Value-Based Analysis of Sociotechnical Approaches to Green Infrastructure Implementation

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

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Spring 2022

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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Introduction

Since it first appeared in early civilizations like Ancient Egypt and the Roman Empire, urban stormwater management has evolved very little until recent times. Much like the world's first cities, the majority of the developed world still relies on so-called "gray infrastructure" – the routing of stormwater (and in some cases wastewater) directly into surface water bodies using gutters, channels and pipes (Batts, 2020). This approach to management curtails natural groundwater recharge, results in dramatically altered flow regimes, and subjects ecosystems to a deluge of harmful chemicals and excess sediment (Subramanian, 2016). Because of the interconnectedness of surface waterways, these negative impacts can often be felt hundreds of miles downstream of cities with poor stormwater management, putting even some coastal ecosystems at risk (Noe et. al., 2020). In response to these adverse impacts, many cities have begun implementing green infrastructure (GI) – stormwater management techniques that use or mimic natural processes of infiltration, detention and filtration. These techniques not only improve the health of surface water ecosystems, but also have been shown to improve quality of life of residents and increase cities' resilience to the effects of climate change (Donovan & Prestemon, 2012; Shade et al., 2020).

After a couple decades of society's use of GI, the lack of equitability of its distribution has emerged as a widespread environmental justice issue. In particular, research has shown that the benefits of GI rarely reach low-income communities of color (LICC). In addition, well-intended, deliberate attempts to place GI in these underserved communities have resulted in the displacement of LICC by driving up property values such that residents can no longer afford to live in the area where GI was located (Arnold, 2021). This phenomenon, known as green gentrification, makes it clear that efforts must go beyond intentionally pursuing GI projects around LICC, but a proper approach to these issues has not yet been defined. Without a resolution to the inequitable distribution of GI and green gentrification, the benefits of this new stormwater management technology will not be experienced by historically marginalized communities that are also already taking the brunt of climate change impacts (Schmeltz, 2021).

In recent years several comprehensive frameworks for implementing, monitoring and amending GI and GI policy have been proposed by various STS scholars. Chini et. al. (2017, p. 1) propose “an experimental framework for policy, implementation, and subsequent evaluation of green stormwater infrastructure within the context of sociotechnical systems and urban experimentation.” They argue that this multi-faceted framework for experimentation with urban GI is critical in order for a necessary urban stormwater regime overhaul to occur. Kronenberg et al. (2021) suggest constant monitoring of GI projects through three sociotechnical lenses – infrastructure, institutions and perceptions – in order to mitigate unintended consequences of implementation. By analyzing what values associated with the frameworks proposed by Chini et. al. (2017) and Kronenberg et. al. (2021) and comparing these to the values held by various actors in a GI system, the approach to equitable GI implementation can be better understood.

Background

What We Know

In a time where environmental sustainability has become an important goal of developed societies, their governments and engineers, GI has become an increasingly important tool in the world of stormwater management. In an effort to remediate impaired waterways and protect critical waterways that may not yet be impaired, many state legislators have imposed strict runoff standards. These standards generally apply to sites that engineers are either redeveloping or developing for the first time and often require that the project’s changes to the site either do not change or even improve (usually for redevelopment of a site) the runoff characteristics of the site. Specifically, legislatures place limits on the kinetic energy in runoff (which translates to erosion potential) and pollutant loading – mainly nitrogen and phosphorous - in runoff. GI systems – like rain gardens, vegetated swales and green roofs – slow down runoff that quickly flows off of roofs and parking lots and allows water to be filtered through some sort of porous medium, making them an engineer's silver bullet for meeting these new standards. A comprehensive study of the efficacy of GI practices in the Pearl River Delta, China yielded many promising results that illustrate just how effective GI is at improving these key runoff parameters. For instance, the study showed that rain gardens, detention basins and constructed wetlands all significantly reduce total nitrogen in runoff. Pervious surfaces (permeable pavers and permeable pavement), detentions basins and constructed wetlands significantly reduced total phosphorous loading in runoff. Finally, rain gardens, vegetated swales, pervious surface, detention basins and constructed wetlands all decreased the amount of lead in runoff (Xing et. al., 2021).

