Fostering Community-Engaged Green Stormwater Infrastructure Through the Use of Participatory Geographic Information Systems (PGIS)

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Abstract: As an emerging technology, Green Stormwater Infrastructure (GSI) is still facing various implementation barriers. Literature findings reveal that contextual background of the community, education on topic, capacity building, a comprehensive participatory framework along with appropriate tools and methods are factors requiring greater focuses in future research and practice. Using literature review and case study methodology, this research provides an enhanced engagement framework for GSI planning and implementation, which integrates the Participatory Geographic Information Systems (PGIS) as an interactive platform to foster contextual analysis, education on topic, and capacity building.

Keywords: Green stormwater infrastructure, community engagement, participatory GIS (PGIS), education, capacity building

1 Introduction

Flooding and water quality challenges associated with urban growth and climate change have become a global problem. Green Stormwater Infrastructure (GSI), which is stormwater management practice (e. g., rain gardens) mimicking natural ecohydrological processes (DHAKAL & CHEVALIER 2017), has gained popularity during the last two decades as a key strategy for restoring the hydrological cycle and addressing flooding and water quality. Communities across the U.S. are taking steps forward to integrate GSI into their infrastructures (NEWELL et al. 2017, FITZGERALD & LAUFER 2017), not only to protect and restore naturally functioning ecosystems, but also to provide a framework for future development that fosters a multitude of ecological, social and economic benefits (BENEDICT & MCMAHON 2002).

Despite the rapid increase in GSI installations, GSI is still facing various implementation barriers, including uncertainties in cost and performance, lack of engineering standards and guidelines, fragmented responsibilities, lack of institutional capacity, lack of legislative mandate, funding constraints, and resistance to change (DHAKAL & CHEVALIER 2017). Among these barriers, socio-institutional and cognitive factors have been recognized as the most critical obstacles to overcome (DHAKAL & CHEVALIER 2017, O'DONNELL et al. 2017). Neglection of critical socio-cultural components that affect GSI acceptance can often lead to "the death of the project" (RIVERA et al. 2014, SIMONS 2017).

Existing literature provides well-documented advantages of embedding community involvement and communication, evaluation, and knowledge production into GSI planning and implementation (CHINI et al. 2017, GREEN 2015). Including local community voices helps to certify that problems are correctly defined, analyzed, addressed, and considered throughout the planning and implementation processes. Bringing community members, especially groups who have been underrepresented, experienced inequities, or have disabilities to participate in

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public meetings, to the table early leads toward procedural democracy, and therefore is often integral to the success of the project. Well-planned community engagement increases the sense of empowerment among local citizens, boosts citizen trust to major stakeholders, fosters community members' knowledge about the scientific aspect of the work (BARCLAY & Klotz 2019), and gives professionals a clear understanding of the contextual background of the place (SHANDAS & MESSER 2008). Local knowledge, sense of place, contextual understanding, wisdom and expertise of the local community (INNES 1998) increases social cohesion (GREEN 2015) which in turn generates better project outcomes (BADENHOPE & SEEGER 2014, CORBURN 2007). As the communities learn to communicate, engage, learn, and share experiences, they build up the base for more resilient green infrastructure projects (MAGIS 2010).

Despite their importance, current community engagement processes for GSI planning and implementation suffer from problems including low-level participation, low-quality community input, unrepresentative response, lack of spatial explicitly, inconsistent decision making, and inadequate budget and time (BARCLAY & Klotz 2019). The absence of a more guided *community engagement framework* with recommendations of appropriate tools and methods contributed to these problems (RIVERA et al. 2014). Due to the limited ability of traditional methods, such as public meetings, surveys, interviews, etc., to address the aforementioned problems, more interactive and spatially-based approaches such as participatory GIS (PGIS) has emerged as a tool to integrate participatory approaches with the spatial planning capabilities of geographic information systems (GIS) (RAMBALDI et al. 2006).

PGIS refers to "spatially explicit methods and technologies for capturing and using spatial information in participatory planning processes" (BROWN & FAGERHOLM 2015). Typically, it integrates a map-based application programming interface (API) and digital annotation tools with various visualization techniques such as interactive 3D models, aerial photographs, satellite imagery, and augmented reality to engage the community in a more interactive process (RAMBALDI et al. 2006, RALL et al. 2019). Because it enables the integration of public involvement in data gathering, content analysis, and information sharing throughout the entire process (BADENHOPE & SEEGER 2014), PGIS shows much promise to powerfully support collaborative spatial decision-making for GSI planning and implementation.

