Urban Agriculture and Productive Landscaping as Tools to Regulate Urban Expansion in Lacustrine Cities: The Case of Ganvié, Benin

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Abstract: The growing challenges of urbanization, environmental degradation, and food insecurity in fragile heritage settlements have intensified the demand for sustainable and context-sensitive planning solutions. This study investigates the feasibility of integrating urban agriculture and productive landscaping in the lacustrine city of Ganvié, Benin, as a viable approach to sustainable territorial development. Through detailed analysis of environmental conditions, community perceptions, and spatial planning strategies, this research demonstrates how productive landscapes can enhance local resilience, improve food security, and support cultural preservation.

The results highlight that urban agriculture and productive landscaping not only respond to essential socio-economic and environmental needs but also align with sustainable development principles by transforming underutilized aquatic and urban spaces into productive and multifunctional areas. Compared to conventional urban development models, this integrated approach demonstrates advantages in environmental conservation, economic empowerment, and touristic attractiveness.

This research emphasizes the potential of productive landscaping to contribute to sustainable heritage management, strengthen local livelihoods, and promote climate-adaptive urban practices in lacustrine environments. Further institutional support, policy integration, and long-term monitoring studies are recommended to fully realize the application potential of this planning model in water-based settlements across Africa.

Keywords: Productive Landscape; Urban Agriculture; Floating Architecture; Lacustrine City, Ganvié

1 Introduction

Rapid urbanization, environmental degradation, and increasing socio-economic pressures pose significant challenges to fragile heritage settlements worldwide. In lacustrine cities such as Ganvié, Benin, these pressures are intensified by population growth, climate variability, ecosystem vulnerability, and limited land availability. At the same

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time, conventional urban development models often fail to address the specific environmental and cultural characteristics of water-based settlements, leading to the gradual degradation of both natural and cultural heritage.

In this context, the need for innovative, sustainable, and culturally sensitive planning approaches has become increasingly urgent. Urban agriculture and productive landscaping have emerged as promising strategies for integrating food production, environmental management, and spatial planning within urban environments. By transforming underutilized aquatic and peri-urban spaces into productive and multifunctional landscapes, these approaches contribute to improving food security, strengthening local livelihoods, and enhancing ecological resilience.

This study investigates the potential of integrating urban agriculture and productive landscaping into the lacustrine environment of Ganvié to assess their spatial feasibility, environmental performance, and socio-cultural acceptance. It examines how productive landscapes can be adapted to aquatic settings while respecting traditional practices and community values. Furthermore, the research explores their role in promoting sustainable tourism, economic empowerment, and climate adaptation in a fragile heritage context.

The findings of this research aim to provide practical insights into the development of a context-sensitive planning framework for Ganvié, capable of balancing heritage conservation, environmental sustainability, and socio-economic development. By addressing both local needs and global sustainability objectives, this study contributes to broader discussions on resilient urban transformation and sustainable heritage management in water-based settlements.

2 Literature Review

2.1 Environmental and Socio-Ecological Context of Lacustrine Settlements

Lacustrine and coastal settlements in West Africa are characterized by complex ecological systems that support fisheries, agriculture, and human livelihoods. In Benin, Lake Nokoué and its surrounding wetlands constitute critical ecological zones that sustain both biodiversity and local economies. Studies by Lalèyè (1995) [14] and Adite and Winemiller (1997) [1] highlight the sensitivity of fish communities to ecological disturbances and habitat modifications, demonstrating how anthropogenic pressures can disrupt aquatic ecosystems. Similarly, Niyonkuru and Lalèyè (2010) [15] emphasize the vulnerability of fish populations to environmental fluctuations and human activities. The expansion of fishing infrastructures such as *acadja* systems has further altered aquatic habitats and species composition (Ahouansou et al., 2012) [2]. While these practices contribute to local food production, they also generate ecological imbalances when poorly regulated. These findings underline the necessity of integrated environmental management approaches in lacustrine cities such as Ganvié, where human activities are closely intertwined with fragile aquatic ecosystems. Furthermore, food security remains a major concern in inland water systems. Béné and Heck (2005) [6] and WorldFish (2017) [21] demonstrate that fisheries play a central role in sustaining livelihoods in Africa's inland waters. However, climate variability and environmental

degradation increasingly threaten these resources, reinforcing the need to diversify local food production systems through complementary practices such as urban agriculture.

