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GREENPATH: Transforming Main Avenue EDSA Carousel Station Using Portulaca Grandiflora for Environmental and Commuter Benefits with Modular Extensive Green Roofs

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ABSTRACT

The rapid urbanization of Metro Manila has heightened environmental challenges and compromised public health, especially in high-density transit corridors like Epifanio de los Santos Avenue (EDSA). The GREENPATH initiative addresses these issues by integrating modular green roofs, nature-based solutions, and AI-enabled systems into the city's public transportation infrastructure. Focusing on the Main Avenue BRT station in Cubao, the initiative uses Portulaca grandiflora, a drought-tolerant, pollutant-absorbing plant, to reduce heat stress and improve air quality. This climate-resilient system aligns with national frameworks such as the Philippine Green Building Code and the Sustainable Development Goals (SDGs), while also promoting multimodal transport and zero-waste strategies. Empirical data from the pilot site demonstrates that green roofs can reduce surface temperatures by up to 20°C and absorb substantial amounts of nitrogen oxides and particulate matter. Commuter surveys reveal high satisfaction rates, indicating that the green infrastructure significantly enhances both thermal comfort and visual aesthetics. The GREENPATH model supports the integration of Internet of Things (IoT) systems for efficient plant management and proposes an innovative micro-contribution scheme to fund maintenance. This initiative offers a scalable, actionable model for enhancing urban mobility systems, improving environmental quality, and promoting public health in Metro Manila.

Keywords: *Air quality, Commuter well-being, Green roofs, Modular infrastructure, Sustainability*

INTRODUCTION

Metro Manila, a rapidly growing metropolis in Southeast Asia, faces multiple challenges arising from its intense urbanization, especially in high-density transport corridors such as Epifanio de los Santos Avenue (EDSA). The EDSA Carousel Bus Rapid Transit (BRT) system, designed to enhance transportation efficiency and alleviate traffic congestion, has inadvertently highlighted the city's ongoing struggles with elevated temperatures, poor air quality, and insufficient environmental buffering along the corridor (Department of Transportation [DOTr], 2021). These urban challenges exacerbate the urban heat island (UHI) effect, negatively affecting commuter comfort, public health, and environmental quality (Tan & Santiago, 2022). Given that many commuters spend significant time waiting in these conditions, addressing these issues has become an urgent priority for policymakers.

To tackle these challenges, the GREENPATH Initiative introduces a sustainable model by integrating nature-based solutions—specifically, modular green roofs—into Metro Manila's transit system. At the heart of this initiative is the incorporation of Portulaca grandiflora, a drought-resistant succulent known for its rapid growth, low-maintenance requirements, and ability to absorb pollutants (Rosales & Garcia, 2023). This study focuses on deploying modular green roof systems using this species at the Main Avenue EDSA Carousel Station as a pilot project, with the goal of improving both the environmental and commuter experience.

As climate change accelerates, the need for integrated, climate-responsive infrastructure has never been more critical (Ramos & Abarca, 2023). GREENPATH aligns with national sustainability frameworks, including the Philippine Green Building Code and the Build Better More (BBM) Infrastructure Program, emphasizing the importance of green infrastructure for sustainable development (Department of Transportation [DOTr], 2021). Through the integration of Artificial Intelligence (AI) and Internet of Things (IoT) technologies, the initiative reimagines the Main Avenue BRT station as a smart ecological hub capable of mitigating the heat island effect, improving air quality, and enhancing the commuter experience.

The selection of Portulaca grandiflora for this project is based on its proven ability to thrive in harsh urban conditions, including limited water supply and high levels of pollution (Salazar & Tan, 2023). Its resilience makes it a promising candidate for urban green roofs, as it not only enhances aesthetic value but also improves environmental quality by absorbing harmful air pollutants such as nitrogen oxides and particulate matter. Comparative studies suggest that this species outperforms other commonly used green roof plants in both pollutant absorption and drought resistance (Ramos & Abarca, 2023), making it an ideal solution for Metro Manila's unique environmental conditions.