2 Research Objective

The primary objective of this study is to leverage the capabilities of PGIS toward an enhanced theoretical framework for community-engaged green stormwater infrastructure. To fulfill the objectives, we aim to answer the following questions using literature review and case study methodology: 1) What are the existing gaps in the community engagement process of GSI planning and implementation? 2) How can PGIS tools facilitate filling critical gaps?

3 Literature Review and Case Study Findings

3.1 Current Community-Engaged GSI Limitations and Considerations

Despite considerable research on community engagement for water resources management and collaborative watershed management, in-depth studies examining the key elements impacting the success of community participation in GSI development remain very limited (BARCLAY & KLOTZ 2019). Most community-engaged GSI studies are theoretical in nature and have not been tested in real-world settings (WAGENET & PFEFFER 2007). Nonetheless, the literature identified "demographic characteristics", "lived experiences" of those experiencing environmental threats, "environmental knowledge" of the stakeholders, their "education on the topic", and "capacity building" as key factors directly related to GSI adoption (CHRISTMAN et al. 2018, BARCLAY & KLOTZ 2019, ANDO & FREITAS LUIZ 2011, BAPTISTE 2014, BAPTISTE et al. 2015, LARSON et al. 2014). In particular, two-way education, as both lay people and professionals contribute their knowledge to the discussions, plays a significant role in community buy-in and advocacy for GSI, and is expected to have a greater impact on future implementation and long-term capacity building (SHANDAS 2015).

Another major driver of GSI project success is the *contextual background* of the community because it directs the priorities of the community members (BARCLAY & KLOTZ 2019). Case studies of community-engaged GSI (EPA 2013, BAPTISTE 2014, MCGARITY 2015, SHANDAS 2015) suggest that most current frameworks are not contextually grounded. Although much effort has been made to expand on the type of methods used to better engage the community as well as the project phases for involvement, the lack of considerations of the social, cultural, economic, or political background of the community remains a critical limitation (SIMONS 2017).

To summarize, literature and case study findings necessitate the refinement of an interactive community engagement framework for GSI development that better integrates the three components of contextual background analysis, education on topic, and capacity building. In the next section, we examine how GIS technologies in general have been applied in GSI development, and the potential for PGIS to better integrate these three components.

3.2 Existing GIS Applications and Potential of PGIS

Applying GIS technologies in GSI development is not new. For over a decade, GIS has been used for selection of suitable GSI types (SHAMSI et al. 2014, STRUCK et al. 2012), spatial suitability assessment of GSI systems (KULLER et al. 2019, ZARĘBA 2014, WARREN et al. 2009, MEEROW & NEWELL 2017), GSI priority score assessment (SULIS 2019), stormwater management performance analyses of GSI technologies (EATON 2018), and other GSI benefits evaluation (JAYASOORIYA et al. 2014, XU et al. 2018, MANDARANO & MEENAR 2017). However, they have rarely been used as interactive tools by the communities themselves to aid the collaborative decision-making in GSI planning and implementation. Efforts are currently emerging to put GIS technologies "in the hands of communities" to make GSI planning more equitable and responsive to community needs (HECKERT & ROSAN 2018), but real-world applications of interactive tools such as PGIS remain nearly non-existent, despite the demonstrated promise of PGIS in related areas such as cultural ecosystem services evaluation (RALL et al. 2019).

3.2.1 PGIS and Contextual Background Analysis

Local citizens are the best resources of place-based values, activities, experiences, and preferences which are part of the daily life experience of the local citizens and not highly technical (ZOLKAFLI et al. 2017). PGIS is one of the most efficient knowledge-based methods for gathering accurate, new, and place-based information for public participation (KAHILA-TANI et al. 2016). With a GIS-based platform, PGIS facilitates the collection and representation of both physical and non-physical conditions of the community (CORBET & KELLER 2005, BOONE 2012). Analysis of both physical and non-physical features is essential for the identification of the pattern of meaningful places, assets, barriers, and desired enhancements needed to be addressed (BOONE 2015).

