Integrated and Sustainable Urban Regeneration Milan – Rio – REMIRIO: Urban Diagnosis based on Integrated Modification Methodology (IMM)

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Abstract. This article examines the application of the Integrated Modification Methodology (IMM) diagnostic procedure within an extended area of Rio de Janeiro, with a specific focus on Vila Operária Salvador de Sá. The study, part of the REMIRIO project, operates under the European Union's "Partnership for Sustainable Cities" program. Beginning with identifying the intermediate scale of the project, the diagnostic procedure evaluates IMM's Key Categories, including Porosity, Proximity, Diversity, Interface, Permeability, Accessibility, Effectiveness, and Green Continuity. This phase aims to identify the transformation catalyst by focusing on the key category where the urban system's inefficiencies that hinder proper functioning are most severe. The results, presented as graded maps and numerical metrics, are objectively assessed within the context of local systems, forming a comprehensive problem identification. Green continuity emerges as the catalyst, ultimately shaping a hierarchical action plan within the Integrated Modification Methodology. This plan tailors to urban policies and local agendas, guiding the development of a comprehensive strategic plan for the REMIRO project.

Keywords: Resilience, Integrated Modification Methodology, Green Continuity, Built Environment, Complex Systems

1 Introduction

The REMIRIO project, operating within the European Union's "Partnership for Sustainable Cities" program, embodies a collaborative effort between the municipalities of Milan and Rio de Janeiro. This initiative seeks to establish common visions and strategies to address the 2030 Agenda for Sustainable Development and the goals outlined by the C40 Cities Climate Leadership Group. The tool-sharing program as the training in the Integrated Modification Methodology (IMM), equipped technicians from Rio de Janeiro with the skills necessary for sustainable urban regeneration planning and implementation. The project's focus areas include the development of an Integrated Sustainable Urban Regeneration Plan (ISURP) in particular for the Vila Operaia area, emphasizing environmental sustainability, social inclusion, and economic growth.

Due to its cultural significance and urban challenges, Vila Operária Salvador de Sá, a historic housing district in Rio de Janeiro, is a compelling case study. Despite its architectural charm, the neighborhood faces maintenance and preservation issues, highlighting the need for comprehensive revitalization efforts. Vulnerable to the urban heat island effect [1] and flooding [2], Vila Operária presents an opportunity to explore strategies for mitigating these challenges through urban design interventions and green infrastructure. Moreover, its socio-economic complexity underscores the importance of addressing equity concerns in urban regeneration initiatives.

Analyzing Vila Operária's resilience strategies can inform broader policy development to enhance climate resilience and sustainability across Rio de Janeiro. Vila Operária thus serves as a valuable case study for advancing sustainable urban regeneration efforts and fostering inclusive, resilient communities in Rio de Janeiro and beyond. The findings of this project will be replicated in other areas of the city, contributing to an overall resilience strategy for Rio de Janeiro. By applying these successful strategies across various neighborhoods, we aim to build a more resilient, sustainable, and inclusive urban environment citywide.

2 Climate-Adaptive Strategies for Neighborhood Resilience: A Brief Background

The literature review on climate-adaptive strategies for neighborhood resilience underscores the critical importance of addressing the multifaceted challenges posed by climate change in urban areas. Drawing upon multidisciplinary research from various fields such as urban studies, environmental science, engineering, and planning, the review synthesizes key findings and identifies gaps in current knowledge.

Green infrastructure, nature-based solutions, and robustness, as the ability of systems to withstand and recover from climate-related shocks, emerge as pivotal components in enhancing neighborhood resilience to climate change, as highlighted by scholars such as Adger et al. [3], Berke and Campanella [4], and Colding and Barthel [5]. These strategies effectively mitigate environmental risks and promote sustainable urban development through robust urban systems.

Additionally, sustainable urban design and land use planning, as advocated by scholars like Bettencourt et al. [6] and Gibson [7], play crucial roles in building resilient communities and reducing vulnerability to climate-related hazards.

Community engagement and social cohesion are identified as critical factors in resilience-building efforts, emphasizing the importance of involving local communities in decision-making processes, as noted by Arnstein [8], Brown and Westaway [9], and Cutter et al. [10].

