HIGH SCHOOL EDITION
Journal of Student Research
Volume 13 Issue 4 (2024)

Green Roofs as a Tool to Combat Climate Change and Maximize Urban Sustainability in the U.S.

Paul Lee

Cranbrook Kingswood Highschool, USA

ABSTRACT

To build more housing and accommodate the ever-increasing world population, humans must remove and build into the natural world. The majority of the process requires the removal of trees, grass, and other greenery, all of which provide environmental benefits. Without this flora, urban areas are experiencing unanticipated issues concerning environmental and climate change. Environmental engineering has brought green roofs as a potential solution to these problems. Green roofs are roofs planted with various types of flora from grasses to succulents to wildflowers, depending on the climate of the area. Green roofs aid in lessening electricity usage through their cooling effects in urban areas and mitigating the urban heat island effect. Furthermore, green roofs act as carbon sinks to remove air pollution and greenhouse gases, which are particularly prominent in urban areas. Another major function of green roofs is stormwater management, as they can absorb rainfall and runoff, resulting in flood prevention in cities not equipped for it. Green roofs are widely accepted and used in Europe but have struggled to grasp a stronghold in America. This research project consisted of primary survey data utilized to gauge the average American high school student's conception of green roofs, or lack thereof. In the results, the findings indicate that when high school students are presented with more information on green roofs they are more willing to adopt them or at least advocate for their adoption with some reserves. This opens the door for greater popularity in the American market.

Introduction

A 2018 report from the United Nations Department of Economic and Social Affairs predicts that 68 percent of the world's population will live in urban areas by 2050, up from 55 percent in 2018 (p. xix). As these urban areas grow in popularity, more space is required to accommodate the traffic. This leads to the need for greater incorporation of sustainable infrastructure solutions in cities. Since they are "concentrated centers of production, consumption, and waste disposal," cities are an ideal environment to study climate and ecology as they are "microcosms of that global environmental change (Grimm et al., 2008, p. 759). The dual impact of urbanization can be seen in how cities contribute significantly to environmental challenges but can also serve as the best grounds for testing sustainability solutions. Researchers such as Marina Alberti (2005) explain how urbanization negatively affects the environment, since "Urban development fragments, isolates, and degrades natural habitats; simplifies and homogenizes species composition; disrupts hydrological systems; and modifies energy flow and nutrient cycling" (p. 169). Such disruptions highlight the need for innovative solutions that can integrate the natural world with manmade environments to mitigate the negative impacts of urbanization. In response to these challenges, the implementation of sustainable infrastructure, such as green roofs, is becoming increasingly critical in ecological balance in the world's largest cities.

While much more established in Europe, green roofs are now emerging as a viable option in North America, offering significant environmental and economic benefits. They are precisely what the name entails, "roofs planted with different kinds of vegetation/plants on the top of growth medium"(Shafique et al., 2018, p. 757). Having existed in some capacity since 4000 BCE, the modern green roof originated in Germany at the turn of the 20th century and in the decades following "many German cities have…introduced incentive programs to promote green-roof technology and improve environmental standards" (Oberndorfer et al., 2007, p. 825). These incentives have been instrumental in

establishing Germany as a global leader in green roof implementation, providing a model that other regions can follow to reap similar environmental benefits. With its popularity in Germany, surrounding European nations are seeing the benefits and adopting initiatives like green roofs. Compared to Europe, a significant barrier to the popularity of green roofs in North America is "a lack of awareness regarding green roofs" (Getter & Rowe, 2006, p. 1282). This lack of awareness, almost apathy, hinders the market growth of green roofs in North America as many potential stakeholders and investors remain unaware of the environmental and economic advantages these systems can offer. Green roofs are a novel environmental engineering feat that incorporates the natural world and human design. They have the potential to enhance urban sustainability worldwide, and with an introduction to the North American market, the environmental impact of green roofs could skyrocket.

