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Urban Landscape and Technological Management in Porto Alegre: Failures, Challenges, and Perspectives after the 2024 Flood

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Paisagem urbana e gestão tecnológica em Porto Alegre: falhas, desafios e perspectivas após a enchente de 2024

RESUMO

Objetivo - Analisar a vulnerabilidade de Porto Alegre frente às enchentes, articulando a evolução urbana, o funcionamento e as limitações do sistema de proteção, bem como as possibilidades em termos de gestão tecnológica.

Metodologia - Pesquisa qualitativa baseada em revisão bibliográfica e levantamento cartográfico de dados vetoriais e matriciais. O geoprocessamento foi utilizado para conversão de formatos, padronização de projeções e análise espacial das áreas afetadas e zonas de risco, além de estudo de caso como complementação.

Originalidade/relevância - O estudo aborda a lacuna existente na integração entre gestão da paisagem e estratégias de resiliência urbana diante de eventos climáticos extremos, relacionando memória histórica, infraestrutura de contenção e novas tecnologias de dados geoespaciais.

Resultados - Identificação das fragilidades estruturais e de gestão do sistema de contenção; mapeamento das áreas atingidas; caracterização dos prejuízos sociais, econômicos e ambientais; e discussão de referências internacionais, como o projeto Helsinki 3D+, para aprimoramento da gestão e preservação.

Contribuições teóricas/metodológicas - Avanço na compreensão das interações entre urbanismo, gestão de risco e da paisagem; aplicação integrada de análise histórica e tecnologias para subsidiar políticas públicas.

Contribuições sociais e ambientais - Proposição de estratégias para reduzir a vulnerabilidade urbana, incentivando políticas preventivas, uso de dados abertos e integração entre meio ambiente e desenvolvimento urbano sustentável.

PALAVRAS-CHAVE: Enchentes. Paisagem urbana. Mudanças climáticas. Tecnologias de gestão urbana. Porto Alegre.

Urban Landscape and Technological Management in Porto Alegre: Failures, Challenges, and Perspectives after the 2024 Flood

ABSTRACT

Objective - To analyze the vulnerability of Porto Alegre to floods, linking urban development, the functioning and limitations of the protection system, as well as opportunities technological management.

Methodology - Qualitative research based on literature review and cartographic survey of vector and raster data. The geoprocessing was used for format conversion, projection standardization, and spatial analysis of affected areas and risk zones, complemented by a case study.

Originality/Relevance - The study is concerned with the gap in integrating landscape management and urban resilience strategies in the face of extreme climate events, connecting historical memory, containment infrastructure, and new geospatial data technologies.

Results - Identification of structural and management weaknesses in the containment system; mapping of affected areas; characterization of social, economic, and environmental damages; and discussion of international references, such as the Helsinki 3D+ project, to enhance management and preservation.

Theoretical/Methodological Contributions - Advancement in understanding the interactions between urban planning, risk management, and landscape; integrated application of historical analysis and technologies to support public policies.

Social and Environmental Contributions - Proposal of strategies to reduce urban vulnerability, encouraging preventive policies, use of open data, and integration between the environment and sustainable urban development.

KEYWORDS: Floods. Urban landscape. Climate change. Urban management technologies. Porto Alegre.

Paisaje Urbano y Gestión Tecnológica en Porto Alegre: Fallas, Desafíos y Perspectivas tras la Inundación de 2024

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RESUMEN

Objetivo - Analizar la vulnerabilidad de Porto Alegre frente a las inundaciones, articulando el desarrollo urbano, el funcionamiento y las limitaciones del sistema de protección, así como las oportunidades en términos de gestión tecnológica.

Metodología - Investigación cualitativa basada en revisión bibliográfica y levantamiento cartográfico de datos vectoriales y raster. Se utilizó geoprocesamiento para conversión de formatos, estandarización de proyecciones y análisis espacial de las áreas afectadas y zonas de riesgo, complementado con un estudio de caso.

Originalidad/Relevancia - El estudio aborda la brecha existente en la integración entre la gestión del paisaje y las estrategias de resiliencia urbana frente a eventos climáticos extremos, vinculando la memoria histórica, la infraestructura de contención y las nuevas tecnologías de datos geoespaciales.

Resultados - Identificación de las debilidades estructurales y de gestión del sistema de contención; mapeo de las áreas afectadas; caracterización de los daños sociales, económicos y ambientales; y discusión de referencias internacionales, como el proyecto Helsinki 3D+, para mejorar la gestión y preservación.

Contribuciones Teóricas/Metodológicas - Avances en la comprensión de las interacciones entre urbanismo, gestión de riesgos y paisaje; aplicación integrada de análisis histórico y tecnologías para respaldar políticas públicas.

Contribuciones Sociales y Ambientales - Propuesta de estrategias para reducir la vulnerabilidad urbana, fomentando políticas preventivas, uso de datos abiertos e integración entre medio ambiente y desarrollo urbano sostenible y sustentable.

PALABRAS CLAVE: Inundaciones. Paisaje urbano. Cambio climático. Tecnologías de gestión urbana. Porto Alegre.

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1 INTRODUCTION

Porto Alegre faces a growing challenge related to flooding, resulting from the combination of natural factors and the intense process of urbanization throughout the twentieth century. The city's historical relationship with Lake Guaíba, together with the hydrological system of the Jacuí River Delta, has consistently required adaptations and responses to extreme climatic events. Since the earliest land reclamation projects and modernization works, the city has sought both proximity to and protection from its main water body, in a process that generated environmental, social, and symbolic impacts that transformed the urban landscape and reshaped how the population relates to water.

However, the rainfall events of 2024 exposed structural weaknesses in urban infrastructure, producing severe impacts on the population, public services, economic sectors, and historic properties. The management model based on physical flood control structu res and fragmented public policies proved incapable of responding with the necessary agility to extreme events. The partial collapse of the system of levees, pumping stations, and floodgates, combined with the absence of integrated monitoring and forecasting tools, revealed the vulnerability of a metropolis that developed along the margins of a water body that, since the nineteenth century, has already demonstrated its magnitude through severe flooding events (Heinzelmann, 2024). The intense rainfall of May 2024 triggered the largest flood in the city's history, with Lake Guaíba reaching a level of 5.50 meters. This event inundated entire neighborhoods, compromising urban mobility and the conservation of historic heritage.