Along with benefits regarding stormwater management, analyses of the efficacy of GI often report the positive effects that GI can have on the quality of life of people living in nearby communities. According to the Biophilia theory which argues that humans have an innate affinity for nature, GI can improve the quality of life of nearby residents simply by exposing them to plant life in their everyday lives (Yeang, 2020). Further, a study conducted in Portland, Oregon concluded that increased tree canopy resulted in reduced violent crime, property crime and overall crime (Donovan & Prestemon, 2010). Another study in Philadelphia showed that proximity to GI was associated with reduced narcotics manufacturing, narcotics possession and burglary (Kondo et. al., 2015).

While GI can clearly be greatly beneficial to the communities it touches, there are systematic disparities in the communities that its benefits reach. Just as we see with access to education, medical treatment and employment, there is a stark socioeconomic divide between those who do and those who do not get access to the perks associated with GI. Tony Arnold and Resilience Justice Project Researchers at William and Mary University (2021) describe "Low-income communities of color in the United States…" as routinely having "…disproportionately less quantity, worse quality, thinner or more uneven spatial distribution, and/or limited access to green and blue infrastructure than do other communities in the region" (p. 678). In addition, they point out that in those low-income communities of color - as opposed to in wealthy, white communities - GI sees a lower overall investment of resources, less maintenance and is less likely to be restored. A paper that looked at the equity of GI distribution in Louisville, Kentucky found that 19 of 21 marginalized neighborhoods fell below the city's median in several metrics used to gauge access to GI (Arnold, 2021, pg. 681). Likewise, a study in Pinellas County, Florida showed that areas with high percentages of people of color or poverty were subject to increased urban heat island, vulnerability to climate change and heat waves – all of which can be partially mitigated using GI (Arnold, 2021, pg. 683). Public officials in major cities all over the U.S. have launched initiatives to combat this inequitable distribution of GI, but have been met with the unintended consequence of green gentrification (Arnold, 2021, pg. 685). This is where greening initiatives drive up the cost of living in an area, driving out low-income residents.

"The combination of environmental, societal, and economic benefits of [GI]…", Chini et al. (2017) posits, "requires… evaluation within the context of a sociotechnical system" (pg. 4). As shown in the Portland study and others like it, when GI implementation is viewed as a sociotechnical system, the costs, benefits and tradeoffs associated with it stretch far beyond stormwater management (Donovan & Prestemon, 2010; Kondo et al., 2015). Suddenly, our watersheds become much more than drainage areas where GI might be useful for controlling stormwater and improving stream health. Rather, they are a complex array of community members, businesses, perceptions, existing infrastructure, natural organisms and an endless chain of downstream implications. While the stormwater benefits of GI have been quantified and well-documented, in order for engineers to facilitate equitable implementation of this technology, they must understand the complex flows of benefits from the GI to the stakeholders (Xing et al., 2021).

Stormwater Management as an Actor Network

It is clear that stormwater management serves as a nexus of interactions – both positive and negative – whose outcomes hold immense social and environmental implications. It is then important for stormwater engineers to stay up to date on the narratives and data that come out of this realm so that they can aim to avoid unintended consequences within it. However, independent papers, anecdotes and data only provide one snapshot of this complicated landscape and can only go so far in guiding an engineer's work. In fact, by paying too close attention to any one issue or interaction when developing technological solutions, engineers have time and again created subsequent issues that are more difficult to address than the original problem they sought to resolve (Ray, 2019). Cases in point include the use of gray infrastructure as a solution to urban flooding leading to severe degradation of aquatic habitats and the intentional implementation of GI in disadvantaged neighborhoods leading to green gentrification (Arnold, 2021, pg. 685; Subramanian, 2016, pg. 425). By mapping the role of each actor in the complex network associated with stormwater management, we can create a more navigable landscape for those responsible for planning and designing stormwater infrastructure. This paper will do so by employing Tommaso Venturini's notion of "cartography of controversies." This approach, in its most simple terms entails "just observ[ing] the controversy and tell[ing] what you see" (Venturini, 2010).