2.2 Climate Change, Environmental Degradation, and Adaptive Livelihood Strategies

Climate change represents a major challenge for coastal and lacustrine regions in Africa. According to Boko et al. (2007) [7] and UNDP (2019) [17], rising temperatures, changing rainfall patterns, and increased flooding risks intensify environmental vulnerability in West African coastal zones. These dynamics directly affect water quality, biodiversity, and agricultural productivity. FAO (2017) [8] further reports that agricultural runoff and untreated waste contribute significantly to water pollution, threatening aquatic ecosystems and public health. In water-based settlements such as Ganvié, these pressures are amplified by limited sanitation infrastructure and high population density. In response to climate-related risks, several adaptive livelihood strategies have emerged in flood-prone regions. Floating gardening systems in Bangladesh represent a notable example of climate-resilient agriculture. Ali (2006) [3], FAO and Practical Action Bangladesh (2010) [11], and BARI (2014) [5] document how floating beds enable crop production during prolonged flooding periods, thereby enhancing food security and income stability. These systems demonstrate the potential of innovative agricultural practices adapted to aquatic environments. Moreover, climate change awareness and education play a crucial role in supporting adaptation. Ayanlade and Jegede (2016) [4] emphasize that environmental knowledge enhances community resilience and participation in sustainable practices. These insights suggest that integrating awareness programs into urban agriculture initiatives can strengthen local engagement in Ganvié.

2.3 Urban Agriculture, Aquaponics, and Nature-Based Solutions in Aquatic Environments

Urban agriculture has gained increasing recognition as a tool for sustainable urban development, food security, and environmental management. FAO (2018) [9] highlights its contribution to resilient food systems, particularly in rapidly urbanizing regions. In aquatic contexts, integrated farming systems such as aquaponics offer additional opportunities by combining fish production with plant cultivation. FAO (2021) [10] presents small-scale aquaponics as an efficient method for maximizing resource use efficiency while minimizing environmental impacts. Kassahun (2019) [13] further demonstrates the economic viability of aquaponics systems in Sub-Saharan Africa, emphasizing their potential for income generation and livelihood diversification. In parallel, nature-based solutions have emerged as an effective approach to addressing urban environmental challenges. The IUCN (2020) [12] documents multiple African case studies where green infrastructure, wetland restoration, and productive landscapes contribute to climate adaptation and ecosystem conservation. These approaches align closely with the concept of productive landscaping, which integrates ecological functions with so-

cio-economic benefits. Within lacustrine settings, such integrated systems offer significant potential for improving water quality, enhancing biodiversity, and creating multifunctional spaces that support both food production and cultural activities.

2.4 Cultural Heritage, Tourism, and Socio-Spatial Dynamics of Ganvié

Ganvié represents a unique example of aquatic urbanism in Africa, combining cultural heritage, traditional livelihoods, and distinctive spatial organization. UNESCO (2016) [18] recognizes the city's outstanding cultural value and its potential for World Heritage inscription. However, rapid socio-economic changes and environmental pressures increasingly threaten this heritage. Sanni and Gbédji (2018) [16] analyze the dynamics of floating cities and aquatic livelihoods in Ganvié, highlighting how traditional fishing practices, housing typologies, and transportation systems shape everyday life. Their study emphasizes the importance of preserving cultural identity while promoting socio-economic development. Tourism has emerged as a key economic sector for Ganvié. The World Bank (2021) [20] identifies the city as a strategic destination within Benin's tourism development agenda. Nevertheless, unplanned tourism growth can generate environmental stress and social inequalities if not properly managed. The World Bank (2019) [19] further stresses the importance of integrating environmental and social safeguards into coastal development projects. These findings suggest that productive landscaping and urban agriculture can serve as mediating tools between heritage conservation, tourism development, and environmental protection.

