

ABSTRACT

Title of Thesis: INTEGRATION OF SUSTAINABLE INFRASTRUCTURE
AT A NEIGHBORHOOD SCALE

Michael Binder, Master of Architecture, 2006

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By concentrating power generation, water treatment and waste management facilities at large centralized sites on the edge of its cities, modern industrial society allows us to ignore our responsibility for the damage we are doing to the environment. This thesis project proposes the integration and distribution of neighborhood-scaled power and waste management functions throughout our urban centers, demonstrating the efficacy of localized infrastructure based on sustainable natural and man-made cycles, making it simultaneously beautiful and providing a desirable amenity to the residents. The heart of this thesis project is the design for an indoor garden space which also integrates solar power management, nature-inspired wastewater treatment and solid waste recycling. The program will include an environmental education center using the facility as an operational example. A site in Northwest Washington DC, bounded by New Jersey Ave., New York Ave., North Capitol and K Streets has been selected for its redevelopment opportunities.

**INTEGRATION OF SUSTAINABLE INFRASTRUCTURE
AT A NEIGHBORHOOD SCALE:**

by

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Dedication

This thesis is dedicated with love to my wife, Martha Wetherholt, without whose constant encouragement and support this work would never have been possible.

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1 INTRODUCTION

Since the dawn of the Industrial Age, developed countries (including the U.S.) have made great strides in improving quality of life for their citizens. Many of these improvements are embodied in our modern infrastructures : transportation, power generation and sewage treatment in particular. These improvements have come with a price, however. The industrial processes that we have come to depend on involve the use of toxic chemicals and create pollution on a global scale. We are poisoning the ecosystem that sustains us and all other life on Earth.

Another hallmark of the Industrial Age has been centralization. In the interests of economy and expediency, we create large regional power plants and waste treatment facilities. When these facilities fail, the impact is widespread, causing power outages for hundred of thousands of people, or allowing large quantities of untreated sewage to overflow into our rivers, lakes and oceans.

People have become too comfortable with the system described above. They consume power without much regard for how it is generated, they discard waste (solid and liquid) without having any real idea what happens to it. Many people are now aware of the impending crisis we face with regard to both energy and waste, but they feel powerless to do anything. They have ceded responsibility for these services to large corporate and government organizations over which they feel they have no control,

In this thesis project, we will begin to explore one path to a solution for the issues cited above. My thesis proposes the reintegration of infrastructure such as power generation and wastewater treatment into the urban context. It explores the creation of a network of small, distributed wastewater facilities to replace the large centralized facilities commonly used today. It also considers the creation of a solar power cooperative in which the majority of homes, apartments and other buildings in a given community include substantial arrays of solar collectors on their roofs and facades.

The potential success of this thesis depends largely on the use of relatively new sustainable technologies for processing wastewater. Solar Aquatic Systems, often referred to by the trade name of “Living Machines™”, purify wastewater using a process inspired by nature. Instead of chemicals such as chlorine, the process uses plants, fish, snails and microorganisms to consume the waste and make the water clean enough to release into the environment, if not necessarily clean enough to drink. The waste treatment plant can thereby be transformed from an industrial facility into a garden of sorts.

Another important aspect of this nature-inspired infrastructure is stormwater management. Surface water from rain and snow generally contain all sorts of contaminants including salt, oil, gasoline and other toxic substances. This water is typically allowed to simply run off into storm sewers and ultimately into our rivers and

lakes. After a particularly heavy downpour, the storm sewers often overflow. In a city like Washington DC, where many of the antiquated storm and sanitary sewers are combined, this overflow often means that raw sewage also overflows, creating a serious public health issue. The waste treatment plants also become incapable of handling the volume of water and allow the raw waste to flow directly into the river or lake or ocean. An alternative to employing this system of regional storm sewers is to use artificial wetlands constructed to filter the contaminated rain water and allow the majority of it to soak into the ground rather than run off into the area waterways. This thesis project will begin to consider the design issues associated with making such constructed wetlands (sometimes called bioswales) part of the urban landscape.

Finally, this thesis project attempts to address the issue of public education. It is not enough to create a sustainable infrastructure that works and is invisible to the people it serves. This thesis proposes that the infrastructure should be a part of people's daily experience with the built environment. Ideally, the infrastructure becomes a source of inspiration and understanding for the community it serves. In the case of the Living Machine™, infrastructure can even provide the amenity of an indoor garden space. The constructed wetlands can be part of a way-finding network that guides people through the community.

In the mid nineteenth century, the people of London built what came to be called the "Cathedral of Sewage". It was a beautifully designed and constructed Victorian building which housed nothing more (or less) than a sewage pumping station. People were rightfully proud of their innovation and wanted to express it architecturally. We are now on the cusp of a new, sustainable revolution that will, I hope, transform our culture and our built environment. This thesis will begin to explore the architectural forms that will express our new pride in finding a better way to live well, and in harmony with the natural environment.