To begin creating a concept map where controversies can be visualized, four subnetworks were identified – stormwater infrastructure, policy/city planning, people and the environment. Table 1 lists these subnetworks and the actors associated with them. From this, connections can be drawn starting with gray infrastructure – the aging "status quo" for stormwater management. From there, as shown in Figure 1, connections are drawn from existing gray stormwater infrastructure that start a chain reaction of negative environmental impacts that ultimately, in the worst cases degrade the health, quality of life and livelihoods of the farthest downstream residents. The detriment of ecosystems along this causal path trigger responses form decisionmakers who implement water quality standards and orchestrate municipality-wide GI projects to reinvigorate ecosystems and provide other environmental services to constituents. These GI projects, as we've seen, relieve the variety of pressures that urban stormwater runoff exerts on ecosystems and delivers environmental services to local residents. As was discussed earlier, these benefits often do not reach marginalized communities and when decisionmakers address that issue, green gentrification occurs. These flows are all illustrated in Figure 1.

Table 1. Subnetworks & associated actors

Subnetwork	Associated Actors
Stormwater Infrastructure	Existing Infrastructure Gray Infrastructure Green Infrastructure
Policy/City Planning	Decisionmakers State Runoff & Pollutant Standards Decisionmakers
People	Average Residents Marginalized Residents Downstream Residents
Environment	Local Waterways Coastal Ecosystems Climate

