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CAMPUS SUSTAINABILITY RETROFITS: A MULTI-CRITERIA SITE SELECTION MODEL FOR LOW IMPACT DEVELOPMENT (LID)

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Abstract

The Edwards Aquifer ecosystem is the only source of drinking water for millions of people in the US Central Texas Region. Approximately 15% of the Stormwater Pollution Prevention Engineering Structures, known as Best Management Practices (BMP), are not functioning sufficiently to prevent non-point source pollution from stormwater infiltration in these highly urbanized areas (GEAA, 2010 [3]). Because our University's main campus is located in the Edwards Aquifer Recharge Zone (EARZ), constructing new facilities or site enhancements on this campus is critical for this sole source of water supply. Funded by two regional agencies, this paper proposes systematic site selection tools using Geographic Information systems (GIS) to develop a geospatial analysis model for assessing the suitability of on-campus structured BMPs for improvement using Low Impact Development (LID) techniques. LID includes bioswale, rain garden, water harvesting, and green roofs as well as sustainable place-making edifices, which were proposed in the redesign phase. Site selection method encompassed: (i) identifying key issues pertaining to LID projects; (ii) analysing secondary data and site audits; (iii) create a GIS site capability model; (iv) analyse site suitability using a geospatial model. Programming and design priorities for a sustainable urbanism and ecological landscape were conducted. Design proposals were developed by an interdisciplinary team of architecture and civil engineering students. The toolkit developed in this paper will be adopted by the funding agencies to educate the general public and community groups on the benefits of adopting LID practices, and will also inform the state agency governing the EARZ regulations.

Keywords:
Low Impact Development; Stormwater Runoff; GIS; Multi-criteria Assessment; Sustainable Campus

1 INTRODUCTION

1.1 Edwards Aquifer Ecosystem

In the US Central Texas Region, the Edwards Aquifer (EA) ecosystem is the only source of drinking water for millions of Texans in different municipal, industrial, and agricultural uses, and at the same time sustains rare and endangered species. Human activities in that region, particularly in urbanized areas could, however face a degrading water quality, and therefore, different agencies have developed the EA rules and guidelines for development activities near the aquifer in order to protect it (Barret, 2005 [1]). One of the eight counties governed by these rules is Bexar County, Texas. The County has slightly over 3,000 engineered stormwater filtration structures located on the Recharge Zone, a sensitive region of the aquifer that feed the entire reservoir (TCEQ, 2015 [2]). Approximately 15% of these structures are not functioning sufficiently to achieve the desired result of preventing pollution from infiltration in the highly urbanized sites (GEAA, 2010 [3]). While some of these inefficient structures are found in residential areas designated for maintenance by neighbourhood and home owner associations' residents, others are located in mixed-use and institutional areas. Our University's main campus and its surrounding neighbourhoods are among these urbanized areas that are also located on the Edwards Aquifer Recharge Zone (EARZ) (See Figure 1). Developments for the campus expansion plans are crucial for the groundwater protection, and therefore, all plans must be approved by the TCEQ prior to any construction activities due to its potential contribution to water contamination. Like most of the engineered stormwater structures throughout Bexar County, campus Best Management Practices (BMPs) structures require regular maintenance and inspection in order to enhance their performance in water treatment and reducing runoff volume.

This paper is part of a broader study to select one of the dysfunctional engineered BMP structures, known as sand filter. Five sand filters are located in the University of Texas at San Antonio's (UTSA) main campus (see Figure 2). Sand filters are stormwater treatment structures that are constructed using engineered concrete systems that lack ecological response, aesthetics, and public open spaces. The broad funded study proposes a redesign of two structures that this paper identifies using the site selection tools. The paper represents a discourse of ecological landscape, urbanization, and stormwater management, and geospatial technology.

