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Sustainable stormwater management: Appreciation of Low Impact Development Techniques (LID) for southern Brazilian municipalities

Gestão sustentável de águas pluviais: Valorização de Técnicas de Desenvolvimento de Baixo Impacto (LID) para municípios sul brasileiros

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Abstract

This study examines the perceptions and knowledge of municipal technicians in southern Brazil regarding Low Impact Development (LID) techniques, aiming to evaluate their relevance, efficacy, and practical challenges for urban flood control and sustainable stormwater management. The research methodology involved three stages: the selection and classification of LID techniques, evaluation of municipalities and professionals, and analysis of results through structured questionnaires. The findings highlighted the widespread use of techniques such as permeable paving and green areas/landscaping, recognized for their effectiveness in addressing urban drainage challenges. Less common practices, including rain gardens, green roofs, and infiltration trenches, were noted for their potential in sustainable urban drainage, while advanced methods like bioretention systems and bioswales remain largely unexplored. These results underscore the opportunity for broader adoption of LID practices to foster positive attitudes among policymakers and urban planners, supporting innovative stormwater management programs in southern Brazilian municipalities.

Keywords:
Urban sustainability techniques, LID, Urban flooding, Landscape enhancement, Sustainability indicators.

Resumo

Este estudo examina as percepções e o conhecimento de técnicos municipais do sul do Brasil sobre técnicas de desenvolvimento de baixo impacto (LID), com o objetivo de avaliar sua relevância, eficácia e desafios práticos no controle de inundações urbanas e na gestão sustentável de águas pluviais. A metodologia de pesquisa envolveu três etapas: a seleção e classificação das técnicas LID,

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a avaliação de técnicos municipais por meio de questionários estruturados e, a análise dos resultados. Os resultados destacaram o uso amplo de técnicas como pavimentos permeáveis e áreas verdes/paisagismo, reconhecidas por sua eficácia no enfrentamento dos desafios de drenagem urbana. Outras abordagens, como jardins de chuva, telhados verdes e trincheiras de infiltração foram apontadas por seu potencial na drenagem urbana sustentável, enquanto métodos avançados, como sistemas de biorretenção e valetas vegetadas, permanecem pouco explorados, Esses resultados ressaltam a oportunidade de ampliar a adoção de práticas LID para fomentar atitudes positivas entre formuladores de políticas e planejadores urbanos, apoiando programas de gerenciamento de águas pluviais em projetos realizados nos municípios do sul do Brasil.
Palavras-chave:
Técnicas de sustentabilidade urbana, LID, Inundações urbanas, Melhoria da paisagem, Indicadores de sustentabilidade.

I. INTRODUCTION

One of the biggest 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 the last years, many urban areas have suffered frequent flooding as a result of climate change and urban expansion (Jemberie; Melesse, 2021). Given increasing urbanization worldwide and the impact of urban stormwater on humans and aquatic ecosystems, managing urban drainage is a critically important challenge (Chocat et al., 2001; Fletcher et al., 2013).

Traditional urban stormwater management strategies often proven inadequate and, in many cases, exacerbate existing issues. In response, an alternative approach known as Low Impact Development (LID), has been developed and implemented, particularly in countries like Canada, the United States, and more recently in New Zealand. LID is a landscape-based strategy aimed at maintaining and replicating natural conditions with urban areas to minimize the impacts of stormwater runoff and pollution on watershed ecosystems (Roy et al., 2008). This approach considers the specific geographical characteristics of each region, promoting solutions adapted to local topography, climate, and vegetation, thereby aligning urban planning with the ecological requirements of drainage areas. LID technology aims to control runoff at the source through structural and non-structural measures (Barbaro et al., 2021). Studies in the area of low-impact development demonstrate that LID techniques reduce the risk of urban flooding by delaying stormwater runoff, as cited (e.g., Brown et al., 2013; Jemberie; Melesse, 2021; Marostica, 2023; Palermo et al., 2020; Trinh; Chui, 2013; Trowsdale; Simcok, 2011; Tzoulas et al., 2007, Walsh et al., 2014) in cities.

In this case, in the development of these low impact technologies, the dissemination of their results with the institutions and bodies responsible for future urbanization in the city would have technological

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potential to build more sustainable environments (Marostica, 2023). Strategies for applying low impact technologies support and innovate the sustainable urban sector by employing a variety of measures and techniques, including retaining, detaining, collecting, infiltrating and filtering runoff to manage stormwater as close as possible to its source and consider stormwater as a resource, not a waste product (Coffman, 2002).

Global research on Low Impact Development (LID) techniques often relies on the expertise and perspectives of municipal technicians to validate and adapt these practices to diverse urban and climatic settings. Studies conducted in countries like the United States (Qi; Barclay, 2021) have underscored the essential role of municipal technicians in implementing and assessing LID solutions, as these professionals provide practical insights into local requirements and constraints. Similarly, research from Australia by Farrelly and Brown (2008) and research from Brazil by Marostica (2023) highlights the importance of practioners´perspectives for advancing urban water management strategies. By collecting and analyzing feedback from these professionals, researchers can better adapt LID solutions to the unique needs and limitations of various urban environments.

Following this established research approach, the present study investigates the perspectives of Brazilian municipal technicians on urban LID techniques through a tailored questionnaire. This survey was specifically restructured to address the particular features of LID techniques identified in the literature review, resulting in focused questions designed to evaluate practical relevance and efficacy. Consequently, this article presents the perceptions of these municipal technicians on the applicability, effectiveness, and sustainability of LID techniques for flood control and rainwater management in southern Brazilian municipalities.

This study examined the knowledge and perceptions of municipal technicians in southern Brazil regarding Low Impact Development (LID) techniques, aiming to assess their relevance, efficacy, and practical challenges for urban flood control and sustainable management. The questionnaire, carefully restructured based on specific LID practices identified in the literature review, sought to evaluate potential improvements, benefits, and disadvantages of these techniques while addressing stormwater management issues in urbanized areas. According to Parasuraman (1991), the design and structuring of questionnaires survey is a set of questions asked to generate the data necessary to achieve the research objectives, highlighting the importance of methodological rigor in this study to accurately capture the insights of municipal technicians.

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II. Material and Method

Therefore, this research involves three stages: the stage of (2.1) selection and set of LID techniques; the stage of (2.2) evaluation of selected cities and professional evaluation of technicians; and the third stage with (2.3) analysis of results and discussion of the questionnaire questions with the aim of investigating the appreciation and recognition of LID techniques and the sustainable management of urban drainage in cities, which were divided into three sections for better statistical analysis.