2 SITE ANALYSIS

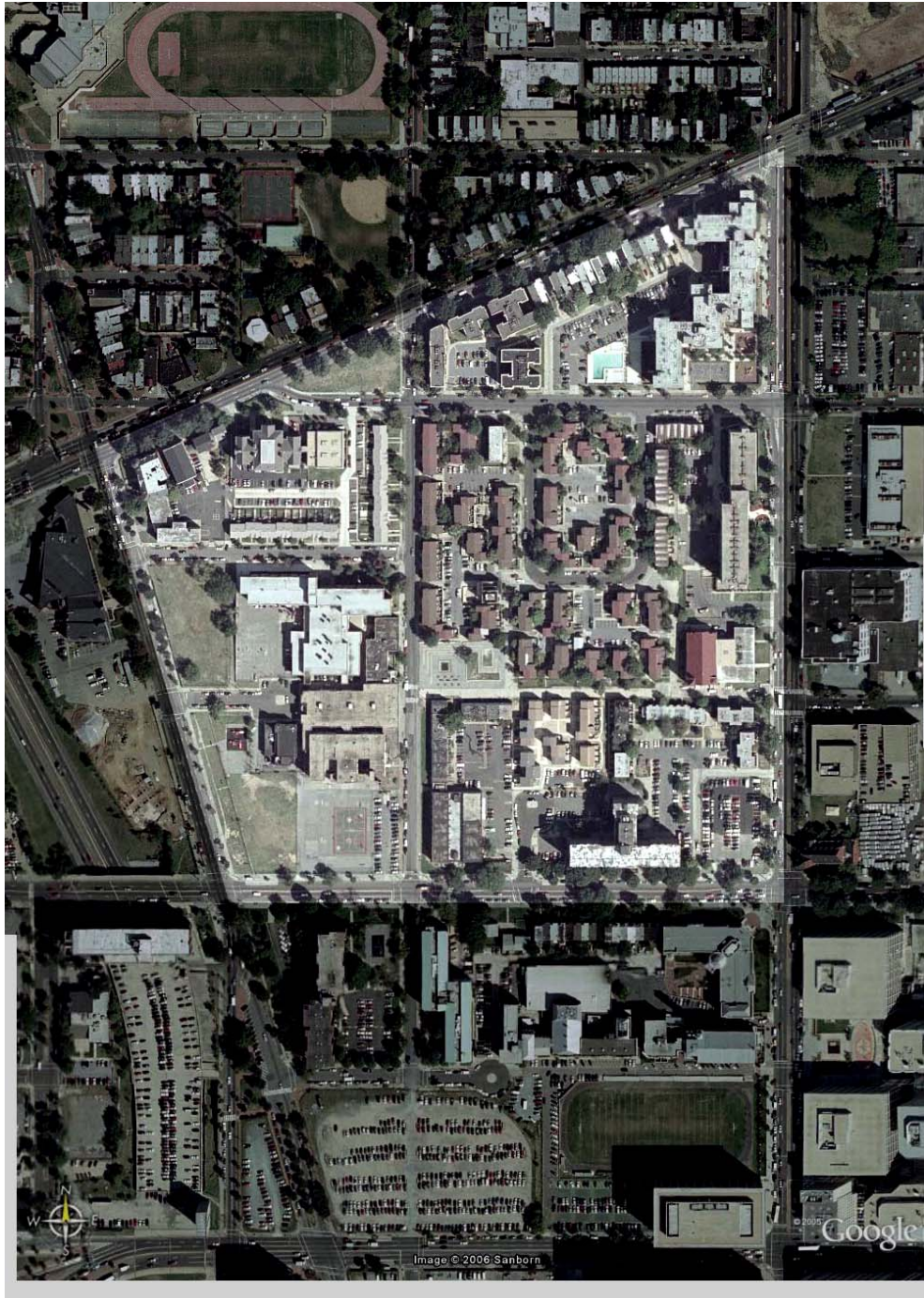


Photo 1 – Aerial View of Site (highlighted) with surrounding context.

The site for the thesis project is located in Washington DC, approximately 0.4 miles northwest of Union Station (see Figure 1). It is comprised of 46 acres of land bounded on the north by New York Avenue, on the south by K Street, on the east by North Capitol Street, and on the west by New Jersey Avenue. An aerial view of the site is shown in Photo 1 above, and it has not changed significantly since this photo was taken. A diagram highlighting the location of the existing buildings is shown in Figure 2 and a rough massing perspective of the buildings on site is shown in Figure 3.

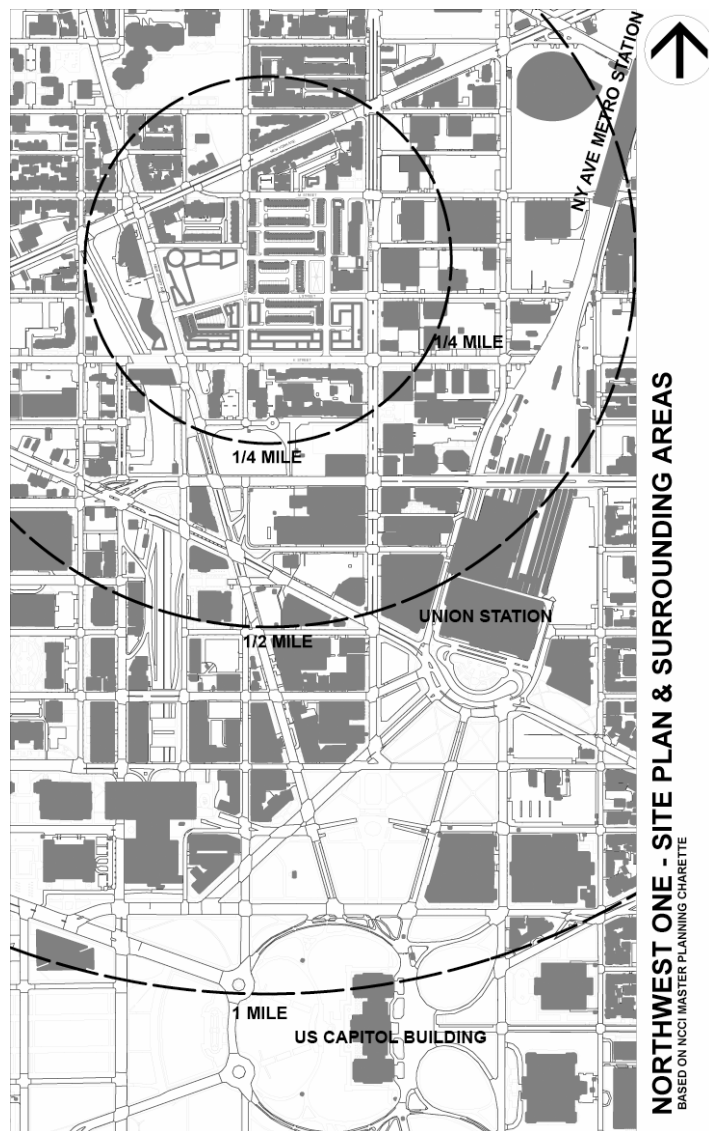


Figure 1 – Larger context of the neighborhood withing Washington DC.

2.1 HISTORY

The site is located in an area of Washington DC generally known as NOMA, an acronym for North of Massachusetts Avenue. Some of earliest settlers in this area of town were Irish immigrants, who called the area Swampoodle, a reference to the marshy conditions created by the flow of Tiber Creek. This area was considered very rough, a common hangout for prostitutes, thugs, gangs of unruly boys and other unsavory characters. After the Civil War, the Tiber was completely enclosed by the city sewer system, and the construction of Union Station destroyed much of the residential area at the heart of Swampoodle ¹. The area became a mixture of industrial uses abutting the railyards, of blighted densely packed rowhouses and alley dwellings. After World War II, there was a call for reform of the housing conditions in the area, and most of the dwellings were demolished and redeveloped through urban renewal programs. These programs included construction of the Sursum Corda apartments in 1968 (Photo 2), intended to provide safer and more decent replacement housing for lower-income residents. Sursum Corda is bounded by M and L streets between Mt Airey Church and First Street. Other housing developments, some sponsored by area churches, were Temple Courts (Photo 3), Golden Rule (Photo 4), Tyler House (Photo 5), and Sibley Plaza (Photo 6). Religious institutions have had a strong part in shaping the area since 1859, when Gonzaga College High School (Photo 7) and St. Aloysius Church (Photo 8) moved to the area. Other prominent organizations in the neighborhood include Mt Airy (Photo 9), Holy Redemeer Church and School, Southern Baptist Church and St. Phillips Church ².

