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There is a growing interest among cities and civil entities in the field of sustainable design. As more projects are undertaken the benefits and potential applications are becoming more apparent. One area where great strides have been taken is in Green Infrastructure or green street design. As defined by the Committee on Science and Technologies, House of Representatives, green infrastructure is the incorporation into the transportation infrastructure of technologies that help absorb and filter excess runoff, rather than funneling it into sewer pipes. Several pilot studies in Seattle, WA and Portland, OR have found that these systems can be very successful in reducing the amount of runoff that enters sewers and filtering it naturally. These pilot studies have led to additional projects in those cities.

The problem is typical of many downtown areas. The large amounts of impervious surfaces lead to a large amount of runoff during a storm event. Currently that runoff is funneled into the sewers and to a treatment facility. Besides the stormwater, the city devotes a large amount of space to surface parking lots, creating “missing teeth” in the urban character.

The research for this project consists of a literature review of green infrastructure and sustainable landscape design to determine general design guidelines. Case studies of successful projects in the Pacific Northwest were used to understand the principals of green infrastructure systems and how they have been applied. In the second part of the project GIS data was used to create a site inventory and that inventory was then analyzed to determine the best locations for green street implementation and the locations of “stormwater parks” and green plazas. The project creates a system of interconnected green streets that provide a more natural method to deal with runoff, and a more pedestrian friendly environment.
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The downtown area of Louisville, Kentucky is very urban, not in size and scale but in the amount of impervious* surfaces. This high percentage of imperviousness leads to a large amount of runoff during a storm event. The current method of runoff removal is typical of any urban environment, funnel the runoff into a sewer systems and then to the nearest water body or treatment facility. This practice has negative effects on the environment and as imperviousness increases the effects become more apparent. These effects include pollution from oils to heavy metals, increased stream flow, decreased stream base flow*, flooding, and erosion as more water is added to streams at an increased rate. A solution to this is to create a green infrastructure system. Green infrastructure allows runoff to be collected in a more natural system where it can then be filtered by plants and soil, while simultaneously decreasing urban heat island* effect by decreasing pavement, and creating a greener and healthier city.

Green infrastructure can be defined as the incorporation into the transportation infrastructure of technologies that help absorb and filter excess runoff, rather than funneling it into sewer pipes. Essentially it is the use of planters and green spaces to handle stormwater runoff. Green infrastructure systems have been shown to successfully reduce the amount of runoff that enters sewers as well as the amount of pollutants in that runoff.

Green Infrastructure systems have been used with great success in cities such as Portland, Oregon and Seattle, Washington. Portland has completed several projects designed to handle street stormwater runoff. The planters in the 12th Avenue Green Street Project are estimated to manage nearly all the 180,000 gallon street runoff (Portland). The Street Edge Alternatives Project or SEA Streets of Seattle has been designed to provide drainage that closely mimics a natural drainage system. Imperviousness has been reduced to eleven percent less than previous street design and a system of swales and detention basins that, over a two year study, reduced the runoff leaving the street by 99 percent (Street Edge Alternatives).

In addition to the industry definition, this project includes bike lanes and pedestrian friendly atmosphere in the definition of green infrastructure. These modes of transportation are friendly to the environment and promote a safer and more enjoyable experience for the downtown.

* See Key Terms appendix a
The Downtown Development Corporation of Louisville Kentucky is striving to develop the downtown environment as a more livable and pedestrian oriented environment. In 2002 the DDC with community involvement identified a number of strengths and weaknesses. Some of the weaknesses identified that are key to this study are: downtown too spread out; too many vacant lots; one-way streets; too many surface parking lots; surface parking breaks up urban character; and traffic moves too fast. They also identified a number of strengths that consist mostly of the diverse collection of destinations. Based on these strengths and weaknesses, the DDC set a number of principals as part of the Louisville Downtown Development Plan. The key principles to be addressed in this design were:

Principle #1
Continue to reinforce Downtown as the unique cultural, business, entertainment, retail, and civic center of the region.

Principle #2
Create a 24-hour Downtown with a focus on residential development, integrated with a mix of commercial, civic, cultural, and entertainment attractions.

Principle #3
Transform Downtown from a “collection of destinations” into one unique “Destination”.

Principle #4
Create active, vibrant, safe and livable public spaces supported by the design of buildings, streets, and open spaces.

Principle #5
Create an interconnected network of streets, transit, and public open spaces.

Principle #6
Enhance Downtown’s attractiveness as a place for investment.

Principle #7
Build on existing strengths with new initiatives and development.