Researchers like Loonen et al. highlight technological innovations and resilient infrastructure systems as crucial components of climate-adaptive strategies [11].

Despite significant progress in research, several gaps remain to be addressed. These include the need for comprehensive approaches that consider the multifaceted nature of resilience, greater interdisciplinary collaboration, and a focus on equity and social justice in resilience interventions.

Future research should prioritize interdisciplinary approaches, community engagement, and integrating nature-based solutions to develop more holistic and contextually relevant climate-adaptive strategies. To analyze and improve neighborhood resilience and align it with the priorities identified in the literature review, the REMIRIO project employed the integrated modification methodology (IMM).

The REMIRIO project, based on IMM, aims to significantly enhance the robustness of Rio de Janeiro's urban systems by developing tailored solutions that address the specific needs and challenges of neighborhoods. REMIRIO aims to enhance neighborhood resilience and contribute to broader efforts in climate adaptation and urban resilience by emphasizing the integration of nature-based solutions and promoting community engagement. Moreover, by integrating green infrastructure, sustainable planning, and technological innovations, REMIRIO addresses the complex challenges of climate change holistically and interdisciplinary. This ensures that the city's urban systems are resilient, sustainable, and capable of adapting to future climatic and environmental uncertainties.

3 Methodology

3.1 Urban Diagnostics: Understanding Complex Adaptive Systems at the Intermediate Scale

Urban diagnostics in the integrated modification methodology (IMM) is a robust approach that assesses urban systems objectively. It combines qualitative and quantitative data to understand urban contexts as Complex Adaptive Systems [12], uncovering the root causes of challenges.

The first step in IMM is the definition of a morphology-based border for the intermediate scale analyses, which is needed to understand the local scale's urban dynamics and assess the impact of possible alternative transformation scenarios.

In the case of Rio's system, the intermediate scale of Vila Operária Salvador de Sá has been identified based on urban morphology characteristics resulting from the examination of 14 bairros. This intermediate-scale diagnostic elucidates the urban dynamics within Rio de Janeiro, bridging micro-level insights and macro-level strategic planning. It explores interconnected urban systems, revealing potential synergies and trade-offs essential for informed decision-making in urban development.

IMM utilizes Horizontal and Vertical Investigations to analyze urban systems comprehensively. In the Horizontal Investigation phase, typological and spatial layers such as built-up volumes, voids, types of uses, and urban networks are individually examined, resulting in basic maps depicting the distribution of urban elements. The Vertical Investigation, on the other hand, studies Key Categories — functional attributes that emerge from these layers — such as Porosity, Permeability, Accessibility, Effectiveness, Interface, Diversity, Proximity, and Green Continuity.

Porosity examines the integration of volumes and voids in urban landscapes, while Permeability assesses how the urban form facilitates movement. Accessibility evaluates the reachability of city parts and public transport availability. Effectiveness focuses on transportation outcomes and the balance between supply and demand. Interface looks at street network quality and movement facilitation. Diversity measures the variety of urban services, Proximity assesses walkability to points of interest, and Continuity examines the interconnectedness of green spaces for ecosystem services and biodiversity support. KCs are visually assessed through maps and measured with 6 spatial metrics each (for a total of 48).[1]

3.2 Data Collection and Analysis Techniques

Geospatial data play a crucial role in the application of IMM. However, data availability can vary significantly across contexts in terms of coverage, quality, granularity, topology, standard, and richness of attributes. Even with high-quality datasets, such as those available in Rio de Janeiro, ensuring coherence between them and the datasets used to consolidate the IMM procedures requires considerable effort. This involves a close collaboration between IMM experts and local contact points to address discrepancies and ensure compatibility. The complexity of this work is compounded by the nested nature of correspondences between elements in the two datasets. This phase, known as Data Mapping, was conducted jointly by Politecnico di Milano (PoliMI) and Instituto Municipal de Urbanismo Pereira Passos (IPP).