At the same time, the disaster highlighted the potential of scientific and collaborative mobilization, as demonstrated by the emergency actions of research groups from the Federal University of Rio Grande do Sul (UFRGS), which employed improvised hydrological models to support civil defense agencies. This effort reinforces the urgency of consolidating permanent public systems for hydrological and hydrodynamic modeling, integrated with open spatial data platforms and decision support systems (PMPA, 2024).

International experiences offer relevant references, such as the Helsinki 3D+ project in Finland, which exemplifies how the integration of technology, public governance, and transparency can enhance urban resilience (Xu et al., 2021). The contrast with Helsinki makes explicit the extent to which Porto Alegre still depends on emergency responses and private platforms subject to high costs, or on solutions developed in an improvised manner due to the absence of institutionalized planning.

This study therefore departs from the analysis of the 2024 flood as a historical milestone to discuss the limits and challenges of water governance in Porto Alegre. It is necessary to understand how urban memory, structural solutions, and access to information are intertwined in the production of vulnerability, and how new technological tools for urban management, when associated with long-term public policies, can contribute to redefining the relationship between the city and the river in the context of climate change.

2 OBJECTIVES

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The overall objective of this article is to analyze the vulnerability of Porto Alegre to flooding by articulating urban evolution, the operation and limitations of the flood protection system, as well as the possibilities related to technological management for future extreme climatic events.

As specific objectives, the study seeks to identify and historically contextualize the relationship between the city and Lake Guaíba and the main flood events, highlighting their effects on urban configuration and collective memory; to evaluate the effectiveness and the weaknesses of the flood control system, considering its original design, maintenance processes, and spatial selectivity; and to discuss technological management strategies and urban resilience approaches, with emphasis on the use of modeling tools, public data platforms, and long-term public policies to address extreme events.

3 METHODOLOGY / ANALYTICAL APPROACH

This research adopts a qualitative methodology, based on a literature review and on cartographic data collection, comprising both vector datasets such as contour lines, flood extent maps, the location of historic sites, and the official state cartographic base, and raster datasets, specifically Digital Elevation Models (DEMs), used for altimetric analysis. In addition, a geoprocessing study is conducted using tools for file format conversion from KML to Shapefile, standardization of coordinate reference systems from WGS 84 to SIRGAS 2000, and spatial analysis of affected areas and identified risk zones. The methodology also incorporates a case study approach, aimed at examining possibilities for urban management through the use of technological tools, allowing the discussion of their applicability and potential contributions to flood risk management and urban resilience.

4 PORTO ALEGRE AND VULNERABILITY TO CLIMATE CHANGE: LAKE GUAÍBA AS AN INDICATOR OF THE FRAGILITY OF THE CITY'S FLOOD INFRASTRUCTURE

The Lake Guaíba, formed by the confluence of the Caí, Sinos, Gravataí, and Jacuí rivers, which together constitute the Jacuí River Delta, has always played a fundamental role in the development of Porto Alegre, acting as a strategic route for transportation and regional integration. Since the eighteenth century, colonizers recognized the value of its location along this water body, which provides access to the Patos Lagoon and, subsequently, to the Atlantic Ocean (Fernandes, 1975). Formal occupation of the area began in 1740, when Jerônimo de Ornellas received a land grant (sesmaria), marking the initial phase of territorial exploitation. The effective process of urbanization took place in 1752 with the arrival of Azorean settlers, who established themselves in Largo da Quitanda, later known as Alfândega's square (Perez, 2019).

During the nineteenth century, Porto Alegre's strategic position in southern Brazil consolidated the city as an entry point for European immigrants, especially Germans and Italians, whose skilled labor contributed to economic growth. The installation of the customs house in 1803 strengthened the city's role as a commercial and regulatory center in the region. Its privileged location enabled connections between inland areas and the coast, favoring river transport and trade (Perez, 2019). In addition, Porto Alegre became a mandatory passage

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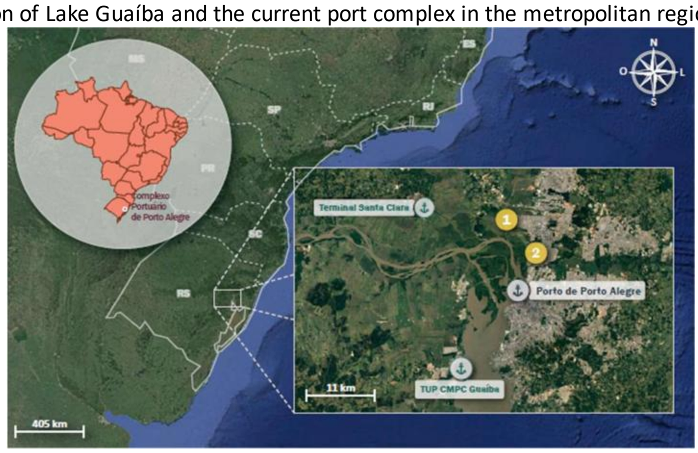
between Rio Grande and Rio Pardo, two important centers at the time, consolidating its position as a commercial entrepôt and a strategic point of defense.

The transition from a city with a colonial character to a tertiary urban center intensified between the late nineteenth and early twentieth centuries. The process of industrialization stimulated the installation of factories and productive units in areas close to the river and the port zone, particularly in the Floresta and Navegantes neighborhoods, transforming these areas into significant industrial hubs (Andrade et al., 2019). Despite the strong connection to river transport, port infrastructure remained limited until that period, consisting mainly of simple wooden piers, which constrained commercial expansion (Alves, 2005).

Figure 1 – Location of Lake Guaíba and the current port complex in the metropolitan region of Porto Alegre



Source: Valente, 2020.