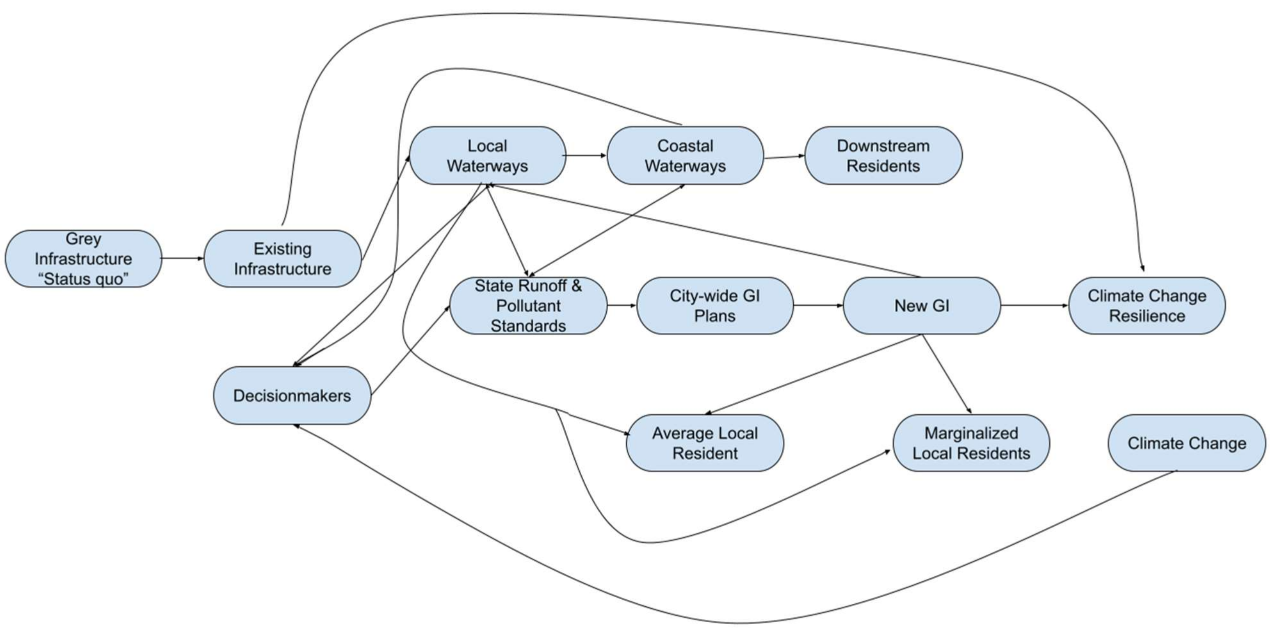

Figure 1. Visual representation of the stormwater management actor network

Upon creating the concept map of this actor network, a couple of key controversies emerged. First, there are two distinct avenues by which decisionmakers (government officials & city planners) choose to implement GI, each of which have great influence on resultant GI implementation. The first and almost undoubtedly the original pathway for decisionmakers choosing to implement GI comes from a need to address environmental concerns. The second, a pathway developed much more recently, is implementing GI in response to societal reason like GI inequity. While other pathways may exist beyond this, it is safe to assume that this sums up the vast majority of cases. In this system, where GI implementation can be reached by one of two fundamentally different routes taken by decisionmakers, there is a heightened chance for GI being implemented as a means to a specific end without consideration for the plethora of effects it can have on its surroundings. For example, in the former avenue, GI may be placed with the sole purpose of improving environmental conditions with no attention paid to equity in who the environmental services provided by the GI reach. In this scenario, inequity in the distribution of GI is likely to be heightened. In the latter avenue, when GI is placed solely to address equity, there is a risk that it is not placed somewhere that makes sense. GI must be placed in specific locations with appropriate design parameters in order to 1) achieve non-negligible improvements in terms of improving stormwater runoff and 2) provide any of the environmental services that make them desirable to have in one's neighborhood. The <u>second controversy</u> is that residents in general – both the average resident and marginalized residents – rarely find themselves being part of the process of GI planning or implementation (Kronenberg et. al., 2021). This presents the glaring issue that those who will be most affected by GI get no chance to offer their valuable insight on what they think is best for their community.

This application of Venturini's idea of cartography of controversies to view stormwater management as an actor network, makes it clear that intervention is needed in the decision-making process associated with GI implementation. This intervention could take many forms, but at the very least, it seems that systems and/or policies should be in place to ensure that conventional decisionmakers take a holistic approach to GI planning that takes into account public opinion on the matter.

Methods

Basis for Value Analysis

Much like in Wiebe E. Bijker's (2007) exploration of the complex challenge of coastal engineering by comparing implicit values expressed in American and Dutch reports on the topic, the overarching goal of this paper is to analyze the values associated with two in depth sociotechnical frameworks created to guide the successful implementation of GI. Before conducting this value analysis, however, it is important to first establish a basis for evaluating the value systems that arise from each framework. Generally speaking, this basis for value analysis is a list of values which should appear in any framework seeking to address the issue of inequitable distribution of GI. The actor network explored in the previous section is a good starting place for constructing this basis for values. In an ideal system, the basis for values will match the sum of the values of all the actors in the actor network. Table 2 lists the values that should be associated with any approach to equitable GI distribution alongside actors that these values are likely to be found in.

Table 2. Basis for Value Analysis

Values	Actor(s) who hold(s) this Value
Approach has support/input from all member of the community	All residents, decisionmakers
Approach does not lead to gentrification	Marginalized residents
Approach addresses inequitable distribution of GI	Marginalized residents
Approach is dynamic/iterative, allows for corrections to mitigate unintended consequences	Decisionmakers
Approach facilitates environmental benefits associated with GI	Environment

Before applying the list in Table 2 in the value analysis, it is important to identify controversies that arise between the actors as a result of differences in their values. In any actor network, one is bound to find competing or incompatible values held by various actors. Because of this, judgements often must be made on what values take priority in addressing the issue at hand. Fortunately, in the case of stormwater management, most of the involved actors want the same outcome – a healthy environment and beautiful green spaces in their neighborhood. That being said, there are several values listed above that could be interpreted as being "in competition." First, the most obvious conflict that arises from this list of values is that, as we have seen, addressing inequitable distribution of GI – presumably by implementing GI in communities that suffer from a lack of GI – leads to gentrification. Another issue that arises from addressing inequitable distribution of GI, is that this motive may prevent the GI system being implemented from achieving its maximum potential for providing benefits to the natural environment. Much of any GI system's ability to provide relief to the effects of urban stormwater runoff relies on its location. Therefore, if a marginalized neighborhood is not situated in the ideal location for a GI project to achieve its maximum potential of environmental benefits, all of a sudden, the values of marginalized residents and the environment are at odds. Last, having input from all members of the community may not be conducive to the approach being dynamic/iterative. Organizing town meetings, surveys or other means of gaining community input before implementation, after implementation and throughout the life of GI projects could feel cumbersome to decisionmakers and threaten the decision-making agility required of a "dynamic" approach.