3.2.2 PGIS and Education on Topic

Studies indicate that local citizens with higher levels of knowledge related to the topic are more willing to be engaged and tend to provide highly valuable input. Integrating a two-way education opportunity among all stakeholders, including both community members and professionals, is therefore important to the success of the project (CHRISTMAN et al. 2018). PGIS has the capability to integrate information on why the community should care about GSI and in what ways specific GSI systems may benefit the community via a multitude of visualization approaches such as 2/3D models, annotated collages, drawings, cross-sections, and augmented reality modeling. Such interactive technologies not only ensure that the participants be equipped with the skills needed for meaningful participation, but also encourages ongoing feedback throughout the project.

3.2.3 PGIS and Capacity Building

Capacity building refers to the "process whereby individuals, groups, and organizations enhance their abilities to mobilize and use resources in order to achieve their objectives on a sustainable basis" (DFID 2008). Case studies have shown that community engagement throughout the process of GSI development transforms the benefits of the GSI practices from a technical and impersonal experience to a more individual one (SHANDAS & MESSER 2008, GREEN et al. 2013). In this case, the sense of empowerment, recognition, and belonging created a greater social bond between the lay people and major stakeholders, setting stage for long-term collaboration.

4 Proposed PGIS-Based Framework

Given the findings from literature and case studies, we propose a refined theoretical PGIS-based community engagement framework (Fig. 1). Built upon existing conceptual frameworks from the areas of environmental planning, participatory watershed management, public engagement, and GIS-based participatory planning, this framework consists of two major sections including the planning phase and the implementation & maintenance phase.

The planning phase of the framework demonstrates how PGIS technologies can be integrated into the overall community engagement process that was initially derived from a framework proposed by EPA (2013). The EPA framework was chosen as it includes the basic multi-step process required for any successful community-engaged GSI development (EPA 2017). However, recognizing the importance of engaging the community earlier and more often, we revised the EPA framework to launch the engagement process as soon as the community groups are identified and targeted for further partnership development. This way, significant community input can be obtained describing the stormwater problems and identifying long-term and achievable goals.