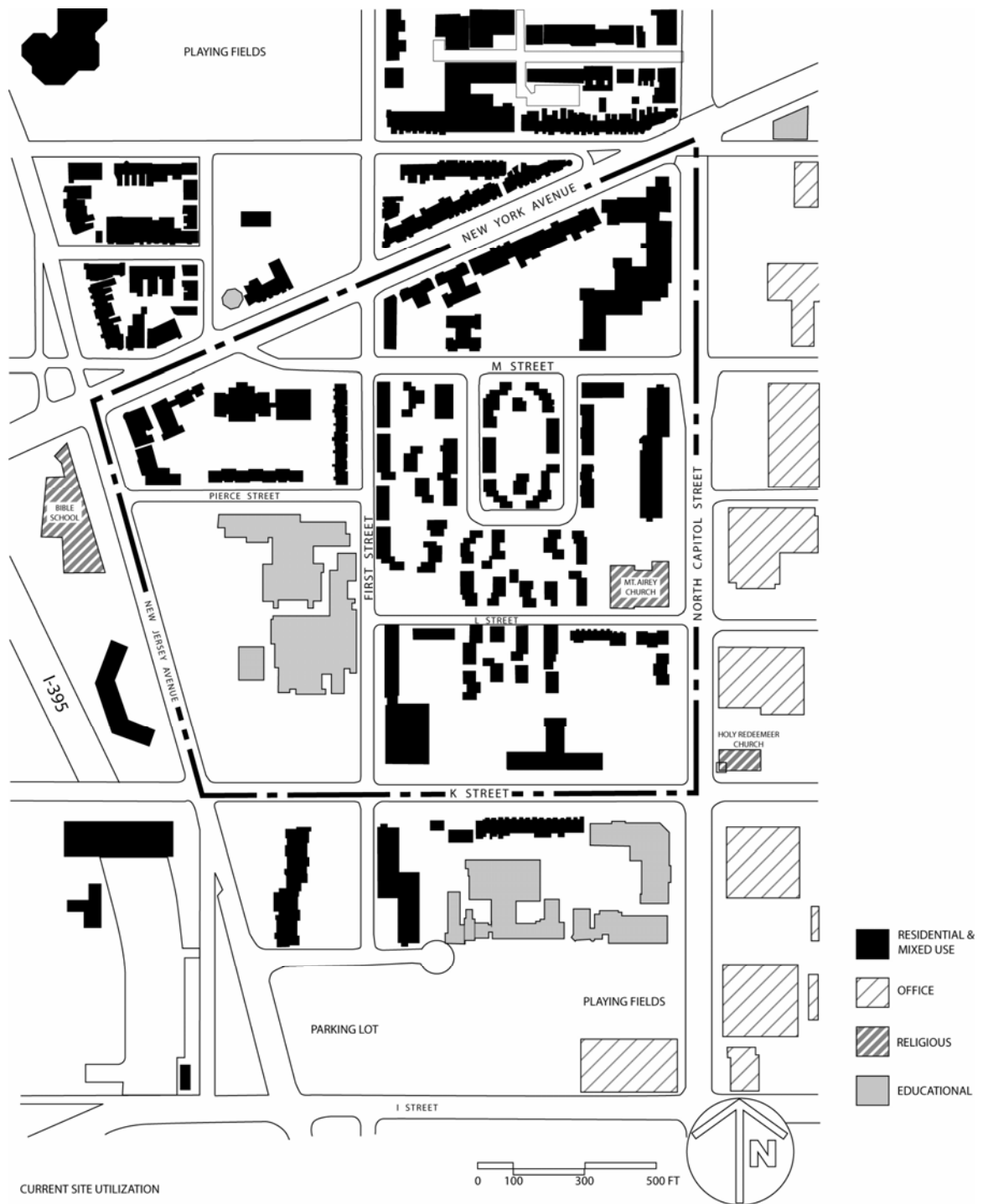


Figure 2 – Existing Site Utilization.



Figure 3 – Aerial perspective view with approximate massing of buildings, as created by GoogleEarth database.



Photo 2 – View of Sursum Corda Cooperative Apartments, built in 1968 as part of urban renewal programs. Buildings are in better condition than most in the neighborhood, but may not be suitable for inclusion in new mixed-income redevelopment.



Photo 3 – Temple Apartments on K Street, North side. One of the buildings to be replaced by new mixed use development.



Photo 4 – Golden Rule Apartment on K Street, South side. Not actually part of the NW1 community area, but will probably be demolished and redeveloped as well.

Sadly, despite the presence of strong civic organizations and the promises of urban renewal, the neighborhood has not prospered. Much of the housing stock has deteriorated; the Sursum Corda complex and adjacent townhomes appear to have fared better than the others, some of which are severely run-down.

The area now appears to serve a predominantly African American population; the ethnic shift probably occurred gradually over the past 150 years, just as it has in so many other American inner cities. Unemployment is high, and many of the residents are dependent on government assistance to survive. Crime in the area has helped make the neighborhood one of the most distressed in Washington DC. These conditions have



Photo 5 – Tyler House Apartments at the corner of New York Ave and North Capitol Street is one of the more attractive complexes in the area, and will be spared from demolition according to the NCCI Master Plan.



Photo 6 – Sibley Plaza, located on North Capitol Street, will be demolished under the City's plan and be replaced with mid-rise mixed-use development.

helped bring the site to the attention of the City government once more. It is to be the first project developed under the *New Communities Citywide Initiative (NCCI)*. The neighborhood has been North-West One (NW1) after the 1960's designation for urban renewal.

Under the NCCI, most of the buildings within the site would be demolished to make room for new housing and mixed used buildings (see discussion of the NCCI Master Plan below) ². It is tempting to suggest that Sursum Corda and some of the other buildings might be saved from demolition, but apparently they are inadequate to attract the market-rate renters that the DC government hopes to attract to the area. The major difference between the NCCI and past urban renewal programs, it would seem, is the priority given to creating a mixed-income population, not simply to provide better housing for low-income residents.



Photo 7 – Gonzaga College High School is located south of the neighborhood on North Capitol Street but still creates a strong presence.



Photo 8 – St. Aloysius Church, which faces the SE corner of the NW1 site, is another strong anchor of the community.



Photo 9 – Mt Airy Church is located within the NW1 community. It will be preserved under the NCCI Master Plan. Currently, its front faces L sStreet, which is little more than an alley, and a rather dismal apartment complex on the other side.

2.2 PHYSICAL DESCRIPTION

2.2.1 Surface Conditions

Approximately 15% of the site is greenspace, some of it enclosed by chain-link fence as playgrounds for the schools. This greenspace is located almost exclusively along the western boundary of the site (New Jersey Avenue).

The remaining 85 % of the site is paved, with only small tree-lawns and small yards fronting some of the buildings. The streets and alleys on the interior run N-S and E-W, but are generally discontinuous, even for pedestrian traffic (only M Street all the way across the site from E to W). This gives the entire neighborhood a rather closed sensation on the interior, perhaps by design.

2.2.2 Infrastructure

Street surfaces on the interior of the site (First Street and L Street) are seriously deteriorated but serviceable. These streets delineate the storm sewer lines through the community as well, as shown in Figure 4. Much of downtown Washington DC still has combined sanitary and storm sewers; This includes the Tiber Creek trunk line that passes along the west edge of the site (under North Capitol Street). The sanitary sewers within the site have been separated from the storm sewers, probably during the 1960 rehabilitation.

