration. **André Luiz Lopes da Silveira**: Conceptualization; Methodology; Validation; Formal analysis; Investigation; Resources; Data curation; Visualization; Supervision; Project administration.

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