1.2 Impact Development and project goals

The United States Environmental Protection Agency (USEPA) divides water pollution sources into two categories: point and nonpoint. Point sources are those causing pollution at specific points or sites that discharge pollution (i.e. pipe, ditch, ship or factory smokestack). Nonpoint sources are surfaces that accumulate different types of chemical pollutants. According to Gaffield et al. (2003 [4]), when these chemicals are transmitted to groundwater during rain events it can cause different types of chronic and acute illnesses to people who drink the water. Pollution from these sources increases with urbanization and urban sprawl due to the increase of the amount of land covered with impervious surfaces such as roofs, roads, and parking lots (USEPA, 2015 [5]). In order to mitigate the impact of urbanization on groundwater contamination, site design techniques using Green infrastructure (GI) and Low Impact Development (LID) practices are proposed. The approach for integrating LID and GI in stormwater management intertwines ecological landscape and site design techniques. They are commonly used to reduce urban runoff and pollutants loading through on-site filtration of pollutants accumulated on nonpoint sources of contaminations such as parking lots. LID techniques perform through capturing water on site, filtering it through vegetation, and then penetrating it into the soil layers, where it can recharge groundwater reservoirs such as the Edwards Aquifer in Texas.

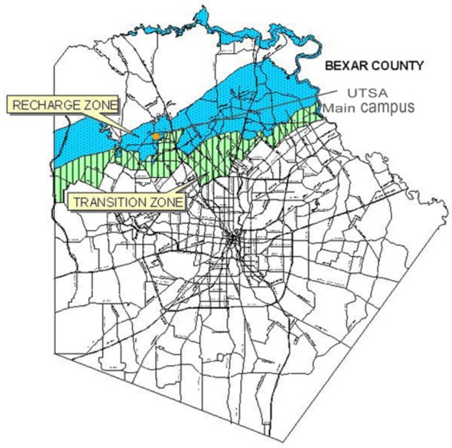

Fig. 1: Edward Aquifer region including Bexar County and the UTSA Campus.

Fig. 2: One of the Five UTSA Campus BMPs.

1.3 Ecology and Campus Sustainability

Ecology is known to be used to portray the mutual relationship between humans and their various environments (i.e. socio-cultural, political, and economic). Ecologies are depicted by multi-complex and insurgent layers that collectively inform the design of our urbanizing landscapes. These landscapes, in turn, continue to shape the ecologies that define us. Waldheim (2006 [6]) has observed that landscape is a synthetic phenomenon that has a lot to offer more than just a two-dimensional surface; and that it is "more than just the lens of representation; it is a medium of construction [and interaction]". If dealing with sites and their context is not limited to the physical components of the ground plane, and extends to embrace socio-cultural, political, and economic dynamics of landscape, new infrastructure typologies will emerge. As such, landscape in contemporary urbanism is defined through a multilayered process that requires a multifocal perspective of an intertwined culture and nature.

Policy makers endeavour to utilize innovative resources and programs to integrate landscape and ecological urbanism throughput North American universities campuses to enhance environmental performance (Mascarelli 2009 [7]). The growing recognition of financial and environmental benefits of adopting water conservation policies appeal to those administrators (Jackson-Smith et al. 2009 [8]).

Given that traditional landscape strategies are no longer practical or sustainable, campus sustainability endeavours raise student awareness of sustainability while maintaining school credits, as well as advance the leadership role of the university while benefiting society (Creighton 1999; Leal Filho 2009 [9] [10]). In Canada, the increase of cost and social demand for environmental stewardship make this challenge a recurring issue on the university agendas (Brandes and Ferguson 2004 [11]). In a move to institutionalize a campus-tailored program, in 2006, the Higher Education Associations Sustainability Consortium (HEASC) conceived a plan to improve campus sustainability. The plan, known as Sustainability Tracking, Assessment & Rating System (STARS), aims to increase awareness and knowledge of sustainability in higher education through establishing benchmark comparisons provided – via self-reporting and collaborative efforts – by all participating departments and offices. STARS guidelines cover various aspects of sustainability including health, social, economic, and ecological issues; it extends to all functions of a campus (i.e. curriculum, facilities, operations, and community engagement) (HEASC, 2006 [12]). STARS premise encompasses both long-term sustainability goals for already high-achieving institutions, and entry points of recognition for institutions that are taking first steps toward sustainability. Like most campuses wishing to apply STARS, UTSA LID design proposals encompass a number of possible credits that could be tracked, measured, and reported to HEASC.