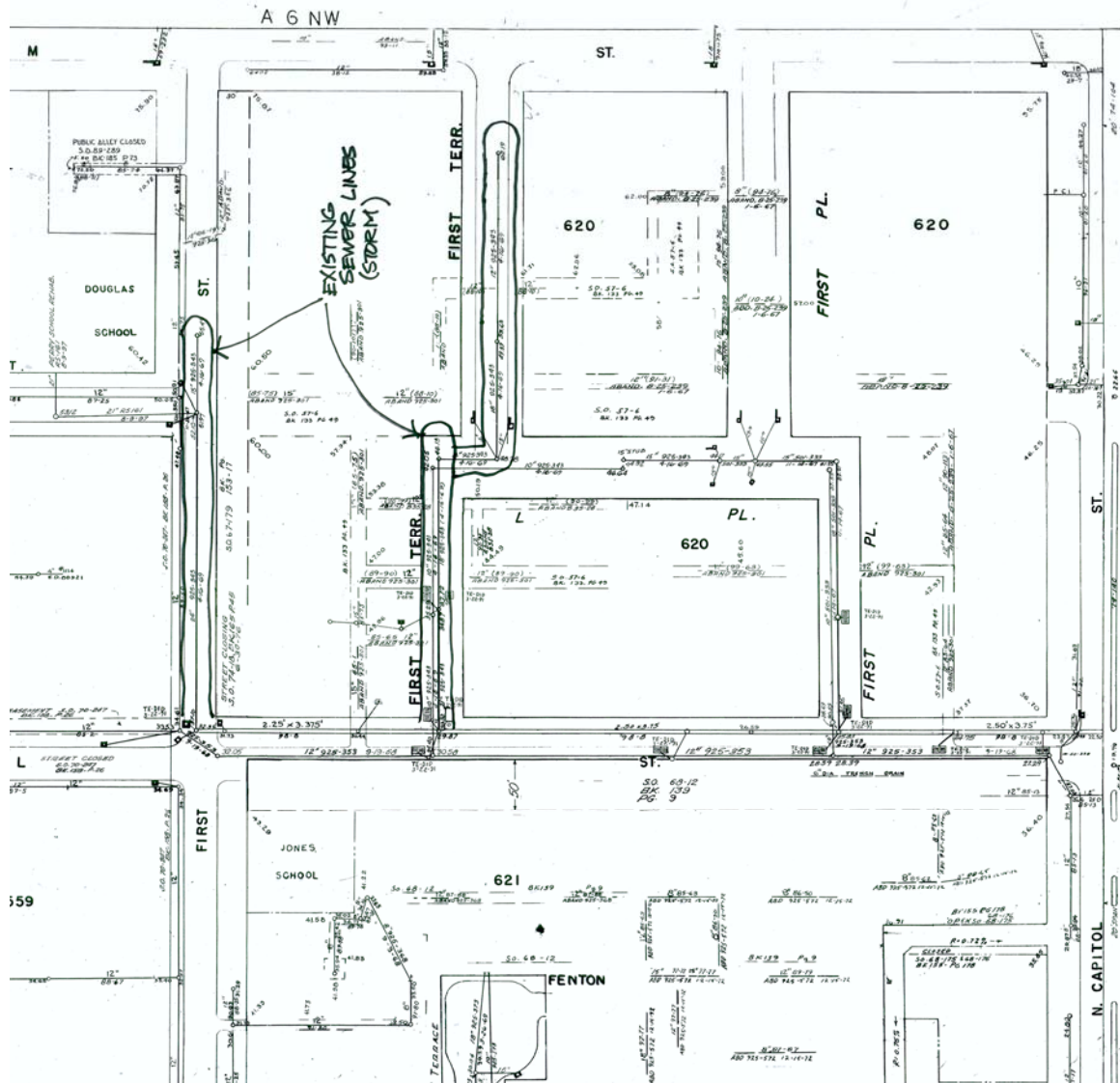


Figure 4 – Sewer Line Map from DC Water Authority

2.2.3 Vegetation

Other than the grassy areas described above, there is an assortment of mature street trees on site, particularly along K Street, New York Ave and New Jersey Avenue (on the west side of that street). There are also mature landscape trees clustered about the Sursum Corda development. A diagram showing the approximate location, size and density of these trees (based on available aerial photographs and confirmed by on-site observations) is shown in Figure 5.



Figure 5 – Major greenspaces are shown as striped, mature trees in the existing community, based on aerial photographs and corroborated by first-hand observations, are shaded. Black areas indicate parking lots and other impervious surfaces (other than streets).

2.2.4 Topography

The site slopes downhill from New York Avenue on the northwest towards the intersection of K Street and North Capitol Street on the southeast (see Figure 6). This topography yields a modest opportunity to exploit the change in grade to increase access to solar energy (stepping the buildings up the grade).

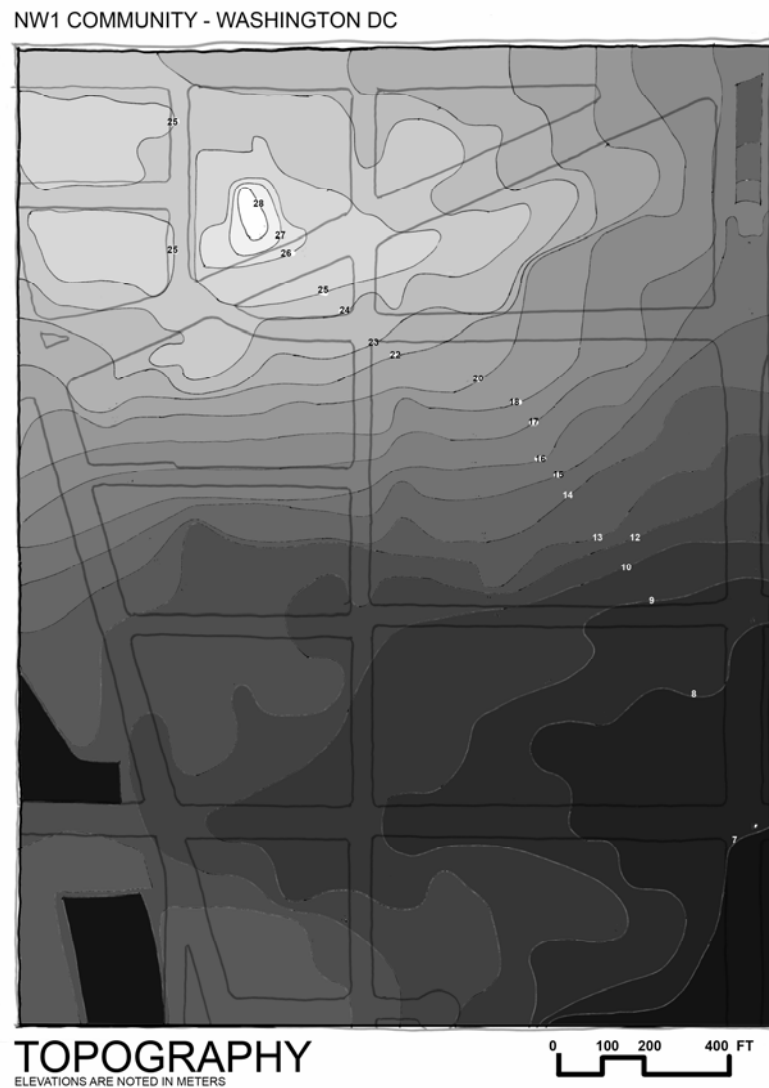
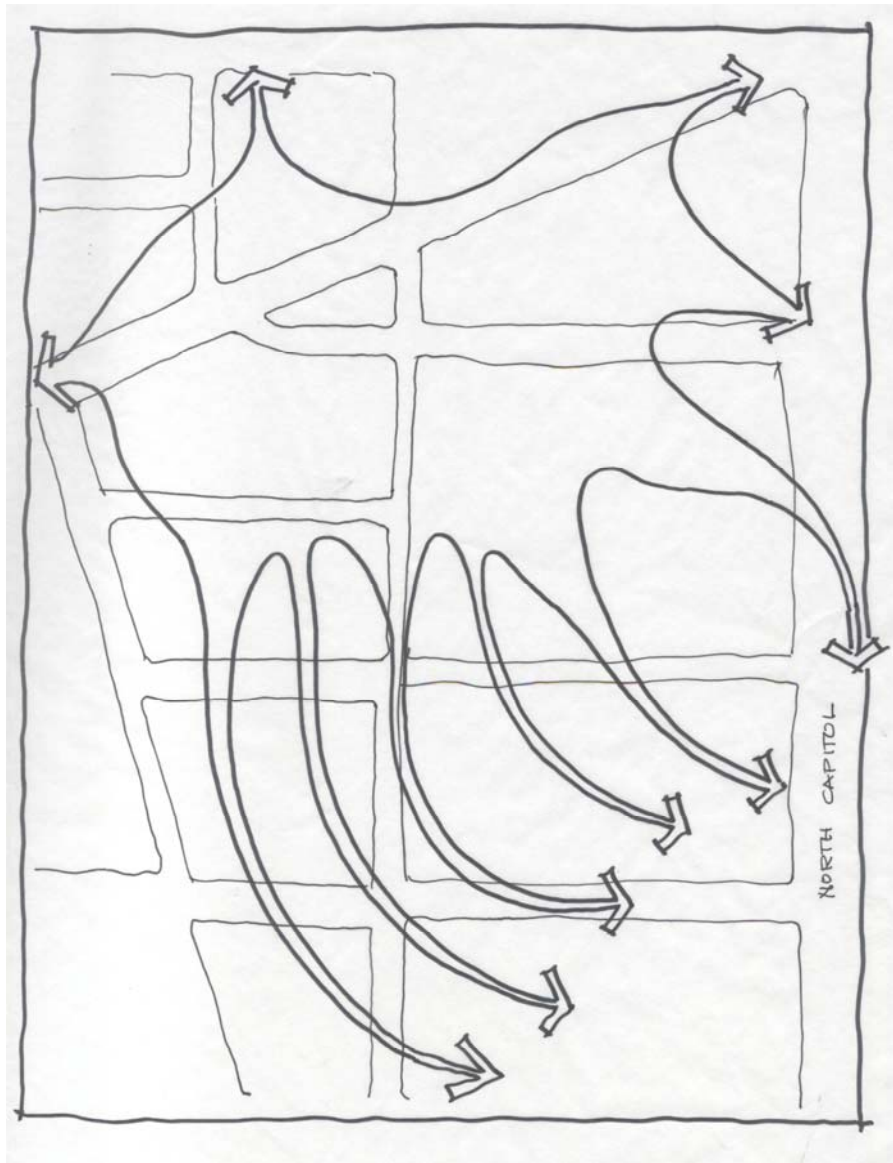


