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Modular Green Roofs for EDS Carousel Station: Harnessing Portulaca Grandiflora for Environmental Restoration and Commuter Well-being

[1]Timothy Virgil V. Lauño
[1]Philippine Christian University, Philippines

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ABSTRACT

The accelerating urban growth of Metro Manila has strained the city's environmental resources, particularly in high-traffic transit hubs like EDSA. The GREENPATH project addresses these challenges by deploying modular green roofs using Portulaca grandiflora, a heat-resilient, pollutant-absorbing plant, at key BRT stations. Starting with the Main Avenue station in Cubao, the initiative combines nature-based solutions with AI-enabled infrastructure to create a climate-adaptive, sustainable transit system. The green roofs provide a range of environmental benefits, including reducing surface temperatures by up to 20°C and improving air quality by absorbing nitrogen oxides and particulate matter. The project is aligned with national and international sustainability goals, such as the Philippine Green Building Code and the United Nations Sustainable Development Goals. Commuter surveys reveal strong approval of the initiative, with 87% of respondents noting enhanced comfort and aesthetics. The project's scalability is supported by the integration of IoT systems for monitoring plant health and irrigation, ensuring that maintenance is both efficient and sustainable. As a model for urban mobility and climate adaptation, GREENPATH offers a pathway for other cities facing similar environmental and infrastructural challenges to follow, with a focus on sustainability, innovation, and public health.

Keywords: *AI infrastructure, Commuter experience, Environmental adaptation, Green roofs, Urban mobility*

INTRODUCTION

As one of the fastest-growing megacities in Southeast Asia, Metro Manila faces a multitude of urban challenges, including poor air quality, rising temperatures, and inadequate public health infrastructure. These challenges are particularly pronounced in high-density mobility corridors, such as the Epifanio de los Santos Avenue (EDSA), where the EDSA Carousel Bus Rapid Transit (BRT) system operates (Bugarin & Mercado, 2023). Although the BRT system has contributed to improved transportation efficiency and reduced vehicular congestion, the environmental conditions within the corridor remain poor, exacerbating the urban heat island (UHI) effect and negatively impacting commuter health and well-being (Santos & Aquino, 2024). This situation highlights the need for more sustainable and climate-resilient urban infrastructure solutions.

The GREENPATH Initiative seeks to address these environmental challenges by integrating green infrastructure into Metro Manila's transit system. By incorporating modular green roofs using Portulaca grandiflora, a drought-tolerant and pollutant-absorbing plant, the initiative aims to reduce surface temperatures, improve air quality, and enhance the commuter experience at the Main Avenue BRT station. This study explores the potential of nature-based solutions, such as green roofs, to provide sustainable and multifunctional benefits in densely built urban corridors (Mendoza & Almonte, 2023).

Portulaca grandiflora was chosen for its resilience in harsh urban environments, including its tolerance for high temperatures, low water needs, and ability to filter pollutants like nitrogen oxides and particulate matter (Santos & Aquino, 2024). Its rapid growth and aesthetic appeal make it an ideal candidate for large-scale green roof deployment. Early studies suggest that the integration of this species into green roofs can significantly mitigate the UHI effect, improve local air quality, and provide visual and psychological relief to commuters in high-traffic transit areas (Rosales & Garcia, 2023).

The theoretical foundation of the GREENPATH initiative draws from Biophilic Design Theory, Urban Ecology, and Sustainable Mobility Theory, all of which emphasize the importance of incorporating natural elements into urban infrastructure (Perez & Tan, 2022). By applying Green Engineering (GE), Transportation Efficiency (TE), and Waste Management (WM) frameworks, the initiative provides a comprehensive model for transforming urban transit systems into sustainable, climate-adaptive spaces. This approach not only improves environmental outcomes but also enhances commuter comfort, safety, and satisfaction.

This paper aims to evaluate the effectiveness of the GREENPATH initiative at the Main Avenue BRT station, examining both environmental benefits—such as temperature reduction and air quality improvement—and commuter well-being, including comfort, aesthetic appeal, and mental relief. Through this evaluation, the study seeks to establish the potential for replicating this model across other transit stations in Metro Manila, providing a scalable solution for improving urban mobility and resilience in tropical megacities.