The Volume component required significant adaptation to transition from the Rio standard (Edificações), which divides buildings horizontally into "projections," to the EU standard, which divides buildings vertically into "volumetric units." To achieve this, we developed a custom GIS algorithm and applied attribute-based filtering (Tipo) to exclude minor volumes. Local checks were also performed to correct specific attribute values.

For mapping IMM Points of Interest we combined IPTU (Imposto sobre a propriedade predial e territorial urbana) cadastral data and information about green areas from the Land Cover (Cobertura Vegetal e Uso da Terra) dataset. However, some activities typically mapped were not included in any of Rio's datasets, such as museums, playgrounds, sports pitches, and outdoor sports activities. These were sourced from OpenStreetMap (OSM). The number and types of categories for Diversity analysis were adapted to fit Rio's specific context, resulting in 11 distinct categories.

Street links required filtering to exclude features like private dead-end streets (Vila) and squares (Praças). We applied various vector geoprocessing operations to optimize the network for routing algorithms. Public transportation data were updated to include missing stops and correct initially planned but unrealized lines. Additionally, we manually edited the Census data to match the new bairros organization.

The overall process spanned approximately six months, with some inconsistencies only discovered during diagnosis execution. In fact, initial examinations, conducted

[1] The complete set of metrics computed for each Bairro is available in the IMM Metrics ReMiRio mendeley data repository.

through random sampling within the case study area, may not have detected local issues.[2]

4 IMM Implementation

Following the most recent IMM application [12], the study area underwent uniform sampling by a 50m hexagonal grid whose cells worked as basic spatial units to gather information on the different urban elements. In addition, novel techniques were tested to improve the overall understanding of the urban system and its relevant dimensions. For each KC, several metrics were computed for each cell of the grid. Assessment maps were generated by overlaying the relative values of each metric within each cell to provide a comprehensive picture of each key category (fig 2). This approach involved ranking each cell based on the accumulated values of each metric pertaining to that specific Key Category compared to other cells. Consequently, five ranking levels were established for each Key Category, ranging from balanced (intense blue, value range: 0.6 - 1.00) to critical (intense red, value range: -1.00 - -0.6). Notably, this method ensures uniformity in interpreting the Key Categories and enhances comprehension of critical zones. Similarly, employing the same logic, an overall synthesis of the Key Categories for the intermediate scale was developed by overlaying the resulting values of each Key Category.

In addition, we introduced and tested a novel KC, Green Continuity, for the first time. Green continuity emphasizes establishing an interconnected and extensive network of green infrastructure that provides ecosystem services, supports biodiversity, and enhances urban resilience. Green continuity integrates various green and blue spaces, such as parks, green roofs, street trees, wetlands, and urban forests, into the city fabric to form a cohesive and interconnected network. The primary objective of green continuity is to assess the level of connectivity and uninterrupted flow between these green spaces, thereby facilitating the delivery of ecosystem services, fostering biodiversity, and offering various advantages to urban dwellers.

Mapping green continuity requires a methodical approach to analyze and visualize urban green infrastructure networks' spatial distribution and connectivity. The process begins by defining the study area's boundaries and organizing geospatial data on natural land covers and urban green spaces, such as parks, gardens, and trees. Utilizing the biodiversity intactness map, zonal statistics are computed to determine the mean biodiversity value for each green space, which is subsequently categorized into levels of ecological influence. Buffer zones are established around each green space based on their ecological relevance, combining size and ecological level. Buffers are used to impacted areas assessing their potential connectivity. We also identify and map barriers, such as buildings and streets, that disrupt green continuity, and subtract them from buffer zones to reveal compromised areas. Spatial metrics, including the Green Space Gini Coefficient, green space coverage, fragmentation index, edge density, greenway network density, and mean normalized difference vegetation index, assess the

[2] The complete Geopackage data are accessible here: appendix.[REMIRIO_DATA]

connectivity and distribution of green spaces. [13]. These metrics, along with maps generated from the analysis, provide a comprehensive understanding of the spatial dynamics of urban green infrastructure networks.

Within the REMIRIO project, we applied Green Continuity using data from the MapBiomas Land Use/Land Cover Time Series and the Cobertura Vegetal e Uso da Terra Uso do Solo dataset to obtain green space data. Following this, we calculated the biodiversity value of each green space, ranging between 0.628 (low) and 0.712 (high) for the intermediate scale.