Figure 6 – Topography of the site, showing how the site slopes relatively gently from the northwest downward to the southeast corner. The contours represent 1 meter increments, starting at 7m on the lower-right and climbing to 28m. The total change in elevation across the site is about 18 m (60 ft).

2.2.5 Hydrology

The topography of the site suggests that storm-water will run off to the southeast corner (Figure 7). If we wish to retain storm-water on site (for filtration, irrigation, etc.), this will probably have to occur on the southern boundary, along K Street. The southwest corner (K and North Capitol) would be the most effective from a topographic and hydrological perspective.



*Figure 7 – Water run-off pattern.
Generally, the site is graded to funnel run-off along streets (both north-south and east-west).*

2.2.6 Access to Solar Income

As noted above, the site is relatively flat, and slopes downward slightly to the south. There are no features, artificial or natural, which would tend to shadow the site significantly. The figure below shows that until about 2 pm on the winter solstice, the proposed site would be free of shadows from surrounding buildings.

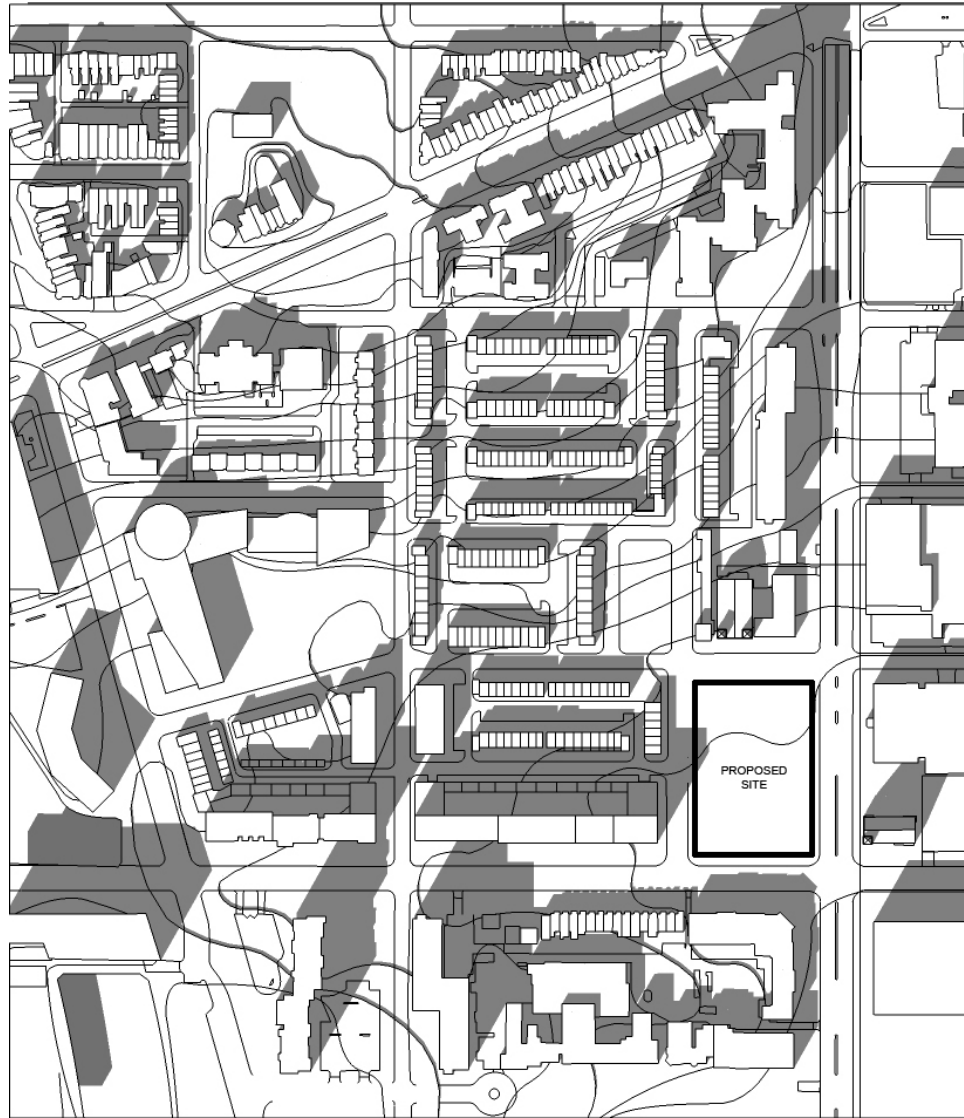


Figure 8 – Shadowing at 2 pm on winter solstice, based on development plans from the City.

The existing and proposed high-rise apartments on the southern border of the site may create some local shadowing issues. If this is found to be a problem, it may be possible to augment solar collection on the high-rise buildings to compensate for the buildings that are shadowed to the north of them. No significant problems are anticipated regarding access to daylight and to direct solar radiation.

2.3 CONTEXT

The basic site strategy for the community appears to have been to create a buffer of apartment, institutional / civic (schools) and commercial buildings around the perimeter of the site, creating a quieter and more intimate environment on the interior, where the garden apartments and townhomes reside. The higher and larger buildings are around the outside, the lower and smaller ones are in the center (see Figure 3). This arrangement helps create a better transition between the residential environment of the site, and the industrial / commercial / institutional context that surrounds it on the east, south, and west sides (Photo 10 through Photo 13). Indeed, the buffer is least significant on the north side of the site where the residential land-use continues north of New York Avenue (row-houses, two-story mixed use buildings – Photo 14).



