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Sustainable Requalification of the Zeferino Vaz Campus Drainage System: Nature-Based Solutions for Climate Resilience

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Abstract. The increasing impermeabilization of soil and intensification of extreme weather events have heightened the risk of flooding at Unicamp's Zeferino Vaz campus. Designed in the 1960s, the current drainage infrastructure is no longer adequate to meet present and future climate challenges. This study proposes the requalification of the drainage system through Nature-Based Solutions (NbS), aligning with Unicamp's 2021-2031 Integrated Territorial Master Plan and the United Nations Sustainable Development Goals (SDGs). NbS promote a shift from traditional rapid runoff models to sustainable drainage strategies that enhance infiltration, evapotranspiration, and retention. The project adopts a multi-scalar methodology, integrating interventions at the lot, street, neighborhood, and watershed levels. Planning is structured into five steps: hydrological diagnosis, mapping of impermeable and flood-prone areas, typology selection, feasibility analysis, and integration into institutional planning. The project is currently in its third step, identifying suitable NbS typologies for priority zones on campus. Supported by Unicamp's sustainability governance, the initiative is embedded in a broader data-driven and participatory approach. It also foresees the integration of educational components, monitoring systems, and partnerships with academic and municipal stakeholders. Preliminary results include a complete hydrological diagnosis, detailed geospatial mapping of impermeable and flood-prone areas, and the preliminary selection of NbS typologies tailored to priority campus zones. The expected outcomes include flood risk reduction, increased biodiversity, enhanced thermal comfort, and the creation of outdoor learning environments. By leveraging its living lab model and long-standing sustainability commitment, Unicamp aims to transform environmental challenges into opportunities for innovation and resilience, and offers a replicable model for universities and urban areas.

Keywords:
Water at campus, Nature-Based Solutions, Hydrological Regime

1. Introduction

Founded in 1966, the University of Campinas (Unicamp) is one of Brazil's leading public research universities. It operates six campuses across the state of São Paulo, with its main campus - Zeferino Vaz - located in the district of Barão Geraldo, in Campinas. The Zeferino Vaz campus covers a total area of 3,884,657m², of which 627,937m² are built structures. In line with its environmental commitment, the campus also includes 787,548.90m² of planted vegetation and 483,386.61 m² of native forest. Unicamp's academic community is composed of 19,838 undergraduate students, 16,834 graduate students, 1,983 faculty members, and 7,234 technical and administrative staff [1].

Unicamp's engagement with sustainability began in the early 1990s through grassroots initiatives addressing environmental issues on campus, particularly waste disposal. The first institutional effort was the creation of the Environmental Planning Group to mitigate improper solid waste deposition in open drainage canals. In 1999, the university introduced the Green Map methodology to capture environmental perceptions of its campus users. These early initiatives laid the foundation for Unicamp's environmental policy, officially established in 2010, and the Sustainable University Management System, formalized in 2014 with the creation of the Sustainable University Steering Group (GGUS). Over time, GGUS expanded Unicamp's sustainability agenda from waste management to a holistic vision that integrates energy, biodiversity, water resources, and environmental education. Through its Technical Management Chambers (CTGs), the university implemented projects in green infrastructure, renewable energy, and community-driven environmental monitoring [2].

Since 2018, Unicamp has strengthened its governance structure for sustainability with the establishment of new units such as the Environmental and Waste Management Coordination (GEARE), the International Hub for Sustainable Development (HIDS), and, more recently, the Sustainability Coordination Office (CSUS) within the Office of Integrated Planning (DEPI). These units spearhead cross-cutting initiatives aligned with the United Nations Sustainable Development Goals (SDGs), including green infrastructure, carbon emissions monitoring, and living labs. The 2021-2031 Integrated Master Plan [3] reaffirmed this commitment, providing a long-term vision for sustainable urban and environmental planning across all campuses. The CSUS now leads institutional representation in global sustainability networks such as UI GreenMetric, ISCN, and Nature Positive Universities, and coordinates flagship projects like PAESUS and the Sustainable Campus Office. Together, these structures have turned Unicamp into a reference model for data-driven, collaborative, and systemic sustainability in higher education.