Selection and set of LID techniques

Based on the literature review and mapping of low impact LID techniques in controlling urban flooding, at this stage the eight LID techniques that demonstrated positive results in relation to minimizing flooding in urban areas were selected. In addition to LID techniques, conventional drainage techniques were also used in data collection through a questionnaire, thus, the techniques mentioned were: (1) Green Roofs, (2) Permeable Paving, (3) Storm drain techniques, (4) Bioswale Systems, (5) Green Areas and Landscape, (6) Detention or Retention Reservoirs, (7) Infiltration Trenches, (8) Plumbing Systems, (9) Grass Strips and Plant Filter Strips and (10) Rain Gardens (Figure 1).

Figure 1 – Techniques selected for applying the questionnaire survey. Source: Compilation by the Authors (2023).

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The study used an online questionnaire as a collection instrument, sending an invitation letter to each respondent. The questionnaire contained a combination of different closed questions, and a photographic elucidation to obtain better information from the respondents. Therefore, the questionnaire survey incorporated ten scenarios from Figure 1, comprising eight low impact development (LID) techniques and two conventional drainage techniques. The addition of these techniques allowed the study to investigate each of these elements in the urban landscape comprising four categories: 1) attractiveness (refers to how visually attractive the presented technique is); 2) perceived effectiveness (refers to the term of effectiveness, whether it achieves sustainability results regarding the presented technique); 3) perceived sustainability (refers to the search for solutions to preserve the environment and quality of life for the population in relation to the technique presented; and 4) applicable to rainwater management (refers to the applicability of the technique in situations such as flooding urban).

Regarding the analysis criteria for choosing the relevant southern Brazilian cities, three factors were taken into consideration: (a) municipalities that are located in the southern Brazilian states (Paraná - PR, Santa Catarina – SC, and Rio Grande do Sul - RS); (b) cities that suffer from urban flooding; and (c) municipalities that have rivers and streams in consolidated urban areas and within the city perimeter.

RESULTS ANALYSIS AND DISCUSSION

With the aim of investigating the appreciation and recognition of low impact development techniques and the sustainable management of urban drainage in cities, the questionnaire requested all respondents to evaluate LID techniques and conventional drainage elements used in cities. The study analyzed the data using statistical procedures and the results are described below through three sections.

ASSESMENT OF SELECTED CITIES AND PROFESSIONAL PERFORMANCE

In the three states (PR, SC and RS), they were sent to a total of 22 cities. In the state of Paraná, the cities of Cascavel, Curitiba, Foz do Iguaçu, Londrina, Maringá and Toledo can be mentioned. In the state of Santa Catarina, they were sent to the cities of Balneário Camboriú, Blumenau, Brusque, Florianópolis, Itajaí, Rio do Sul and Joinville. In the state of Rio Grande do Sul, they were sent to the cities of Caxias do Sul, Erechim, Ijuí, Passo Fundo, Pelotas, Porto Alegre, Santana do Livramento, Santa Maria and Uruguaiana. Participant demographics are shown in Figure 2.

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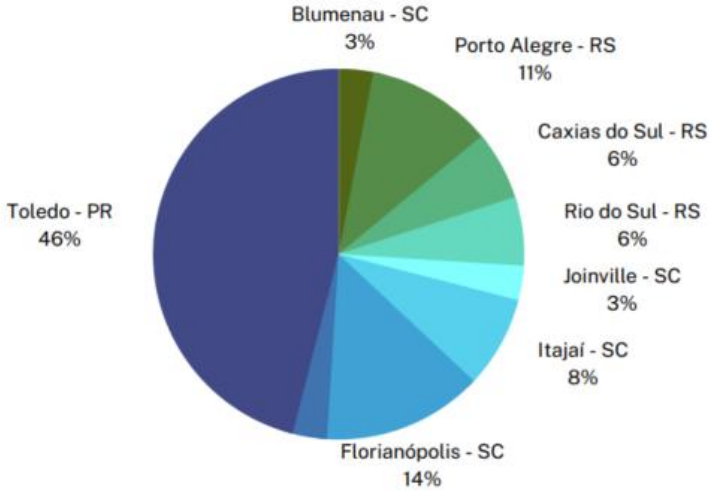

Figure 2 – Demographic data of responding municipalities. Source: Elaborated by the Authors (2023).

Invitations were sent to a total of 59 departments and secretariats of city halls, with the aim of distributing the questionnaires to respondents on a voluntary basis. The research set as a target the expected number of 40 respondents, thus, 35 questionnaires were complete correctly until completion, thus having a return rate of 87.5%. It is important to highlight that this data collection through a questionnaire was considered for a group of highly educated respondents (Figure 3).

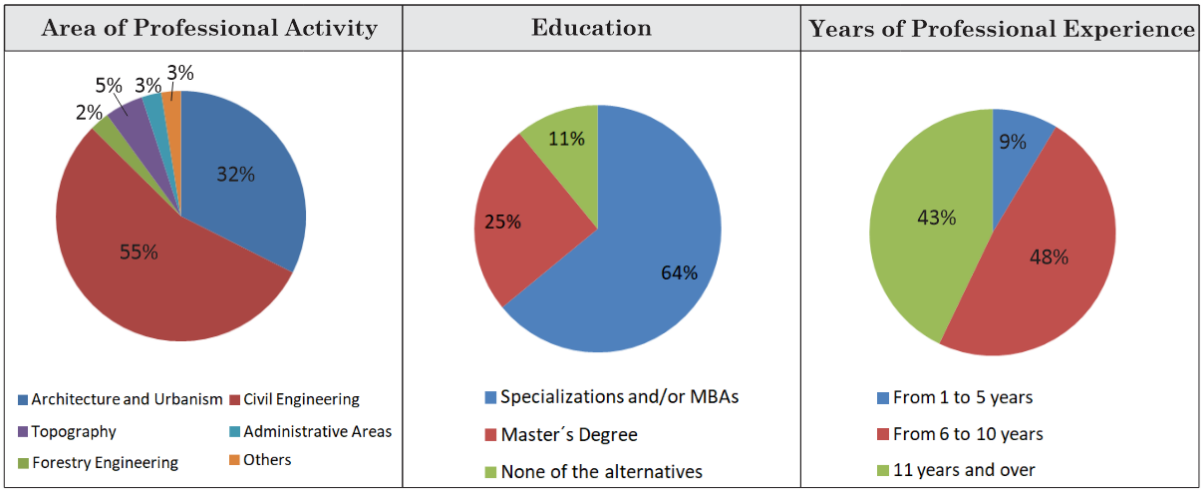

Figure 3 – Profile of questionnaire survey participants. Source: Elaborated by the Authors (2023).