Between 1892 and 1895, during the administration of the municipal intendant Alfredo Augusto de Azevedo, the engineer Guilherme Ahrons, then Director of Municipal Works, prepared the first quay project for Porto Alegre. This proposal primarily aimed at coastal sanitation, involving sewage collection and drainage, with the objective of combating insalubrity and promoting public health. In parallel, the state government developed the project "Porto Alegre, Porto de Mar", which proposed the deepening of navigation channels in Lake Guaíba and the Patos Lagoon to allow long distance navigation. The construction of a modern port significantly altered the city's relationship with Lake Guaíba, transforming its waterfront and symbolizing the aspirations of local elites to project an image of a progressive city. These interventions particularly reshaped the northern edge of the historic center, reinforcing its role as an economic and logistical core.

At the end of the nineteenth century and the beginning of the twentieth century, hygienist movements exerted strong influence on urban improvement discourses in Brazil, with an emphasis on preventing epidemics (Costa; Diniz, 2021). Urban improvements in Porto Alegre began after successive cholera outbreaks recorded until 1860, which led to the creation of the Porto-Alegrense Hydraulic Company, aimed at improving water supply. Although the city was located near abundant water sources, all waste disposal occurred directly into Lake Guaíba and its tributaries. The company initiated the distribution of water from springs located in the surrounding highlands to the urban area. Concern with the urban environment intensified, and in 1912 the Commission for Urban Improvement and Beautification was established (Abreu Filho, 2006).

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During this period, the state government promoted sanitation and urban beautification interventions aligned with the principles of hygienist urbanism, such as the redesign of Praça da Alfândega (Alves, 2005). In the 1920s, the first regulations controlling building heights were introduced, encouraging verticalization, particularly in central areas. Urban growth until the 1930s was driven by strategic infrastructure works, including the opening of Avenida do Porto, later renamed Avenida Mauá, Avenida Júlio de Castilhos, and the construction of Avenida Borges de Medeiros.

The northern waterfront of the city, where the port was located, concentrated intense commercial, transportation, and service activities. Dense occupation, combined with the lack of adequate infrastructure such as sewage systems and waste collection, created an unhealthy environment conducive to the spread of diseases (Alves, 2005). Port related insalubrity was perceived as a chronic problem that compromised both public health and the city's image. In this context, land reclamation served a dual function: expanding available land for port and urban uses while simultaneously sanitizing the margins of Lake Guaíba.

The construction of the Port of Porto Alegre took place in the early twentieth century as part of the modernization process of both the city and the state of Rio Grande do Sul. The project also symbolized the development agenda promoted by the Rio-Grandense Republican Party, which was then in power. According to Kühn and Scott (2023), the river port became a strategic link between the Port of Rio Grande, the state capital, and inland territories.

Located within the Jacuí River Delta, the port region is formed by multiple channels or river arms that converge into one another. This type of river mouth is characteristic of low gradient rivers, due to gentle slopes and reduced discharge capacity, which favor sediment accumulation. According to Menegat (2008/2009), the Jacuí Delta forms a distinctive archipelago resulting from the confluence of the Jacuí, Caí, Sinos, and Gravataí rivers, composed of 18 islands intersected by 15 sinuous channels. Among them, Ilha das Flores is the largest, while Ilha Grande dos Marinheiros is the most extensive. The Jacuí Delta State Park and the Jacuí Delta Environmental Protection Area encompass the archipelago and adjacent floodplains, ensuring environmental preservation.

Lake Guaíba, whose name derives from the Guarani language and means "meeting of waters" or "inlets", holds major environmental significance for surrounding cities. The lake forms a freshwater reservoir with an approximate volume of 1 km^3 and constitutes virtually the sole source of water supply for Porto Alegre. In addition, it plays a fundamental role in receiving urban liquid waste discharges (Menegat, 2008/2009).

The removal of wetlands and the creation of urbanized spaces aimed to combat insalubrity and improve sanitary conditions in central Porto Alegre (Alves, 2005). Hygienist urbanism in the early twentieth century advocated the control and transformation of nature to meet the demands of modern urban life.

Despite these interventions, the city's relationship with Lake Guaíba remained marked by vulnerabilities. Recurrent floods recorded in 1873, 1889, 1897, 1905, 1912, 1914, 1916, 1928, and 1936 demonstrate the exposure of the region to hydrological variability within the Jacuí Delta fluvial system (Devos, 2007).

In the twentieth century, the 1941 flood stands out as the most devastating event recorded in Porto Alegre, reaching a record level of 4.75 meters above the port quay reference

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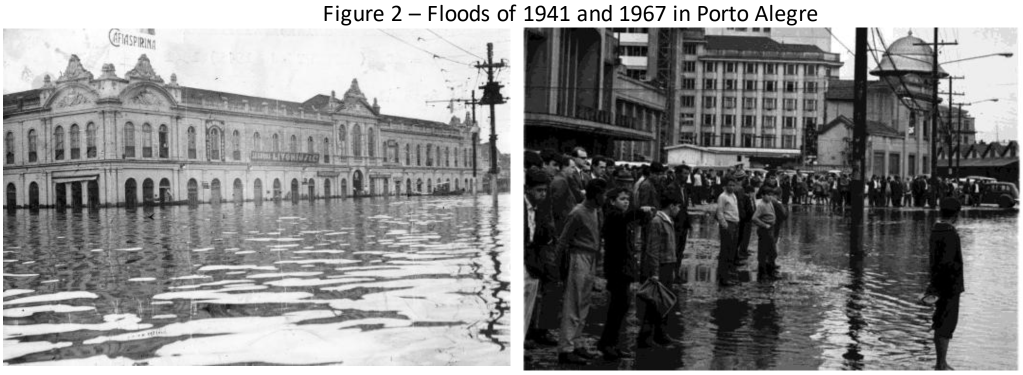
(Silveira, 2020). This event caused severe damage to urban infrastructure, affecting the Gasômetro Power Plant, which was essential for electricity generation, and interrupting potable water supply for thousands of residents (Valenti et al., 2012). Approximately 70,000 inhabitants were displaced, corresponding to about 26 percent of the city's population at the time (Lersch, 2003).

The 1940s were marked by modernization plans, such as the Gladosch Plan (Abreu Filho, 2006), which intensified debates on the need for flood protection. Following the 1941 flood, the National Department of Works and Sanitation analyzed different alternatives and opted for the construction of protective levees and an integrated flood control system (Bohrer, 2001).