5 Results

5.1 Urban Diagnostic Findings and Environmental Performance Assessment

In the REMIRIO project, an exhaustive investigation of all Key Categories was conducted through the evaluation of a diverse array of structural metrics and multilayered mapping. For instance, we analyzed Accessibility using metrics such as public transportation mode share, generator/attractor values, line-stop ratio, public transportation covered area, and block-building ratio These metrics described this key category in terms of walkable access to public transportation stops, the presence of different transportation modes in specific areas, intermodal transportation availability, and more (fig 1). The Key Categories were visually represented through metric-associated maps at the intermediate, barrios, and local scales. [3]

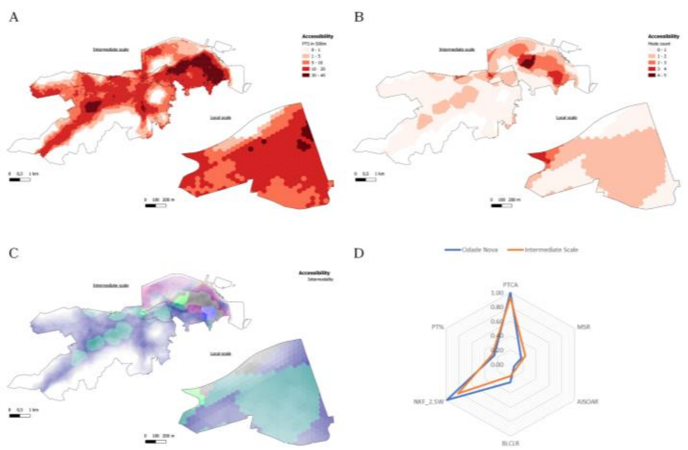

Fig. 1. Investigation of Accessibility on Local and Intermediate Scale: A. Public transportation Stops in 500m B. Mode count C. Intermodality D. Metrics Diagram

[3] The complete maps for the rest of the Key Categories can be found here: appendix. [REMIRIO1]