Regarding the profile of participants by area of professional activity, level of education and years of professional experience (Chart 1), with reference to the area of professional activity, 55% of respondents correspond to the area of Civil Engineering and 32% to the area of Architecture and urbanism. Regarding education, the number of specializations and/or MBAs was prominent, corresponding to 64% of participants,

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master's degrees, 25%, and none of the alternatives, 11%. Regarding the predominance of years of professional experience, 48% worked for 6 to 10 years, 43% for 11 years or more, and 9% for 1 to 5 years of professional experience.

Chart 1 – Demographic data of South Brazilian Municipalities.

South Brazilian Municipalities (%) Total of 35 Respondents	**PARANÁ** Toledo (46%) Foz do Iguaçu (3%)		**SANTA CATARINA** Itajaí (8%) Blumenau (3%) Joinville (3%) Florianópolis (14%)		**RIO GRANDE DO SUL** Caxias do Sul (6%) Porto Alegre (11%) Rio do Sul (6%)	
TOTAL (%)	**49%**		**28%**		**23%**	
Participant Profile						
Area of Professional Activity (%)	Civil Engineering (55%)	Architecture and Urbanism (32%)	Topography (5%)	Administrative Area (3%)	Others (3%)	Forestry Engineering (2%)
Education (%)	Specialization and/or MBA (64%)		Master's degree (25%)		None of the Alternatives (11%)	
Years of Professional Experience (%)	From 1 to 5 years (9%)		From 6 to 10 years (48%)		11 years or more (43%)	

Source: Elaborated by the Authors (2023).

The distribution of questionnaires across 22 cities in three southern states of Brazil ensured a diverse geographic representation, which strengthens the study´s applicability to urban contexts with varying socio-environmental conditions. The high response rate (87.5%) and the significant participation of professionals from Civil Engineering (55%) and Architecture and Urbanism (32%) underscore the relevance of the insights gathered, particularly given their direct involvement in urban planning and infrastructure development.

The high educational level of respondents, with 64% holding specializations or MBAs and 25% holding master´s degrees, provides confidence in the technical robustness of their responses. Moreover, the substantial professional experience, with 91% having more than six years in their fields, suggests that the data reflects seasoned perspectives. However, it is worth noting that the focus on highly educated respondents might limit the inclusion of alternative viewpoints, such as those from non-technical stakeholders or community representatives, who are also integral to urban development processes.

Future studies could aim for broader inclusivity by incorporating perspectives from diverse educational and professional backgrounds to capture a more holistic understanding of urban challenges and solutions.

ASSESSMENT OF SUSTAINABLE AND MUNICIPAL DRAINAGE PROJECTS

Regarding the evaluated results (section 01), it was possible to observe that there is low design demand in relation to urban drainage projects in southern Brazilian municipalities (Chart 2), this may be related to the

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fact that the control of point loads in drainage urban microdrainage and macrodrainage is still ineffective in cities. Therefore, urban drainage management is a critically important challenge (Chocat et al., 2001; Fletcher et al., 2013) in South Brazilian cities.

Chart 2 – Demand for public-private drainage projects.

Earthworks projects and/or topographic studies	Lots of Project Demand (25.72%)	Average Project Demand (48.57%)	Low Project Demand (25.71%)
Public microdrainage projects	Lots of Project Demand (20%)	Average Project Demand (40%)	Low Project Demand (40%)
Public macrodrainage projects	Lots of Project Demand (20%)	Average Project Demand (20%)	Low Project Demand (60%)

Source: Elaborated by the Authors (2023).

The analysis of the question related to the respondents' opinion regarding the importance of the aforementioned items that contribute to the occurrence of urban flooding in the city in which the respondent lives and/or works (Chart 3 and Figure 4), it was possible to observe that the three items classified as very important by respondents highlighted the increase in the frequency and volume of rain (62.86%), the waterproofing of the soil due to urban occupation (62.86%) and the lack of public investment in urban drainage techniques (37. 14%). The perception regarding the increase in rainfall aligns with findings from studies such as Reckziegel (2007), which analyzed natural disasters in the state of Rio Grande do Sul and highlighted changes in precipitation patterns as a contributing factor to urban flooding. Furthermore, a study by Marengo et al. (2021), identified a significant increase in extreme precipitation events in southern Brazil. These changes are associated with a more intense hydrological cycle, potentially driven by global temperature increases. Such studies emphasize the pressing need for urban planning policies that address these evolving climatic patterns to mitigate flooding impacts.

Chart 3 – Issues related to the occurrence of urban flooding.

Question number						
01	**02**	**03**	**04**	**05**	**06**	**07**
Increase in the frequency and volume of intense rains (62.86%) 22 out of 35 respondents	**Soil waterproofing due to urban occupation (62.86%) 22 out of 35 respondents**	**Lack of public investment in urban drainage techniques (37.14%) 13 out of 35 respondents**	**Lack of conventional urban infrastructure (37.14%) 13 out of 35 respondents**	**Lack of sustainable urban infrastructure (54.28%) 19 out of 35 respondents**	**Excessive accumulation of garbage and discarded materials in the drainage system (37.14%) 13 out of 35 respondents**	**Drainage works with inefficient designs and/or implementation (40%) 14 out of 35 respondents**
Very important	Very important	Very important	Important	Important	Important	Important

Source: Elaborated by the Authors (2023).