Principle #8
Integrate Downtown seamlessly with its adjacent neighborhoods, the City, and the region.

Principle #9
Forge Public/Private Partnerships to coordinate high priority initiatives and oversee Plan implementation.

Literature Review

This literature review will serve to explain the environmental impacts of the current urban solution to stormwater treatment and to explain the retrofit solutions to create a green infrastructure system. It will also cover case studies of successful projects. Sources will be reviewed for pertinent information about urban water quality and solutions to environmental impacts.

Urbanization, the spread of urban spaces, has led to a change in the natural flow of surface runoff. As cities become more urban we typically increase the amount of hard, impervious surfaces. This in turn causes an increase in the amount of runoff and decreases groundwater recharge (US EPA Natural, 10). Principal pollutants of urban stormwater include hydrocarbons (oils), sediment, heavy metals, and trash (US EPA Natural, 21). The current approach to stormwater runoff is to remove it from the site via underground pipes to a treatment facility or the nearest body of water. Often these pipes are combined sewers, sewers that convey both stormwater and sanitary sewage, which frequently overflow during heavy storm events (Mays, 18.1). Besides combined sewer overflows, conveying stormwater to a treatment plant means an increased workload on treatment facilities, increased spatial requirements for facilities and increased cost in treatment. Historically, it was the Industrial Revolution that brought about the “big pipes” approach to water management as cities grew and needed a more efficient way to handle large amounts of water (Newman, 242).
Prior to the Revolution, water was managed much more naturally, with rain collection and drainage part of the street design (Newman, 241). This is the approach that brought about the idea of new green infrastructure.

According to Newman and Kenworthy, the fundamental goal is to restore the natural systems in and around the city so that they have more of their ecological integrity (243). While traditional systems focused on conveyance, removing runoff as quickly as possible, new thinking has focused on systems of storage and infiltration as well as conveyance (Newman, 235).

Methods to accomplish this include the use of infiltration strips near impervious areas, the use of bioswales for conveyance, and systems such as stormwater planters and rain gardens, and detention and retention basins to collect and infiltrate runoff. Other methods of infiltration include filter strips and porous pavement (US EPA Preliminary, 5-7). Another is constructed wetlands. Though this review is not about constructed wetlands, these are very effective systems for water treatment, and the principals of constructed wetlands can be adapted to urban use, perhaps in the form of a small park or green space used as an end-point for the integrated street systems.

One successful use of bioswale usage was the Oregon Museum of Science and Industry (OMSI). These systems have been designed to slow down water and allow it to infiltrate the soil, while any overflow can be directed to drains. Designers anticipate that through infiltration and plant uptake pollutant capture can be as high as ninety percent (Thompson, 183). Portland, Oregon has been at the forefront of integrated stormwater system design. They have completed several projects using a series of stormwater planters to collect street runoff and allow it to infiltrate the soil. The planters in the 12th Avenue Green Street Project are estimated to manage nearly all the 180,000 gallon street runoff (Portland). Like Portland, Seattle, Washington has taken great strides in green infrastructure. The Street Edge Alternatives Project or SEA Streets has been designed to provide drainage that closely mimics a natural drainage system. Imperviousness has been reduced to eleven percent less than previous street design and created a system of swales and detention basins that, over a two year study, reduced the runoff leaving the street by 99 percent (Street Edge Alternatives).