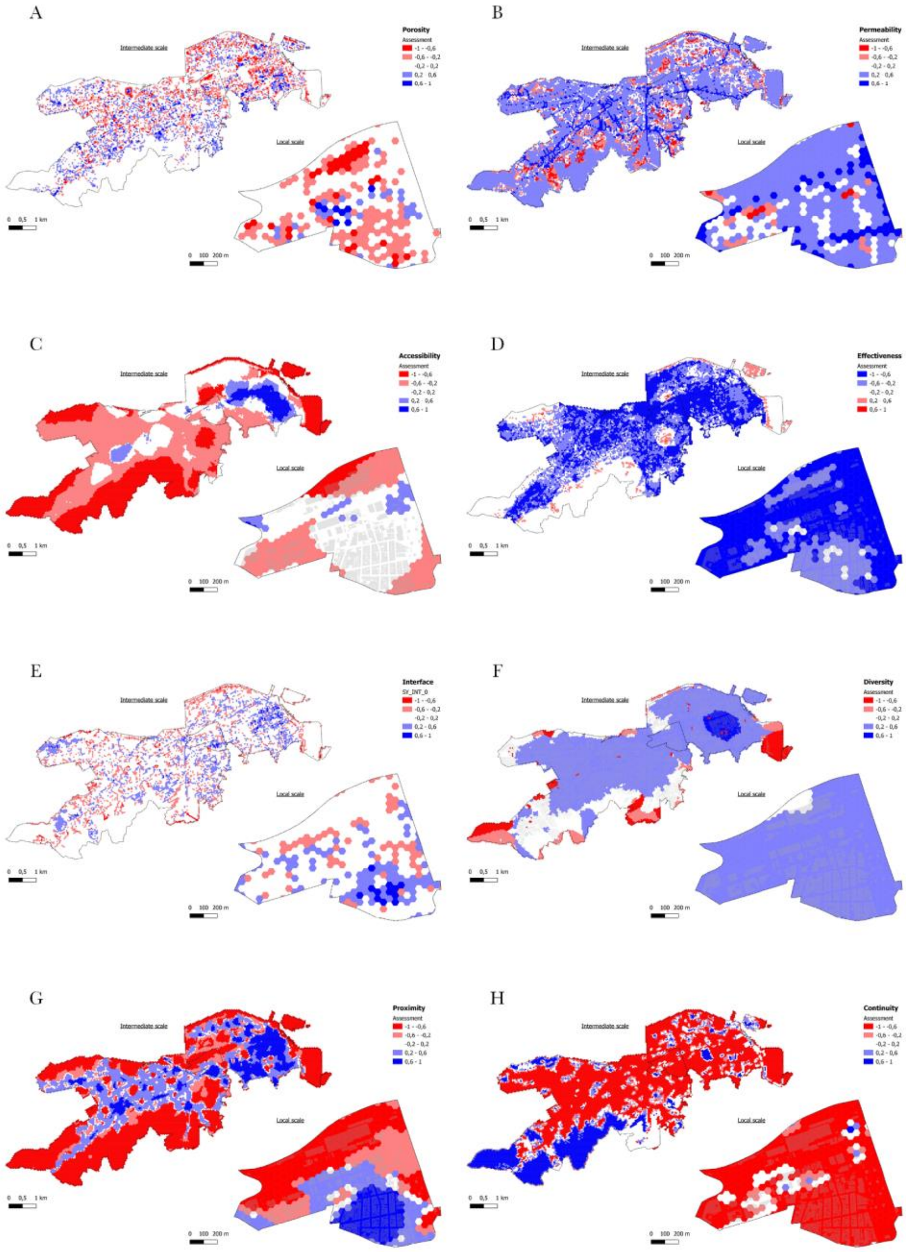

Fig. 2. Investigation of IMM Key Categories (Assessment Maps) on REMIRIO's intermediate and local scale: A. Proximity B. Permeability C. Accessibility D. Effectiveness E. Interface F. Diversity G. Proximity H. Continuity

Figure 2 illustrates the assessment analysis, a novel method of mapping key categories. These maps aggregate information into a single image, facilitating a more effective visual comparison.

Fig. 3. Influential urban features within the Cidade Nova area

The porosity analysis within the project area delineates contrasting characteristics rooted in the variety of block typologies. The built-up layer of Cidade Nova and its surroundings primarily features traditional buildings at its central parts, exhibiting relatively high densities and lower court areas. In contrast, the adjacent areas of President Vargas Boulevard to the north and Sambadrome to the east display a different morphology, characterized by bulky buildings with public, commercial, or administrative functions, such as City Hall and the similar blocks on its eastern side, which have uneven densities and larger openings. Central do Brasi (Central train station) intensifies this discontinuity in morphological patterns at the intermediate scale acting as a strong barrier element. Its extensive railroad infrastructure consumes a large area and creates sharp typological differences on either side. These differences at the local scale not only create a noticeable disproportion in porosity values but also negatively impact effectiveness potential due to the consequent density drop in the mentioned border areas. Accessibility follows the same pattern, with relatively high public transportation coverage in the core of the project area significantly reduced on the northern and eastern sides. These elements visibly decrease overall permeability too. However, Salvador de Sá Street, serving as a direct axis and local distributor, enhances permeability in the center of the project area. Although this link forms a micro street network with integrated local geometry, the northern and eastern barriers, along with Feri Caneca Street to the south, disrupt network continuity and consequently downgrade the interface from an intermediate perspective. Moreover, while the Cidade Nova area benefits from its proximity to Rio City Center, enjoying a high concentration of diverse uses, the aforementioned barrier effects are also evident in the border regions of the proximity and diversity assessments.

Among the key categories, nevertheless, the most critical assessment pertains to green continuity, due to the absence of structural connections between green elements across the entire intermediate scale.

5.2 Identification of the Catalyst of the Transformation

The IMM diagnosis phase unveils the underlying structural dynamics, thereby facilitating systemic problem identification. Within the context of REMIRIO, the prevailing infrastructure and the functional significance of the site within the urban framework foster a general equilibrium across most Key Categories. Nonetheless, the principal challenges appear rooted in structural disruptions affecting permeability and green continuity.