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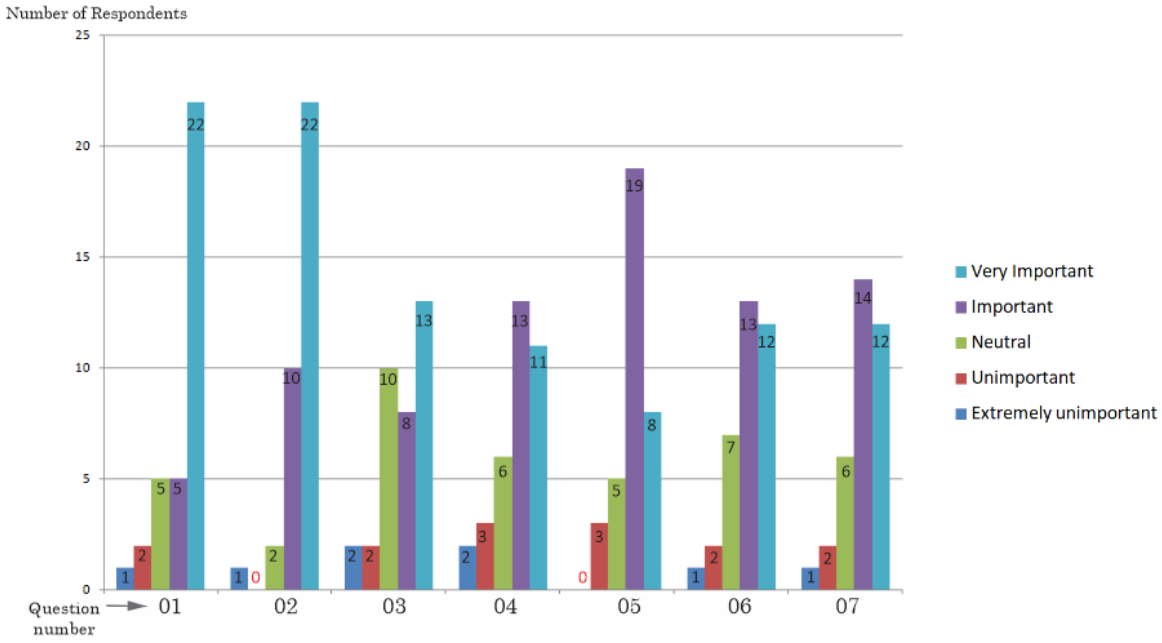

Figure 4 – Items that contribute to urban flooding. Source: Elaborated by the Authors (2023).

In the question related to the demand for sustainable projects in the urban space of cities (Chart 4 and Figure 5), the questionnaire shows that solar energy reuse projects (31.42%) were considered very frequent by respondents and rainwater reuse projects (40%) were classified as rarely. In general, he observed that projects in the sustainable area were few carried out by southern Brazilian cities.

Chart 4 – Questions related to sustainable projects in urban space.

Question number					
1	2	3	4	5	6
Solar energy exploitation project (31.42%) 11 of 35 respondents	Urban afforestation and reforestation project (37.14%) 13 out of 35 respondents	Sustainable drainage project (40%) 14 out of 35 respondents	Garbage disposal and solid waste reuse project (42.85%) 15 out of 35 respondents	Rainwater reuse project (40%) 14 out of 35 respondents	Sustainable urban mobility project (40%) 14 out of 35 respondents
Very Frequent	Occasionally	Occasionally	Occasionally	Rarely	Occasionally

Source: Elaborated by the Authors (2023).

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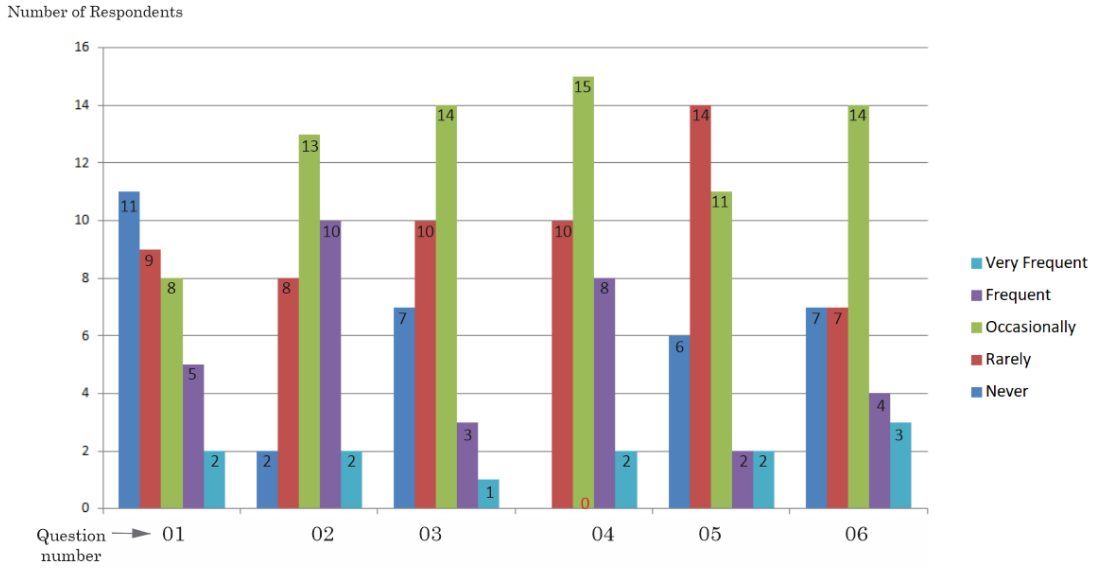

Figure 5 – Demand for sustainable projects in urban space. Source: Elaborated by the Authors (2023).

The importance of the reported items for the sustainable growth of cities was presented (Chart 5), a positive perception of the participants was observed in which the seven reported items were classified as very important by the interviewees. Among the most positive perceptions in the survey (Figure 6), the item reforestation and enhancement of green areas (68.57%) and the item rainwater collection and drainage (68.57%) stand out.

Chart 5 – Issues related to the sustainable growth of cities.

Question number						
01	**02**	**03**	**04**	**05**	**06**	**07**
Improvements in the local microclimate (51.42%) 18 out of 35 respondents	**Improvements to the urban drainage system (65.71%) 23 of 35 respondents**	**Reduction of heat islands and global warming (45.71%) 16 out of 35 respondents**	**Reforestation and enhancement of green areas (68.57%) 24 of 35 respondents**	**Urban waste recycling (51.42%) 18 out of 35 respondents**	**Non-polluting means of transport (42.85%) 15 out of 35 respondents**	**Rainwater collection and drainage (68.57%) 24 of 35 respondents**
Very Important	Very Important	Very Important	Very Important	Very Important	Very Important	Very Important

Source: Elaborated by the Authors (2023).