Urban Heat Islands and Air Pollution

Green roofs offer substantial environmental benefits, particularly in reducing urban heat islands (UHI) and improving air quality. UHIs are urban areas that experience higher temperatures than adjacent areas because all the man-made structures absorb and reemit the sun's heat more than natural ecosystems (Environmental Protection Agency, 2024). The dense concentration of buildings and pavement in cities exacerbates heat retention, leading to higher ambient temperatures. The increase in temperatures not only affects human health and comfort but also increases energy consumption due to the higher demand for cooling at all hours of the day. All of this points to UHIs being a critical issue that warrants greater attention. A 2008 study in New York City found that green roofs' "thermal resistance and evapotranspiration reduce the heat fluxes through the roof," as well as saving energy usage in heating and cooling offices by 40 to 110 percent (Susca et al., 2011, p. 2124). This study shows how green roofs can significantly mitigate the UHI effect by acting as insulators and cooling agents. Reducing heat flux through green roofs decreases the need for artificial cooling, lessening energy usage, which is critical in combating the excessive energy use typically associated with urban areas. By reducing urban temperatures and improving energy efficiency, green roofs provide a vital solution to the environmental challenges posed by UHIs, contributing to more sustainable and livable cities in the long term.

Additionally, green roofs contribute to carbon dioxide sequestration and reduce greenhouse gas emissions in urban environments. This is an area where people are actively seeing and feeling the problem green roofs can fix because urban cities are known to be heavily polluted, even going as far as having smog events for some. Green roofs can act as carbon sinks since "carbon is a major component of plant structures and is naturally sequestered in plant tissues" and, with enough time, green roofs will reach "a carbon equilibrium (plant growth = plant decomposition)" (Rowe, 2011, 2103). Over time, the balance between plant growth and decomposition helps stabilize the carbon levels in the urban environment, making green roofs an effective tool in reducing the overall carbon footprint of cities by adding carbon sinks cities removed as they expanded. In a study of green roofs in Chicago, Illinois, Yang et. al (2008) found that 19.8 hectares of green roofs removed 1675 kilograms of total air pollution (p. 7269). The findings from Chicago reinforce the environmental benefits of green roofs, showing their capacity to sequester carbon and reduce other airborne pollutants. This dual function enhances air quality and contributes to healthier urban environments, showing green roofs do more than just carbon reduction as any plant can do. Through carbon sequestration and pollution reduction, green roofs can play a critical role in mitigating the environmental impact in urban areas, supporting the broader goal of sustainable urban development and climate change mitigation.

Stormwater Management

One of the green roofs' most significant environmental engineering benefits is their ability to manage and reduce stormwater runoff. In this case, a reduction is defined by green roofs' ability to "(i) delaying the initial time of runoff due to the absorption of water in the green roof system; (ii) reducing the total runoff by retaining part of the rainfall;

(iii) distributing the runoff over a long time period through a relative slow release of the excess water that is temporary stored in the pores of the substrate" (Mentens et al., 2006, p. 218). Green roofs act as natural sponges; they absorb and retain a portion of rainfall, which delays the onset of runoff and decreases the total volume of water that eventually flows into the urban drainage systems. By spreading the release of stormwater runoff over a longer period, green roofs also effectively reduce stormwater pressure on infrastructure. In a comparison of green roof and conventional roof runoff peaks, it was found that "57% of peaks on a [green] roof were delayed up to 10 min as compared with peaks from a conventional roof" (Berndtsson, 2010, p. 353). Green roofs are not only effective in reducing runoff volume but also in delaying peak runoff times. Green roofs can be crucial in sustainable urban water management by managing and reducing stormwater runoff, offering a practical solution to a growing problem in modern cities, which are more prone to flooding due to poor drainage systems in place.