Historically, urban drainage systems in Brazil were designed to remove stormwater as quickly as possible, with little regard for environmental or hydrological processes [16]. This conventional approach, prevalent in the mid-20th century, led to the extensive canalization of watercourses, the burial of streams, and the paving over of natural infiltration areas. The Zeferino Vaz campus, developed between the 1960s and 1970s, adopted this model, relying heavily on underground pipes and impermeable surfaces.

Over the decades, the campus has expanded significantly, both in terms of built area and impermeable coverage, reflecting broader urbanization trends, often characterized by unplanned land occupation and the fragmentation of green areas. This process has significantly increased vulnerability to flooding, erosion, and water quality degradation. In recent years, the intensification of the water crisis and the growing frequency of extreme weather events have highlighted the inadequacy of drainage infrastructure conceived for past climatic and urban conditions [4]. Changes in rainfall patterns, with longer drought periods interspersed with more intense precipitation events, have amplified socio-environmental risks, particularly in areas with high imperviousness and deficient drainage systems [5]. Such challenges are further exacerbated in contexts of uncoordinated urban growth, where hydrological connectivity is disrupted, and natural retention areas are progressively reduced.

This scenario calls for a paradigm shift in water management, embracing solutions that work with, rather than against, natural processes. Nature-Based Solutions (NbS) have emerged as a global response to urban environmental problems, offering multifunctional benefits such as flood control, water purification, biodiversity enhancement, and improved public spaces [17]. These strategies are closely aligned with the United Nations Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action), as well as with the principles of resilient planning outlined in the university's Master Plan [18].

The growing recognition of the limitations of conventional grey infrastructure has stimulated global interest in Nature-Based Solutions (NbS) as multifunctional approaches to urban water management [19]. According to the International Union for Conservation of Nature [6] and Herzog et al. [7], NbS are "actions to protect, sustainably manage, and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." In the urban drainage context, these solutions aim to restore hydrological processes, enhance infiltration, retain and reuse stormwater, and promote ecological connectivity within the built environment [20].

International experiences have demonstrated the potential of NbS to improve water security, reduce disaster risk, and deliver cost-effective and long-term resilience compared to traditional approaches [4; 8]. The BiodiverCities strategy aims to transform the relationship between nature and urbanization by 2030 [9], through placing nature at the center of decision-making and infrastructure investment. Consistently, Childers et al. [10] argue that urban ecological infrastructure, understood as the network of natural and semi-natural systems within cities, is essential for urban resilience.

In Brazil, the incorporation of NbS into stormwater management remains incipient, often limited to pilot projects or isolated interventions. Nevertheless, various inspiring solutions have been catalogued in the country, promoting an integrated vision of natural infrastructure, such as the Green Infrastructure Implementation Guide [11] and the Brazilian Catalog of Nature-Based Solutions [12]. These initiatives highlight the potential for broader adoption, while underscoring the need for further academic research and institutional application in large-scale contexts, such as university campuses.

The requalification of the Zeferino Vaz campus drainage system through NbS represents a strategic opportunity to address current vulnerabilities while generating multiple co-benefits. Unlike conventional grey infrastructure, NbS incorporate vegetated elements, permeable soils, and integrated landscape management to promote infiltration, delay surface runoff, and improve water quality. In addition to mitigating flood and erosion risks, these measures contribute to carbon sequestration, urban heat island mitigation, and biodiversity enhancement. These techniques have been widely studied and supported by federal, state, and municipal public institutions for urban resilience in Latin America, including the development of stormwater management plans [13].

In line with this global movement and responding to the sustainability directives of its Integrated Territorial Master Plan [3], Unicamp seeks to requalify its drainage system through the integration of NbS. This paper presents the conceptual basis, methodological approach, proposed actions, and expected outcomes of this initiative.

2. Methodology

Several typologies of NbS have been documented in the literature and in public policy frameworks. According to Solera [11], these include green roofs, rain gardens, bioswales, constructed wetlands, permeable pavements, and riparian buffers. UN-Water [8] categorizes NbS functions in water security, quality improvement, and risk mitigation. Marques [13] highlights their role in urban resilience, especially in Latin American cities with high hydroclimatic vulnerability.