While there is no silver bullet for addressing these controversies that arise from competing values, this is where community engagement becomes helpful. By allowing the actors involved to carry out an active discussion with one another about needs, tradeoffs and compromise, a fitting solution to these controversies may be reached.

Comparing Proposed Frameworks to my Basis for Values

Utilizing the basis for value analysis (Table 2), "The Thorny Path" (Kronenberg et. al., 2021) and "The Green Experiment" (Chini et. al., 2017) – two recent, in depth, proposed sociotechnical approaches to successful GI implementation – were compared. First in this comparison, the values associated with the approaches offered by each set of authors were identified. Then, the values associated with each approach were compared against the basis for value analysis (Table 2) presented above. The results of this comparison for each approach were then analyzed and compared to one another.

Value Analysis and Results

"The Thorny Path" by Kronenberg et. al. (2021)

Kronenberg et. al. (2021) propose a framework that focuses primarily on the assessment of GI projects by paying close attention to the flow of benefits from GI to urban inhabitants by three different means: infrastructures, institutions and perceptions. Infrastructures refers to physical structures; institutions refers to rights associated with ownership, intention behind policy surrounding GI projects, and social norms; and perceptions refer to how an urban inhabitant views or values access to environmental services provided by GI. The authors apply this framework to 6 case studies, first identifying mechanisms for unintended consequences in GI projects. Then, they turn their attention to identifying and strengthening factors that enable implementation of GI.

From this approach proposed by Kronenberg et. al. (2021), a number of values emerge. Initial observation of the terminology used by the authors in building this framework suggests that the authors of this approach value a systems perspective – one that is concerned not only with the discrete experiences of each of the relevant actors, but rather one that is keen to the "flows" and "networks" that connect them. This perception of all of the actors being interconnected manifested itself in the authors' goal (though it may be unrealistic) of satisfying the land use needs of all residents through their approach. Next, the inclusion of perception as one of the three key mediators of the flow of GI benefits reflects the value that the authors place on shaping appropriate mental models to achieve equitable GI implementation. In addition, the authors state that they value minimizing the negative impacts – green gentrification and inequity - associated with GI projects more than maximizing the positive impacts. Throughout several of the case studies addressed, a lack of community associativity was identified as a key challenge to successful GI projects, and thus fostering associativity throughout neighborhoods became a key value. All of these things considered, the values associated with the framework presented in The Thorny Path can be distilled down to: achieving fairness via a systems approach that bolsters community associativity through increased intracommunity communication.

Once these values associated with Kronenberg et. al.'s (2021) framework were identified, they were assessed using the basis for value analysis (Table 2) presented in the methods section. Table 3 shows the results of this assessment.

Table 3. Results of the value analysis of Kronenberg et. al. (2021) based on basis for value analysis from Table 2.

Values	Addressed in this framework?
Approach has support/input from all member of the community	Yes, community engagement is identified as an "enabling factor" for GI projects
Approach does not lead to gentrification	Not really, provides avenue for identifying gentrification but not for mitigating it
Approach addresses inequitable distribution of GI	Yes, emphasizes fairness (or equity) first.
Approach is dynamic/iterative, allows for corrections to mitigate unintended consequences	No, this framework is for assessment & doesn't outline avenues for applying results of the assessment
Approach facilitates environmental benefits associated with GI	No, this framework has no measure for assessing how well GI is improving the environment

"The Green Experiment" by Chini et. al. (2017)

Chini et. al. (2017) propose open-ended urban experimentation as a way to achieve an urban stormwater management overhaul that they deemed necessary for a sustainable future. This continuous, iterative, experimental framework encapsulates the entire life of a GI project. This approach focused on four major steps in a closed loop cycle: policy creation, construction/management of GI, evaluation/operation of GI, and using results to inform best management practices for the future. This framework relies heavily on what the authors refer to as a policy feedback cycle (PFC) – where experimental findings are constantly motivating new policies, which in turn generate new findings. In sum, the green experiment is a "guess and check" approach to resolving equity issues associated with GI. This is done by establishing a regular communication between policymakers and experts referred to as “knowledge brokers”, that observe and analyze the results of certain policy and report back to the policymakers.