Green roofs can alleviate the burden on urban drainage systems and reduce the risk of flooding. Based on studies from U.S. cities like Chicago, Philadelphia, and Portland, some researchers have claimed that "75% of rain-water was retained by extensive green-roofs" (Villarreal & Bengtsson, 2005, p. 2). Green roofs can retain a large percentage of rainfall, preventing it from entering the drainage system altogether. By capturing and holding this water, green roofs help mitigate the risk of flooding, especially in densely populated areas where impermeable surfaces, such as concrete, dominate. A study of rainfall runoff and green roofs done by Carpenter and Kaluvakolanu (2011) found that "The ability of the green roof to capture and slowly release rainfall runoff was very pronounced for events less than 2.54 cm, which historically represents more than 90% of all rainfall events in the northern temperate climate of Michigan" (p. 169). Beyond major storm and rainfall events, green roofs are particularly effective in managing smaller, more frequent rain events, which constitute the majority of precipitation in more temperate regions. Even with smaller storms, green roofs help prevent the cumulative impact on urban drainage systems, reducing the risk of flooding over time. Through their ability to reduce significant amounts of rainwater and release it slowly, green roofs reduce the strain on urban systems, making them the strategic choice in flood prevention and urban planning in flood-prone areas.

Challenges and Opportunities in the North American Market

Despite their known environmental benefits, the widespread adoption of green roofs in North America still faces several challenges, including high installation costs and a lack of public awareness. As with many building facilities, the cost of green roofs stretches past installation but includes operation, maintenance, and disposal costs. Installation costs of green roofs range depending on how intensive they are, from 147 USD/m^2 for semi-intensive systems to 409 USD/m^2 for intensive systems. In addition to installation costs, maintenance costs average at 4.84 USD/m^2/year, 8.78 USD/m^2/year, and 6.37 USD/m^2/year for extensive, semi-intensive, and intensive green roofs, respectively. Lastly, disposal costs must be considered for roof replacement, recladding, and renewal at 14 USD/m2 to 29 USD/m^2 (Manso et al., 2021, pp. 11-13). Taking the average American 1,700 ft2 (or 158 m2), a semi-intensive green roof can cost 24,613.24 USD for only installation and maintenance of the first year. These figures show the significant financial investment required for green roofs, which can deter many property owners. The initial high costs, ongoing maintenance, and eventual disposal expenses make green roofs less accessible, especially in areas without financial incentives. The economic barriers are not short-term but are a long-term financial commitment. International surveys find "the compliance with employing extensive green roof systems in the existing buildings is very low due to the lack of financial support and professional experts, which cannot address the complex construction process and technique difficulties within the extensive green roof technologies" (Zhang et al., 2012, p. 316). Without adequate finances and a workforce trained in green roof technologies, adoption rates will remain low. The technical and financial hurdles exacerbate each other, creating an endless cycle of inaccessibility that limits the mainstream potential for green roofs in North America. These challenges illustrate the barriers that must be overcome for green roofs to be more widely adopted across North America.

However, recent policy incentives and public-private partnerships are creating new opportunities for the spread of green roofs in the region. Cities like New York City offer property tax abatements for buildings that install

green roofs. As of June 2024, the NYC abatement would include a tax abatement of $10/ft^2, a depth of soil requirements of 1.5 inches, and a total program cap of 4 million USD (New York State Senator Liu, 2024). Through a program like this, it shows that governments can reduce the economic burden of green roof installations for property owners. By providing a tax abatement, NYC effectively lowers the barrier to entry, making green roofs a more attractive and accessible option. On the other side of the U.S., a 2017 San Francisco law "establish[ed] requirements for certain new building construction facilitating development of renewable energy facilities and living roofs" (Ordinance No. 221-16, 2017, p. 1). San Francisco's approach to mandated green roofs on new constructions is an example of a proactive policy that drives the adoption of sustainable technologies. By integrating green roofs into building codes, the city can promote environmental sustainability and normalize the practice. This, in turn, encourages developers and property owners to consider green roofs in their building designs. Both of these policies are instrumental in overcoming the challenges previously faced by green roofs, making them a much more viable and reasonable option for sustainability in North America.