2 DATA AND METHODS

Site selection model is a process for identifying one of the five existing water treatment sand filters in the UTSA main campus. Selected site is identified as a candidate site that is suitable for implementation of one – or more – type of Low Impact Development (LID) practices. Current sites assessed for this selection process are engineered stormwater infiltration BMPs that could benefit from a redevelopment using LID and could contribute to an improvement of campus life. The process was conducted by creating a geospatial site selection model that was developed using Geographic Information System (GIS). A review of LID-scholarly literature was used to develop two research parameters: (i) site characteristics, and (ii) pollutants loading from the areas around each engineered BMPs. Secondary data obtained from different sources (i.e. campus facilities planning office, and site audit), were compiled and used to create a univariate analysis for different attributes. A multivariate model using two-step analyses (capability, and suitability) was then created using the univariate analysis according to the weight of each attribute. Weights were assigned to the attributes using feedback solicited from funding agencies and partners.

2.1 Key Issues Pertaining to LID Design

To embark on identifying the attributes for the site selection model, LID design goals were conferred using a method similar to Austin's working group task committee (City of Austin, 2015 [13]). In consultation with the funding agencies, and incorporating their vision of LID projects, we identified the following goals that are centred on the site characteristics and design strategies:

- Maximum exposure to raise awareness
- Re-naturalizing spaces to enhance liveability
- Ease of access
- Feasibility of plugging in sustainable edifices to enhance wayfinding
- Integrate xeriscaping practices
- Designs that improve and regulate efficient maintenance schedule

Building on the studies by (LaGro, 2001; Henderson et al., 2007; and Oiamo et al., 2015 [14] [15] [16]), the following attributes were used to measure the two research parameters: (i) land use, density, sensory, circulation, and high-traffic areas for measuring site characteristics. (ii) Street network, vehicle density, and distances associated with pollutants loading including nitrogen monoxide (NO), nitrogen dioxide (NO2), volatile organic compounds (VOC), and particulate matter (PM). A univariate GIS map for each attribute was created using the appropriate metrics listed in the literature (see Figure 3). Additional maps were added using on-site observation and documentation, known as site audit.

2.2 Site Audit using Systematic Observations

Audit forms are largely used in direct observation and assessment of public spaces and streets. System for Observing Play and Recreation in Communities (SOPARC) protocol (McKenzie, et al. 2006, and Whiting, J. W, et. al., 2012 [17] [18]), was utilized in active living research to document activity types and magnitudes. For this paper, audit form was used to document four site characteristics: (i) site visibility; (ii) access to site; (iii) activity areas by location and type; and (iv) primary nodes, and high traffic areas. Using the four types of activities categories by Gehl (2011 [19]), activities were classified based on type (walking, standing, sitting, and sporting), and time (morning and afternoon). The cumulative count of persons by each type and time of activity was estimated, and digitized using GIS point layer. A final GIS map was created for each activity. Accessibility by location and means (vehicle, pedestrian, bikes, and buses) as well as site visibility and nodes were observed, documented, digitized, and analysed using similar methods.