MATERIALS & METHODS

The GREENPATH initiative utilized a set of carefully selected materials to deploy modular green roofs on the Main Avenue EDSA Carousel Station. Portulaca grandiflora was chosen as the key plant species due to its drought resistance, rapid growth, and ability to absorb air pollutants, particularly nitrogen oxides and particulate matter (Santos & Aquino, 2024). The modular green roofs were prefabricated using a combination of lightweight concrete and synthetic geotextile materials that support efficient drainage and plant growth (Lopez & Tan, 2022). These modules were designed to integrate seamlessly with the existing infrastructure while providing a low-maintenance solution to improve environmental conditions. Automated irrigation systems were incorporated into the modules to ensure plant health with minimal water usage, addressing the city's water scarcity issues.

Environmental data collection for the study involved deploying temperature and air quality sensors at the pilot station before and after the installation of the green roof system. Temperature sensors were placed both on the green roof surfaces and on adjacent bare concrete areas to measure temperature variations over a 12-month period (Perez & Tan, 2023). Air quality was monitored through the installation of NO_x and PM2.5 sensors, which were used to measure pollution levels in the station's immediate vicinity. To complement this, commuter satisfaction was assessed through a questionnaire survey conducted with 120 regular commuters at the station. The survey addressed aspects such as visual satisfaction, perceived thermal comfort, and general feelings of well-being (Bugarin & Mercado, 2023).

The environmental data were analyzed using paired t-tests to assess significant changes in surface temperature and pollutant levels between the pre-installation and post-installation periods (Salazar & Tan, 2023). The analysis of commuter satisfaction was conducted using both descriptive statistics and a Likert scale to measure the perceived impact of the green roofs on commuting comfort and environmental quality. The study methodology aligns with recent research on the use of green infrastructure in urban transit settings, which has shown promising results in terms of reducing urban heat island effects and enhancing commuter experiences (Mendoza & Almonte, 2023). This mixed-methods approach ensures a comprehensive understanding of the benefits and challenges associated with integrating green roofs into Metro Manila's public transportation system.

RESULTS AND DISCUSSION

Table 1
Demographic Profile of Survey Respondents

Demographic Category	Percentage (%)
Age 25-34	44%
Age 35-44	28%
Female	51%
Male	46%
LGBTQ+/Non-Binary	3%
Employment Rate	75%
Residents of Metro Manila	89%
Frequency of BRT Usage (Daily)	5%

The survey sample accurately represents the commuter population of Metro Manila, with a focus on the 25–34 age group (44%), which is typically highly active in the workforce and dependent on public transport. The gender distribution (51% female and 46% male) is reflective of the general commuter demographic. A noteworthy 75% of respondents are employed, which demonstrates a strong representation of individuals who rely on public transit as their primary mode of transportation (Lopez & Tan, 2022).

Additionally, the high percentage (89%) of respondents living within Metro Manila ensures a sample that is familiar with the environmental and infrastructural challenges of the EDSA corridor. Despite only 5% of respondents using the EDSA Carousel BRT system daily, awareness of the green roof initiative at Main Avenue Station was high, suggesting that urban environmental improvements attract attention even from occasional commuters (Garcia, Soriano, & Tan, 2021).

Table 2
Commuter Perceptions of Environmental Benefits of Green Roofs

Survey Item	Mean Score (1-5)	Interpretation
Heat Reduction (Cooling Effect)	4.33	Strongly Agree
Air Quality Improvement (Pollutant Absorption)	4.35	Strongly Agree
Oxygenation (Psychological Benefits)	4.28	Strongly Agree
Aesthetic Value (Visual Appeal)	4.47	Strongly Agree

Commuters overwhelmingly agreed that green roofs have significant environmental benefits, particularly in heat reduction (M = 4.33) and air quality improvement (M = 4.35). These findings are consistent with the literature on the effectiveness of green roofs in mitigating urban heat island (UHI) effects, where green roofs can reduce surface temperatures by 15–30°C (Chen & Zhao, 2021; Sorenson & Harber, 2024). The strong support for "oxygenation" (M = 4.28) reflects the recognized psychological and health benefits of green spaces, which have been shown to reduce stress and improve emotional well-being in urban settings (Beyer et al., 2014).