Even after major flooding events, land reclamation continued to be used as an instrument of urban expansion. The Praia de Belas landfill, conceived in the 1930s and executed between the 1950s and 1970s, became one of the largest landscape transformation projects in Porto Alegre. The area now hosts Marinha do Brasil Park and Maurício Sirotsky Sobrinho Park, as well as administrative centers, radically altering the city's relationship with Lake Guaíba (Andrade et al., 2019). Prior to intervention, Praia de Belas functioned as a leisure and social gathering space, frequented for swimming and recreational activities, where residents enjoyed the landscape and direct contact with the lake (Branco Filho; Basso, 2005).

Figure 2 – Floods of 1941 and 1967 in Porto Alegre



Source: Correio do Povo (2024); Zero Hora (2015). Available at: https://www.correiodopovo.com.br; https://gauchazh.clicrbs.com.br. Accessed: 08 Aug. 2025.

The land reclamation techniques employed during the 1960s and 1970s were based on the direct deposition of debris and various materials into Lake Guaíba, generating negative environmental impacts and contributing to the degradation of the water body. Ilha Coroa dos Bagres was completely destroyed due to material extraction for the Praia de Belas landfill. The construction of the containment wall along Avenida Mauá intensified the physical and symbolic separation between the city and Lake Guaíba (Branco Filho; Basso, 2005). This rupture has been interpreted by many as a significant loss for Porto Alegre, distancing the city from a central element of its identity and history.

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Figure 3 – Construction of the Mauá Wall in the 1970s

Source: Zero Hora (2023). Available at: https://gauchazh.clicrbs.com.br. Accessed: 10 Aug. 2025.

In 1967, another flood occurred, reaching a level of 3.13 meters and accelerating the completion of the flood protection system, finalized in 1974 with the construction of the Mauá Wall. The structure extends 2,647 meters in length and reaches 3 meters in height, designed to prevent large scale flooding events (Valenti et al., 2012). The wall integrates a levee system totaling 68 kilometers in length, conceived to protect areas vulnerable to flooding, particularly the central zone, where the City Hall, the Post and Telegraph Building, the State Treasury Secretariat, the Rio Grande do Sul Museum of Art, and the historic center are located (Valenti et al., 2012).

The absence of major floods in the decades following the construction of the wall led to questions regarding its actual necessity and fostered proposals for its removal, aimed at revitalizing the waterfront and reintegrating the city with the lake (Devos, 2007). However, the floods of 2024 reaffirmed the strategic importance of the Mauá Wall for the protection of the urban core.

4.1 The 2024 flood and its impacts on the urban landscape of Porto Alegre

The intense rainfall events of May 2024 resulted in the most severe flood ever recorded in Porto Alegre, with Lake Guaíba reaching a water level of 5.50 meters. The event inundated entire neighborhoods, displaced more than 200,000 people, and caused economic and social losses of considerable magnitude. Failures in the flood protection system revealed critical structural problems, particularly the inability of drainage pumping stations to evacuate excess water volumes, which led to the flooding of areas that were expected to remain protected (O Sul, 2024).

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Figure 4 – Flooded area in the Cais Mauá region during the 2024 flood

Source: Ascom Portos RS, 2024. Available at: https://www.estado.rs.gov.br/. Accessed: 05 Dec. 2024.

The most affected areas included the central region, the Sarandi and Humaitá neighborhoods, the islands of the Jacuí River Delta, and parts of the southern zone of the city, compromising urban mobility and the distribution of potable water. Essential services were disrupted, including electricity supply and the operation of the water treatment plant. The consequences affected not only public infrastructure but also the productive sector, which recorded losses in industrial output, interruptions in commercial activities, and logistical damages, with particular emphasis on the disruption of fluvial freight transportation (Nemer et al., 2026).

Between 27 April and early May 2024, the state of Rio Grande do Sul experienced persistent rainfall for more than ten consecutive days, overloading the hydrographic basins of the Taquari, Caí, Pardo, Jacuí, Sinos, and Gravataí rivers. Simões (2024) observed that whenever the water level of Lake Guaíba exceeds 3.00 meters, the port area becomes flooded, characterizing a rare event that nevertheless occurred twice in 2023 and again in 2024.

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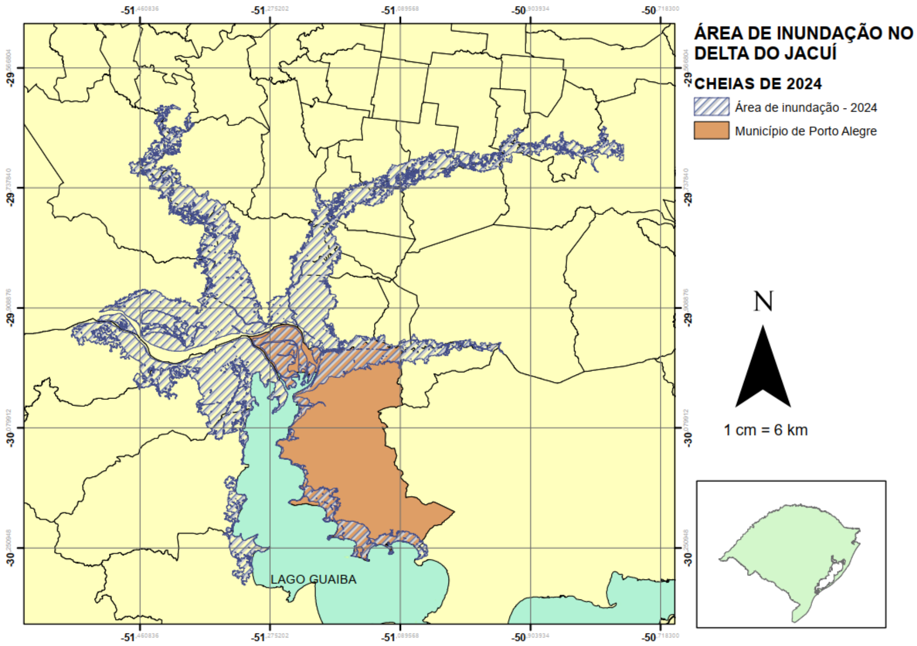
Figure 5 – Flooded area in the Jacuí River Delta during the 2024 flood events



Source: Elaborated by the authors based on data collected from the databases of the Municipality of Porto Alegre and the Federal University of Rio Grande do Sul.