Methodology

This study explores environmental engineering, the benefits of green roofs, and how they can be popularized in North America through a comprehensive review of existing literature and primary research. This study utilized peer-reviewed scholarly articles, past research studies, and current pieces of legislation to build its foundation. The research focused on three primary questions: 1) What are the atmospheric benefits of green roofs? 2) What are the most significant benefits of green roofs? and 3) With all its benefits, why are green roofs not widely adopted in North America, as opposed to their European counterparts? Despite the amount of literature and research behind this study, several limitations exist. Firstly, the study's generalized view of urban areas does not leave room for variables that could impact the benefits of green roofs, such as climate differences, economic conditions, or policy environments. Secondly, the data on green roof adoption, performance, and cost can vary widely in terms of quality and availability, depending on the source, region, and time of year. This means the data collected may be less comprehensive due to the variability. Lastly, environmental policies and incentives can change rapidly, as shown in the press release earlier. These changes can be influenced by changes in political leadership, economic conditions, and public opinion. Further research could incorporate comparative analysis across different regions, including various geographic areas, climates, and rural settings. This would leave space to expand on the advantages and disadvantages of different kinds of vegetation used and survival through more extreme climates. Furthermore, since green roofs have been around for quite a while, research could investigate the impact of climate change on the performance of green roofs. Climate change continues to influence weather patterns, which makes it essential to understand how these changes could impact all types of environmental engineering.

The primary research of this study used a survey to gather data on people’s awareness of sustainable infrastructure technology, green roofs, and their environmental effects. A questionnaire was created, comprising six preliminary questions to provide demographic information and 20 primary questions. The primary questions were split into 10 questions before providing information on green roofs and 10 questions after to see how awareness impacted peoples’ willingness to adopt sustainable infrastructure. The primary question answer options followed the Likert scale to rate the participants’ opinions and attitudes, the options given were “strongly agree,” “agree,” “neither agree nor disagree,” “disagree,” and “strongly disagree.” The survey was distributed electronically via Google Forms and completed by a sample of 21 adolescents and young adults between the ages of 15 to 19. The respondent pool was made through convenience sampling of American backgrounds to better understand the American apathy towards green roofs that was referenced in the literary research. The data collected from the survey and its results were analyzed using descriptive statistics and visual charts to identify any patterns or relationships. Participants were asked about their awareness of sustainable building technologies from the costs to government incentives. They rated their agreement with statements regarding their comfortability with the concept of green roofs before and after learning more

about them to provide insight into how far information can go in the younger generation's support and adoption of sustainable infrastructure.

Results

This survey aimed to mainly address American unawareness of green roofs, and sustainable infrastructure as a whole. By having questions split into a before and after of learning more information about green roofs, the research reflects how the presentation of new information can change a person's willingness to adopt new technology. The average American high school student may not be the most environmentally conscious, but this lack of interest becomes a greater issue when we look at how widely adopted sustainable solutions must be in order to be effective. The most relevant results from the survey have been visualized in the three figures below. The results indicate that there is potential for the growth of green roof adoption in the North American market once the environmental benefits are presented, but the high cost of green roofs continues to be a deterrent.

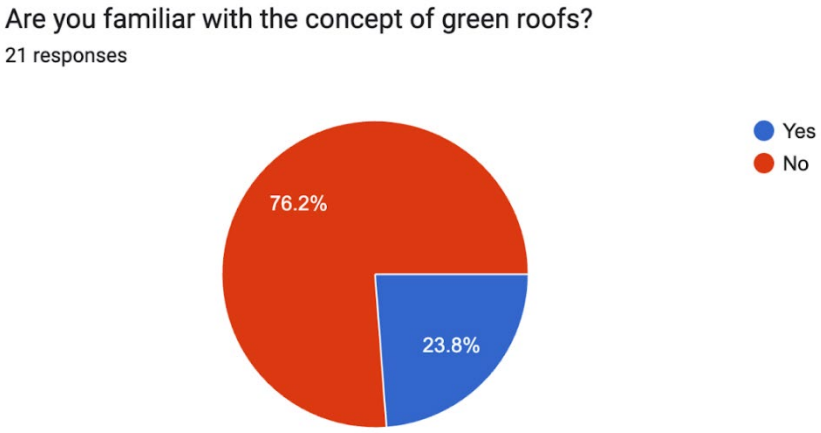

Figure 1. The preliminary question shows a general awareness of green roofs.