The high score for "Aesthetic Value" (M = 4.47) confirms that commuters view green infrastructure not only as a functional solution but also as a way to improve the visual environment of often congested and stressful transit spaces. This finding aligns with Tzoulas et al. (2007), who emphasized that aesthetic enhancements contribute to the broader acceptance and success of urban greening projects.

Table 3
Perceived Operational Benefits and Commuter Comfort

Survey Item	Mean Score (1-5)	Interpretation
Improvement in Commuter Comfort	4.49	Strongly Agree
Willingness to Use Public Transport More	4.15	Likely
Overall Satisfaction with Green Roof Features	4.51	Strongly Agree
Willingness to Pay PHP 1 for Maintenance	4.42	Strongly Support

The high mean scores for "Improvement in Commuter Comfort" (M = 4.49) and "Overall Satisfaction with Green Roof Features" (M = 4.51) reflect the significant positive impact green roofs have on the commuter experience. These results confirm earlier studies, including the work of Beyer et al. (2014), that green infrastructure can improve commuter comfort by mitigating heat stress, enhancing visual appeal, and providing psychological relief.

Additionally, 4.15 mean score for "Willingness to Use Public Transport More" indicates that green roofs could have a positive impact on increasing public transport usage. This finding is supported by Banister (2008), who suggests that environmental quality improvements in public transport systems can lead to higher usage rates. The willingness to pay PHP 1 for maintenance (M = 4.42) suggests that commuters are not only supportive of the green roofs but are also willing to contribute financially, aligning with findings from the Green Climate Fund (World Bank, 2020) on public-private funding models.

Table 4
Commuter Feedback on Financial Feasibility and Support

Survey Item	Mean Score (1-5)	Interpretation
Support for Public-Private Partnerships (PPPs)	4.12	Likely Support
Willingness to Contribute to Maintenance Costs	4.42	Strong Support
Importance of City Investment in Green Roofs	4.30	Extremely Important
Financial Viability of Green Roofs	4.20	Supportive

Commuter support for Public-Private Partnerships (PPPs) (M = 4.12) and their willingness to contribute to maintenance costs (M = 4.42) indicate a recognition of the financial feasibility of green roofs, especially when considering external funding sources (Rodrigues & Slack, 2019). The strong emphasis on the "Importance of City Investment" (M = 4.30) highlights that the public views government involvement as crucial for the long-term success of such infrastructure projects, echoing the findings from the Green Climate Fund and other urban sustainability frameworks (World Bank, 2020).

Respondents also showed a positive view of the financial viability of the project (M = 4.20), suggesting that public-private partnerships could be a viable model for financing green roofs in Metro Manila's public transit systems. This supports earlier studies, such as those by Ghisellini et al. (2016), which argue for leveraging both public and private sector resources to sustain green infrastructure projects.

Table 5
Expert Feedback on Technical Feasibility and Sustainability

Survey Item	Mean Score (1-5)	Interpretation
Technical Feasibility (Plant Survival)	3.88	Agree
Maintenance Requirements (Watering, Pruning)	4.21	Strongly Agree
Long-Term Sustainability (Climate Resilience)	4.08	Agree
Suggestions for Improvement (Smart Irrigation)	4.34	Strongly Agree

Expert feedback generally agrees on the technical feasibility of implementing green roofs, particularly in terms of plant survival (M = 3.88). However, concerns about long-term sustainability and maintenance were prevalent, with experts highlighting the need for smart irrigation systems, regular pruning, and monitoring (Garcia et al., 2021). The suggestion for smart irrigation systems (M = 4.34) is in line with recent studies, such as those by Sorenson & Harber (2024), which emphasized the role of IoT technologies in ensuring the sustainability of green roofs by optimizing water usage and minimizing maintenance costs.

Experts also expressed confidence in the climate resilience of Portulaca grandiflora (M = 4.08), supporting its use in tropical climates prone to extreme weather (Chen & Zhao, 2021). However, continuous monitoring and adaptive systems, including water retention basins and advanced drainage systems, were recommended to ensure long-term success under varying climatic conditions.

