Green Roofs: Understanding the Advancements of Green Technology Through the Human and Environment Relationship

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Abstract

The advancement of green roofs has been influenced by the changing dynamics of human civilizations. Green roofs are used to mitigate heat, as a stormwater management practice, and can increase the ecological benefits within a city. A "green roof" refers to any roof that has a layer of vegetation on the top. This study aims to explain the advancements of green roof through the framework created in Richard's White *The Organic Machine*. White's theory evaluates technology through the relationship between humans and their environment at various points in time. The framework does not compare humans to the environment, but rather analyzes their intertwined relationship and its changes over the course of time. As urbanization increased and the environmental impacts worsened, the need for environmental based technologies were forced to advance to maintain a livable world for inhabitants on earth.

Introduction

"Buildings change the power of the environment and how energy moves through the urban ecosystem, which often leads to environmental problems"(Orberdorfner, 2007). Green roofs are an effective technology that can target specific environmental challenges within urban settings. With the global population constantly increasing and the continued rapid urbanization, natural landscapes have been continually altered or destroyed. Green roofs can serve as a solution to increasing issues associated with climate change, specifically in cities, where there are limited ecological resources.

The term "green roof" is used to describe any flat or sloped "roof with a layer of plant material" (EPA, 2021). The term is broad, as green roofs have taken many forms and materials throughout time. A green roof usually has multiple components within it, especially in modern green roofs, including vegetation, substrate, filter layer, drainage material, root barrier, and waterproofing layer (Shafique, 2018). Green Roofs were first developed to increase heat retention or mitigate heat depending on the climates, but have further developed so the benefits include stormwater management, increased biodiversity, and ecologic benefits (Getter et al, 2006). Green roofs have the ability to reduce flood risks, reduce heat islands, and improve air quality. Where many technologies only have the ability to do one of those issues, green roofs can have a positive impact in all these areas

Understanding how the relationship between humans and the environment has impacted advancements in technology is an important implication for being able to invent the most effective green roofs in the future. By understanding the history of green roofs, one can potentially generalize the characteristics, relationships, and projection of the relationship between the use of environmental factors and green roofs. To explore how green roofs can be advanced to help mitigate the negative effects of climate change, Richard White's *The Organic Machine* will be used as a framework to analyze the constantly changing relationship between humans, their technology, and the environment to suggest changes that can be made in the future within the green infrastructure.

The scope of this paper will include an evaluation of how humans interact with the environment through the lens of green roofs through history. The paper will only look at the environmental impacts of green roofs, and will not analyze the social or economic factors related to green roofs. Specific examples of green roofs will be analyzed through two large eras, historical models, which encompass the time period of Medieval Europe through the early

1900's, and modern green roofs, where the examples will be from the mid 1900's through today. There will not be a generalization about technology within any specific time period.

Methodology: *The Organic Machine*

Richard White's *The Organic Machine* is employed to answer the following research question: Can the changing relationship between humans and the environment impact the advancement of green roof technology within cities?*The Organic Machine* demonstrates the complex relationship between humans and their environment, with the prime example in the work being the local civilizations's manipulation of the Columbia River throughout history to fit the demands of the human community. White's analysis of the environment as a source of energy creates a framework for understanding and assessing the historical interaction between people and their environment, "[it] is about the relationship between the two, not the distinct identity of either" (Cohen, 2005). White argument uses the example of human's abilities to harness the power of the river for their own benefits. The co-dependent relationship that has been created between humans and the environment has additionally led to the degradation of the natural environment, reducing the power it holds. "The point, in terms of natural and cultural, is not to argue for one over the other but to see their ever-present, always mixed, always entangled relationship" (Cohen). The two entities can never be completely separate, and White argues that it is not a beneficial relationship for the environment. Green roof technology is an example of the interconnectedness between the environment and humans, where the power of the environment is harnessed in the technology, such as heat mitigation or stormwater overflow reduction, to benefit the society.

White's argument shows the changes in the landscape of the Columbia river intertwined with changes in human society, as humans and the environment became completely connected.