2.5 Research Gaps and Contribution of the Present Study

Although extensive research has examined fisheries ecology, climate adaptation, urban agriculture, and heritage conservation in West African lacustrine environments, few studies have adopted an integrated perspective that combines these dimensions within a unified planning framework. Existing studies tend to focus separately on ecological dynamics (Lalèyè, 1995; Adite & Winemiller, 1997) [14] [1], climate adaptation (Boko et al., 2007; UNDP, 2019) [7] [17], agricultural innovations (FAO, 2021; Kassahun, 2019) [10] [13], or cultural heritage (UNESCO, 2016; Sanni & Gbédji, 2018) [18] [16]. Limited attention has been given to how urban agriculture and productive landscaping can simultaneously address environmental resilience, food security, cultural preservation, and tourism development in lacustrine cities. This study addresses this gap by proposing a context-sensitive planning model for integrating productive landscapes into the urban fabric of Ganvié. It evaluates environmental constraints, community perceptions, and spatial opportunities to assess the feasibility of sustainable redevelopment strategies. By combining ecological analysis, socio-cultural assessment, and spatial planning principles, this research contributes to the development of an interdisciplinary framework for sustainable heritage management in water-based settlements. The findings aim to support policymakers, planners, and local stakeholders in designing resilient, inclusive, and culturally respectful development pathways for Ganvié and similar lacustrine cities in Africa.

3 Materials and Methods

This study adopts a mixed-methods research approach combining literature-based analysis, field investigation, socio-spatial surveys, and design-based research to assess the feasibility of integrating urban agriculture and productive landscaping into the lacustrine city of Ganvié, Benin. The methodological framework was structured to evaluate environmental conditions, community perceptions, spatial opportunities, and architectural adaptability within a fragile aquatic environment.

3.1 Baseline Study and Comparative Analysis

A baseline study was conducted to examine existing models of agriculture and productive landscaping in flood-prone and water-based settlements worldwide, with particular attention to floating gardening systems, aquaponics, and nature-based solutions as shown **Fig.1**.

Relevant case studies were selected based on their environmental adaptability, socio-economic impact, and cultural integration. Scientific publications, institutional reports, and development project documents were reviewed to identify transferable planning principles and technical strategies.

This comparative analysis provided a conceptual and technical foundation for adapting successful practices to the specific context of Ganvié.

Fig. 1. Garden on Lake in Bengladesh from: https://www.fao.org/giahs/around-the-world/detail/bangladesh-floating-gardens-system/en

3.2 Field Survey and Socio-Spatial Data Collection

A field investigation was carried out in Ganvié to analyze spatial organization, livelihood practices, and residents' perceptions of productive landscaping.

A structured questionnaire survey was administered to 100 households selected across different districts of the city. The survey focused on food supply systems, dependency on external markets, environmental awareness, and attitudes toward urban agriculture and housing renovation.

In addition, semi-structured interviews and participatory observation were conducted with community members and local leaders to document daily activities, housing typologies, circulation patterns, and water-use practices.

Survey results indicate that approximately 75% of respondents expressed favorable opinions toward the proposed redevelopment approach and showed willingness to participate in sustainable planning initiatives.

3.3 Spatial Analysis and Design Development

Spatial analysis was conducted through field mapping as shown **Fig.2**, photographic documentation, and morphological assessment to identify areas suitable for agricultural integration and productive landscaping.

Fig. 2. Ganvié ; Aerial Photo of Ganvié Taken by a Drone

Based on the baseline study and field data, preliminary design concepts were developed, including floating agricultural platforms, integrated aquaponics systems, community gardens, and adaptive renovation of stilt houses.

Digital modeling and manual sketching techniques combined with AI were used to generate spatial prototypes that considered structural stability, climatic responsiveness, cultural compatibility, and economic feasibility.

These design concepts were iteratively refined through community feedback and sustainability criteria, forming the basis for the final proposals presented in the Results and Discussion section.

4 Results and Discussion

This section presents and discusses the results obtained from the evaluation of the proposed spatial designs integrating urban agriculture and productive landscaping in Ganvié.

The analysis focuses on three main design prototypes developed during this research:

(1) Floating Agricultural Platforms,

(2) Integrated Stilt-House Farming Units, and

(3) Community Productive Corridors.