Table 6
Perceived Barriers to Implementation and Recommendations

Survey Item	Mean Score (1-5)	Interpretation
Maintenance Complexity (Irrigation, Pruning)	4.10	Agree
Structural Concerns (Load-Bearing, Drainage)	3.95	Agree
Recommendations for Further Testing (Pilot Projects)	4.27	Strongly Agree
Interest in Expanding to Other Transit Stations	4.42	Strongly Agree

Survey respondents expressed concerns about the complexity of maintaining green roofs, particularly in terms of irrigation and pruning (M = 4.10), aligning with expert feedback on the technical challenges of sustaining plant systems in high-density urban environments (Loder, 2014). Structural concerns regarding load-bearing and drainage (M = 3.95) also highlight the need for careful engineering planning before large-scale deployment, reflecting similar concerns noted in studies by Patel & Patra (2011).

However, there is a strong consensus for piloting green roof systems before scaling up, with 4.27 for the "Recommendations for Further Testing" item. This cautious yet optimistic approach is in line with international best practices for green infrastructure, where phased implementation allows for adjustments based on real-world performance (Vijayaraghavan et al., 2017).

Table 7
Commuter Satisfaction with Green Roof Aesthetic and Comfort

Survey Item	Mean Score (1-5)	Interpretation
Aesthetic Appeal of Green Roofs	4.47	Strongly Agree
Psychological Comfort (Reduction in Stress)	4.30	Strongly Agree
Perceived Coolness and Comfort During Peak Hours	4.49	Strongly Agree

Commuters overwhelmingly agreed that the aesthetic appeal of the green roofs (M = 4.47) contributed significantly to their overall satisfaction, reinforcing the importance of visual elements in urban greening projects (Tzoulas et al., 2007). The score for "Psychological Comfort" (M = 4.30) aligns with findings from Beyer et al. (2014), who found that exposure to greenery can significantly reduce stress and improve mental well-being. Moreover, the high score for perceived coolness and comfort during peak hours (M = 4.49) supports the effectiveness of green roofs in reducing heat stress, particularly in dense urban transit corridors.

CONCLUSION

The GREENPATH initiative's modular green roof system, utilizing Portulaca grandiflora, has shown significant potential to improve the environmental quality, commuter comfort, and overall aesthetic appeal of Metro Manila's public transit infrastructure. The positive feedback from commuters and experts confirms the value of green roofs in mitigating heat stress, enhancing air quality, and contributing to a more pleasant commuting experience. These findings are consistent with global best practices that emphasize the dual benefits of green infrastructure for urban climate resilience and public health (Chen & Zhao, 2021; Sorenson & Harber, 2024).

While the initiative has garnered strong public support, key challenges such as maintenance, climate resilience, and financial sustainability must be addressed. The long-term success of the GREENPATH initiative depends on the successful integration of adaptive design features, effective financing models, and institutional commitment.

Recommendations

Further Validation through Expanded Pilots. To ensure the scalability and effectiveness of green roofs in different transit corridors, additional pilot projects should be implemented in other parts of Metro Manila, such as Ortigas and Taft, with detailed monitoring of environmental and social impacts.

Adopt Smart and Adaptive Technologies. Integrating smart irrigation, automated temperature sensors, and data-driven monitoring systems is essential for optimizing resource use and ensuring the system's resilience to weather variations, as suggested by Sorenson & Harber (2024).

Explore Public-Private Financing Models. Developing PPPs and exploring green bonds or climate resilience financing options should be prioritized to secure funding for large-scale green roof installations. These financial models can help offset the high upfront costs and ensure the system's long-term viability.

Develop a Comprehensive Maintenance Framework. A clear, structured maintenance plan should be established to address concerns related to drainage, plant health, and irrigation systems. This plan should integrate IoT-based monitoring systems to reduce manual interventions and improve system sustainability.

Engage the Public through Education and Incentives. To build greater public buy-in, targeted campaigns should be launched to educate commuters about the benefits of green roofs and offer incentives, such as fare discounts or eco-points, to encourage participation in maintaining and supporting green infrastructure.

Institutionalize Green Roofs in Urban Planning Regulations. Green roofs should be incorporated into the urban planning and development regulations, aligned with national policies such as the Philippine Green Building Code (PGBCode) and local climate resilience frameworks, to ensure their widespread adoption in future urban projects.

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