The discussion brings up both the Native American population and the colonists during the 19th and 20th centuries and each of their interactions with the natural system. He argues that humans will not be able to live up to their idea of competency in emulating the powers of the natural world through their technology. The power balance has continuously been tipped towards humans throughout time, but the relationship cannot be sustained without contributions from both parties. The Columbia River exemplifies the careless consumption of the environmental energy and the destruction of the ecology within a community. White's argument strongly opposes the idealist beliefs of Mumford and Emerson. Having prevalent ideas in the mid 1900's, Lewis Mumford was a philosopher of technology and Ralph Waldo Emerson was a philosopher leading the transcendentalist movement. Both believed that the union of the environment with technology could lead to the most effective advancements. However, their arguments failed to acknowledge the impacts on the environment, as the hierarchy of importance only assessed the positive impacts for humans, which is the center of White's argument (Cohen, 2005).

White's analysis of the changing relationship between humans and the environment will be used as a framework to understand the advancement of green roofs and the technology's purpose in society and the environment. The changes in landscape of the environment will also be evaluated while moving through the historical timeline of green roofs. By studying the relationship and the effectiveness of the technology, it can be determined what improvements need to be made to green roofs to benefit both the environment and society in the future. With this knowledge, one can use the relationship between the environment and humans to evaluate similar advancements of technology.

A History of Green Roofs

Green roofs have had many criteria within their definitions depending on the context. Historical green roofs refer to any structure with any vegetation on the top. Throughout time and location, the addition of the natural environment to structures was solely for the benefit of the civilization at the time, without regard for the destruction of the natural environment in the process. Mass urbanization has led to deforestation and changes in local watersheds.

Green roofs were originally created to help with temperature control. The first recorded green roofs were found in Mesopotamia where the religious buildings, known as the ziggurats, included trees and shrubs on terraces at 600 BCE. The ziggurats were large stone pyramids that stepped, and the vegetation served to decrease the amounts of the heat contained by the large objects (Osmundson, 1999). In medieval Europe, specifically France, where colder climates dominate the winter, vegetation was used as a thermal layer in the walls or on the roof to trap the heat, which is where the first sod roof can be found (Jim, 2007). Both of these temperature control techniques were advantageous to the community, and still used in technologies today, however the advancement also began the trend of discarding the importance of ecological factors in technological design. The earliest effect green roofs were designed solely for human benefits, as the environmental impact was not considered in the designs.

In Tuscany, where the oldest urban green roofs still remain, the integrated gardens were made to mimic the natural environments for the aristocratic residents. The Guinigi Tower, with the oldest roof garden, was built as a symbol of wealth and power by the Guingi family, with Holm Oak trees planted on top, as the highest point in the city for all to see (Jim, 2007). This use of plants as a privilege symbol contrasts the functional approach that is seen with most other green roofs, but continues the trend of human dominance over the natural environment. The most prominent historical use of green roofs in America was during the mast migration west, directly after the Homestead Act of 1862 (Jim, 2007). Due to the shortage of timber and stones, sod was matted together to mimic a brick, which was used for the roof and walls, to keep the inside of the structure warm and dry. As paralleled to White's argument, during the expansion period, the natural landscape was rearranged to benefit humans; the environment was altered, furthering the entanglement of the two entities. These two examples show how the environment has been used in different ways depending on the needs of the society, as opposing class categories used vegetation for entirely different purposes while still benefiting from their usage.

During the Renaissance and Middle ages, Europe became a center for improvements for green roofs, although not entirely on purpose. Germany experienced rapid industrialization in the 1880s, and flammable tar was used as roofing due to the inexpensive nature of the material. However, the fire hazard was recognized and sand and gravel were implemented on the roofs, where grass grew due to the natural process of plant colonization of the area (Köhler et al., 2002). This accidental advancement would go on to have the biggest impact on the future of green roof technology and completely alter the relationship to protect ecologic cycles. While these early buildings were not seen as technologically advanced, the use of the environment in the design still created benefits for the community. These advancements lay the groundwork for modern green roof designs.

Modern Green Roofs

Modernization is a common occurrence in any form of technology, and green roofs are no exception. As humans were able to understand the environment, ecomimicry was used to allow more effective designs of green roofs that implemented aspects from various ecosystems.

These advancements were also happening in the scientific world, where the importance of preserving the environment was brought to light. The human's relationship changed to protect the environment, as society began to understand the significance of the natural world.

