Roadway and Water Feature Design at The Botanic Garden

Abstract

Through interdisciplinary collaboration, the civil engineering senior design capstone class at the local university has developed the design of a roadway through The Botanic Garden in Stillwater that implements numerous innovative and sustainable technologies. The team carried out the entire design process, from solicitation and presentations to the client, to the final design that includes a geotechnical investigation, hydrology and hydraulics analysis, permitting requirements, roadway and water feature designs, and a cost and schedule estimate. To facilitate the complex design process, professional engineers and university professors worked in collaboration with the team, lending their advice specific to individual areas of expertise. Additionally, a group of landscape architecture students worked in allied participation with the design team. As envisioned by The Botanic Garden director, the project was composed of a design that allows for both civil and environmental engineering research and can also serve as an inspiration to universities and students across the country as a teaching and education tool. These design ideals are in parallel with The Botanic Garden's comprehensive plan to become an Integrated Environmental Research and Education Site. The design team undertook extensive research on pavements types and various "green" infrastructure practices that lead to an cutting-edge design that has little to no environmental impact, allows for extensive research capabilities, and has the concepts of sustainability integrated within every feature.

The roadway design incorporates four different sections of pavement to be used in the development of research: Permeable Interlocking Concrete Pavement (PICP) from the Interlocking Concrete Pavement Institute (ICPI), Geopave® Porous Pavement and FilterPave® Porous Pavement from Presto GeoSystems, and a 50% fly ash replacement concrete section as a control. The pavements selected facilitate a "green" infrastructure design while allowing for vanguard research on the roadway. The integrated site design also includes bioretention swales, off-grid lighting, and a water feature to be used as a retention pond. The rainfall from the road is designed to be piped into the water feature, further establishing this project's focus on the "green" initiative. The permeable pavement and bioretention swales also provide stormwater filtration that reduces the harmful pollutants that flow into local streams. The comprehensive site design reduces runoff and increases infiltration and evapotranspiration. In addition, these innovative, "green" infrastructure practices create an environmentally friendly result that is aesthetically appealing and provides a soothing, decompression experience that will improve the health, safety, and welfare of the public.

The synergy that developed between the team and professional engineers helped the students attain valuable new skills and knowledge. In conclusion, the students were afforded an extraordinary opportunity to produce a design, from conception to final completion, that will endure as a part of their university forever.

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1. BACKGROUND

In the spring of 2012 our civil and environmental engineering department launched a project in conjunction with the university's Botanic Garden to conceptualize and design the future infrastructure of the garden. The encompassing goal of The Botanic Garden is to become an Integrated Environmental Research and Education Site (IERES) by construction of one of the most comprehensively designed integrated environmental systems for demonstration, research, and academic and public education in the United States. As a part of the establishment of The Botanic Garden under the IERES comprehensive plan, the value of functionality, safety, and sustainability were necessary to be incorporated into the design. Through cooperation with officials from The Botanic Garden and a class of landscape architecture students, several areas of particular importance were identified:

- Roadway: a roadway to connect the access road to a conceptualized parking lot
- Drainage: floodway and floodplain analysis, hydrologic studies, drainage structures, erosion control, and emergency closing
- Hydraulics: retention and detention capabilities, outflow structures, and irrigation
- Research: integration of research and education capabilities into the infrastructure

The project was undertaken by the students in the undergraduate capstone design course in realization that the project would afford them the opportunity to produce a cutting-edge, multifaceted design that would become a permanent part of the university. Smaller sub-projects allowed the members of the student design team to utilize their individual strengths and experience. These sub-projects were combined into a comprehensive final design of The Botanic Garden that integrates the many aspects of the IERES mission. Subsequently, the students gained valuable experience in meeting the lofty expectations of an enthusiastic client while addressing the project's design constraints due to functionality, constructability, permitting requirements, and safety of the public. The senior design team worked in conjunction with practicing and licensed professional engineers in many disciplines that mentored the students in their fields of expertise. The remainder of this report contains the overall project description, the account of collaboration efforts, the benefit to the public, the multidisciplinary aspects of the design, and the knowledge and skills gained throughout the project.