The preliminary questions were used to synthesize demographic information. Figure 1 shows the answers to the most topic-relevant question, "Are you familiar with the concept of green roofs?" Since all of the participants were American, this question can be used as a sample of what the average American high school student thinks of when it comes to green roofs. Of the 21 responses, 16 participants (76.2%) were not familiar with the concept of green roofs, and a heavy majority of the people were. This supports previous claims and mentions of American apathy towards green roofs.

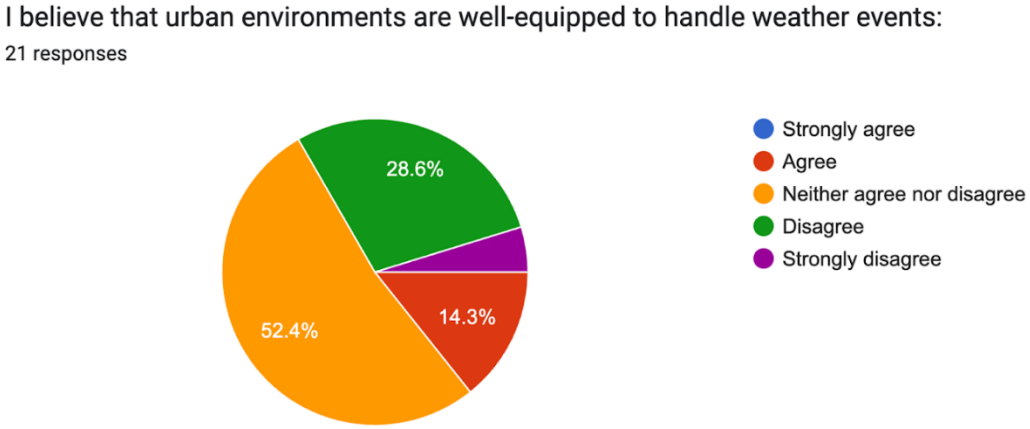

Figure 2. The primary question is to see what people thought of urban environments' ability to handle climate events.

Figure 2 shows the results of the agreement levels to the statement "I believe that urban environments are well-equipped to handle weather events." This statement was within the first 10 primary questions, which were asked before the participants were presented with information about green roofs. With just over half (52.4%) of participants responding "Neither agree nor disagree," this research found high school students as neither caring about this topic in their daily life. When looking at the remaining responses that provide a solid opinion, 33.3% of participants disagreed with the statement to some extent. This result shows that more students do not see cities and urban spaces as environmentally sustainable or ready for the impacts of climate change than students who do see them as prepared for the increasingly extreme weather events.

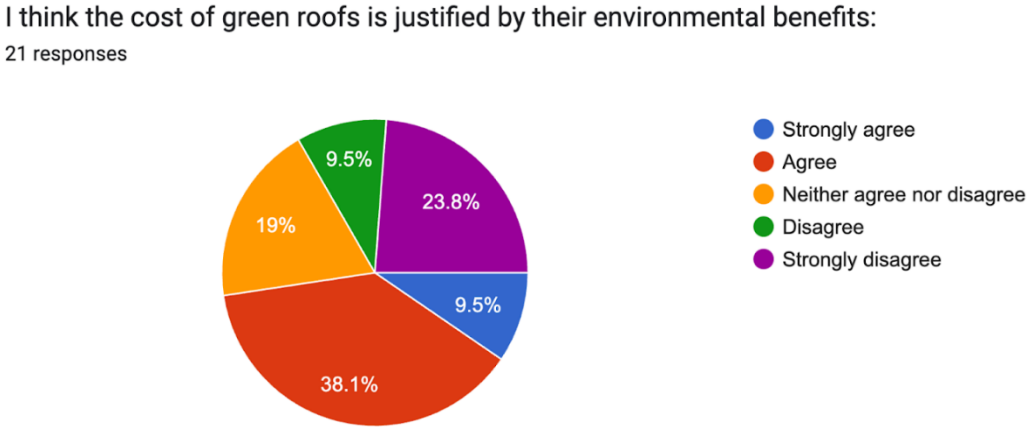

Figure 3. After being presented with information, participants weighed the financial burden versus the environmental benefit.