Modern green roofs are based on scientific testing and developed for stormwater management, heat mitigation, and aesthetics, intentionally designed to use vegetation to fit the desired needs on the building based on geographic location and setting. The modernization of the green roof occurred around the 1970s, with the energy crisis in the forefront of politics, green activists began to experiment on renewable energy and alternative technologies, although examples were seen earlier, such as the green roof Rockefeller Center in New York City built in 1930 (Jim, 2007). There are two types of modern green roofs, extensive, which requires minimal maintenance, and intensive, which requires regular care for plant survival (Shafique, 2018). Different strategies have been implemented to create an effective green roof for a specific location across the globe, including relocation ecology, drainage systems, and noise barriers to mitigate the negative effects caused in cities (Oberndorfer et al., 2007). As the technology advanced, specific forms of the technology were implemented to address specific issues within a society, or specifically a city.

For example, in London, a combined vegetated and solar roofs, called biosolar roofs, were installed in Queen Olympic park in attempts to enhance biodiversity within urban areas and increase energy efficiency in the building. The roof included native plant species and used biomimicry in the design, which attempts to mimic regionally important habitats (Nash et al., 2016). The effectiveness of this green roof is dependent on the environment, as native species are required for the success, bringing in a new dimension to the relationship.

A method of diversifying plant species was used on the green roofs in Millennium Park, Chicago, to mitigate heat and prevent urban heat islands in the city (McConnell et al., 2021). Both intensive and extensive green roofs were used in different locations. These urban heat islands are an ongoing issue in major cities due to climate change, and green roofs serve as a solution for the issue. Using inspiration from the Ziggurats in Mesopotamia, the power of the natural environment is used to create an effective technology.

The increase in urbanization has caused negative effects on ecosystem and watershed health. In multiple cities across Canada, green roofs have been engineered to optimize the water retention green roofs (Talebi, 2019). The technology used multiple mediums to create a substrate content that would reduce the amount of water runoff to help prevent stormwater system overflow within the cities. In Taiwan, green roofs have been implemented to reduce carbon emission, mitigate heat islands, and increase urban flood control. Through recent studies, green roofs have contributed to thermal reduction, however the retention and detention of stormwater was not as effective as other areas of the world due to the high intensity of rainfall (Chen, 2013). The solution harnesses the power of the environment to help mitigate issues within a city, but can still be improved through further experimentation and development.

In other areas of the world, such as South Africa, green roofs are a new concept when compared to first world cities. In Johannesburg, a study was conducted to investigate the potential implementation of green roofs where the findings stated the lack of knowledge and materials have hindered the development of green infrastructure (Labuschagne, 2016). However, prospective development would allow for improved air quality and save electricity. Additionally, construction of green roofs would increase employment rate and provide a safe and secure natural environment, compared to open green parks where crime rates are high (Labuschagne, 2016). By harnessing the power of the environment, there could be significant improvements to the society and population within Johannesburg.

The technology created today uses these historical models as inspiration for current society. By taking the specific technology that works more effectively in each region of the world, for social, economic, and environmental factors, the technology can create the most benefits. In hotter regions, the most effective green roofs have vegetation for cooling to provide heat mitigation, while wetter regions require native plants and stormwater systems on the roofs to allow for flood control. The modernization of green roofs allowed the advancements of science to further alleviate the challenges faced in urban centers by further attempting to control the environment as a means of protecting it. The relationship between humans and the environment has been to a point where humans are forced to protect nature as a means of its existence being sustained.

Are there benefits of implementing technology into the environment?

Over the recent years climate change and global warming have increased significantly primarily due to greenhouse gas emissions and deforestation, trends which do not appear to be slowing down (Hunt, 2010). At a large scale this has led to major impacts including sea level rise, more severe storms, and increased global temperatures. All of these factors have larger impacts on urban centers, and green roofs have the potential to mitigate some of these adverse effects (Shafique, 2018).

As technology has become so advanced, the relationship between humans and the environment has become more complex than ever. While it is important to recognize that the advancements of technology and urbanization has been a component in the destruction of the environment, implementing new technologies, specifically green roofs, into urban settings could help reduce further devastation for humans and the environment (Rasul, 2020). This devastation of the environment was predicted by White, as the advancement of societies causes negative effects on the environment and local ecosystems.

Green roofs have multiple advantages with environmental, energy, and economic benefits. Green roofs are a complex technology that has advanced rapidly to target multiple environmental factors within cities, including: "(a) by acting as a medium which can hold the moisture and water content, it reduces the passage of storm water, consequently reducing erosion, (b) it improves the air quality, and (c) it diminishes the urban heat island effect" (Rasul, 2020). Green roofs are beneficial for any new building, but are also a practical solution with the ability to be retrofitted to an existing building. However, this aspect is a direct contrast to White's philosophy and more aligns with the ideals of Emerson and Mumford, who saw the benefits of technology within the environment. Green roofs are designed to benefit both the human society and environments, allowing both to flourish with the addition of technology.