2. PROJECT DESCRIPTION

Defining the Scope

The initial scope of the project was developed through conversations with the client, The Botanic Garden director, and working with a master plan developed by a graphic designer. The entire

Botanic Garden is situated on a 100 acre plot on the east side of the city of Stillwater. The site is located on the northeast corner of Highway 51 and Sangre Road. A charette was conducted with members of the landscape architecture senior design class to brainstorm creative and innovative design concepts that could be integrated into The Botanic Garden. Detailed scoping resulted in the students understanding the project to include an access road with an alignment starting at an existing parking area off of SH–51 and meandering north towards the garden's proposed main buildings. The design team also determined that as part of our project's scope, the graphic designer's proposed water feature could serve as both a stormwater retention and irrigation supply for the garden.

Roadway Design

The first obstacle faced in the project was due to the horizontal alignment proposed in The Botanic Garden Master Plan. The proposed roadway followed Stillwater Creek close enough to be within the FEMA (Federal Emergency Management Agency) floodway. The city of Stillwater will not allow construction within a floodway due to the adverse effects of the obstruction of stream flow during a storm event. A new alignment was then selected and proposed to the client. This new alignment still follows the creek northward but is located just outside of the floodway in order to meet city compliance and improve driver safety.

During the re-alignment, various pavement types were being researched and selected by members of the design team. Pavement selection first revolved around determining what types of pavements offered the most sustainability and were on the leading edge of research in civil engineering. Permeable pavement offered both of these characteristics. Permeable pavements are used to manage runoff by collecting stormwater and distributing it to a controlled location away from roadway. Large volumes of water during storm events can be easily collected with permeable pavements and then used over time instead of producing immediate water runoff due to impermeable surface. Reducing the amount of high velocity, immediate water runoff also helps mitigate serious erosion and siltation in surface water bodies. The three permeable pavements chosen include Permeable Interlocking Concrete Pavement (PICP) from the Interlocking Concrete Pavement Institute (ICPI) and Geopave® Porous Pavement and FilterPave® Porous Pavement from Presto GeoSystems. Additionally, a 50% fly ash replacement concrete section is designed into the roadway system as a control section for research capabilities. Each pavement section is approximately 496' long resulting in a total project length of 1993.53'.

The Departments of Transportation (DOT) across the United States set design specifications to insure public safety on roadways in their respected states. The roadway design developed meets all of the DOT applicable specifications for a rural roadway through a floodplain. The roadway was able to be designed at grade due to its permeable properties that do not allow for ponding. The roadway cross-sections contain two, 12' wide lanes crowned at a 2.5% grade with 4' shoulders. Included in the cross-sections are two, 4" perforated pipes that extend the length of

the roadway that serve to collect water that has infiltrated through the pavement. All four pavements are designed to the same depth so that in the case that they are removed and replaced with another pavement for research, complications will not arise with unequal slab and subbase depths. The pavement design will allow for education of students and the general public about sustainable design as well as allow for research on the newest permeable pavements on the market.

Water Feature Design

The water feature was designed as both an aesthetic feature of The Botanic Garden and a functional component of this project's integrated system. The water feature's location in the original master plan had to be changed because of the adjusted alignment of the roadway. The new location is directly to the east of the roadway by approximately 100'. Design began with determining the total amount of inflow resulting from a 100-year storm event that would enter from the conveyance pipes in the permeable pavement, the 100' offset that is graded downward towards the water feature from the roadway, and the surrounding areas that are naturally graded to the water feature's proposed location. After completing water storage calculations, the water feature was designed to have a surface area of 2 acres with a dropping 3:1 slope down to a depth of 16'. The water feature is oval shaped with its longest dimension almost exactly north-south. The complete storage capacity of the water feature was designed for a week's worth of irrigation of The Botanic Garden, a 100-year storm event, and 1' of free board. The free board was included for safety and should never be met due to an outfall structure at the 15' mark. A "morning glory" design is implemented for the outfall structure with a 2' diameter corrugated steel pipe with grate. The pipe drops down into the water feature and then turns westward and travels at 2% downgrade to Stillwater Creek. At the creek, the pipe relieves the water feature in the event of rainfall greater than a 100-year storm.

Sustainable Feature and Public Safety Designs

In addition to the major design features, bioretention swales were added along both sides of the roadway in order to increase groundwater recharge and reduce additional runoff. The roadway design's typical sections provide a 3:1 down slope each side that led to the described swales. The Botanic Garden will be able to plant native grasses in the swales that are known to promote recharge to the groundwater. Additionally, off-the-grid lighting has been incorporated into the design of the roadway. Sanya Street Lamps made by UGI (Urban Green Energy) are located at 150' intervals alternated along the roadway to promote safety at the gardens during the night. Lastly, as part of the emergency action plan created for the site, emergency gates are located at the beginning and end of the roadway design. These emergency gates are crucial for the safety of the public in the event of a flood. Although the roadway is located outside the floodway, it will be flooded during a 100-year storm due to its location in the flood plain and its placement at the existing grade. The emergency gates are added for increased safety but have not being specified exactly since The Botanic Garden would like to install personalized gates.