Figure 3 presents the results of a question from the second set of 10 questions, which were answered after being presented with information on green roofs. The statement presented was "I think the cost of green roofs is

justified by their environmental benefits" and respondents were able to provide their opinions on the matter. The results are some of the most diverse among all the responses to the survey. Figure 3 shows all five answer options representing a significant part of the chart. Of the participants, 47.6% said they agreed with the statement and 33.3% said they disagreed. While this shows that a majority of the students see the benefits outweighing the costs, the strength in opinion is worth noting. Only 9.5% of participants "strongly agreed," but 23.8% "strongly disagreed." The large disparity in severity shows one reason why green roofs are difficult to adopt. If one person only "agrees" and another "strongly disagrees," the side with a stronger opinion can resist for longer.

In summary, the survey reflects the varying points of the thought process when it comes to sustainability in America among younger generations. From a lack of knowledge of green roofs but a slight awareness of what is sustainable versus unsustainable to the problem everyone experiences: financial burdens.

Discussion

A large reason the average American high school student is unfamiliar with the concept of a green roof comes from its lack of adoption throughout North America. When considering the sheer size of the continent and differences within each individual state or province, there is no way to keep up with every new development unless it becomes wildly popular. National use and popularity of a concept like green roofs is particularly difficult due to the variability of climates and ecosystems within North America. Unlike Europe, which is a much smaller continent with multiple countries sharing similar climates, green roof research in North America has only studied 14 ecoregions ranging from the subtropical Blackland prairies of Austin, Texas to the mixedwood plains St. Lawrence lowlands of Quebec City, Quebec (Dvorak & Volder, 2010, pp. 204-5). Where the mixed environments create a gap in research on how suitable green roofs are for each ecoregion, it is no wonder why only 23.8% of the study's respondents have an idea of what green roofs are (Figure 1). Furthermore, commercial, public, and residential buildings and their owners are currently most benefitting from the installation of green roofs (Asl, 2023, p. 53). As with most topics, high school students are most concerned with the ones that directly impact them and, even then, these topics must have a substantial impact. To increase awareness of the lack of sustainability in urban environments, the direct problems this causes should be generally known by the national population to spark a movement towards better sustainability practices.

As mentioned previously, cities are feeling the direct impacts of climate change through the urban heat island effect and greater levels of air pollution. They are also seeing the problems of city infrastructure and how unprepared they are for handling the growing weather events due to poor stormwater management. The UHI effect exacerbates urban air pollution, creating an endless cycle where one worsens the other unless some intervention is introduced (Piracha & Chaudhary, 2022, p. 13). Floods, the most common of these weather events, pose a significant threat to urban areas because they are subject to the same natural forces as rural weather, but when combined with the lack of proper infrastructure, urban spaces see a significant proportion of these floods (Jha et al., 2011, p. 17). When survey participants were asked to respond to the statement, "I believe that urban environments are well-equipped to handle weather events," a striking 52.4% neither agreed nor disagreed, suggesting a lack of awareness or concern about urban resilience (Figure 2). This opinion fits with the respondent pool considering 85.7% of them live in suburban areas with the remaining 14.3% living in urban areas. Even so, a third of the response pool disagreed with the statement, which reflects broader concerns about the sustainability and readiness of urban environments because some students are aware of city problems, even if they do not live in these environments.