Photo 10 – East Boundary of NW1 Site. Looking along North Capitol Street from the corner of K Street, with the U.S. Capitol Dome clearly visible at the end of the street (looking South).



Photo 11 – East Boundary of NW1 Site. Looking North along North Capitol Street from the corner of K Street. St. Phillips Baptist Church is in a prominent landmark.



Photo 12 – West Boundary of NW1 Site, looking South along New Jersey Avenue. The Temple Bible School is in the foreground.



Photo 13 – South Boundary of NW1 Site, looking East along K Street. It is anticipated that the entire K-Street corridor will be redeveloped in coming years, replacing lower density land uses like the rowhouses seen here with mid-rise and high-rise apartments (up to 90 feet) and mixed-use buildings.



Photo 14 – Northern boundary of the NW1 Site, showing the lower density neighborhood to the North. The North edge of the neighborhood will be largely unchanged (except for renovation), and no buffer zone of taller apartments is needed here.

Given the nature of the buffer described above, it follows that the buildings on the site’s interior do not directly connect to prominent landmarks outside of the site. The Capitol Dome is clearly visible from the edges of the site, however, especially along North Capitol Street (Photo 10) and New Jersey Avenue. It has also been observed that 1st Street (facing south) provides a clear unobstructed view of the National Association of Realtors building several blocks south (Photo 15). This building is important because it is one of the first LEED rated buildings constructed in Washington. Given its iconic form and environmental significance, the NAR building might be another alignment opportunity (Figure 9).



Photo 15 – Looking South along 1st Street from the NW1 site, the National Assn. of Realtors building is clearly visible. This is one of the first LEED buildings to be built in Washington DC and its iconic shape is a powerful symbol of the change that the sustainable design community wishes to advance.

2.4 ACCESS TO PUBLIC TRANSPORTATION

The recently completed New York Avenue Metro Station (Figure 10 and Figure 10) is another significant piece of the urban context. The Metro is not highly visible from the thesis site, but the NW1 neighborhood is the first community that visitors encounter when they leave the station and walk west down M street. There may be another gateway opportunity to be addressed here.

Figure 10 also shows bus-lines serving the community.

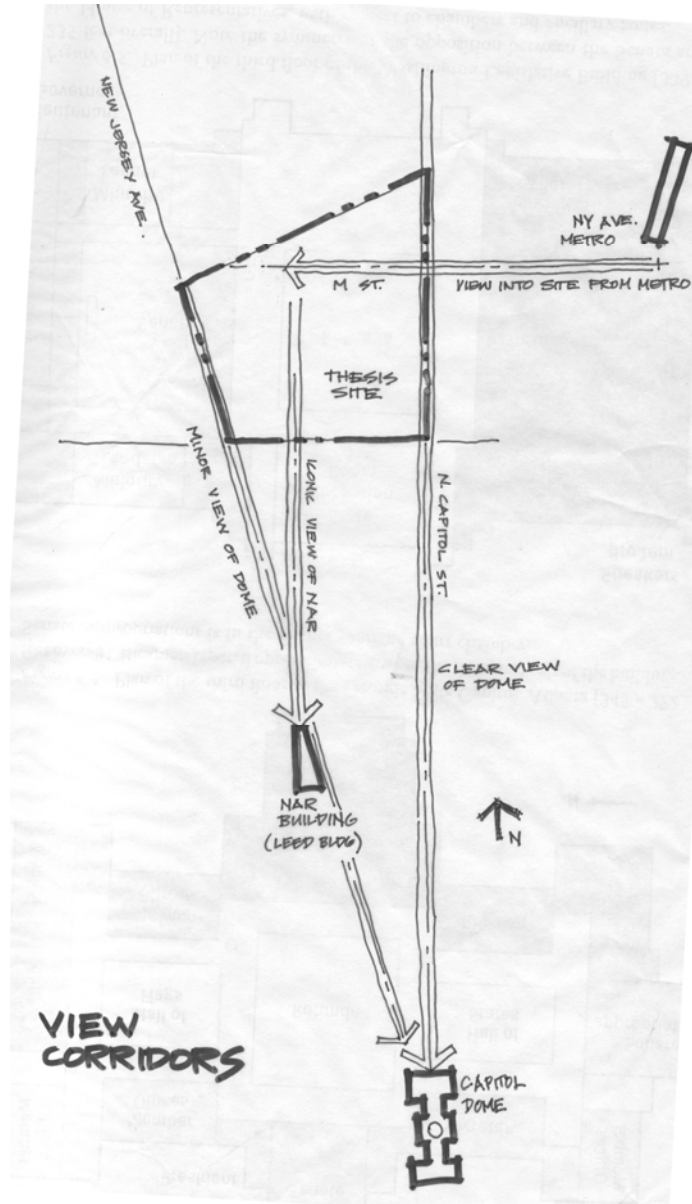


Figure 9 – View Corridors from the NW1 site and into it. Visual connections with the Capitol Dome and the NAR LEED building. The M St. and NY Ave. corridors represent gateways into the NW1 neighborhood.