The multiscalar approach adopted in this project reflects the spatial heterogeneity of the Zeferino Vaz campus, which integrates densely built areas, forest fragments, ecological corridors, and natural and channelized water bodies. Implementing NbS across multiple scales enables simultaneous interventions in both micro-level processes (e.g., runoff from individual buildings) and macro-level dynamics (e.g., watershed-scale retention), fostering synergies among environmental, infrastructural, and social systems.

The sustainable requalification of the Zeferino Vaz Campus drainage system adopts a multi-scalar approach, with coordinated interventions designed to operate synergistically from the smallest to the largest spatial units. This framework, grounded in the Green Infrastructure Implementation Guide [11] and the Multiscalar Strategy for NbS in Campinas [14], ensures alignment with local public policy and academic expertise [15]. At the lot scale, measures include green roofs, vertical gardens, permeable pavements, and rainwater harvesting systems to manage runoff at its source. At the street scale, bioswales, rain gardens, tree-lined streets, and multifunctional sidewalks enhance infiltration and microclimatic regulation. The neighborhood scale integrates community gardens, wetlands, open retention basins, and ecological corridors to strengthen biodiversity and social engagement. Finally, at the watershed scale, stream dechannelization, riparian restoration, floodplain recovery, and the creation of linear parks restore ecological functions and improve hydrological resilience across the campus. By implementing these interventions within a living lab framework, the campus serves as an open, collaborative environment where solutions are co-created, tested, and refined through active participation of researchers, students, technical staff, and community stakeholders, generating knowledge transferable to other urban contexts.

Following this approach, the planning process includes five steps. The first one is the diagnosis of current hydrological conditions and drainage inefficiencies. This initial phase involved a technical assessment of the existing drainage infrastructure, rainfall patterns, runoff behavior, and hydrological vulnerabilities across the Zeferino Vaz campus. Using both historical data and on-site inspections, the team identified areas where the drainage system fails to manage stormwater effectively, contributing to flooding, erosion, and water pollution. The most critical flood events were observed during intense and short-duration rainfalls typical of the rainy season, when the drainage system proves incapable of absorbing and properly redirecting the excess water volumes. The campus's topography, combined with a high density of impervious surfaces, further aggravates this situation by accelerating the accumulation of stormwater and causing uncontrolled runoff. As a result, various negative impacts were recorded: slope erosion, overloading and blockage of storm drains, damage to road pavement, and increased risk to infrastructure located near flood-prone areas. In addition, a significant accumulation of sediments was observed in campus streams and lagoons, compromising the retention and flow capacity of these natural structures and contributing to environmental degradation. This diagnostic stage provided the foundation for all subsequent planning efforts.

The second step is the mapping of impermeable surfaces, preservation areas, and critical flood-prone zones: through geospatial analysis and remote sensing data, impermeable areas such as roads, rooftops, and parking lots were mapped in detail. Combined with historical flood records and topographic data, this step allowed the identification of hotspots where stormwater accumulation and surface runoff are most problematic. These maps were essential for understanding the spatial distribution of flood risks and for targeting areas most in need of intervention. This process was conducted using ArcGIS software and incorporated data layers produced by Unicamp's Geoprocessing Service, in collaboration with the Technical Chamber for Water Resources. Specific attention was given to low-lying areas near Bertrand Russel Street, which overlies a canalized stream and consistently registers high flood risk. The mapping also integrated protected and restoration zones identified in the Ecological Corridors Project, highlighting synergies between water management and biodiversity recovery.

Selection of appropriate NbS typologies based on function and scale is the third step. Based on the identified challenges and site characteristics, specific NbS typologies were selected to address hydrological and ecological needs. Criteria included the intended function (e.g., infiltration, retention, evapotranspiration), spatial scale (from individual buildings to the watershed), and landscape context. The selection process prioritized multifunctionality, aiming for interventions that could offer not only flood mitigation but also aesthetic, educational, and biodiversity benefits. At this stage, priority was given to areas where NbS could be rapidly integrated into ongoing projects, such as green roofs for new buildings in the HIDS territory, bioswales in flood-prone parking areas, and stream restoration between Fazenda Argentina and the Zeferino Vaz campus. These preliminary selections are being refined in consultation with campus planners and sustainability coordinators, supported by the Sustainable Design Guidelines and data from the Unicamp Atlas.