When asked about environmental sustainability as a priority, only 38.1% of survey respondents affirmed its importance, which indicates a significant portion of the population is either indifferent or unconvinced of its importance in their daily lives. Here, the green gap makes headway in comparison to the results shown in Figure 3. The green gap refers to the difference between people saying the environment is a priority that should be protected and the actual actions to help the environment (Gleim & Lawson, 2014, p. 503). This gap is evident in various aspects of consumer decision-making because the perceived environmental benefits of purchasing expensive environmentally friendly alternatives do not outweigh the benefits of spending money in "necessary" areas, such as paying bills and

saving for a house (Johnstone & Tan, 2015, p. 809). As seen in Figure 3, there are similarly mixed sentiments where 47.6% of participants agreed the cost of green roofs was justified by their environmental benefits. While this is a higher percentage than the number of participants who prioritize environmental sustainability, an almost 50-50 split illustrates why green roofs face adoption challenges. Even when offered financial incentives by the government, the average American high school student sees other priorities in their life they need to focus on, especially if they have to spend over 24,000 USD just to start one path towards environmental sustainability.

Conclusion

Green roofs represent an exciting intersection of environmental engineering and urban development, offering multiple benefits that can significantly enhance urban sustainability. Oberndorfer et al. (2007) put the functions of green roofs succinctly: "Green roofs represent a class of technology that can be considered bioengineering or biomimicry: the ecosystem created by a green roof's interacting components mimics several key properties of ground-level vegetation" (p. 831). Green roofs are a fusion of environmental engineering and natural ecosystems. They not only replicate natural ecosystems but also provide engineered solutions to urban challenges, such as heat reduction, air quality improvement, and stormwater management. The UHI effect is mitigated by green roofs' capacity to reduce surface temperatures and energy consumption. Green roofs can significantly reduce urban runoff by slowly releasing water, lessening flood risks, and removing the burden on urban drainage systems. Exploring government policies shows how these frameworks are essential in overcoming the barriers to green roof adoption in North America. The research conducted indicates the American attitude towards green roofs can be changed through the introduction of information, providing an avenue for governments and companies to consider when approaching environmental changes and sustainability. As the need for more sustainable living becomes clearer, green roofs offer a chance to better the environmental and economic health of American cities.

Limitations

Even with researched and thought-out survey questions, the research found still has several limitations. As with most self-reporting surveys, there is a potential response bias, particularly in the case of the environment, climate change, and sustainability. If a person believes being more knowledgeable and environmentally conscious makes them a more likable or simply better person, they may answer the questions according to what will present them in the best light, even with an anonymous survey. This can continue to happen, especially after being exposed to information that frames green roofs positively. Additionally, the information provided may not be uniformly understood by all the participants, leading to varying degrees of understanding that could skew the results in the second half of the primary questions. Finally, this survey's response pool had areas for improvement. For one, the response pool was quite small with only 21 responses. With a larger pool, the results can be a more accurate representation of the population. More responses could also address the other issue with the response pool, the age range. Since all the participants were between the ages of 15 and 19, these were people who mostly lived at home in the suburbs and had no firsthand experience in urban environments, which could impact the rest of their responses. By expanding the response pool, the results allow for more diverse results and greater accuracy in the conclusions drawn.

Acknowledgments

I would like to thank my advisor, Ms, Crowl, for their support and insight throughout the research and writing process.

References

Alberti, M. (2005, April). The Effects of Urban Patterns on Ecosystem Function. *International Regional Science Review, 28*(2), 168-192. 10.1177/0160017605275160.

Asl, S. R. (2023). Rooftops for Whom? Some Environmental Justice Issues in Urban Green Roof Policies of Three North American Cities. Environmental Policy and Law, 53, 49-60. 10.3233/EPL-220015.

Berndtsson, J. C. (2010). Green roof performance towards management of runoff water quantity and quality: A review. *Ecological Engineering, 36*(4), 351-360. 10.1016/j.ecoleng.2009.12.014.

Carpenter, D. D., & Kaluvakolanu, P. (2011). Effect of Roof Surface Type on Storm-Water Runoff from Full-Scale Roofs in a Temperate Climate. *Journal of Irrigation and Drainage Engineering, 137*(3), 161-169. 10.1061/(ASCE)IR.1943-4774.0000185.

Dvorak, B., & Volder, A. (2010, June). Green roof vegetation for North American ecoregions: A literature review. Landscape and Urban Planning, 96(4), 197-213. 10.1016/j.landurbplan.2010.04.009.