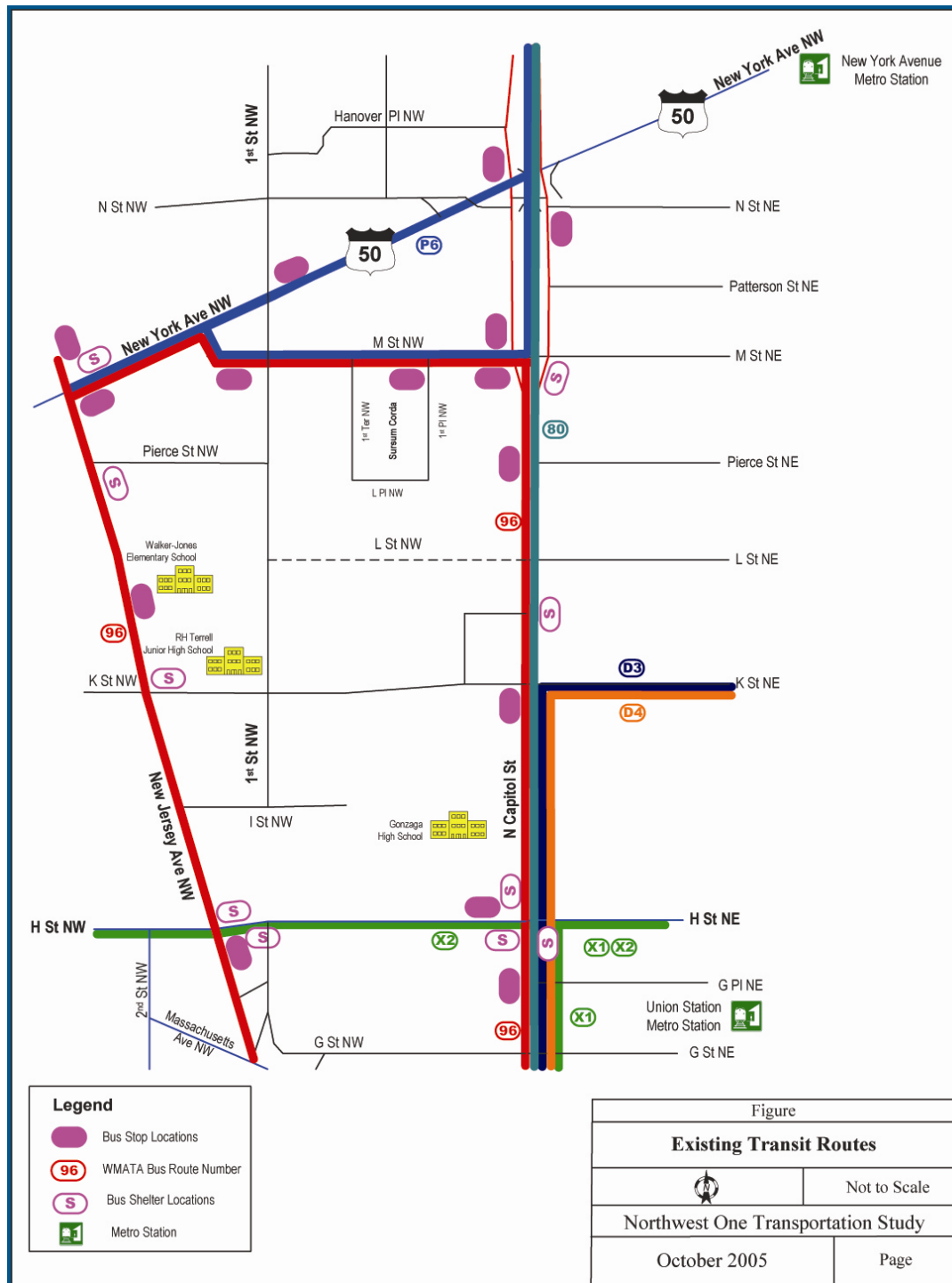


Figure 10 – Access to Public Transportation. Metrobus routes provide reliable public transportation for the NW1 neighborhood. The recently opened New York Avenue Metro rail station has entrances along both New York Avenue and M Street. Metro access will be an essential element in the development of a sustainable mix-income community here. (bus route map is taken directly from graphics included in the NCCI Master Plan (Ref. 2).

2.5 NEW COMMUNITIES INITIATIVE CITYWIDE MASTER PLAN

Thus far, analysis has focused on the existing context and site conditions. As stated previously, the City of DC already has plans to revitalize this neighborhood, assuming that they can acquire the land from the current owners and address other political issues. During a preliminary design charrette held in July of 2005, planners, architects and city officials met with current members of the community and as a result came up with a preliminary Master Plan for the neighborhood ³. This plan is described in Reference 2 and the site plan is shown in Figure 11. This thesis project will assume that the basic requirements, land uses and organization of the new community should be based on this plan, modified only where there is a compelling ecological reason. It is this new proposed plan, not the current condition, that will form the context for whatever buildings and other interventions we make in the neighborhood.

As it turns out, many of the qualitative conditions of the existing neighborhood will be preserved according to the Master Plan. High-rise apartments (up to 90 ft. in height) will be arrayed along the southern and eastern edges of the site (K St and North Capitol St respectively). A new K-8 school and recreation center will be built on the western boundary (New Jersey Ave), replacing the existing schools at that approximate location. The more historically significant and contextually sensitive buildings on the north edge of the site (along New York Ave.) will be renovated instead of being replaced. New rowhouses, duplexes and garden apartments will occupy the interior of the site. Thus, the new plan calls for the same sort of arrangement as in the current site, with taller buildings

creating a buffer between the commercial context around the site, and the relatively smaller residential buildings on the interior.

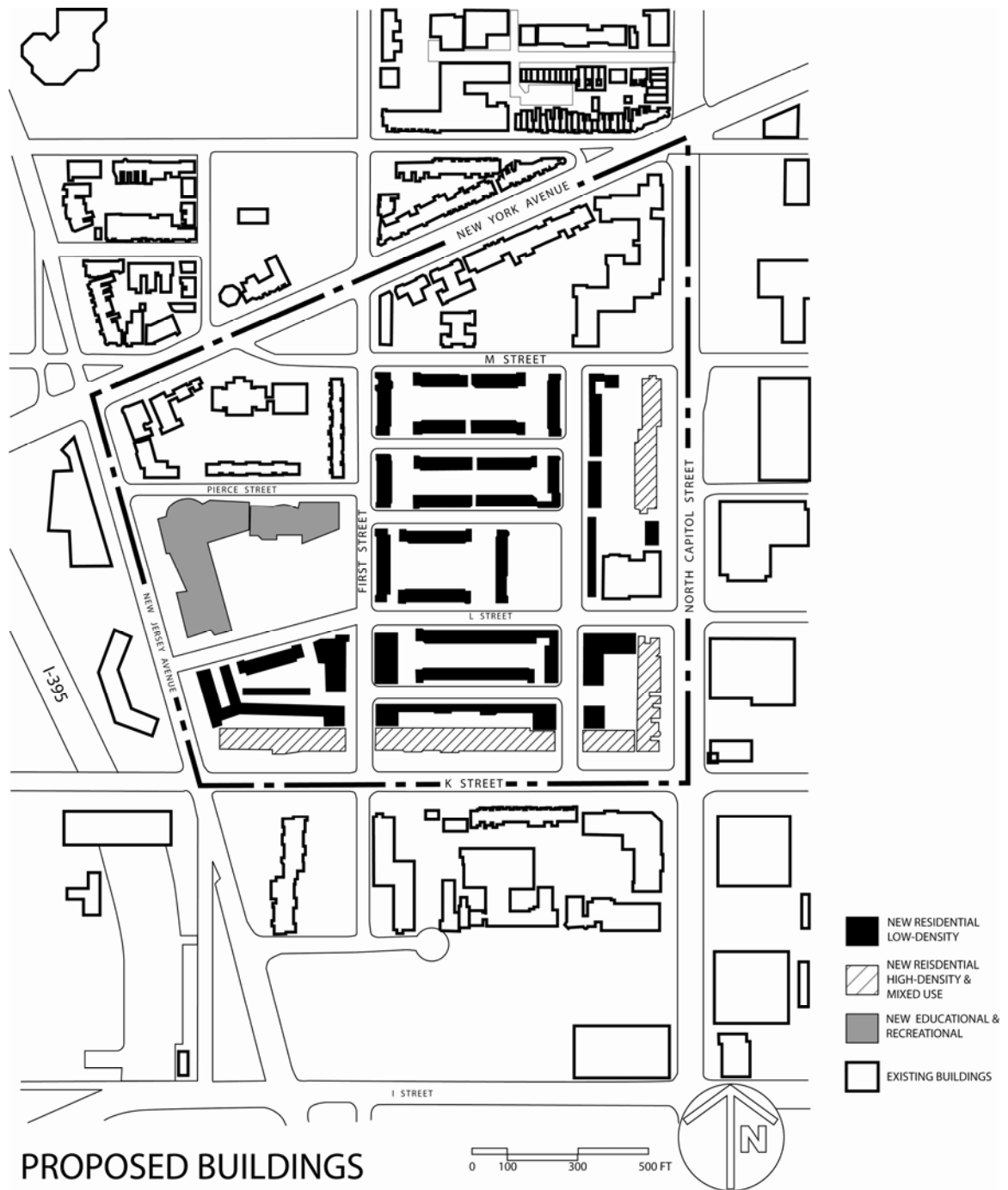


Figure 11 – Site plan as proposed by NCCI program, showing new residential, educational, recreational elements. The areas between row housing is intended for parking. The open area adjacent to the school (on New Jersey Ave.) is for new playing fields.

There is no evidence from the reports found to date that the City intends to change the basic topography or hydrology of the site. The only real difference here is that the newproposed plan seems to call for more paved (impervious) surfaces within the site (parking lots, roads, etc.). The greenspace is concentrated into recreational fields adjacent to the school and a small park next to Mt. Airey Church (which is not be demolished). The new plan may involve a very modest increase in the number of street trees on the site, but of course these trees will, in general, be considerably smaller than the existing trees on site for many years to come.