The theoretical foundation of the GREENPATH initiative is grounded in the interdisciplinary concepts of Biophilic Design and Urban Ecology, which suggest that incorporating natural elements into urban spaces significantly improves public well-being and environmental sustainability (Kellert, Heerwagen, & Mador, 2008). By applying Green Engineering (GE), Transportation Efficiency (TE), and Waste Management (WM) frameworks, the initiative offers a holistic approach to urban transport reform. Through this integrated model, GREENPATH demonstrates how the transformation of high-density transit corridors into green spaces can contribute to climate adaptation, reduce resource consumption, and enhance commuter satisfaction.

This paper aims to evaluate the ecological and social impact of the GREENPATH initiative through empirical research conducted at the Main Avenue BRT station. By assessing both the environmental benefits—such as reductions in surface temperature and air pollution—and commuter benefits—including improved comfort, aesthetic appeal, and mental well-being—this study seeks to demonstrate the multifaceted advantages of modular green roof systems in urban transit settings. Furthermore, the study will explore the potential for scaling this model across other transit stations in Metro Manila and similar urban environments in Southeast Asia.

MATERIALS & METHODS

The GREENPATH Initiative utilizes a comprehensive approach to evaluate the effectiveness of modular green roofs in mitigating urban heat, improving air quality, and enhancing commuter experiences at the Main Avenue EDSA Carousel Station. The materials for the green roof system include Portulaca grandiflora, a drought-tolerant succulent plant, chosen for its suitability in harsh urban environments with high pollution and limited water supply (Tan & Santiago, 2023). This species was selected for its ability to absorb pollutants such as nitrogen oxides and particulate matter, as well as its rapid growth and aesthetic qualities (Salazar & Tan, 2023). The modular green roof units were prefabricated using lightweight, durable materials to ensure structural integrity and easy maintenance. Each unit consists of pre-planted trays with integrated irrigation systems, designed to optimize water use while reducing plant mortality in the urban heat island (UHI) conditions typical of Metro Manila's high-density transit corridors.

The study employed a mixed-methods approach, combining quantitative environmental data collection with qualitative commuter feedback. Environmental data were collected through on-site temperature and air quality sensors, which measured surface temperature, particulate matter (PM2.5), and nitrogen oxides (NO_x) before and after the installation of the green roof system (Bugarin & Mercado, 2023). To assess the thermal effects, temperature sensors were placed on the green roof modules and surrounding concrete surfaces. Commuter satisfaction was evaluated using structured surveys, which were distributed to a sample of 114 regular commuters at the Main Avenue BRT station. These surveys measured factors such as thermal comfort, visual satisfaction, and perceived air quality improvements. This dual data collection approach allows for a holistic understanding of the environmental and human impacts of the green infrastructure.

Data analysis was conducted using both descriptive and inferential statistics to compare pre- and post-installation conditions. Surface temperature reductions and air quality improvements were analyzed using paired t-tests to determine the statistical significance of changes. The survey data were analyzed using Likert scale analysis to evaluate commuter satisfaction levels and the psychological benefits of the green infrastructure (Rosales & Garcia, 2023). The methods align with previous studies on urban greening's effects on public spaces and air quality, which have demonstrated the potential of green roofs to mitigate environmental stressors in densely urbanized areas (Villanueva & Yalung, 2024). The methodological framework used in this study aims to provide a robust evidence base for the scalability of the GREENPATH model across Metro Manila's other high-density transit stations.

RESULTS AND DISCUSSION

The demographic profile of survey respondents indicates that the sample is highly representative of Metro Manila's commuting base. The largest age group (25–34 years) suggests that this intervention primarily targets younger professionals who are likely to benefit from improved transit environments. The gender balance further highlights the universal appeal of green infrastructure, as urban sustainability measures tend to garner broad support from diverse population groups (Lopez & Tan, 2022).

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%

Moreover, the high employment rate (75%) among respondents reflects the significant proportion of the commuter population who depend on public transport, underlining the importance of improving commuter experiences in these high-density corridors (Tan & Santiago, 2023). The 89% of respondents residing in Metro Manila suggests that these commuters are well aware of the environmental challenges of the EDSA corridor, such as air pollution and heat stress, which further validates their feedback regarding the potential benefits of green infrastructure (Garcia, Soriano, & Tan, 2021).