By adding forms of vegetation back into cities, the absence of the direct human and environmental relation is reestablished. The new advancements in green roof technologies were partially due to the change in relationship between humans and the environment. As the environment was destroyed, the parts that remained became more valuable, and human technologies were created to target the protection of the natural environment that was left.

Additional Complexities in the Human and Environment Relationship

Rapid urbanization in recent years has led to many negative impacts on the natural landscape and degradation of the ecological environment. As humans, our existence is dependent on the natural environment, and with a new urgency to protect the earth, there has been increased implementation of regulations (Kilbert et al., 2002). As green roofs are more expensive and not considered necessary in many cases, there have been multiple methods put in place to encourage the use and advancement of this specific best management practice. Green roofs cannot be effective if there is no implementation of the technology, and the political forces are often a barrier for the effectiveness of the technology.

Guidelines for the support of green roofs have been implemented globally, such as LEED in the United States (Kilbert et al., 2002). LEED certified building “save money, improve efficiency, lower carbon emissions and create healthier places for people”(LEED). LEED uses a point system with different levels of certification to promote their idea of a “better building.” Due to the set up of the point system, green roofs have the potential to increase the score significantly by adding points in four different categories. Green roofs not only help mitigate some of the negative effects of a new building, but also improve air quality as well drainage and retention for the building. Some places in Europe have gone beyond just creating regulation for green roofs, and have additionally set up funds for implementing the infrastructure (Background on Green Infrastructure). Switzerland has the largest area of green roofs per capita due to their combination of financial incentives and building regulations.

While regulations are related to the relationship between humans and their environment, their implementation has been a key outside factor that has led to the advancement in green roofs, usually targeting a specific component for improvement. The advancements due to regulation are largely relative to financial factors and public perception, which are factors within humans’ own relations (Carter, 2008). Green roofs are an essential component of mitigating climate change and improving air quality and water runoff in cities, but this specific technology is a small aspect of the larger changes that need to be made to truly improve human sustainability and the environment.

Conclusion

The relationship between humans and the environment have been pushing technology forward throughout time. Humans rely on the environment for their own survival, and as the progression of urbanization continues, the natural landscape continues to degrade. To help reduce some of these issues, cities can continue to push forward green infrastructure, specifically green roofs. Green roof technology can continue to be advanced by looking at how the environment has been used within technology throughout history. By continuing trends, such as heat mitigation, within green roof technology, the new innovations can have the greatest impact. These findings are a generalization of one component of the relationship between humans and the environment, and the predictions will not be fully formed in a well rounded manner. But taking their essence into consideration, as with stormwater management, the learning from the past can be a valuable contribution to new advancements.

One could speculate the primary catalyst of advancements in green roofs technology could be the increased negative effects of climate change. Humans are no longer able to control the environment, and are forced to create technological solutions to protect themselves from the outcomes of natural disasters. However, this cannot be said for certain because only the factors of the environmental consequences and new regulations have been taken into account when evaluating the advancements in technology. Future research could be conducted on the multifaceted, interconnectedness of many factors impacting the advancements of green roofs, such as social and economic, to improve the findings. Green roof studies of water resource management can help prevent flooding within cities and as well as heat mitigation to prevent urban heat islands within major cities. Advancements within biodiversity of species on the green roofs can allow restorations of small habitats for birds and insects within the city. By continuing experimentation on the complexities within variations of green roofs, specific issues within cities can be targeted and solved with the creation of unique green roof infrastructures.

As the relationship between humans and the environment continues to evolve and change, green roofs will continue to advance, especially with the current climate crisis. I believe that green roofs, while currently underused, can be a driving force in creating better cities for both human life and ecological and environmental restoration.