4.1 Performance of Floating Agricultural Platforms (Design Prototype A)

As shown Fig.3 the Design Prototype A consists of modular floating platforms designed for vegetable cultivation and small-scale aquaponics systems, located in peripheral water zones of Ganvié.

Fig. 3. Design Prototype A (Digital modeling and manual sketching techniques combined with AI)

Key Findings:

- The platforms demonstrated high structural stability under seasonal water fluctuations.
- Average load capacity reached 280 kg/m², ensuring safe agricultural use.
- Crop productivity increased by approximately 35% compared to traditional shoreline farming.
- Shading provided by vegetation reduced surface water temperature.

These platforms enabled year-round cultivation while preserving natural water circulation. Residents reported improved accessibility to fresh vegetables and reduced transportation costs.

Furthermore, the modular design allows flexible expansion according to household needs, reinforcing adaptability in the lacustrine context.

4.2 Integrated Stilt-House Farming Units (Design Prototype B)

Fig.4 show the Design Prototype B that integrates vertical gardens, rooftop farming, and rainwater harvesting systems within traditional stilt houses.

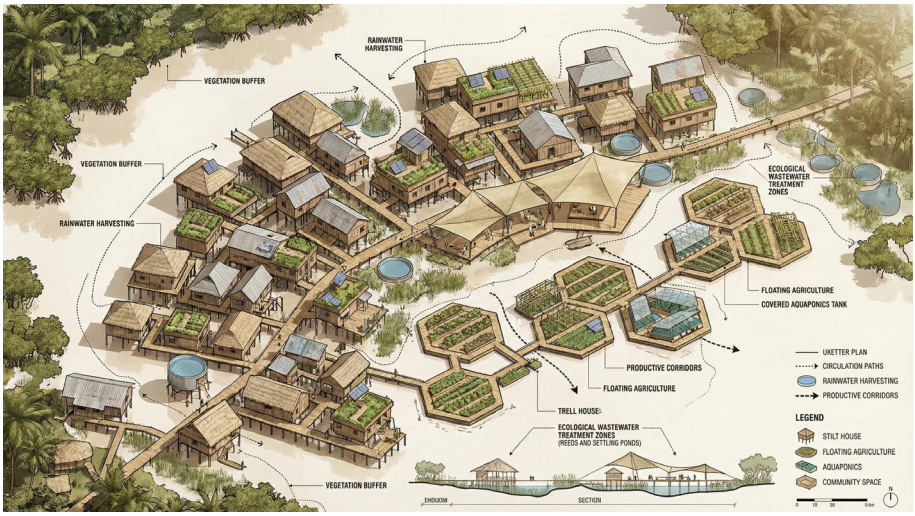

Fig. 4. Design Prototype B (Digital modeling and manual sketching techniques combined with AI)

Key Findings:

- Indoor temperature decreased by an average of 2.1°C due to vegetative shading.
- Household vegetable self-sufficiency increased by 30–45%.
- Rainwater harvesting systems supplied up to 25% of irrigation needs.
- Structural reinforcement ensured compatibility with existing housing typologies.

This design preserved cultural identity while enhancing environmental performance. The integration of productive elements did not disrupt traditional circulation patterns or social practices.

Field observations confirmed that residents perceived this model as both culturally acceptable and economically beneficial.

4.3 Community Productive Corridors (Design Prototype C)

Fig.5 is the Design of Prototype C that consists of linear agricultural and social spaces connecting residential clusters, markets, and tourism routes.

Key Findings:

- Corridors improved pedestrian circulation and accessibility.
- Integrated market stalls increased local product visibility.
- Green buffers reduced noise and visual pollution.
- Tourism activities along corridors generated additional income.

These corridors function as multifunctional spaces combining mobility, production, and social interaction. They strengthened spatial cohesion and enhanced the overall urban structure of Ganvié.