The El Niño climatic phenomenon, by raising sea surface temperatures in the Pacific Ocean above historical averages, intensified precipitation patterns and resulted in rainfall volumes significantly higher than normal. As a consequence, the water level of Lake Guaíba rose rapidly, exceeded the official flood threshold, and reached the historical record of 5.33 meters on 5 May 2024 (Heinzelmann, 2024). The map presented in Figure 5 illustrates the extensive flooded area within the Jacuí River Delta, where floodwaters persisted for several weeks.

The flood control system of Porto Alegre comprises more than 60 kilometers of levees, designed to contain flood events of up to 6 meters, and includes 23 pumping stations equipped with 86 pumps, with a total discharge capacity of 170 m³/s, which connect the Flood Protection System to the Urban Stormwater Drainage System (PMPA, 2024). During the 2024 flood, the levees performed as intended; however, some floodgates were unable to fully retain the water, and the main failures occurred at the pumping stations, which were unable to provide sufficient discharge capacity, became inundated, and subsequently suffered equipment burnout.

The water, unable to drain adequately, overflowed from retention structures and returned to the streets through the stormwater inlets. These failures can be attributed to the lack of proper maintenance over the years. Problems had already been identified in previous periods, such as failures in floodgates in 1983 and again in 2023, without corrective interventions being carried out (Marko, 2024). The absence of sustained investment in the maintenance and preservation of this critical infrastructure contributed to the severity of the disaster, leaving affected areas submerged for approximately one month.

Figure 6 – Flooded area in the region of the Porto Alegre Municipal Market during the 2024 flood

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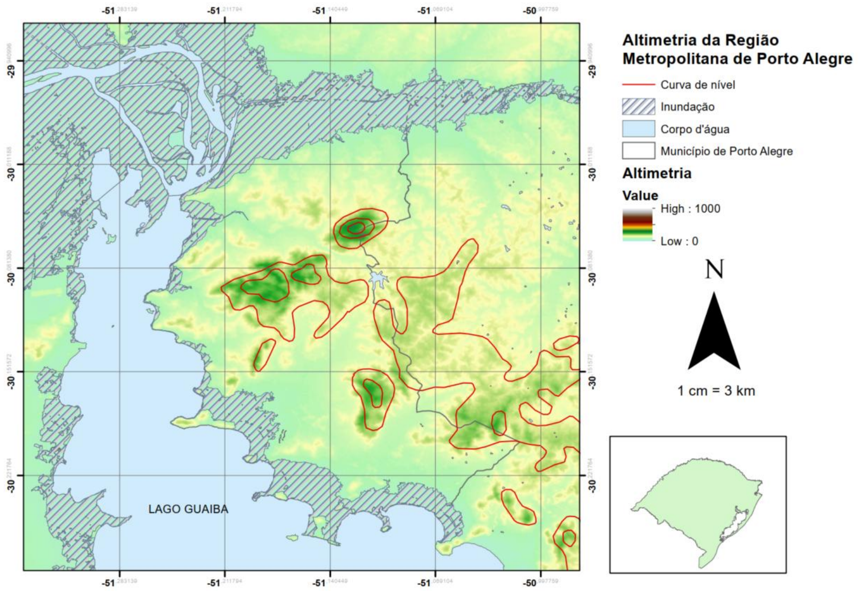
Source: Ascom Portos RS, 2024. Available at: https://www.estado.rs.gov.br/. Accessed: 05 Dec. 2024.

The port, located at an elevation of 3.00 meters, was completely inundated. With the river level reaching 5.50 meters, port operations remained suspended for 45 days to allow for cleaning activities and structural repairs. Electromechanical equipment, such as weighing scales, was destroyed, making cargo weighing operations impossible. In practical terms, port activities were interrupted for nearly three months, considering the time required for water recession and subsequent recovery works (Simões, 2024).

Figure 7 – Altimetry and flooded area in the Jacuí River Delta during the 2024 flood events



Source: Elaborated by the authors based on data collected from the databases of the Municipality of Porto Alegre and the Federal University of Rio Grande do Sul.

The Figure 7 presents the altimetric characteristics of the Greater Porto Alegre region, indicating that a significant portion of the city is located in areas susceptible to flooding. Factors such as low elevation, proximity to watercourses, and the occupation of historically flood prone areas increase this vulnerability. Soil impermeabilization, resulting from unplanned urban expansion, further aggravates the limitations of natural drainage processes.

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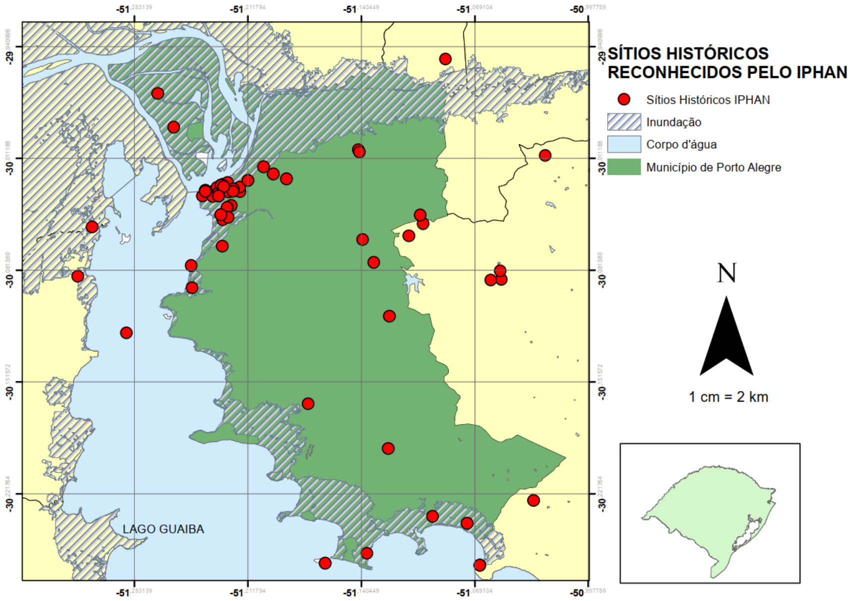
According to Simões (2024), port warehouses were covered with mud, approximately 200,000 tonnes of goods were lost, mainly fertilizers and barley, and nearly all office furniture and equipment were destroyed. These losses affected both the private sector and public authorities, leading to a decline in tax revenues.