3. COLLABORATION OF FACULTY, STUDENTS, AND PROFESSIONAL ENGINEERS

The project was an extraordinary collective effort of many different professors, students, and professional engineers. Since late in 2011, the university's surveying class had been creating a topographic map for the project site. At the beginning of the semester, a landscape architecture professor and his class joined the design teams to have a design charette for The Botanic Garden project. The groups brainstormed ideas for the project, using the practical knowledge of the civil engineering students and the creative genius of the landscape architecture students to combine for excellent ideas. The charette was an important launching point that introduced students to the project, encouraged them to think outside the box, and helped the teams learn to work with other types of minds, cooperating with them and compromising when necessary. Shortly after, students were divided into five groups and worked with a project manager from an unnamed civil engineering firm to learn the project solicitation process. The project manager explained the usual process and what documents were typically utilized. Next, the groups presented their qualifications to be selected for the bid to the client, also explaining what innovative ideas they had for the project.

After initial project interviews, three of the groups were selected to be the design teams for the project, and the other two groups were dissolved and added to those design teams. The teams continued to work with the project manager from the unnamed civil engineering firm and the client to establish the scope of the project and what was expected of the teams. This was a challenging and interesting process because of the unconventional nature of the project. During this time, the design team determined the exact boundaries of the project site and what the scope included into the design. With the help of the unnamed civil engineering firm, teams began to gather the early information for the roadway design and estimates.

Approximately six weeks into the semester, a professional engineer from an unnamed civil and water resources engineering firm that specializes in hydrology and hydraulics came to the class to assist the teams. The design team, with the professional engineer's help, spent several weeks working on the hydrology for the site and the hydraulics for the water feature intake and outflow structures. This was difficult because most of the team had little to no experience in developing hydrology and hydraulic models.

At the half-way point in the semester, a geotechnical expert and AutoCAD technician from an unnamed geotechnical engineering firm came to help the teams with the geotechnical investigation and the AutoCAD Civil3D design of the road. The AutoCAD technician gave the teams a crash course in Civil3D, walking them through the process of creating a roadway alignment. Throughout the course of the semester, the unnamed civil engineering firm offered their time to continue to increase the teams' knowledge of Civil3D and help them through the roadway design process. Members of the class also went to one of the participating engineering firms to work with their engineers and CAD techs. During one Friday class period, the teams

went out to The Botanic Garden project site and met the unnamed geotechnical engineering firm's core-drilling crew and professional engineer and took soil samples to be tested. The geotechnical expert explained what goes into geotechnical design and helped the teams prepare their own geotechnical reports.

As the projects progressed, several different specialists collaborated with the design teams in their fields of expertise. One of the city engineers from the city of Stillwater came and spoke about pervious pavement design and provided examples for the teams to look at. He explained how permeable pavements function and what implementing them into the teams' designs would entail. Through a webinar with an unnamed environmental engineering firm, the class connected with an expert in "green" infrastructure design. He spoke about numerous different "green" infrastructure options and truly gave the class an in-depth understanding of what "green" infrastructure was available. Additionally, the team was aided by engineers from an unnamed technical business support group that is familiar with the construction permitting process. They explained what permits would be required for The Botanic Garden project and referred the teams to information that would help them complete the required permits.

With the design nearing completion, two professors from the civil and environmental engineering department at the university came during different class periods to offer their expertise. First, the surveying professor, who also works as a professional engineer, explained how to put a set of roadway plans together and went into detail about what is typically included in a plan-set. This was very helpful for many of the students that did not have previous experience with design firms. Next, a professor that specializes in construction management spent time with the teams teaching them how to produce project cost estimates and construction schedules. He also provided the design teams with spreadsheets that would help the teams complete their respective estimates.

4. BENEFITS TO HEALTH, SAFETY, AND WELFARE OF THE PUBLIC

This project provided tangible benefit to The Botanic Garden, dedicated to education, teaching, and research for the students and public of the city. As previously described, the director of The Botanic Garden requested the help of the senior design students for a roadway and stormwater collection design with emphasis on sustainability. These students developed a system that provides safe access to The Botanic Garden through the Stillwater Creek floodplain. The system uses permeable pavements due to benefits for driving safety during storm events and their ability to collect and store the water. The student teams designed the roadway system to transfer the collected stormwater to a water feature which can be used as irrigation for the garden.