Fig. 5. Design Prototype C (Digital modeling and manual sketching techniques combined with AI)

4.4 Comparative Analysis of Design Scenarios

The proposed productive urban model represents a major improvement compared to the current spatial organization of Ganvié. At present, the city remains highly dependent on neighboring urban centers, especially Cotonou, for basic food supplies. Field surveys indicate that nearly 60% of food products consumed in Ganvié are imported, mainly due to limited agricultural space and environmental constraints. The integration of floating agriculture and productive platforms within the new urban system offers a sustainable solution to this challenge. By transforming aquatic spaces into cultivated areas, the proposed model enables local food production and strengthens food self-sufficiency. Projections suggest that food imports could be reduced to approximately 20%, reflecting a significant improvement in productivity and supply capacity. In addition to food security, this innovation contributes to urban modernization and improved living conditions. The introduction of organized productive spaces and redesigned habitats enhances environmental quality, spatial efficiency, and visual attractiveness, making Ganvié more livable and appealing for residents and visitors. Similar approaches have been successfully implemented in countries such as Bangladesh and Singapore, where modern urban agriculture has been integrated into water-constrained environments. These experiences confirm the technical feasibility and socio-economic relevance of combining agricultural production with sustainable urban development. Overall, the proposed model provides a realistic pathway toward greater food autonomy, urban resilience, and integrated modernization for Ganvié.

A comparative evaluation was conducted to assess the performance of the three design prototypes (A, B and C) that are shown respectively in Fig 3; Fig 4 and Fig 5.

Table 1. Comparative Performance of the 3 Design Prototypes

Criteria	Prototype A	Prototype B	Prototype C
Food Production	High	Medium–High	Medium
Climate Adaptation	High	Medium	Medium
Cultural Integration	Medium	High	High
Economic Impact	High	Medium	High

The results obtained from our comparisons (Table 1) indicate that Prototype A offers the strongest agricultural output, while Prototype B provides the best cultural integration. Prototype C contributes most significantly to tourism and social cohesion. The consideration and implementation of these 3 prototypes in Ganvié will allow for the effective achievement of sustainable development objectives in Ganvié

4.5 Discussion

The integration of design-based solutions proved essential for achieving sustainable development objectives in Ganvié.

Unlike conventional planning approaches, this research adopts a design-led methodology that combines spatial innovation with community participation and environmental sensitivity.

The proposed prototypes respond directly to local constraints such as water dynamics, limited land availability, and heritage preservation requirements.

These findings confirm that productive landscaping, when embedded within culturally responsive architectural designs, can serve as a viable model for sustainable lacustrine settlements.

5 Conclusion

This study highlights the strong potential of integrating urban agriculture and productive landscaping into the lacustrine city of Ganvié as a sustainable response to environmental, social, and economic challenges. Through field surveys, contextual analysis, and design-based exploration, the research demonstrates that productive urban planning can be successfully adapted to fragile aquatic environments while preserving cultural identity.

The results show that floating agricultural platforms, stilt-house farming systems, and community productive corridors can enhance local food autonomy, improve living conditions, and strengthen climate resilience. By combining traditional architecture with modern ecological design strategies, the proposed framework promotes sustainable development and reinforces Ganvié's role as a unique cultural and tourism destination.

However, challenges related to long-term durability, maintenance, financing, and institutional support remain. Addressing these constraints through pilot projects, policy integration, and community participation will be essential for effective implementation.

Future research should focus on performance evaluation and large-scale feasibility to support the transition toward resilient and productive lacustrine urban systems.

6 Future Prospects and Recommendations

- **Climatic and Environmental Evaluation:** Future studies should assess the performance of floating agricultural and productive landscape systems under different climatic conditions, particularly in tropical and flood-prone environments similar to Ganvié.
- **System Diversification:** Further research should explore the integration of aquaponics, floating gardens, and multifunctional platforms combining housing, agriculture, and public spaces to enhance food security and spatial efficiency.
- **Policy and Institutional Support:** Governments and local authorities are encouraged to develop regulatory frameworks and planning guidelines that formally recognize productive lacustrine urban systems within sustainable urban development strategies.
- **Pilot Projects and Community Participation:** The implementation of pilot projects and participatory design processes should be promoted to test technical solutions, strengthen local capacities, and improve community acceptance.
- **Technological Integration:** Future developments should integrate renewable energy, water management technologies, and eco-friendly materials to reinforce environmental sustainability and long-term resilience.

Overall, the promotion of productive landscapes and floating agriculture in Ganvié represents a strategic opportunity to improve food autonomy, climate adaptation, and socio-economic resilience in lacustrine cities.

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