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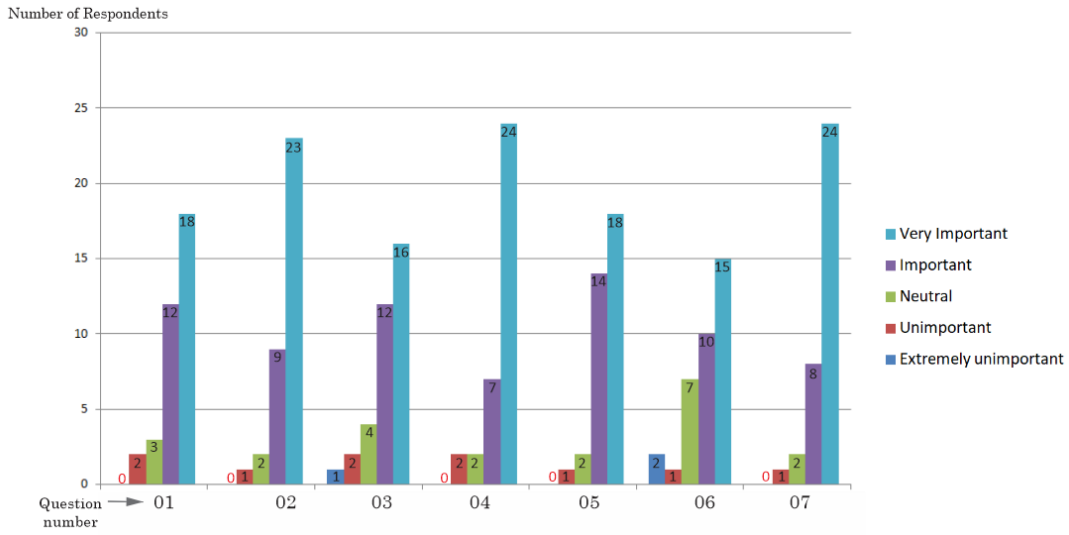

Figure 6 – Importance of the issues mentioned for the sustainable growth of cities. Source: Elaborated by the Authors (2023).

Seeking to understand all the questions in this section of the questionnaire survey, it was demonstrated that many of the technicians were knowledgeable about the demand for public and private urban drainage projects and sustainable projects. Furthermore, many also highlighted that the lack of public investment in urban drainage techniques still occurs in southern Brazilian municipalities, which allows generating reflections for the refinement and validation of the entire questionnaire survey considered in this research.

This finding is consistent with broader challenges identified globally. For instance, Francisco et al. (2023) highlight significant hurdles in urban drainage development due to limited funding and technical capacity in Brazilian municipalities, echoing the concerns raised by respondents. Similarly, Tellman et al. (2018) emphasize the critical role of investments in natural infrastructure to enhance urban water security across Latin America, suggesting that public underinvestment exacerbates vulnerabilities to urban flooding. Wild et al. (2020) further demonstrate how integrating nature-based solutions into urban planning can address gaps in conventional drainage systems, offering sustainable alternatives that align with the demands expressed by technicians in this study. These perspectives collectively reinforce the need for refining and validating the questionnaire to ensure it addresses the multidimensional aspects of urban drainage challenges and opportunities.

EVALUATION OF LID TECHNIQUES IN THE URBAN LANDSCAPE

Through this section of the questionnaire (section 02), applicants were asked to rate their appreciation of the site's aesthetic attractiveness, perceived functional efficiency and perceived ecological performance using a 5-point attitude scale, with 1 meaning not appreciating at all and 5 means appreciate a lot.

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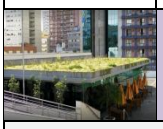
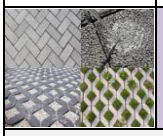
Furthermore, technicians were asked whether they recognized the benefits of sustainable urban stormwater drainage from the sites, assessing the extent to which the site's landscape design was sustainable in terms of sustainable management, using a 5-point attitude scale, since where 1 means Strongly Disagree and 5 means Strongly Agree.

Overall, in the statistical analysis in which respondents appreciated LID techniques (Chart 6), the techniques selected for the questions included LID techniques in addition to conventional drainage techniques: Green Roofs, Permeable Paving, Drain Techniques, Bioswale Systems, Green Areas and Landscape, Detention or Retention Reservoirs, Infiltration Trenches, Plumbing Systems, Grass Strips and Plant Filter Strips, and Rain Gardens.

Chart 6 – Assessment of LID Techniques in the urban landscape (%).

Green Roof Technique	**Attractiveness** (45.71%) 16 out of 35 respondents	**Perceived Effectiveness** (42.85%) 15 out of 35 respondents	**Perceived Sustainability** (45.71%) 16 out of 35 respondents	**Applicable in rainwater management** (37.14%) 13 out of 35 respondents
	Partially agree	Partially agree	Partially agree	Partially agree
Permeable Pavement Technique	**Attractiveness** (51.42%) 18 out of 35 respondents	**Perceived Effectiveness** (60%) 21 out of 35 respondents	**Perceived Sustainability** (60%) 21 out of 35 respondents	**Applicable in rainwater management** (51.42%) 18 out of 35 respondents
	Partially agree	Partially agree	Partially agree	Totally agree
Drain Technique	**Attractiveness** (34.28%) 12 out of 35 respondents	**Perceived Effectiveness** (34.28%) 12 out of 35 respondents	**Perceived Sustainability** (37.14%) 13 out of 35 respondents	**Applicable in rainwater management** (51.42%) 18 out of 35 respondents
	Partially disagree	Totally agree	Partially agree	Totally agree
Bioswale System Technique	**Attractiveness** (65.71%) 23 of 35 respondents	**Perceived Effectiveness** (48.57%) 17 out of 35 respondents	**Perceived Sustainability** (62.85%) 22 out of 35 respondents	**Applicable in rainwater management** (60%) 21 out of 35 respondents
	Totally agree	Totally agree	Totally agree	Totally agree