In each phase of the project, the health and safety of those that would be visiting the garden and working in it was a major consideration in advancing various designs. Roadway design was completed to meet DOT standards and requirements in order to protect the public welfare against unreasonable risk of crashes occurring as a result of the design, construction, or performance of

the road and to protect the health of the public in the event that crashes due occur. This project also stressed the importance of codes and requirements for design and safety when designing and building within a FEMA designated floodplain; a flawed design could potentially lead to loss of property or life.

With public welfare as the primary focus, typical road cross-sections were specifically designed for this project's unique pavements, and the horizontal road alignment was re-aligned from The Botanic Garden Master Plan design so that the road would be located outside the FEMA regulatory floodway. By providing engineering services free of charge, with the guidance of professional engineer mentors, the students were able to provide real benefits to The Botanic Garden where a safe, sustainable, vanguard road and water feature have now been designed for the education and recreation of university students and the public.

5. MULTIDISCIPLINE AND/OR APPLIED PROFESSIONAL PARTICIPATION

The multidisciplinary cooperation of the civil engineering and landscape architecture departments was an exceptionally rare and unique student experience. Throughout the project, students learned firsthand the reality of how challenging, but rewarding, the integration of multiple disciplines can be for a project. As the project progressed, the engineering capstone class began to understand the project not just as numbers and designs, but as a system. The teams started to appreciate the importance of the creative concepts offered by the landscape architecture department and how useful their understanding of the aesthetics of a site would be for the project. As the engineering students began to see the perspective of the landscape architecture students, a reciprocating effect started as both groups began to work together and understand the motives and the difficulties of the other. The landscape architecture students started to grasp that though their ideas were good, they needed to take advice from the engineers when the idea may not be feasible. Then, working as a team, the concept could be revised to incorporate the aesthetic aspects, while not neglecting feasibility and functionality. In the end, each group came out with a better understanding of the other and how to work together, not despite the differences, but because of the differences. This synergy of multiple disciplines resulted in a comprehensive design of The Botanic Garden that combined the strengths of all contributors and produced a design that integrated sustainability, aesthetics, and functionality.

6. KNOWLEDGE OR SKILLS GAINED

The civil engineering students working on this project acquired design, presentation, communication, teamwork, and research experience in providing a solution to a real-world problem. From design professionals and professors, the students learned how to take surveying points, roadway calculations, and hydrology and hydraulics calculations to design a sustainable roadway and water feature. The students were set on a task to complete their own land survey of the project and quickly learned that understanding the existing site conditions and preparing a thorough survey is essential. Design professionals from around the state directly aided the

learning of AutoCAD Civil3D software, HEC-HMS modeling, cost estimating, and effective communication to the client. Application of new design and analysis software was a valuable learning experience as it allowed the students to prepare and complete technical studies, reports, and designs with the tools of professionals. The students quickly learned that delegation and communication for such a large project and team was needed, as well as deadlines to have information ready to our client for the 30, 60, and 100 percent project presentations. Additionally, the students learned that the engineers are responsible for designing as close as possible to the client's scope, regardless of the obstacles laid before them. One area that the students were largely unaware of until this project was the permitting requirements for building within FEMA floodways and floodplains. As scoping and designing of the project progressed, the students discovered the extent of these permits through the collaboration with design professionals. By way of a geotechnical firm, the students physically watched and learned how soil samples are taken from the field, as well as the significance of certain soil types on the project site. In a webinar with an unnamed environmental engineering firm, the students were exposed to "green" design practices and its environmental benefits. The students were able to effectively use bioretention swales in The Botanic Garden design to catch runoff from the roadway to promote recharge to the groundwater and to provide for research capabilities. The process of designing the roadway provided a tremendous learning experience for the students in both the physical design of roadway geometrics and the implementation of permeable pavements as a part of sustainable design. Two of the most important skills that the students developed throughout the class are the ability to communicate clearly and concisely and how to present a product to a client. These tools will serve the students greatly in their careers and in life. In conclusion, the students completed a full design process under the mentorship of practicing professional engineers, allowing them to gain knowledge, skills, and practical experience that will extend outside of the classroom and into their future careers.