The city contains a nationally significant historic heritage, recognized by the National Institute of Historic and Artistic Heritage (IPHAN), including buildings, public squares, and urban ensembles representative of different periods of Brazilian history. Among the most affected assets are the Historic Center of Porto Alegre, the Municipal Hall, the Public Market, Cais Mauá, the Gasômetro Power Plant, São Pedro Theatre, the Metropolitan Cathedral, and several townhouses of architectural and symbolic value. Figure 8 shows the spatial distribution of these historic sites, revealing that many are located in flood susceptible areas, particularly near Lake Guaíba and its tributaries.

Figure 8 – Location of cultural heritage sites and flooded areas in the Jacuí River Delta during the 2024 flood events



Source: Elaborated by the authors based on data collected from the databases of the Municipality of Porto Alegre, the Federal University of Rio Grande do Sul, and the National Institute of Historic and Artistic Heritage (IPHAN).

Studies on the vulnerability of built heritage to climate change and extreme events indicate that prolonged exposure to water accelerates material degradation and requires specific protection and conservation strategies (Pereira et al., 2021). According to Civil Defense records, the 2024 disaster resulted in 85 fatalities, 339 injured individuals, 134 missing persons, and more than 201,000 people displaced, of whom 153,824 were temporarily displaced and 47,676 were sheltered in public facilities.

4.2 Current urban governance in Porto Alegre and possibilities for technological improvement

The flood that affected Porto Alegre in 2024 revealed structural vulnerabilities within the city, but also exposed deficiencies in the management and access to essential urban data required for planning, monitoring, and emergency response. The dispersion of information,

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stored across multiple private and public sources that are often inaccessible or incompatible, hindered rapid and coordinated action by researchers, managers, and public authorities. The lack of integrated public systems for flood monitoring and management highlighted the city's reliance on emergency based solutions. One example was the creation of a digital platform developed on a voluntary basis by different sectors of the Federal University of Rio Grande do Sul (UFRGS), in collaboration with external researchers. The platform brought together water level forecasting models, mapping of affected areas, and critical information to support crisis response.

The platform developed by the Institute of Hydraulic Research (IPH/UFRGS), in cooperation with dozens of researchers and external volunteers, represents a significant effort of collective mobilization in response to the collapse of information flows during the 2024 crisis (Possantti; Müller; Ruhoff, 2024). The system integrated hydrological and hydrodynamic forecasts, daily bulletins on Lake Guaíba water levels, interactive maps, and open databases for public use, providing estimates of flooded areas and direct impacts across the Lake Guaíba Hydrographic Region.

Figure 9 – Flood events in Rio Grande do Sul: databases and geographic information for the Lake Guaíba Hydrographic Region and the Patos Lagoon in 2024

Source: Possantti; Müller; Ruhoff (2024).

Although the initiative provided strategic inputs for public managers, local authorities, and researchers, its emergency driven and voluntary nature reveals a structural gap, namely the absence of a continuous, integrated, and real time state operated system capable of supporting decision making before, during, and after extreme climatic events. The reliance on external platforms and the dispersion of information, some of which was accessible only through private tools such as Google MyMaps, reinforce a scenario of informational vulnerability. Beyond fragmentation, there is a growing global concern regarding data control by large private corporations. Initially, these companies offer free or low cost services to public institutions, gradually creating technological dependence. Subsequently, they begin to enclose data access, restricting availability and imposing high fees for service continuity. This phenomenon, known as data enclosure or digital enclosure, places governments in a vulnerable position, particularly when they fail to invest in their own technologies for data storage and management (Zuboff, 2020).

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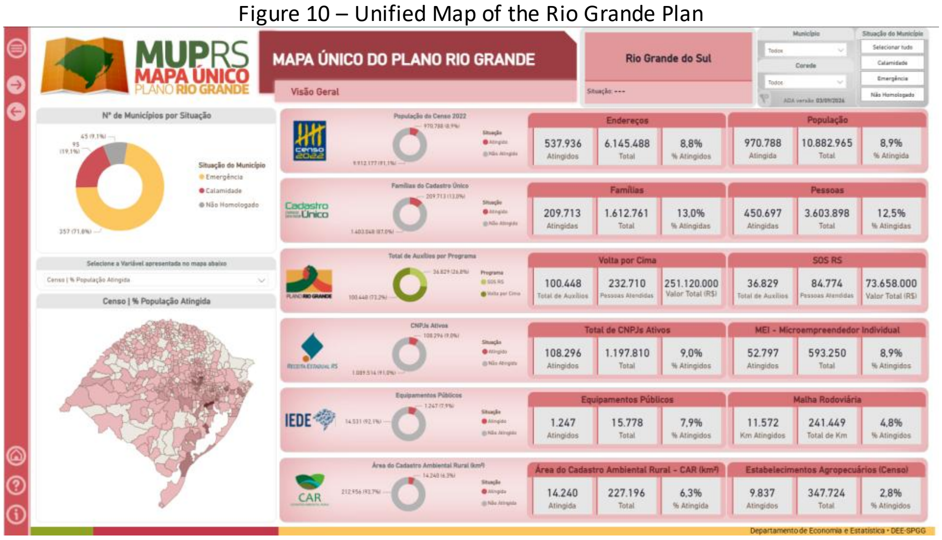
The strategy adopted by Google exemplifies this process of data enclosure and was described by a former executive and Chief Strategy Officer, who publicly acknowledged the use of practices that create barriers to free access to essential data and services in pursuit of progressive monetization. This dynamic has recently become evident in Brazil, when major corporations such as Google and Microsoft revised their cloud storage policies, directly affecting universities and public agencies that rely on these services for the storage and sharing of scientific and academic data, as reported by the newspaper O Globo (Alfano, 2024).