This literature review has been used to explain some of the problems of urban runoff. The problems covered were: treatment plant overload, combined sewer system overflows which introduce sewage at sewer outflow points, and urban street pollutants flowing into water bodies. I have reviewed sources that cover the various types of systems suitable to urban retrofit project, from bioswales to stormwater planters to constructed wetlands. Finally I reviewed some projects that illustrate the effectiveness of these systems.
In March of 2007 the city of Portland adopted the “Green Streets Resolution” to establish guidelines for the use of green streets in the city. It was found that 60 to 70% of stormwater runoff is attributable to paved streets and runoff directed from private property and concentrated in the public right of way. It was established that 60 million gallons of stormwater will need to be removed from the Combined Sewer System annually by 2011, through implementation of sustainable projects such as Green Streets. One project of note, the 12th Ave. Green Street has been a highly successful pilot project for urban spaces. Developed as a system of four planters, runoff enters the planters through curb cuts and channels. Each planter has an infiltration rate of 4 inches per hour, and as one planter overflows the runoff re-enters the street and continues downhill to the next planter. It is estimated that this system handles nearly all of 12th Avenue’s 180,000 gallon annual runoff.
Located on 2nd Ave NW, between NW 117th and 120th Streets, Seattle’s pilot Street Edge Alternatives Project (SEA Streets) was completed in the spring of 2001. It is designed to provide drainage that more closely mimics the natural landscape prior to development than traditional piped systems. Impervious surfaces were reduced to 11% less than a traditional street. 2 years of monitoring showed a 99% reduction in runoff.
Green Infrastructure has been proven effective in the Pacific Northwest. But can it be used in the Midwest? Louisville Kentucky would be an ideal place for the use of green infrastructure. The city has excessive surface parking and hard surfaces that lead to excess runoff. Additionally Louisville is beginning to redevelop to make the downtown a more appealing destination. This project will show that Green Infrastructure can help to mitigate urban runoff and create a more pedestrian friendly downtown.
In order to address the public, civil, and technical challenges with adapting existing urban streets to a green infrastructure design, I used information collected from library, web, and primary (designers, developers, etc.) sources to review the challenges faced in similar projects. I used urban design guidelines, both general and from the Downtown Development Corporation, to address the challenges according to city guidelines. Case studies from Seattle Washington and Portland Oregon were reviewed as the primary source for addressing the specific challenges. Additional data was collected from city and was analyzed to identify suitable locations and solutions. This data will be site specific and include GIS data, aerial maps and photographs, and information about the sewer and stormwater systems on site.

Since storage and infiltration space is a major component of Green Infrastructure, on site and near site storage opportunities were identified using maps, GIS, and zoning information. These storage areas also serve as public green spaces. Sites were selected according to connection to green streets and where they serve best as public amenities.
The 9 principles can be condensed into three program guidelines:

1. Connectivity. The new infrastructure design will serve to connect to amenities, open spaces, and adjacent neighborhoods.

2. Aesthetics. The design will create a street aesthetic that unifies the downtown environment and improves its attractiveness.

3. Investment. The design will include private spaces into the design to encourage private interest. The design will be attractive to future investment by increasing both live and work populations in the downtown environment.

In addition to those based on the pre-existing principles, a fourth key design guideline will be:

4. Environmental. The green infrastructure system will handle stormwater runoff in a way that is based on nature. Runoff will be handled by a system of stormwater planters, bioswales, and “stormwater parks” that allow runoff to infiltrate naturally rather than enter a sewer.
- Green Infrastructure: Incorporate into the right-of-way stormwater systems
  - Use systems to handle road and roof runoff
- Create additional green spaces within downtown
  - Create “stormwater parks” as endpoints for collection and infiltration
  - Remove surface parking in favor of green spaces and parking structures
- Connect downtown with surrounding areas and parks
- Increase pedestrian feel
  - Use green infrastructure to create a more pedestrian friendly environment
- Encourage public/private effort in green infrastructure
  - Incorporate private entity solutions into overall system
Opportunities (+) and Constraints (-)

- One way street systems is restrictive, confusing for visitors
- Excessive surface parking
- "Missing teeth" break up
- Distinct separation of downtown and surrounding neighborhoods
- Downtown destinations disconnected

- Major developments adding to downtown environment
  - Center City District
  - Liberty Green
  - Downtown Arena
  - Variety of Downtown destinations
  - West Main Street
  - 4th Street Live!
  - Louisville Slugger Field
  - Waterfront Park
  - Kentucky Center for the Arts
  - Public interest in reducing surface parking
  - Potential for reuse of vacant buildings
  - Private interest in downtown development
  - Louisville Downtown Management District
  - Riverfront access

- Highway ramps occupy several blocks. Green spaces here mostly inaccessible
- 1-64 blocks views to river, restricts access
- Highway ramps create barrier
- Multiple lanes and high rate of travel create barriers
- Connection to Neighboing areas
- Connection to Nieghboring areas
- Riverwalk creates pedestrian connection from Waterfront Park to proposed West Waterfront Park and beyond
- Multiple lanes and high rate of travel create barriers

- Public interest in reducing surface parking
- Private interest in downtown development
- Louisville Downtown Management District
- Riverfront access

+ Variety of Downtown destinations
+ Waterfront Park
+ Kentucky Center for the Arts
+ Louisville Slugger Field
+ Downtown Arena
+ Louisville Downtown Management District
+ Public interest in reducing surface parking
+ Potential for reuse of vacant buildings
+ Private interest in downtown development
Green Streets were selected based on usage and location. Main and Market were selected because they are important streets to the downtown environment. Many of the major attractions are located on Main and Market Streets. Historically they are part of the “T” shaped business district. The other part of the “T” historically was 2nd St. 2nd St. also is one of major entrances to the downtown area and, like Main and Market, links many of the major destinations. Roy Wilkins currently acts more like a barrier a needs to be addressed to make it less of an obstruction.