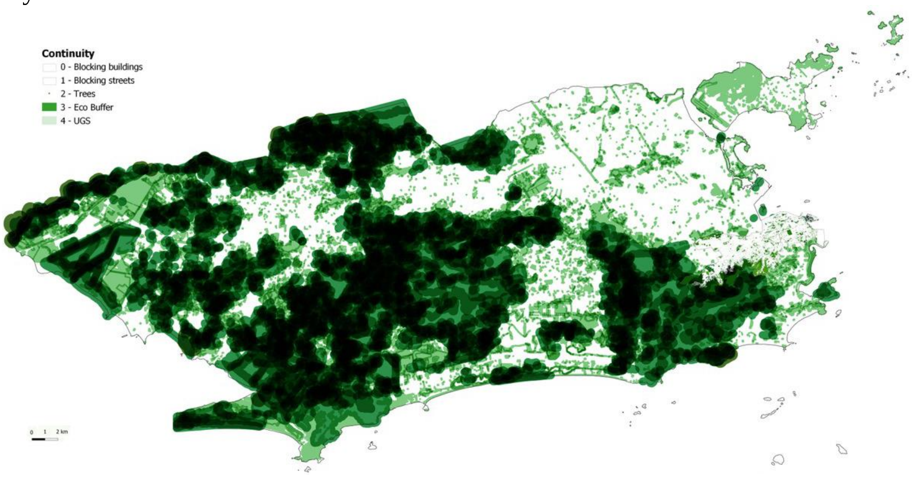

Fig. 4. The Investigation of Green Continuity in the REMIRIO Urban Scale

In tandem with the diagnostic revelations, these challenges manifest in localized phenomena such as traffic congestion, urban heat island effects, water management issues, flood vulnerabilities, and deficiencies in ecosystem services and sewage systems. Moreover, the absence or fragmentation of green continuity poses several challenges and vulnerabilities to the urban system at the scale of the project. These include habitat loss, reduced biodiversity, and ecosystem degradation. Fragmented green spaces can make urban areas more susceptible to heat-related health risks and increase energy consumption for cooling. Additionally, limited access to green spaces negatively impacts residents' quality of life and weakens the city's resilience to climate-related hazards, exacerbating environmental vulnerabilities. These factors delineate the project's scope, guiding its initial conceptualization. As candidates for catalyzing transformation, pivotal attention is drawn to green continuity, deemed the linchpin for strategic planning.

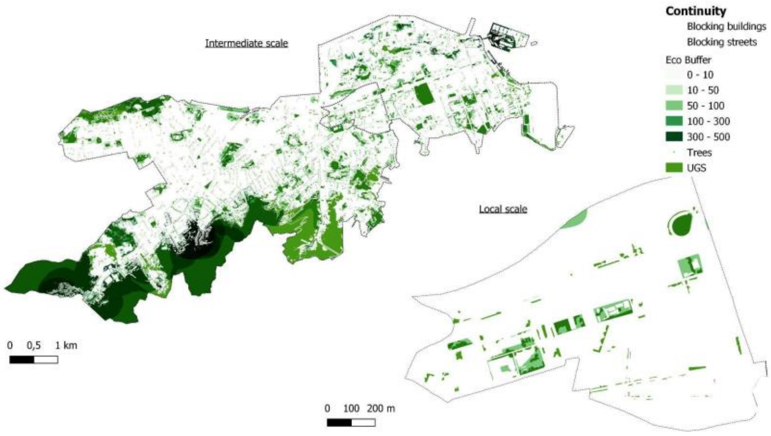

Fig. 5. The Investigation of Green Continuity in the REMIRIO intermediate and local scale

The examination of green continuity across local, intermediate, and urban scales reveals Rio's substantial potential to integrate urban green spaces with natural features (Fig 4 and Fig 5). This integration is key to establishing an effective natural buffer and bridging disconnected elements within the city. It lays the groundwork for defining more inclusive ecosystem services, advancing Rio toward a more resilient urban form. Additionally, incorporating blue infrastructure for water management can enhance resilience by optimizing water resources, mitigating flooding risks, and promoting sustainable urban development. Embracing these choices could unlock opportunities to reintegrate the city with the Atlantic forest, further enhancing its environmental sustainability and resilience on a broader scale. Moreover, the ecological restoration of existing blue infrastructures at the intermediate scale and their new role at the local scale can be crucial in optimizing water management, mitigating flooding risks, and fostering the city's resilience.