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Green Areas and Landscapes Technique	**Attractiveness** (88.57%) 31 of 35 respondents	**Perceived Effectiveness** (48.57%) 17 out of 35 respondents	**Perceived Sustainability** (62.85%) 22 out of 35 respondents	**Applicable in rainwater management** (60%) 21 out of 35 respondents
	Totally agree	Totally agree	Totally agree	Totally agree
Detention or Retention Reservoir Technique	**Attractiveness** (45.71%) 16 out of 35 respondents	**Perceived Effectiveness** (65.71%) 23 of 35 respondents	**Perceived Sustainability** (60%) 21 out of 35 respondents	**Applicable in rainwater management** (60%) 21 out of 35 respondents
	Totally agree	Totally agree	Totally agree	Totally agree
Infiltration Trench Technique	**Attractiveness** (60%) 21 out of 35 respondents	**Perceived Effectiveness** (51.42%) 18 out of 35 respondents	**Perceived Sustainability** (57.14%) 20 out of 35 respondents	**Applicable in rainwater management** (60%) 21 out of 35 respondents
	Totally agree	Totally agree	Totally agree	Totally agree
Plumbing Systems Technique	**Attractiveness** (45.71%) 16 out of 35 respondents	**Perceived Effectiveness** (37.14%) 13 out of 35 respondents	**Perceived Sustainability** (40%) 14 out of 35 respondents	**Applicable in rainwater management** (45.71%) 16 out of 35 respondents
	Partially disagree	Partially agree	Neutral	Partially agree
Grass Strips/ Vegetable Filter Strips Technique	**Attractiveness** (65.71%) 23 of 35 respondents	**Perceived Effectiveness** (45.71%) 16 out of 35 respondents	**Perceived Sustainability** (48.57%) 17 out of 35 respondents	**Applicable in rainwater management** (51.42%) 18 out of 35 respondents
	Totally agree	Partially agree	Totally agree	Totally agree
Rain Garden Technique	**Attractiveness** (62.85%) 22 out of 35 respondents	**Perceived Effectiveness** (51.42%) 18 out of 35 respondents	**Perceived Sustainability** (60%) 21 out of 35 respondents	**Applicable in rainwater management** (65.71%) 23 of 35 respondents
	Totally agree	Totally agree	Totally agree	Totally agree

Source: Elaborated by the Authors (2023).

Specifically, low impact development techniques received very positive ratings in the category items, either for their attractiveness (refers to how visually attractive the presented technique is); perceived effectiveness (refers to the term of effectiveness, whether it achieves sustainability results regarding the

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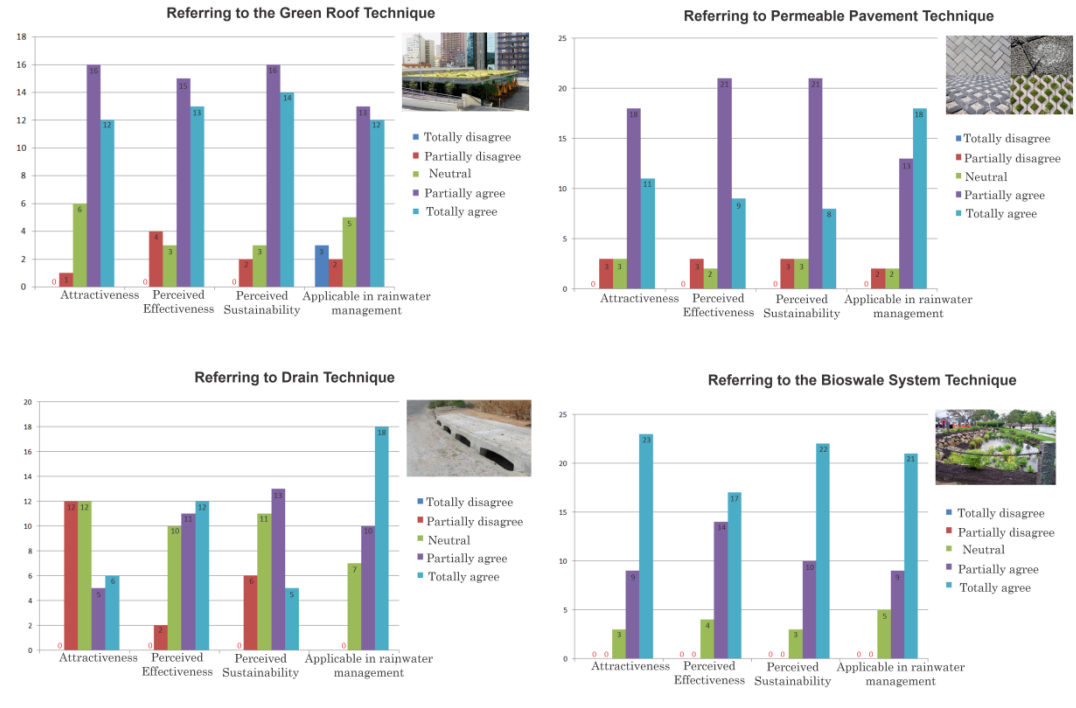
presented technique); perceived sustainability (refers to the search for solutions to preserve the environment and quality of life for the population in relation to the technique presented); and application in rainwater management (refers to the applicability of the technique in situations such as urban flooding) (Figure 7).