In the case of Porto Alegre, a new geoportal associated with the State Spatial Data Infrastructure (Iede) was launched, developed using ArcGIS Enterprise. Despite representing a relevant advancement, the platform became available only in 2025, one year after the flood event. This timing demonstrates that, during the critical period, there was no consolidated and integrated public technological infrastructure capable of facilitating access to and analysis of geospatial data to support emergency decision making. It should be noted that, although ArcGIS has not adopted abusive pricing policies, the geospatial technology market is dominated by a small number of private companies, which may result in high costs and future limitations on access for the public sector.

Figure 10 – Unified Map of the Rio Grande Plan



Source: Rio Grande do Sul (2025). Available at: https://mup.rs.gov.br/. Accessed: 06 Aug. 2025.

The lack of integration and of public technologies, identified in the Dutch Disaster Risk Reduction and Surge Support Programme (DRRS) and made available by the Municipal Department of Water and Sanitation of Porto Alegre, highlights the urgency of developing advanced modeling tools capable of supporting both immediate crisis management and long-term planning. The development of such tools is considered an essential non-structural measure for flood management in Porto Alegre, and several studies and services cited in the report emphasize the need to create or enhance these simulation instruments (PMPA, 2024).

These tools serve multiple purposes and applications, enabling a comprehensive understanding of the water system by describing hydrological, hydrodynamic, environmental, and morphological processes that extend from upstream river basins to the Atlantic Ocean. In this way, they are fundamental for scenario analysis and sensitivity assessment, allowing the

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evaluation of options to reduce discharge bottlenecks along the Jacuí River Delta and associated lagoons, thereby increasing floodwater conveyance capacity and reducing flood levels. Another application concerns early flood warning systems, in which hydrological and hydrodynamic models provide water level forecasts with the greatest possible lead time. The tools also allow the assessment of the impacts of increasing discharge capacity at the Barra de Rio Grande, which requires specific water quality models and ecological analyses to understand phenomena such as saline intrusion and their effects on ecosystems.

The development of these tools requires different types of models (PMPA, 2024). A hydrological model is necessary and applicable to the basins of the Jacuí, Caí, Sinos, and Gravataí rivers, as well as to the basins surrounding the Guaíba River and the Patos Lagoon. Although the Institute of Hydraulic Research (IPH/UFRGS) already operates a distributed hydrological model, the calibration of this system needs to be improved based on data from the May 2024 flood events and on long-term monitoring series of water levels and discharges.

A 2D/3D hydrodynamic model is also required to describe flow dynamics in the Guaíba River and the Patos Lagoon, with particular attention to wind effects and simulations under different wind scenarios. This model becomes essential if the feasibility of increasing discharge capacity toward the Atlantic Ocean is confirmed, as it involves the modeling of saline intrusion, ecological effects, and morphological evolution of both the Delta and the Guaíba River, as well as the northern portion of the Patos Lagoon.

The report recommends the use of two platforms for these purposes (PMPA, 2024). Delft3D, which is widely used worldwide for hydrodynamic and morphological modeling, is a free and open-source platform developed in the Netherlands by Deltares. Brazil currently represents the fourth largest user community of this tool, which facilitates its adoption. Delft-FEWS is indicated as the platform for the flood forecasting system and is also free and open source.

At this point, it is important to emphasize that international experiences offer relevant perspectives for the development of an advanced and open system in Porto Alegre. In Finland, the Helsinki 3D+ project provides an example of how a local government can assume leadership in the creation and open management of urban data. Initiated with a budget of approximately one million euros and funded by the City of Helsinki, the project's main objective was the development of two detailed three-dimensional models of the urban area, employing state-of-the-art technologies for data acquisition and processing.

The process combined several advanced techniques, including airborne LiDAR for the accurate capture of topography and urban surfaces, as well as the acquisition of more than 50,000 oblique images using specialized cameras. These images were processed using advanced software such as Bentley ContextCapture. The use of more than 600 ground control points ensured spatial accuracy of up to 10 centimeters, guaranteeing high fidelity of the resulting models (Xu et al., 2021).

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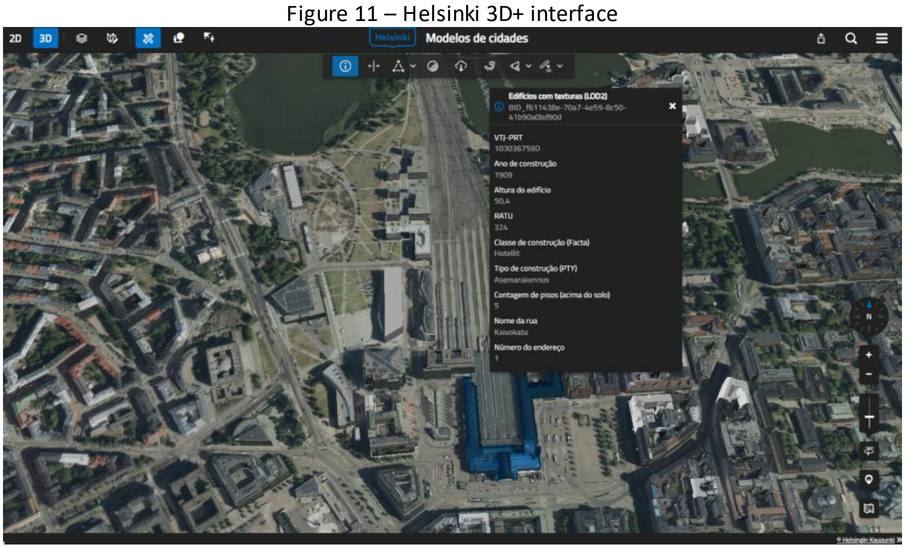
Figure 11 – Helsinki 3D+ interface



Source: Helsinki (2025). Available at: https://kartta.hel.fi/3d/. Accessed: 08 Jul. 2025.

In addition to producing a three-dimensional mesh with high visual quality, Helsinki 3D+ developed a semantic model based on the CityGML standard, which goes beyond mere visual representation and enables complex analyses, such as estimates of energy consumption, building information management, greenhouse gas emissions, and assessments of environmental impacts caused by urban traffic (Geoweek News, 2021). This semantic approach greatly expands the potential uses of the data, allowing more efficient and sustainable urban simulations and planning processes.