Aside from minimal green elements along Salvador de Sá Street and other fragmented eco buffers, the project area is largely devoid of green spaces. On the urban scale, given the proximity to natural green patches descending from Corcovado, Praça da República in the city center, and the extensive greenery of Grajaú, Cidade Nova holds significant potential to host green corridors in multiple directions. This would greatly enhance ecosystem services, resilience, and the overall robustness of Rio de Janeiro.

The selection of green continuity as the transformational catalyst prompts a focused approach toward prioritizing Design Ordering Principles (DOPs) within the IMM framework, particularly emphasizing the urban green system. One of the most immediate strategies for enhancing green continuity is evaluating various scenarios for defining green corridors. An optimal green corridor system not only increases the capacity for improving green and blue infrastructure at multiple scales but also facilitates a new dynamism of mobility by creating an integrated and connected system of urban links. Consequently, in the future steps, the REMIRIO Project will involve a series of pertinent actions, further adapted to local policies, thereby shaping the comprehensive strategic agenda for the REMIRIO project.

6 Conclusion

The REMIRIO project is a compelling case study demonstrating the importance of comprehensive urban diagnosis in guiding urban regeneration initiatives, strategic planning, and policy formulation. The focal point, Vila Operária Salvador de Sá, faces numerous socio-economic and environmental challenges, including social conflicts, flood susceptibility, heat island effects, traffic congestion, and connectivity issues. Addressing these challenges requires a nuanced understanding of their complex interplay to ensure structural resilience and alignment with local agendas across different scales.

To tackle these multifaceted issues, the REMIRIO Project deployed the Integrated Modification Methodology (IMM) for a comprehensive diagnosis of local areas, identifying malfunctioning urban subsystems with disintegrated structural elements that jeopardize the city's resilience and sustainability. The project addresses critical gaps in the city's strategic planning, particularly in Vila Operária, by emphasizing the need for interdisciplinary collaboration and robust data integration, which are lacking in current siloed approaches. Despite existing sustainable planning instruments, local strategies must better align with global Sustainable Development Goals, especially SDG 11.

IMM's systemic investigative tools, which demonstrate local-adaptive capacity in REMIRIO, effectively uncover the structural dynamics influencing urban system performance. This methodology provides a comprehensive understanding of the urban system's current state, allowing data-driven insights to inform decision-making. This approach enables planners to identify specific urban needs, prioritize impactful actions, and allocate resources efficiently, thereby enhancing urban resilience and sustainability. The diagnostic phase identifies local areas with high potential for systemic transformation, aiding in the design of strategies for systemic improvements. By integrating IMM insights into structured activities and work packages, REMIRIO aims to enhance urban resilience and sustainability while aligning with the city's official agenda and policies like Rio de Janeiro's Plan for Sustainable Development and Climate Action, RIOResiliente, and the Plano Diretor da Cidade do Rio de Janeiro. The project focuses on strengthening local capacity in urban diagnostics, developing an integrated sustainable urban regeneration plan, and applying a social and environmental impact assessment methodology to ensure measurable outcomes.

In Vila Operária Salvador de Sá, despite its historical significance and proximity to Rio de Janeiro's city center, the IMM diagnosis highlighted the transformative potential of green continuity. Green continuity, adaptable and scalable, is crucial for enhancing urban resilience and can be replicated in integrated local and regional projects. The findings from REMIRIO's diagnosis phase empower local decision-makers to tailor results to the urban political agenda, crafting a strategic plan that addresses local concerns while being replicable in similar contexts. By rigorously studying and analyzing urban systems, the REMIRIO project aims to prevent misinterpretation of contextual structures that could lead to socio-economic and environmental risks.

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