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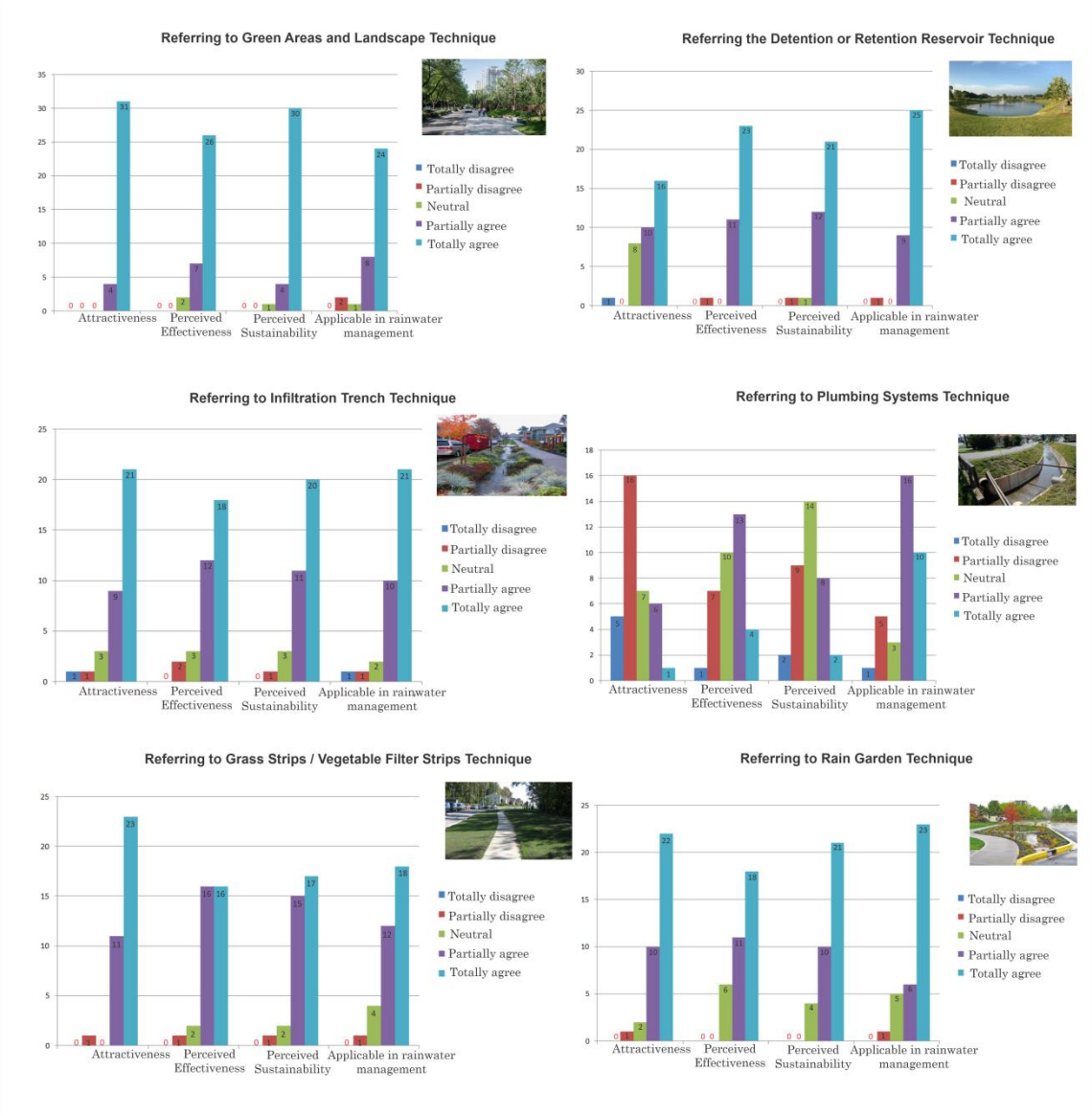

Figure 7 – Statistical analysis of LID and conventional drainage techniques. Source: Elaborated by the Authors (2023).

In general, it is possible to perceive sustainable knowledge levels among participants in relation to LID techniques and the depreciation of conventional drainage techniques, despite respondents considering techniques applicable to rainwater management.

This situation demonstrates a favourable position for the use of low impact techniques by technicians in South Brazilian municipalities. The final results of these techniques inserted into the questionnaire (Figure 8) statistically demonstrate the respondents' perception regarding the selected techniques.

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Figure 8 – Approval of LID techniques according to respondents. Source: Elaborated by the Authors (2023).

Concerning to green roof techniques in the general overview of the classificatory items of the questionnaire survey, it can be concluded that 100% of respondents partially agreed in terms of attractiveness, perceived effectiveness, perceived sustainability and applicable in stormwater management.

Regarding the Grass Strips and Vegetable Filter Strips techniques, 25% of respondents partially agreed and 75% completely agreed in terms of attractiveness, perceived effectiveness, perceived sustainability and applicable in rainwater management of the techniques mentioned. While the Permeable Pavement technique, participants partially agreed with 75%, and 25% chose to completely agree with the four classification categories.

As regards to conventional drainage techniques mentioned such as Drain Techniques and Plumbing systems, they were not well accepted by all respondents. The storm drain technique totaled 50% of respondents who completely agreed with the technique, 25% partially agreed and 25% partially disagreed with the use of this technique for sustainable means in cities. As for the plumbing system technique, 25% of the

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respondents partially disagreed with the use of this technique for the sustainable development of cities, 25% of the respondents remained neutral regarding the technique, and 50% partially disagreed with its use in the application of sustainable management of cities.

Finally, the five techniques mentioned above (bioswale systems, green areas and landscapes, retention or detention reservoir, infiltration trenches and rain gardens) received 100% approval from respondents in the items of attractiveness, perceived effectiveness, perceived sustainability and applicable in rainwater management. Thus, it was demonstrated that the value of these LID techniques in sustainable drainage projects in cities is recognized by technicians from South Brazilian municipalities.

KNOWLEDGE OF SUSTAINABLE MANAGEMENT AND LID TECHNIQUES

In section three of this questionnaire survey, respondents were query to rate their experiences and knowledge about sustainable stormwater management. Regarding events and programs that addressed sustainable techniques such as those presented, 60% of respondents stated that they had never participated in research with these characteristics and 40% stated positively (Chart 7). For respondents who said positively, they were asked to indicate learning options in the area of urban drainage management and sustainable techniques.

Chart 7 – Experience and knowledge about sustainable management.

Participated in events and programs that addressed sustainable techniques for improving rainwater management	Yes (40%)	No (60%)
Accordingly, indicate the learning options that justify your answer	TV / Radio (20%)	
	Participated in exhibitions (33,3%)	
	Researched websites and online sources (60%)	
	Participated in classes and workshops (60%)	
	Read publications and articles (86,7%)	

Source: Elaborated by the authors (2023).

Seeking to identify how participants consider the existence of standards, laws and manuals for the analysis of sustainable projects (Table 1), the main reasons responsible for this question were (69%) there is a lack of laws and standards in the sustainable area for the analysis of urban projects and also (69%) the existence of a lack in the area of sustainability in relation to manuals and books with sustainable urban applications.

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Table 1 – Existence of Standards and laws for sustainable analysis.

There is a lack of laws/standards in the sustainable area for analyzing urban projects (69%)	There are sustainable laws/standards, but there is a lack of capacity for implementation by public authorities (57.10%)	There is a lack in the area of sustainability in relation to manuals/books with sustainable urban applications (69%)	Sustainable solutions are generally only considered when they also offer a financial advantage. There is a lack of awareness and intentionality in approaching projects with a focus on sustainability. (2.90%)	Standards and laws exist, but users lack awareness and interest in implementing them and carrying out appropriate maintenance. (3%)

Source: Elaborated by the Authors (2023).

Secondly, with (57.10%) the reason for the existence of laws and regulations, but lack of capacity for implementation by public authorities. Therefore, it is possible to conclude that the lack of laws and standards and public implementation for cities still has development flaws, and there is no specific regulatory basis on sustainable rainwater drainage techniques. Furthermore, a larger collection of manuals and books for sustainable application in cities and available to municipal technicians would help in the better development of urban projects in southern Brazilian cities.