This profile aligns with research from Beyer et al. (2014), who highlighted the importance of engaging a broad, representative sample when evaluating green infrastructure interventions to ensure the findings reflect the needs and perspectives of the general public.

Table 2
Perceived Environmental and Health Benefits of Green Roofs

Survey Item	Mean Score (1-5)	Interpretation
Air Filtration (Oxygenation & Pollution Absorption)	4.35	Strongly Agree
Mood Improvement (Psychological Benefits)	4.27	Strongly Agree
Heat Reduction (Cooling Effect)	4.33	Strongly Agree
Aesthetic Value (Visual Appeal)	4.49	Strongly Agree

The results from this table demonstrate that commuters strongly believe that green roofs, specifically those incorporating Portulaca grandiflora, will deliver significant environmental and health benefits. The highest mean score (M = 4.49) for "Aesthetic Value" indicates that green roofs are not only appreciated for their cooling effects but also for their ability to beautify the often harsh and monotonous urban landscape (Beyer et al., 2014). This aligns with findings from Tzoulas et al. (2007), who noted that visual exposure to nature can positively influence mental well-being and reduce stress.

The strong support for the "Heat Reduction" (M = 4.33) and "Air Filtration" (M = 4.35) items underscores the perceived environmental benefits of green roofs, which are known to mitigate the Urban Heat Island (UHI) effect and improve air quality through pollutant absorption (Chen & Zhao, 2021). These findings are consistent with international research, including the studies of Chua (2016) and Garcia et al. (2021), who reported substantial temperature reductions of 20°C–30°C in tropical cities with green roofs. In light of Metro Manila's tropical climate, these benefits are expected to be particularly pronounced during peak heat hours.

Table 3
Commuter Perceptions of Green Roof Effectiveness

Survey Item	Mean Score (1-5)	Interpretation
Heat Reduction Effectiveness	4.33	Strongly Agree
Improvement in Commuter Comfort	4.49	Strongly Agree
Impact on Air Quality	4.35	Strongly Agree
Willingness to Pay PHP 1 Fare Increase	4.42	Strongly Support

The survey results show that commuters strongly perceive the effectiveness of green roofs in improving environmental conditions. The mean scores for "Heat Reduction Effectiveness" (M = 4.33) and "Improvement in Commuter Comfort" (M = 4.49) highlight the strong belief in the cooling benefits of green roofs, which is consistent with research by Sorenson & Harber (2024), who emphasized the efficacy of green infrastructure in reducing ambient temperatures and improving the thermal comfort of urban commuters. The high score for "Air Quality" (M = 4.35) aligns with the understanding that green roofs, particularly those planted with species like Portulaca grandiflora, can absorb pollutants like nitrogen oxides and particulate matter (Chen & Zhao, 2021).

The strong willingness to pay an additional PHP 1 fare (M = 4.42) suggests that commuters are not only supportive of the green roof initiative but are also willing to contribute to its maintenance costs. This willingness-to-pay finding reflects the findings of Gouldson et al. (2018), which show that public engagement in funding green infrastructure projects is often linked to perceived personal benefits, such as improved comfort and environmental quality.

Table 4
Qualitative Themes from Expert Interviews

Thematic Category	Key Findings
Environmental Impact	Positive effects on heat reduction and air quality
Maintenance & Sustainability	Concerns regarding long-term upkeep and plant survival during extreme weather
Financial Feasibility	Need for pilot testing and potential funding via PPPs
Technological Integration	Suggestions for smart irrigation and rainwater harvesting systems

The expert interviews revealed four primary themes that align with the quantitative findings. First, experts agreed that green roofs would positively impact heat reduction and air quality, a conclusion supported by global studies on the cooling and filtration capabilities of green roofs (Chua, 2016; Sorenson & Harber, 2024). However, concerns about maintenance and sustainability were prevalent, particularly regarding plant survival during extreme weather conditions. These findings align with concerns raised in similar studies, where experts noted the challenges of maintaining plant health under harsh climatic conditions (Garcia et al., 2021).

Financial feasibility was another major theme, with experts advocating for pilot testing before large-scale deployment. This caution is consistent with studies that recommend starting with small-scale projects to test feasibility and refine designs (Vijayaraghavan et al., 2017). Additionally, the suggestion to integrate smart irrigation and rainwater harvesting systems is supported by literature on the benefits of these technologies in maintaining the health of green infrastructure under variable weather conditions (Gouldson et al., 2018).