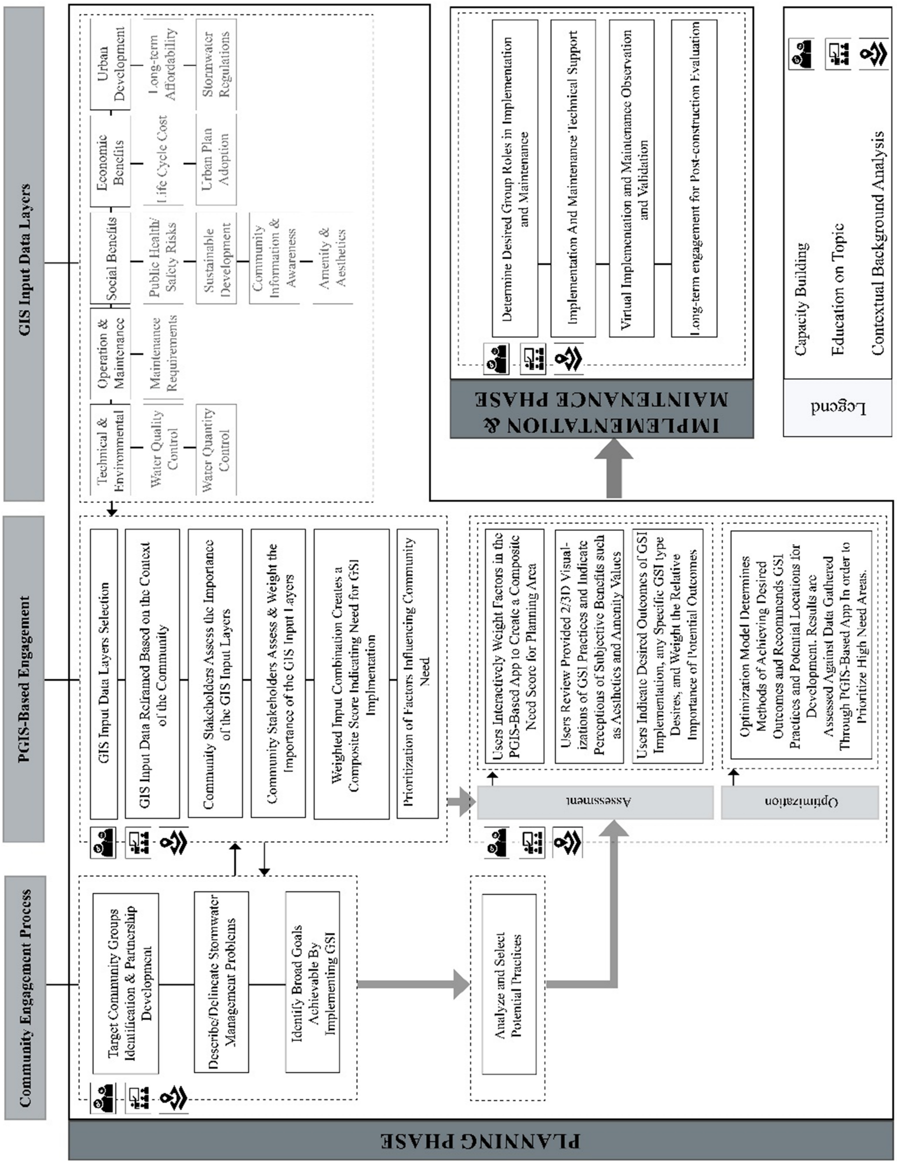

Fig. 1: PGIS-Based Community Engagement Framework for GSI Development

The assessment and optimization of potential GSI selections are organized based on recommendations by VIAVATTENE et al. (2008) and HECKERT & ROSAN (2018). The former provided a robust set of GIS Input Data Layers that help communities identify their critical needs that could be addressed through GSI implementation. Depending on the community's goal, the GIS Input Layers may lay in one of the following categories; technical and environmental, operation and maintenance, social and community benefits, economic benefits, and urban development. As community stakeholders assess the provided GIS data based on their importance, a composite score will be developed to prioritize community needs.

Next, HECKERT and ROSAN'S (2018) planning workflow has been adapted to support our goal of better integrating contextual background analysis, education on topic, and capacity building. To this end, the contextual background of the project area can be analyzed through an online app as users interactively weight key selected community GIS input data layers (e. g., the Equity Index by HECKERT & ROSAN 2018) and assess the current conditions and needs of their community. This component educates the community on how GSI practices work and how they may respond to their needs. Users assessment could be facilitated by 2/3D visualizations showcasing alternative scenarios of GSI practices and their performances. Users could then indicate their perceptions against any of the subjective benefits presented. Based on information provided by both community members and experts, an optimization model will determine recommendations for GSI practices and potential locations that will best fit the context of the community.

Despite the potential for PGIS to powerfully support GSI planning and implementation, its broad application requires substantial future efforts to overcome technical limitations such as lack of data and GIS input layers, low data quality, lack of integrated evaluative models and difficulty in integrating multi-media visualizations. Other limitations may include the cost of adopting PGIS tools, the community's willingness to accept PGIS as an alternative to traditional engagement tools, unrepresentative cultural groups or demographics, etc. Accordingly, it is necessary at this stage to consider PGIS as a complement of other types of community engagement methods.

The Implementation & Maintenance phase follows the assessment and optimization and starts with determining desired group roles in implementation. An online PGIS-based application can play a role in this phase as well by providing access to knowledge of what GSI technologies are, how they function, what benefits they provide, in addition to the much-needed maintenance knowledge and experience.

5 Conclusion

This study seeks to add to the growing literature to foster a stronger connection between community and GSI planning and implementation. Based on a review of existing literature and case studies, this study identifies the lack of a guided community engagement framework as a key barrier in community-engaged GSI development. In addition, the three components of contextual background analysis, education on topic, and capacity building need to be better integrated into the engagement process. This study proposes the integration of PGIS as a component of a comprehensive engagement framework towards a more informed and collaborative decision-making process while building the community's capacity for long-term problem-solving. The proposed theoretical framework expands upon existing engagement frameworks from the areas of environmental planning, participatory watershed management, public engagement, and GIS-based participatory planning. The advantages of this framework include the integration of traditional and technology-mediated engagement methods, inclusion of public input early and often throughout the planning, implementation, and maintenance phases, and providing the community with the opportunity to analyze, assess, and optimize their desired GSI planning in a long-term process. Future work will aim to prototype a PGIS-based online application developed according to the theoretical framework above and test it in certain Pennsylvania communities. This process, in turn, helps us to evaluate the degree to which the application fosters the engagement process, especially in the aspects of the gaps identified in literature.

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