Stormwater Park locations were selected according to where they will be most beneficial and where parking is most excessive. Attempts were made to place them near major attractions to serve as public amenities.

Bike Lanes are to be a major component of the green streets to encourage more cycling downtown.

Stormwater Plazas are private plazas redesigned to handle the plaza and roof runoff. Stormwater plazas will also connect to the green infrastructure.
a. Center City District
b. Proposed West Waterfront Park
c. Downtown Arena site

Liberty Green
West Main Street

buildings
proposed green streets
road condition/right of way concept
new developments
proposed green spaces/“stormwater parks”
stormwater private plazas
Right of Way Concepts vary based on the amount of right of way available, street type, and balance of uses.

Road condition:
   A – One way street corridor with 90 ft R.O.W.
   B – Two way street corridor with 100 ft R.O.W.
   C – Two way divided street corridor with 150 ft R.O.W.

Balance of uses: how much space is devoted to each use and the spatial relationship
   1 – Dedicated Bike Path
   2 – Sharing the Road
   3 – Back in Angle Parking

I attempted to find a balance between stormwater uses, pedestrian uses, bicycle uses, while reducing the amount of space devoted to automotive traffic.

Concept 1- Dedicated bike paths provide physical separation between bike paths, pedestrian paths and roadway. Where possible the separation zones double as the stormwater handling zone.

Concept 2- Sharing the Road is typical of most areas where bike paths and roadways interact. The bike path is dedicated but within the roadway. This presents a conflict between the two uses but provides safe maneuvering space vehicles enter and exit parking spaces.

Concept 3- Similar to concept 2, but the parking is back-in angle parking. Transportation specialists have found this to be a safer parking situation because it improves line of sight and is considered easier to maneuver in and out of the space.
road condition A-
90 ft ROW, One-way
concept 1-
Dedicated Bike Lane
road condition B- 
100 ft ROW, Two-way 
concept 1- dedicated bike paths 

right of Way Concepts.
road condition C
150 ft ROW, Two-way with planted median
concept 1-
dedicated bike paths
road condition B-
150 ft ROW, Two-way with planted median
concept 1-
Dedicated Bike Path
road condition A-
90 ft ROW, One-way
c
c
concept 2-
Sharing the Road

right of Way Concepts.
road condition A-90 ft ROW, One-way concept 2-Sharing the Road
road condition B-100 ft ROW, Two-way concept 2-
Sharing the Road
road condition B - 100 ft ROW, Two-way concept 2 - Sharing the Road
road condition C-
150 ft ROW, Two-way with planted median
concept 2-
Sharing the Road
road condition B-
150 ft ROW, Two-way with planted median
concept 2-
Sharing the Road
road condition A-
90 ft ROW, One-way
concept 3-
Back in Angle Parking
road condition A-
90 ft ROW, One-way
concept 3 -
Back in Angle Parking
Right of Way Concepts.
road condition B-
150 ft ROW, Two-way with planted median
concept 3-
Back in Angle Parking
After evaluation of the concepts, I opted to further pursue Concept 3- Back in Angle Parking for road conditions A and C.

Condition B- 2 way traffic with 100 ft R.O.W. was not suited to the application of back in angle parking. Implementing this concept would have necessitated removal of either the bike lanes or the stormwater zone/center turn lane.

The Dedicated Bike path concept created a double crossing for pedestrians, who would first have to cross the bike path and then several lanes of traffic. For the cyclist this concept presented conflicts at intersections where pedestrian may block the path while waiting for the crossing signal. It could also be hazardous since the separation may prevent vehicles turning right from immediately seeing a cyclist. Cyclist wishing for less obstructed travel would have to slow and check for traffic at intersections.

The Sharing the Road concept was more typical of cities with bike paths in the R.O.W. Parallel parking on the same side as the bike path posed a dangerous conflict of use, but the extra width provided by bike path allowed for maneuvering room for vehicles parking. To make room for the stormwater zone, on street parking was restricted to one side; existing conditions have parking on both sides in most areas of road conditions A and some areas with road condition B. Seeing on street parking as an excellent solution for reducing surface parking lots, the loss of on street spaces in this concept did not fit within the goals of this project.