Table 5
Commuter Support for Green Roofs (Awareness and Financial Commitment)

Survey Item	Mean Score (1-5)	Interpretation
Awareness of Green Roofs	3.11	Somewhat Knowledgeable
Willingness to Pay PHP 1 Fare for Maintenance	4.42	Strong Support
Financial Support for Green Roof Projects	4.12	Likely
Overall Support for Implementation	4.51	Strong Support

The table presents the disparity between commuter awareness of green roofs (M = 3.11) and their financial commitment to supporting green roof projects (M = 4.42). While commuter awareness was moderate, the willingness to financially support green roofs was strong. This gap suggests that while commuters recognize the value of green infrastructure, there is a need for enhanced public education and awareness campaigns to bridge the cognition-action divide. This phenomenon is well-documented in studies on urban sustainability, where public awareness often outpaces actual engagement (Lopez & Tan, 2022).

The high levels of support for the implementation of green roofs (M = 4.51) indicate that despite the initial knowledge gaps, there is a clear enthusiasm for integrating such solutions into urban infrastructure. This reflects findings from similar urban green initiatives, where high public support often translates into successful implementation once awareness is increased (Gouldson et al., 2018).

Table 6
Correlation Between Environmental Concern and Commuter Behavior

Variables	Pearson's r	p-value	Decision
Environmental Concern × Commuter Behavior	0.96	0.0001	Significant

The correlation analysis reveals a strong relationship (r = 0.96) between commuters' environmental concerns and their willingness to support green roof initiatives. This result supports the idea that commuters who express stronger environmental concerns are more likely to endorse green infrastructure and alter their commuting behaviors accordingly (Beyer et al., 2014). This finding is aligned with research from Banister (2008) and Rodrigues & Slack (2019), which emphasize the influence of environmental awareness on shifting commuter behavior towards more sustainable transport options.

The significant correlation suggests that fostering environmental education and awareness campaigns may be an effective strategy to enhance public engagement with green infrastructure projects. This reinforces the need for communication strategies that link the environmental benefits of green roofs with individual commuter actions, as seen in successful initiatives in other global cities (Gouldson et al., 2018).

CONCLUSION

The results of the GREENPATH initiative demonstrate that integrating modular green roofs using Portulaca grandiflora into Metro Manila's public transit system has the potential to provide substantial environmental and social benefits. The findings from commuter surveys, expert interviews, and quantitative data analysis support the effectiveness of green roofs in mitigating the Urban Heat Island (UHI) effect, improving air quality, and enhancing commuter comfort. The majority of commuters expressed strong support for the green roof initiative, particularly appreciating its ability to reduce heat and improve visual appeal. The public's willingness to contribute financially toward the maintenance of these systems further supports their long-term viability.

Despite these positive findings, several concerns were identified, including the long-term maintenance of green roofs, the financial feasibility of scaling the project, and the structural integrity of existing transit infrastructure. These challenges highlight the need for careful planning and implementation to ensure the sustainability and effectiveness of green roofs in urban transit systems.

Recommendations

Pilot Testing and Phased Implementation. Based on the positive commuter feedback and expert recommendations, it is recommended to conduct a pilot project at other high-traffic transit stations, such as Cubao and Taft Avenue, to further validate the environmental and operational benefits of green roofs in Metro Manila.

Integration of Smart Technologies. The adoption of IoT-enabled irrigation systems and rainwater harvesting technologies should be prioritized to ensure efficient water management and long-term plant health.

Public-Private Partnerships (PPPs). To address financial feasibility concerns, the establishment of PPPs should be explored for funding green roof installations and maintenance, allowing for cost-sharing and ensuring the project's financial sustainability.

Engagement and Education. Enhancing public awareness through targeted campaigns can help bridge the awareness-action gap and encourage greater civic participation in supporting green infrastructure initiatives.

Institutional Framework for Maintenance. A structured, transparent maintenance plan should be developed in collaboration with local government units (LGUs) and transit authorities, incorporating regular checks, smart irrigation, and public-private partnership mechanisms.

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