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2.3 Geospatial Model for Site Selection

GIS provides flexibility, accuracy, and efficiency as a platform for its aptitude in visual and quantitative analysis (Collins et al., 2001; Malczewski, 2004; and Saleh and Sadoun, 2006 [20] [21] [22]). It is capable of linking location data with multiple attributes that are quantitatively coded. Its ability to perform spatial analyses on large amounts of data, makes it an effective visual and analytical tool for site suitability and geodesign approaches (McElvaney, 2012 [23]). Using GIS, a multivariate analysis model, comprised of two steps (capability, and suitability) of the five existing BMP sites on the university campus was conducted. The model follows the Massner (2012 [24]) geodesign approach, and was applied on the existing five BMP sites to eliminate those BMP structures that do not support the project goals.

2.4 Sites Capability Model

The first step of the geospatial analysis, a capability model, incorporated the univariate analysis to assess BMP sites potential to support design and site requirements for each typology (rain garden, swale, and bioretention basin). The following attributes were identified using six case studies of policy reports that discussed LID design and site requirements:

- Slope, including site with a maximum slope of 15%.
- Floodplain, including distance from the projected 100-year floodplain.
- Maximum exposure of site, including visibility.

2.5 Sites Suitability Model

The suitability model also integrated various variables, each represented through a series of univariate GIS maps (see Figure 4). The analysis encompassed the following parameters and attributes:

- Circulation: pedestrians, and buses
- High-traffic areas: main passages
- Activity areas: walking, sitting, standing and sporting
- Proximity to primary zones, academic buildings, and main passage
- Pollutants loading: including NO, NO_2, VOC, and PM.

The two-step model compares the five campus BMP sites according to the attributes' metrics used in the scholarly literature, and assigns a ranking system based on a scale of 1-5 (worst to best) to each site. A cumulative score was calculated for each site.

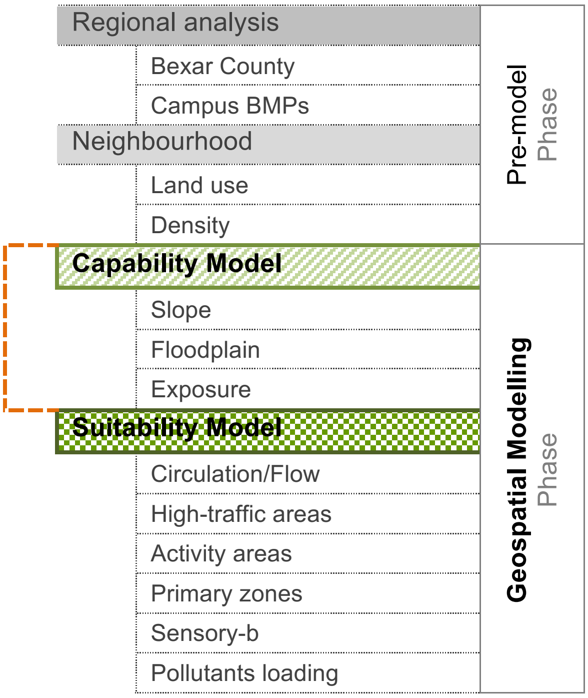

Fig. 3: Site Selection Process.

3 RESULTS AND DISCUSSION

The Geospatial site selection Model developed in this study was supported by scholarly literature as well as best practices of LID design criteria. The model aims to improve the dysfunctional stormwater treatment BMPs in the main campus of the University of Texas at San Antonio and, at the same time, to increase campus' STARS sustainability score. The five BMP sites examined in this study were analysed using quantitative and spatial analyses of secondary data and site audits. The five BMP sites were compared using reliable metrics associated with two parameters: site characteristics and pollutants loading. Out of the five sites, structures C & D met most of the capability and suitability criteria, and therefore were advanced to programming and development using LID design techniques.

C and D sites and their adjacent open spaces were redesigned by three multidisciplinary teams of senior and graduate students in architecture department as well as civil and environmental engineering department. Design concepts, program, and a GIS hydrology model for each water treatment site was developed, assessed, and fine-tuned. Proposed designs adopted the ecological landscape using xeriscaping for water conservation, in addition to incorporating local and affordable materials; and integrating a multi-treatment LID structures (rain gardens, bio swale) and water harvesting system.