The most innovative aspect of Helsinki 3D+ lies in its open data policy, which makes datasets freely available to the general public, universities, private companies, and public authorities. Free access to these models enables the development of a wide range of applications, from digital games, such as Minecraft Helsinki, to tools for participatory urban planning, public space quality assessment, and energy modeling in collaboration with internationally renowned institutions such as the Technical University of Munich (Geoweek News, 2021).

This openness fosters a collaborative ecosystem in which citizens can actively participate in urban governance, universities can develop advanced research, and companies can create innovative solutions. The Helsinki model serves as an inspiration for strengthening urban resilience and addressing climate change, supporting clearly defined goals such as carbon neutrality by 2050, which are underpinned by accurate and accessible data (Geoweek News, 2021).

The comparison between Helsinki and Porto Alegre reveals distinct trajectories in data governance and urban modeling. While the Finnish capital has established a policy of transparency and open access capable of supporting research, technological innovation, and citizen participation, Porto Alegre remains dependent on emergency driven initiatives, fragmented platforms, and private solutions subject to high costs and future access restrictions. This disparity reinforces the need to transform the lessons learned from the 2024 flood into structural public policies that consolidate permanent systems for monitoring, modeling, and public management of information.

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Within this context, local debates have emerged regarding structural interventions, such as the dredging of tributaries in the Jacuí River Delta and in Lake Guaíba. Simões (2024) argues, while acknowledging the controversial nature of the proposal, in favor of dredging navigation channels and deeper sections of the lake, considering them essential for improving water conveyance. Heinzelmann (2024) adds that the absence of an active memory of the 1941 flood contributed to the neglect of flood protection system maintenance, a phenomenon associated with the erasure of long-term traumatic memories. According to this perspective, the so-called "post-memory" of that event, transmitted in a fragmented manner, was insufficient to sustain preventive awareness.

In conclusion, Simões (2024) states that Porto Alegre can prepare to face future floods of similar magnitude, given that the city already possesses a levee system of approximately 70 kilometers, designed for a 6.00-meter elevation, which exceeds the maximum level recorded in 2024. Pumping stations are being resized, electrical control systems relocated to higher elevations, and floodgates have been revised or permanently sealed. However, neighboring municipalities and the island regions remain highly vulnerable, as they lack levee systems and are characterized by irregular settlements located in flood-prone areas.

5 Final Considerations

The relationship between Porto Alegre and Lake Guaíba has historically shaped the urban landscape, sustaining economic activities and influencing the organization of urban space, while simultaneously exposing the city to permanent risks. Over time, processes of urban modernization have produced environmental and symbolic impacts that distanced the population from its main water body and brought to the fore the need for containment systems to control rising water levels during extreme climatic events.

The floods of 2024 revealed structural failures in the flood protection system and exposed the fragility of technological governance, as well as the absence of integrated systems capable of supporting rapid, data informed decision making. The experience of the Federal University of Rio Grande do Sul (UFRGS) demonstrated the potential of scientific and collaborative mobilization, but also reinforced the urgency of institutionalizing permanent mechanisms for monitoring, modeling, and information sharing.

Preparing the city for future extreme events therefore requires strategies within urban governance. On one hand, it demands the maintenance and modernization of levees, pumping stations, and floodgates, as well as broader discussions regarding structural interventions. On the other hand, it makes indispensable the investment in public data platforms and advanced technological tools capable of supporting preventive planning. Dependence on improvised solutions, combined with the concentration of data within private platforms, reveals how digital enclosure also operates within the dynamics of capital accumulation, transforming information into a commodity and increasing the vulnerability of the public sector.

In this regard, the contrast with international initiatives such as the Helsinki 3D+ project demonstrates that open data policies and technological integration strengthen urban resilience by fostering innovation, social participation, and democratic urban governance. The

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Finnish experience points to the need for Porto Alegre to move from fragmented management and reliance on emergency solutions toward a structural and long term policy framework.

In this way, rethinking the relationship between Porto Alegre and Lake Guaíba requires planning approaches that articulate urban development and environmental protection, ensuring that the city's historical memory and identity are preserved in the face of contemporary challenges. This process also entails questioning the contradictions of prevailing urbanization models, which have historically privileged economic accumulation at the expense of collective safety.

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DECLARATIONS

AUTHOR CONTRIBUTIONS

- **Conceptualization and study design:** Felipe Gustavo Silva, responsible for the central idea of the study, definition of objectives, and development of the methodology.
- **Data curation:** Felipe Gustavo Silva, organization and verification of data to ensure quality and reliability.
- **Formal analysis:** Felipe Gustavo Silva, execution of analyses and application of specific methods.
- **Funding acquisition:** No external funding was obtained for this study.
- **Investigation:** Felipe Gustavo Silva, conducting data collection and practical investigations.
- **Methodology:** Felipe Gustavo Silva, development and refinement of the applied methodologies.
- **Writing – original draft:** Luciana Nemer and Felipe Gustavo Silva, preparation of the first version of the manuscript.
- **Writing – review and critical revision:** Luciana Nemer and Felix Carriello, critical review of the text, improving clarity and coherence.
- **Review and final editing:** Luciana Nemer and Felipe Gustavo Silva, final review and adjustments to ensure compliance with journal guidelines.
- **Supervision:** Luciana Nemer and Felix Carriello, coordination of the work and assurance of the overall quality of the study.

DECLARATION OF COMPETING INTERESTS

We, Felipe Gustavo Silva, Luciana Nemer, and Felix Carriello, declare that the manuscript entitled "**Urban landscape and technological governance in Porto Alegre: failures, challenges, and perspectives after the 2024 flood**" presents no conflicts of interest, as detailed below:

1. **Financial relationships:** The authors declare that there are no financial relationships that could influence the results or the interpretation of this work.
2. **Professional relationships:** The authors declare that there are no professional relationships that could affect the analysis, interpretation, or presentation of the results.
3. **Personal conflicts:** The authors declare that there are no personal conflicts of interest related to the content of the manuscript.