The fourth step is the technical, environmental, and legal feasibility analysis: before implementation, proposed NbS will be evaluated for feasibility regarding engineering constraints, environmental impact, regulatory compliance, and land use compatibility. This step included simulations of hydrological performance, soil permeability tests, analysis of vegetation suitability, and a review of municipal and university regulations. The analysis ensured that interventions would be both effective and compliant with institutional and public standards.

The last step consists in the integration of selected solutions into campus development plans. Finally, the chosen NbS strategies will be incorporated into Unicamp's broader campus development framework, ensuring their alignment with the Integrated Territorial Master Plan [3] and other institutional initiatives. This step emphasized long-term sustainability, scalability, and the capacity for maintenance and monitoring.

By embedding NbS into existing and future urban planning processes, the sustainable requalification of the Zeferino Vaz Campus drainage system ensures their continuity and replicability beyond the pilot phase. Throughout all stages, the project applies a living lab approach, using the campus to co-create, implement, and monitor NbS in real-life conditions. This framework facilitates continuous learning, stakeholder engagement, and the generation of transferable knowledge for other urban contexts. Currently, the project is in its third step, focusing on the selection of appropriate NbS typologies for different campus areas.

3. Implementation

The original environmental characteristics of the area now occupied by the Zeferino Vaz campus — formerly a rural zone with forest remnants, springs, and water bodies — were poorly preserved during the occupation process. The development model adopted for the campus largely disregarded these natural conditions.

The requalification project proposes a set of integrated actions aimed at addressing structural problems that affect the environmental quality and functionality of the campus. These issues are related to inadequate infrastructure and planning, such as the occupation of flood-prone and flood-risk areas (Figures 1 and 2), the channeling of streams, and the lack of connectivity between forest remnants — aspects highlighted in the environmental mapping of the campus's water and soil resources (Figure 3).

The proposed actions are designed to restore ecological functions and enhance urban resilience on campus (Figure 4), which include dechannelization and renaturalization of streams, involving replacing concrete canals with naturalized streambeds and vegetated buffers to slow runoff and enhance infiltration; riparian vegetation restoration, which involves replanting native species along watercourses to stabilize banks, filter pollutants, and create habitats for local fauna; rain gardens and bioswales, which involve installing depressions and vegetated channels to collect, filter, and infiltrate runoff from streets, rooftops, and parking lots; green roofs and permeable surfaces, which involve implementing green roofs in new buildings and replacing asphalt with permeable materials to reduce peak flow and increase groundwater recharge; and constructed wetlands and floodable parks, which involve creating multifunctional open spaces that retain water during storm events and offer recreational and educational opportunities.