The back in Angle Parking concept combined several benefits from the previous concepts and has some unique benefits. The bike path is located in the R.O.W. to allow cyclists to move with traffic and avoid conflicts at intersections. The back in parking on one side maintains a similar number of parking spaces on the street. It also helps to create a secondary stormwater zone to handle runoff from the impervious surfaces on that side of the street. It also creates a curb extension to reduce pedestrian crossing distance.
Roy Wilkins Ave. and Market St.
Roy Wilkins Ave. and Market St.

As one of the main entrances to the downtown because of the intersection of Roy Wilkins, Market, and I-64, it was important to show the interaction of uses. This block of Roy Wilkins does not have the back in parking on the concept since there is no need for parking here. The plantings and ease of pedestrian and bike access that continue into and out of downtown to create a unified feel rather than one of separation. Street runoff flows to stormwater spaces on the north side of the street. Secondary spaces within the parking row handle sidewalk and other spaces on the south side of Market. If you refer back to the master plan you will see that the large parking is proposed to be a stormwater park and parking structure. A currently unused space under the I-64 ramp (along Roy Wilkins) can be used as infiltration space for runoff from the ramp. One sidewalk was shifted to the west side of the ramp, if it continued along Roy Wilkins pedestrians would be between traffic on the ramp and traffic on Roy Wilkins.
Roy Wilkins Avenue Perspective
2nd St. Stormwater Park

Located across 2nd St. from the Convention Center, this stormwater park reduces the surface parking on that block while creating a public space and infiltration space. Runoff from the street and remain parking flows to the low point in the large grassy area. Rather than runoff flowing on top of the paved space, the pavers “float” to allow runoff to flow underneath. A sub-surface lot under the surface lot compensates for the reduction of surface parking. A portion of the street runoff is directed to center green median.
Main St. at Downtown Arena

As a new key destination of the downtown environment, it was important to connect the Downtown Arena to the green infrastructure of Main St. Main St. has been reduced to three lanes to make crossing more pedestrian friendly. Runoff from Main St. flows to the stormwater zone on the South side of the street. For runoff from sidewalks and other hard surfaces on the North side of Main St., secondary stormwater planters are created by the parking row.
Main and Market Perspectives.
Because public/private partnerships are desirable for the downtown, the design connects runoff from roofs and other private spaces to the green infrastructure system. Runoff from the arena roof and plaza first flow to the central water feature through channels. As the water level rises it overflows to a series of planters, each planter overflowing to next and ultimately to the secondary stormwater zones along the street. Besides the stormwater connection, the arena plaza is connected by a transitional paver zones combines both the concrete pave of the plaza and the brick pave of the sidewalk like that of West Main St.
Arena Plaza. Runoff from the arena roof and plaza connects to the stormwater handling spaces on Main St. Roof runoff is directed by the angled awnings first to planters surrounded by a seating wall. The runoff then flows to the water feature and ultimately to the planters on the street.
Swale Section typical of swales on Main and Market.

Swale Profile typical of swales on Main and Market. Check dams located adjacent to trees slow runoff and allow pooling and increase infiltration.

2nd street Stormwater Park section. Runoff flows under the floating pavers to the grassed infiltration space.

Floating Pavers allow runoff to pass underneath the surface to the infiltration space.
Bike Lanes give cyclists a safe zone to travel in. By using them throughout downtown and extending into the neighboring areas and parks, we can encourage more riders into and out of the downtown.

Bike Boxes give cyclists a safe zone for making a left turn.

Back in Angle Parking is safer than traditional parallel parking because of the improved view of oncoming traffic. In Tucson bike/vehicle accidents went from 3-4 per month to no reported incidents in 4 years following implementation (Nelson).

Swales can have a wide variety planting to suite aesthetic and maintenance desires.
Incorporating Green Infrastructure into the downtown fabric is not a difficult concept. As long as compromises are willing to made and a balance found, green infrastructure can fit within the existing right of way. By including pedestrian friendly spaces and bike lanes, and reducing the vehicular influence, a more inviting downtown is created. Excessive surface parking that creates gaps in the urban fabric are replaced with parking structures and stormwater parks that create greenspaces downtown. Green Infrastructure can significantly reduce the amount of runoff entering the sewers and overflowing into streams and rivers.
Definition of Terms

Green Infrastructure - the incorporation into the transportation infrastructure of technologies that help absorb and filter excess runoff, rather than funneling it into sewer pipes. As defined by the Committee on Science and Technologies, House of Representatives.

Impervious surfaces - paved surfaces that do not allow water to penetrate the surface.

Base flow - normal flow of a stream, provided by groundwater flowing into the channel.

Heat island - effect of paving materials increasing air temperature over surrounding, less paved areas.