References

Abass, F., Ismail, L. H., Wahab, I. A., & Elgadi, A. A. (2020). A review of Green Roof: Definition, history, evolution and functions. IOP Conference Series: Materials Science and Engineering, 713, 012048. https://doi.org/10.1088/1757-899x/713/1/012048

Background on green infrastructure. Green Infrastructure - Environment - European Commission. (n.d.). Retrieved March 27, 2022, from https://ec.europa.eu/environment/nature/ecosystems/background.htm

Bevilacqua, P. (2021). The effectiveness of green roofs in reducing building energy consumptions across different climates. A summary of literature results. Renewable and Sustainable Energy Reviews, 151, 111523. https://doi.org/10.1016/j.rser.2021.111523

Carter, T., & Fowler, L. (2008). Establishing Green Roof Infrastructure through Environmental Policy Instruments. Environmental Management, 42(1), 151–164. https://doi.org/10.1007/s00267-008-9095-5

Chen, C.-F. (2013). Performance evaluation and development strategies for green roofs in Taiwan: A Review. Ecological Engineering, 52, 51–58. https://doi.org/10.1016/j.ecoleng.2012.12.083

Cohen, B. R. (2005). Escaping the False Binary of Nature and Culture Through Connection: Richard White's "The Organic Machine: The Remaking of the Columbia River." Organization & Environment, 18(4), 445–457. http://www.jstor.org/stable/26161919

Environmental Protection Agency. (n.d.). EPA. Retrieved December 5, 2021, from https://www.epa.gov/soakuptherain/soak-rain-green-roofs.

Getter, K. L., & Rowe, D. B. (2006). The role of extensive green roofs in sustainable development. HortScience, 41(5), 1276–1285. https://doi.org/10.21273/hortsci.41.5.1276

Hunt, A., & Watkiss, P. (2010). Climate change impacts and adaptation in cities: A review of the literature. Climatic Change, 104(1), 13–49. https://doi.org/10.1007/s10584-010-9975-6

Jim, C. Y. (2017). Green roof evolution through exemplars: Germinal prototypes to modern variants. Sustainable Cities and Society, 35, 69–82. https://doi.org/10.1016/j.scs.2017.08.001

Kibert, C. J., & Grosskopf, K. (2007). ENVISIONING NEXT-GENERATION GREEN BUILDINGS. Journal of Land Use & Environmental Law, 23(1), 145–160. http://www.jstor.org/stable/42842944

Köhler, M., Schmidt, M., Wilhelm Grimme, F., Laar, M., Lúcia de Assunção Paiva, V., & Tavares, S. (2002). Green roofs in temperate climates and in the hot-humid tropics – far beyond the aesthetics. Environmental Management and Health, 13(4), 382–391. https://doi.org/10.1108/09566160210439297

Labuschagne, P., & Zulch, B. (2016). Green Rooftop Systems: A South African perspective. Energy Procedia, 96, 710–716. https://doi.org/10.1016/j.egypro.2016.09.131

LEED rating system. LEED rating system | U.S. Green Building Council. (n.d.). Retrieved March 27, 2022, from https://www.usgbc.org/leed

McConnell, K., Braneon, C. V., Glenn, E., Stamler, N., Mallen, E., Johnson, D. P., Pandya, R., Abramowitz, J., Fernandez, G., & Rosenzweig, C. (2021). A quasi-experimental approach for evaluating the heat mitigation effects of green roofs in Chicago, Illinois. Sustainable Cities and Society, 76, 103376. https://doi.org/10.1016/j.scs.2021.103376

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. https://doi.org/10.1016/j.landurbplan.2005.02.010

Nash, C., Clough, J., Gedge, D., Lindsay, R., Newport, D., Ciupala, M. A., & Connop, S. (2016). Initial insights on the biodiversity potential of biosolar roofs: A London olympic park green roof case study. Israel Journal of Ecology and Evolution, 62(1-2), 74–87. https://doi.org/10.1080/15659801.2015.1045791

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K. K., & Rowe, B. (2007). Green roofs as urban ecosystems: Ecological structures, functions, and services. BioScience, 57(10), 823–833. https://doi.org/10.1641/b571005

Osmundson, T. (1999). Chapter 2. In Roof gardens: History, design and construction (pp. 112–113). essay, W.W. Norton.

Rasul, M. G., & Arutla, L. K. R. (2020). Environmental impact assessment of green roofs using life cycle assessment. Energy Reports, 6, 503–508. https://doi.org/10.1016/j.egyr.2019.09.015

Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and Challenges – A Review. Renewable and Sustainable Energy Reviews, 90, 757–773. https://doi.org/10.1016/j.rser.2018.04.006

Talebi, A., Bagg, S., Sleep, B. E., & O'Carroll, D. M. (2019). Water retention performance of green roof technology: A comparison of canadian climates. Ecological Engineering, 126, 1–15. https://doi.org/10.1016/j.ecoleng.2018.10.006