Figure 1. Map of floodable and flood-risk areas


Figure 2. Images of flooding on campus 2016

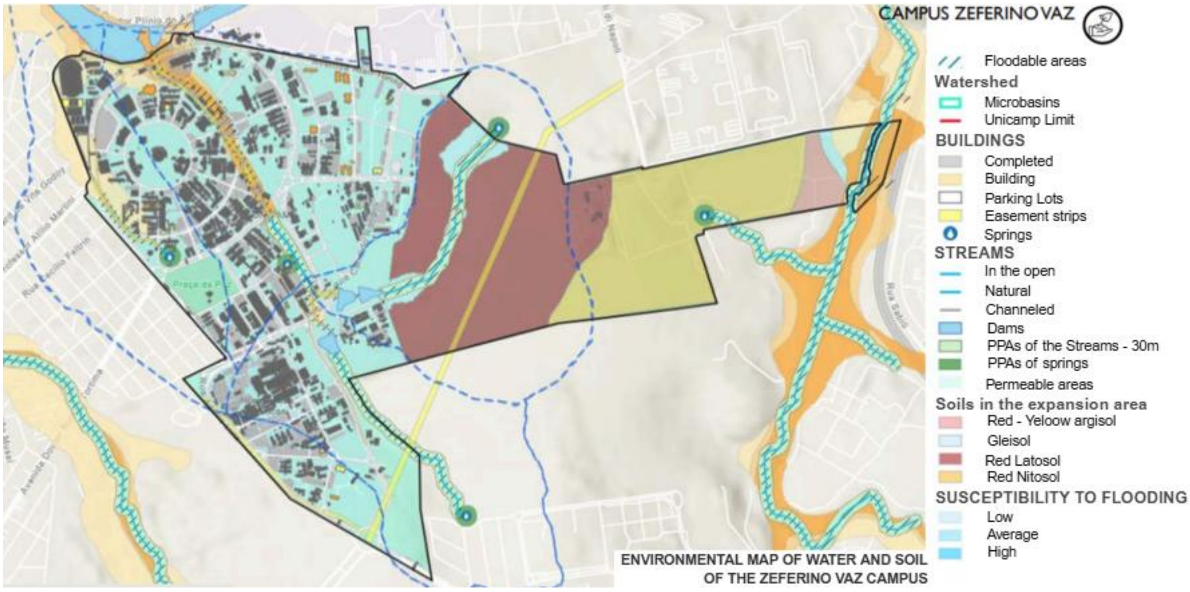

Figure 3. Environment mapping of water and soil resources at the Zeferino Vaz Campus

Figure 4. Images of Nature-Based Solutions (NbS) proposals for the Zeferino Vaz Campus

To ensure territorial relevance, the proposed NbS typologies are being aligned with specific areas of the Zeferino Vaz campus. At the lot level, all new constructions must comply with the Sustainable Design Guidelines outlined in the university's Integrated Territorial Master Plan [3], which recommend the use of green roofs. In addition, buildings planned for the HIDS (International Hub for Sustainable Development) area are required to include green roofs by design. At the street level, bioswales and rain gardens are planned for parking lots located in lower-altitude zones, particularly along Bertrand Russel Street—an area directly above the canalized stream and among the most vulnerable to flooding. At the neighborhood level, the ongoing Ecological Corridors Project envisions over 300,000 m² of ecological restoration, including native vegetation planting, soil correction, and streambed rehabilitation between the Fazenda Argentina (HIDS) and the Zeferino Vaz campus. At the watershed scale, Unicamp is actively working to secure the legal and environmental approvals required for the dechannelization of key watercourses, including the main central stream and the tributary that runs behind the Institute of Biology. These site-specific actions reinforce the campus's role as a testing ground for replicable, evidence-based NbS solutions.

These interventions will be accompanied by educational signage, community engagement activities, and monitoring systems to track hydrological and ecological performance. At this stage, the project remains in its planning phase, currently refining typology selection for pilot areas, focused on selecting the most suitable NbS typologies for different zones of the Zeferino Vaz campus, based on technical diagnostics and geospatial mapping developed by Unicamp's sustainability governance structures. The project also envisions partnerships with research groups and municipal authorities to enhance its scientific and policy relevance.

The development of the project relies on high-resolution spatial and environmental data, generated and managed through institutional partnerships. Geospatial mapping and land-use analysis were conducted using ArcGIS, with support from Unicamp's Geoprocessing Service, which is responsible for producing georeferenced layers and thematic maps of the campus. Hydrological assessments and scenario planning are supported by the Technical Chamber for Water Resources, which provides expertise in drainage analysis and water flow dynamics. The project also plans to incorporate LiDAR surveys, in-situ field sensors, and hydrological simulations in upcoming stages, as part of a broader effort to calibrate interventions to real environmental conditions. These tools will be integrated into the Unicamp Atlas platform, ensuring open access to spatial intelligence for decision-making and transparency. Together, these technical foundations ensure that NbS implementation is data-informed, legally compliant, and responsive to the specific hydroclimatic conditions of the Zeferino Vaz campus.

The initiative is aligned with the Unicamp 2021-2031 Integrated Territorial Master Plan [3] and the institutional sustainability strategy led by the Sustainability Coordination Office (CSUS). It also builds upon the university's legacy of environmental planning, integrating data generated by the Geoprocessing Service and supported by the Campus Sustainable Office. These synergies strengthen the implementation strategy and reinforce the role of the campus as a living lab for sustainability transitions.