The underlying values that emerge from the close inspection of The Green Experiment echo some of those identified in The Thorny Path, however, the experimental nature of this framework garners several key differences. Similar to in The Thorny Path, Chini et. al. (2017) focus on problem-solving – mitigating the negatives brought about by GI projects – rather than maximizing the benefits of GI. In addition, the authors of this paper also insinuate value in community engagement with the added care of specifying that knowledge brokers should be present when policymakers, planners and engineers engage with the community in order to fill epistemic gaps between various members of the community. The authors also reveal that the motivation for creating this framework is ultimately to move towards a stormwater management regime that is sustainable for humanity. Policy changes, according to the authors, will perhaps be the most valuable tool in moving towards this sustainable future. Last, authors of The Green Experiment place immense value on the adaptability of their framework to variety of contexts – community size, community demographics, geography, etc. In summary, this framework reflects value of achieving sustainable future via the PFC. Within the PFC, value is placed on the constant sharing of new knowledge with both policymakers and community members who are allowed to give input on GI projects.

As was done with the other framework, after the values associated with Chini et. al.’s (2021) framework were identified, they were assessed using the basis for value analysis (Table 2) presented in the methods section. Table 4 shows the results of this assessment.

Table 4. Results of the value analysis of Chini et. al. (2021) based on basis for value analysis from Table 2.

Values	Addressed in this framework?
Approach has support/input from all member of the community	Yes, community engagement is cited as one of "three important needs for green infrastructure experimentation"
Approach does not lead to gentrification	Not directly addressed, but iterative process and focus on policy may help mitigate green gentrification
Approach addresses inequitable distribution of GI	Not directly, but community engagement and the inclusion of social scientists as key knowledge brokers will likely lead to this being addressed
Approach is dynamic/iterative, allows for corrections to mitigate unintended consequences	Yes, the policy feedback cycle is inherently dynamic and iterative
Approach facilitates environmental benefits associated with GI	Yes, goal of sustainability has positive environmental implications, and environemental factors are cited in paper as one of the "external motivators for policy creation" in this framework

Discussion & Conclusion:

The results from the value analysis show that the framework proposed in The Green Experiment addressed the values from Table 2 slightly more thoroughly than the framework proposed in The Thorny Path. Shortcomings in the approach proposed in The Thorny Path were generally a product of the fact that this framework was geared towards the assessment of GI projects and did not specify appropriate avenues of response to the results of the assessment. In addition, the scope of this framework was limited almost entirely to social considerations and therefore none of its components reflected value of the environment (Kronenberg et. al., 2021). In the case of The Green Experiment, gaining community input and dynamic response to negative consequences of GI are both deeply baked into framework. Further, this framework's emphasis on sustainability and inclusion of environmental factors as one of its reasons for implementing GI policy suggests that it would likely lead to GI outcomes that catered to the values of the environment. While it did not directly address equitable distribution of GI or green gentrification, its strong roots in policy and community engagement and the iterative nature of PFC indicate that these values would likely also be addressed (Chini et. al., 2017). In short, The Thorny Path framework addressed two of the five values from the basis for value analysis, while The Green Experiment framework, either directly or indirectly addressed all five.

While the basis for value analysis (Table 2) developed for this paper is far from comprehensive, assessing the framework from Kronenberg et. al. (2021) and Chini et. al. (2017) alongside it illuminated the fact that even the most well thought out sociotechnical approaches to GI implementation fail to capture the values of all actors in the system. Therefore, even with these sophisticated frameworks, unequal outcomes are still likely to result from GI projects. This is, in part, because it is not possible for a framework to capture the values of all actors in a system where actors hold competing values. However, I argue that this is also because there is more work to be done in this area. Before embarking into future work pertaining to the use values analysis to further move towards equitable GI, it would be helpful to develop a much more comprehensive basis for value analysis by issuing surveys to actors in stormwater infrastructure systems across the country and around the world. Once this basis for value analysis is more refined, said future work might include conducting value analyses on many more sociotechnical approaches to GI Implementation like the ones looked at in this paper. By stepping back and taking the time to understand the values held by the actors in the complex actor network associated with stormwater management and how they are represented in frameworks for GI implementation, one can help identify shortcomings of these types of frameworks and better understand how they arise.

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