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4 CONCLUSIONS

This paper presents a case study of water treatment design using Low Impact Development (LID) design techniques. The case study also explores the use of geospatial analysis model using GIS as well as site audit in site selection for mitigating water pollution and reduced runoff volume. LID design tools were strategized to replace existing engineered, and dysfunctional, BMP water treatment sites located in the UTSA campus. The improvement of two structures (C and D) will also promote sustainability through increasing the existing STARS score, and raise awareness through the exposure of the –yet to be- LID structures. The broader research that is inclusive of this paper will integrate the site selection model as a prototype for further implementation across the neighbourhoods and home owner association located on the Edwards Aquifer Recharge Zone. Criteria for the project goals and attributes in the two-step model (capability and suitability) could be replicated in other university campuses, neighbourhoods, and mixed-use areas.

The results of this paper raise awareness of the future professionals and ecologists who will be engaged in designing efficient stormwater pollution prevention structures, and mitigating stormwater runoff. It helps policy makers who are developing data-driven selection tools for allocating the resources for retrofitting engineered dysfunctional stormwater structures and sites through LID design techniques.

It also serves as a learning tool for future multidisciplinary courses on sustainability and water conservation that university campuses could implement to raise awareness of the benefits of using native and drought-tolerant plants, conserving water, and enhances water quality through infiltration. Upon implementation of the proposed designs (see Figure 4), the site's visual quality and aesthetics will be improved, and the campus STARS score will be increased. Other benefits include the ease of maintenance, re-use of harvested water for irrigation, and the creation of spaces for outdoor social and educational activities around LID sites. The paper also informs future research and practices on the importance of integrating scientific metrics and geospatial models as data-driven tools that would inform design decisions. This paper highlights the significance of multidisciplinary collaboration in the study of urban sustainability, ecological landscape, and LID practices. Funding agencies of this study will adopt the site selection model in their pursuit to facilitate LID strategies and an incentive program across hundreds of communities, neighbourhood associations, and businesses in Bexar County, Texas.

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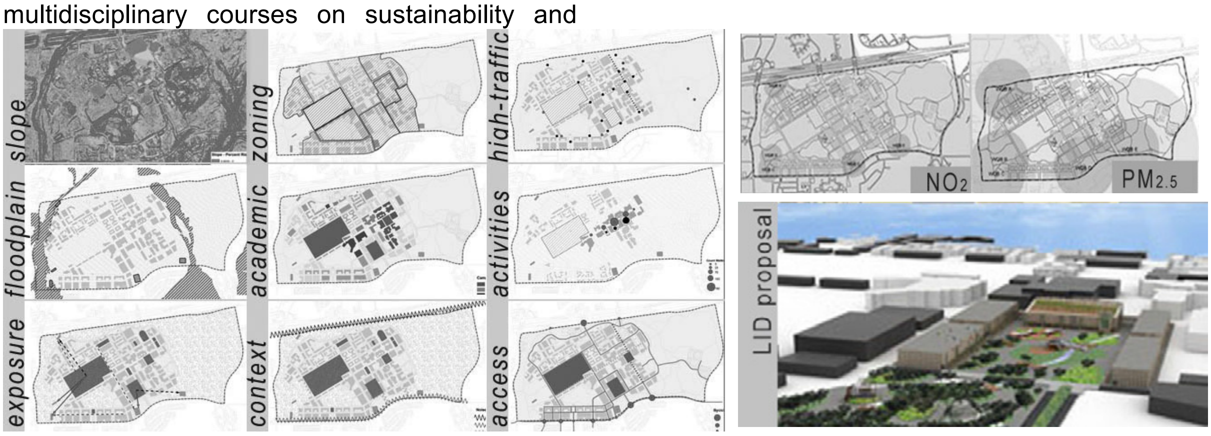

Fig. 4: Attribute used in the Univariate Analysis and One of the Two Proposed Designs.

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