Within this governance and planning framework, baseline spatial indicators have been established to quantify current conditions and guide performance evaluation over time. Baseline mapping indicates that native vegetation currently covers 18% of the campus area, with a target increase to 20% after NbS implementation. Total green area accounts for 53% of the territory, with a target of 55%. Permeable surfaces presently represent 10% of the total campus area, with a target of 22% following the implementation of planned NbS projects. These indicators, derived from high-resolution ArcGIS mapping, will be monitored to assess the effectiveness of NbS interventions in enhancing ecological connectivity, stormwater infiltration, and overall environmental quality.

These baseline and target values provide a quantitative reference for assessing the extent to which the project achieves its intended benefits. The expected outcomes include a measurable reduction in flood frequency and severity, improved water quality entering local streams, increased biodiversity and ecological connectivity, redesign of green areas to enhance stormwater infiltration and retention capacity, while providing additional ecological functions, enhanced thermal comfort and landscape quality, creation of outdoor learning environments for students and visitors, and lower maintenance costs and higher system resilience.

For implementation, the project envisions the use of a prioritization matrix that considers the availability of financial resources, the impact on flood-prone areas, and the need for functional improvements across the campus. This matrix will be aligned with opportunities for interventions in urbanized areas, particularly in the context of renovations and retrofit projects. Its design draws on sustainability indicators developed by Unicamp and submitted to international platforms, such as UI GreenMetric. Funding sources may include institutional budgets, public environmental funds, and international grants aimed at climate change adaptation. The monitoring component will be structured based on indicators such as infiltration rates, water quality parameters, vegetation cover, and user satisfaction levels.

Table 1. Baseline and Target Values of Key Spatial Indicators for Campus NbS Implementation

Indicator	Baseline (current)	Target (Post-NbS Implementation)	Source/Method
Proportion of native vegetation cover (%)	18	20	ArcGIS mapping
Proportion of total green area (%)	53	55	ArcGIS mapping
Proportion of campus area with permeable pavement (%)	10	22	ArcGIS mapping

4. Conclusions and Future Perspectives

This project presents a comprehensive proposal for the requalification of the drainage system of the Zeferino Vaz campus at Unicamp through NbS. The approach integrates hydrological engineering, urban planning, ecology, and education, reflecting a systemic vision to address sustainability challenges. By working with natural processes and rethinking the spatial logic of water, the proposed interventions aim to transform drainage infrastructure into an asset for climate adaptation, biodiversity conservation, and campus livability. The initiative positions the Zeferino Vaz campus as a living laboratory where innovation, science, and community engagement converge.

Thus far, the project has produced a detailed hydrological diagnosis, comprehensive geospatial mapping of impermeable surfaces, preservation areas, and flood-prone zones, as well as a preliminary selection of NbS typologies tailored to different spatial scales and site-specific needs. These outputs provide an evidence-based foundation for the upcoming phases, which include technical, environmental, and legal feasibility analysis, followed by integration into Unicamp's broader campus development framework.

Looking ahead, the success of this initiative will depend on institutional commitment, stakeholder participation, and adaptive management. Future developments may include the creation of a campus NbS plan, the incorporation of NbS criteria into building regulations, and the establishment of a permanent observatory for monitoring and dissemination. By leveraging Unicamp's mature ecosystem of sustainability governance and geospatial planning, and building on a robust legacy of environmental initiatives, this project enhances its potential for continuity, scalability, and replication in other universities and urban territories facing similar environmental challenges.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Authors Contribution

G.M.R. and **T.S.D.** jointly conceptualized the study and defined its overall research framework. **G.M.R.** led the methodological design, coordinated the hydrological diagnosis, and conducted the analysis of drainage inefficiencies, impermeable surface mapping, and flood-prone area identification. **T.S.D**. contributed to the methodological refinement, ensured alignment with the Integrated Territorial Master Plan, and supported the development of the multi-scalar NbS strategy. Both authors collaborated on data interpretation, integration of geospatial information, and the articulation of NbS typologies within institutional planning frameworks. **G.M.R**. drafted the manuscript and prepared the figures and mapping descriptions, while **T.S.D.** contributed to critical review, theoretical framing, and revision of the final text. Both authors discussed the results, reviewed the manuscript extensively, and approved the final version submitted for publication.

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