Environmental Protection Agency. (2024, June 6). Heat Island Effect | US EPA. Environmental Protection Agency (EPA). Retrieved August 9, 2024, from https://www.epa.gov/heatislands.

Getter, K. L., & Rowe, D. B. (2006, August). The Role of Extensive Green Roofs in Sustainable Development. *HortScience, 41*(5), 1276-1285. 10.21273/hortsci.41.5.1276.

Gleim, M. & Lawson, J. (2014). Spanning the gap: an examination of the factors leading to the green gap. Journal of Consumer Marketing, 31(6/7), 503-514. 10.1108/JCM-05-2015-0988.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science, 319*(5864), 756-760. 10.1126/science.1150195.

Jha, A., Lamond, J., Bloch, R., Bhattacharya, N., Lopez, A., Papachristodoulou, N., Bird, A., Proverbs, D., Davies, J., & Barker, R. (2011, May). Five Feet High and Rising: Cities and Flooding in the 21st Century. The World Bank. https://uwe-repository.worktribe.com/index.php/preview/963156/World%20Bank%20Policy%20Research%20Paper%20WPS5648.pdf.

Johnstone, M. L., & Tan, L. P. (2015). An exploration of environmentally-conscious consumers and the reasons why they do not buy green products. Marketing Intelligence & Planning, 33(5), 804-825. 10.1108/MIP-09-2013-0159.

Manso, M., Teotónio, I., Silva, C. M., & Cruz, C. O. (2021). Green roof and green wall benefits and costs: A review of the quantitative evidence. *Renewable and Sustainable Energy Reviews, 135*, 1-16. 10.1016/j.rser.2020.110111.

Mentens, J., Raes, D., & Hermy, M. (2006). Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landscape and Urban Planning, 77*(3), 217-226. 10.1016/j.landurbplan.2005.02.010.

New York State Senator John C. Liu. (2024, June 24). With temperatures hitting record highs across the northeast, legislators and environmental advocates call for the extension of NYC's green roof tax abatement before it expires

[Press release]. https://www.nysenate.gov/newsroom/press-releases/2024/john-c-liu/temperatures-hitting-record-highs-across-northeast.

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K. K. Y., & Rowe, B. (2007, November). Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. *BioScience, 57*(10), 823-833. 10.1641/B571005.

Piracha, A., & Chaudhary, M. T. (2022). Urban Air Pollution, Urban Heat Island and Human Health: A Review of the Literature. Sustainability, 14(9234), 1-19. 10.3390/su14159234.

Planning, Green Building Codes - Better Roof Requirements, Including Living Roofs, Ordinance No. 221-16 (2017).

Rowe, D. B. (2011). Green roofs as a means of pollution abatement. *Environmental Pollution, 159*(8-9), 2100-2110. 10.1016/j.envpol.2010.10.029.

Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities, and challenges - A review. *Renewable and Sustainable Energy Reviews, 90*, 757-773. 10.1016/j.rser.2018.04.006.

Susca, T., Gaffin, S. R., & Dell'Osso, G. R. (2011). Positive effects of vegetation: Urban heat island and green roofs. *Environmental Pollution, 159*(8-9), 2119-2126. 10.1016/j.envpol.2011.03.007.

United Nations Department of Economic and Social Affairs. (2018). World Urbanization Prospects: The 2018 Revision.

Villarreal, E. L., & Bengtsson, L. (2005). Response of a Sedum green-roof to individual rain events. *Ecological Engineering, 25*(1), 1-7. 10.1016/j.ecoleng.2004.11.008.

Yang, J., Yu, Q., & Gong, P. (2008). Quantifying air pollution removal by green roofs in Chicago. *Atmospheric Environment, 42*(31), 7266-7273. 10.1016/j.atmosenv.2008.07.003.

Zhang, X., Shen, L., Tam, V. W.Y., & Lee, W. W. Y. (2012). Barriers to implement extensive green roof systems: A Hong Kong study. *Renewable and Sustainable Energy Reviews, 16*(1), 314-319. 10.1016/j.rser.2011.07.157