Regarding the participants who have already used LID techniques in projects in the municipalities in which they live and/or work (Table 2), the predominant use of two low impact development techniques is the permeable paving/paver technique and green areas and landscapes with 88.2% of respondents. These techniques have proven effective in initiatives such as Chicago´s Green Alley Program (EPA, 2021), which employs permeable paving in alleyways to mitigate flooding and reduce pollution from surface runoff. Regarding the rainwater drainage technique, which 79.4% of respondents have used, Curitiba, Brazil, serves as a notable example with its comprehensive rainwater management system that includes drainage channels integrated into green spaces to reduce urban flooding (Climate Action, 2013). Additionally, 58.8% of respondents used the technique of vegetable grass strips and grass strips.

Next, three techniques were employed by technicians in 8.8% which were green roofs, rain gardens and infiltration trenches. Green roofs, prominently used in cities like Toronto, Canada, under the Green Roof Bylam, provide insulation, reduce urban heat, and manage stormwater effectively (Portland, 2024). Rain gardens are widely adopted in Portland, USA, as part of the city´s Green Streets Program, which prioritizes capturing runoff at its source (Portland, 2019). Infiltration trenches, on the other hand, are utilized in Freiburg, Germany, where urban planners have integrated them into sustainable housing developments to enhance groundwater recharge.

Finally, the buffer reservoir technique was used by around 2.9% of respondents, similar to the retention basins in Singapore´s Bishan-Ang Mo Kio Park, which doubles as a recreational area and flood mitigation tool.

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However, bioretention systems and bioswales were not selected in this question by technicians, remaining at 0%. This contrasts with cities like Seattle, USA, where bioswales are central to the Natural Drainage Systems Program, reducing pollutants and managing water sustainably.

These global examples underscore the diverse applicability and benefits of LID techniques. They also highlight the need for expanded adoption and knowledge transfer in southern Brazilian municipalities, where a broader range of techniques could enhance urban resilience and sustainability.

Table 2 – Sustainable techniques used by municipalities.

Permeable Pavement Paver (88.2%)	Green Areas and Landscapes (88.2%)	Stormwater Runoff (79.4%)	Green Roofs (8.8%)	Bioretention Systems/ Bioswales (0%)	Rain Gardens (8.8%)	Vegetable Grass Strips / Grass Strips (58.8%)	Infiltration Trenches (8.8%)	Detention or Retention Reservoir (2,9%)

Source: Elaborated by the Authors (2023).

Bring to a conclusion the research through a questionnaire, respondents were asked about the level of experience they each had in relation to Low Impact Techniques – LID (Table 3). Thus, the question presents the level of experience of the participants, using a 5-point attitude scale, since 5 means that the respondent has mastery of the content related to LID techniques and 1 means that they have little or no knowledge about these sustainable techniques.

Table 3 – Experience level of participants.

Scale of Knowledge				
Lack of Knowledge **1** (43%) 15 of 35 participants	**Some Knowledge** **2** (31,40%) 11 of 35 participants	**Neutral** **3** (23%) 8 of 35 participants	**Lots of Knowledge** **4** (2,90%) 1 of 35 participants	**Domain of Knowledge** **5** (0%) 0 of 35 participants

Source: The Authors (2023).

With regard to scale number 1, 43% of participants were found, demonstrating that the interviewees themselves still have lack of knowledge about the technique described. Regarding scale number 2, 31.40% of participants had some knowledge, while 23% selected the option for scale number 3, that is, they have neutral knowledge on the subject. Then, scale number 4 received 2.90% of respondents, corresponding to a lot of knowledge about low impact techniques and 0% of participants selected the option scale number 5, in which the professional has full control over the subject of LID techniques.

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III. Effective Results of the Research

The research provided valuable insights into the doption and effectiveness of Low Impact Development (LID) techniques in southern Brazilian municipalities. Techniques such as permeable paving and green areas/ landscaping emerged as the most widely applied, with 88.2% of respondents recognizing their effectiveness in addressing urban drainage challenges. Stormwater drainage systems were similarly well-utilized, with a reported adoption rate of 79.4%. Techniques like rain gardens, green roofs, and infiltration trenches, although less common (8.8%), were acknowledged for their potential in sustainable urban drainage. Notably, advanced methods like bioretention systems and bioswales remain unexplored, highlighting areas for future implementation.

Regarding the selection criteria for the surveyed cities, three factors were prioritized: (a) municipalities within the southern Brazilian states of Paraná, Santa Catarina, and Rio Grande do Sul; (b) cities experiencing significant urban flooding; and (c) municipalities with rivers and streams in consolidated urban areas and within the city perimeter. While these criteria ensured the study´s relevance to urban centers facing pressing drainage issues, it is important to acknowledge that criterion (c) inherently excluded smaller cities and towns where LID techniques could be applied more feasibly and cost-effectively. Future research could expand the scope to include these smaller municipalities, which may offer promising opportunities for the broader adoption and success of LID strategies.

The findings further underscore the importance of enhancing public investment and developing comprehensive legislation and technical guidelines to support sustainable urban drainage management. By addressing these gaps, southern Brazilian municipalities can strengthen their capacity to integrate LID techniques and achieve greater resilience to urban flooding and environmental challenges.

This refined discussion integrates the strengths of the study while addressing its limitations, paving the way for broader, more inclusive applications of LID techniques.

IV. Conclusions

This study provided empirical information relevant to the appreciation and recognition of LID techniques for controlling urban flooding in southern Brazilian municipalities, and which can probably be applied to other Brazilian municipalities.

The implementation of low-impact development techniques as presented requires support from municipal management and, therefore, requires the understanding of public managers and society in relation

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to sustainable techniques. The results demonstrated that southern Brazilian municipal technicians appreciated and recognized the techniques demonstrated for projects with LID applications. Despite the technicians' lack knowledge of the techniques mentioned, respondents still considered the lack of laws and standards in the sustainable area, as well as the lack of manuals and books with sustainable urban applications for the development of cities.

In conclusion, the results of this study indicate that the application of low impact development techniques as presented can be used in the realities of southern Brazilian municipalities and in other urban realities for better implementation of sustainable techniques and awareness of LID techniques by public authorities, by technicians and southern Brazilian municipalities.

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