As stated previously, the qualitative nature of the site has not changed significantly (taller buildings around the edges, smaller at the center). On the other hand, the built environment will, it is hoped, be very different from that currently found on the site. Some sketches from the Master Plan document (Ref. 2) depict what the City would like to achieve in the community (Figure 12 - Figure 14).



Figure 12 – NCCI sketch showing L Street as they would like it to appear after NW1 redevelopment. Mt. Airey is on the left, North Capitol Street is straight ahead. (Image taken from NW1 MasterPlan (Ref. 2))



Figure 13 – NCCI's conceptual sketch for apartments lining North Capitol Street (on the West side). St. Philip Baptist Church is visible on the right, St. Aloysius is on the left in the foreground.



Figure 14 – NCCI's sketch for the K-Street corridor (the NW1 site could be on either side of the street in this sketch. (Image taken from NW1 Master Plan (Ref. 2)

2.6 ZONING REGULATIONS

A current zoning map for the area is shown in Figure 15. The specific setbacks, FAR, height limits and so on are cited for each zoning type under Title 11 of the DC Municipal Regulations. It seems clear that the area will require at least some rezoning under the NCCI Master Plan, most notably creating an R-5 (medium to high-density residential) or CR (mixed-use residential/commercial) district along K Street (see Figure 15). No information has been found related to the City's rezoning plans related to the NCCI proposal. I have therefore assumed that the final Master Plan would provide a new zoning overlay for the entire project site.

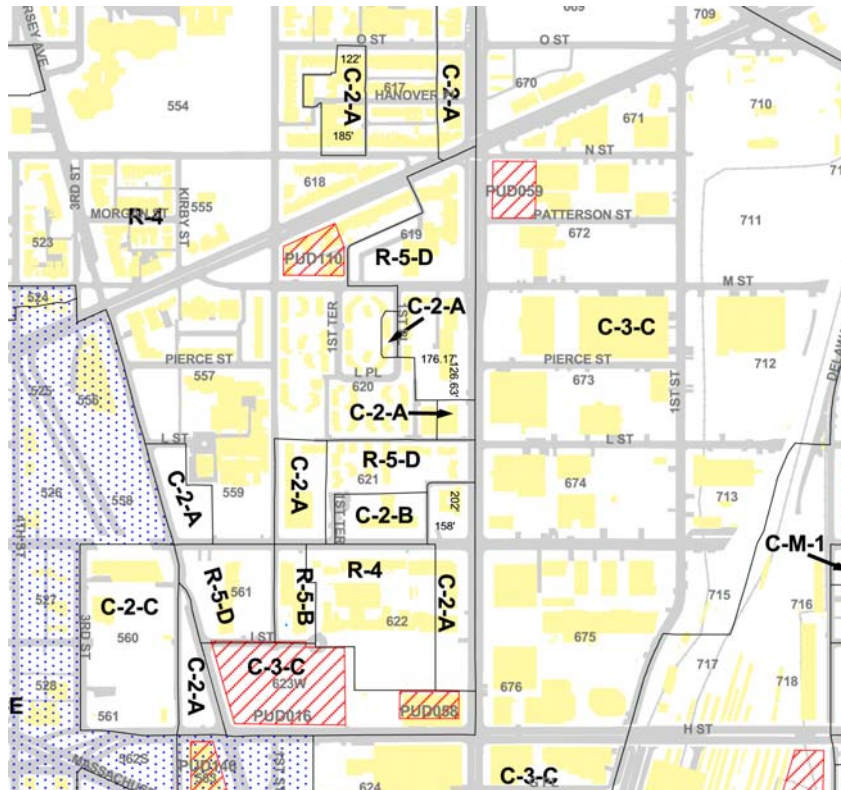


Figure 15 – Current Zoning Map as downloaded from the DC Zoning Office website on May 14, 2006. Most of the neighborhood is zoned R-4 : low density row housing. The highrise apartments on the south and east edges are subject to R-5-D zoning. C-2-A and C-2-B are light commercial and apparently allow religious institutions as well. The entire area east and south of the site is zoned for higher density commercial and light industrial uses (C-3-C).

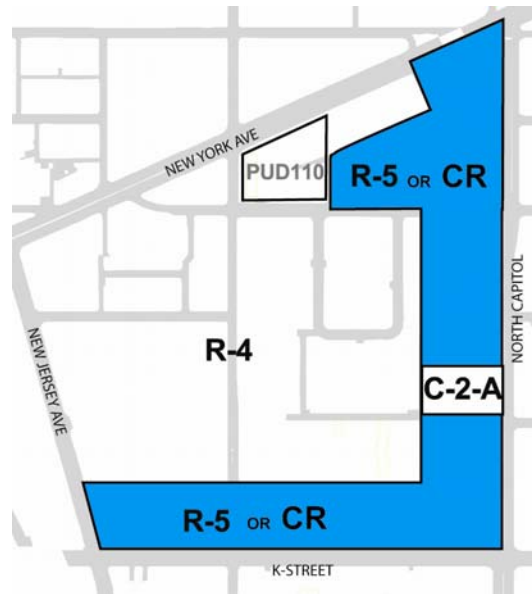


Figure 16 – Proposed simplified zoning map for the NW1 neighborhood (to allow high-rise development cited in NCCI plan).

One challenge here would be the classification of the Neighborhood Solar Regeneration Center (NSRC) for zoning. It might be considered as industrial in some sense, and as recreational, and as a greenhouse or horticultural nursery. Depending on how it is categorized, it may or may not conform with the zoning regulations. If it is considered industrial, the zoning is likely to be very tight. If it is considered as a greenhouse, it can be located in an R-5 district (according to Section 350 of the Title 11 regulations). There is no mention of greenhouses in the context of mixed-use (CR zone) development. It may or may not be considered acceptable. It would appear that the recreational aspect of the program would fit with either R-5 or CR zoning. Of course, it is likely that the current zoning laws would have to be modified or expanded to allow the integration of sustainable infrastructure within dense urban neighborhoods. This would clearly complicate the matter. In the end, the best course of action is probably to demonstrate that the possible negative impacts of these facilities can be managed effectively. Otherwise, a detailed zoning analysis is beyond the scope of this thesis project.

3 PRECEDENT ANALYSIS

As noted previously, the program for this building makes it hard to define in conventional terms. It is a recreational and educational facility that functions also as a greenhouse, a waste water treatment plant, a solid waste collection center, power substation and more. As far as I am aware, no other such facility of this scale and context has been built to date, though the idea has been proposed in many circles of the sustainable design community. The precedent analysis will focus on the idea of creating a beautiful public or semi-private space in close proximity to an industrial use, particularly waste treatment.

3.1 ADAM J. LEWIS CENTER FOR ENVIRONMENTAL STUDIES AT OBERLIN COLLEGE – OBERLIN, OHIO.

This educational building (Photo 16) was designed by visionary architect William McDonough; construction was completed in 2000. The building itself is intended to be an extension of the curriculum, making visible to the students the constant flow of energy, water, waste and nutrients around us in the built environment and the natural world. This building's program has many similarities with that of the NSRC but at a different scale. The development of the building was the brainchild of David Orr, the director of the Environmental Studies Center at Oberlin.

"Is it possible to design buildings so well and so carefully that they do not cast a long ecological shadow over the future that our students will inherit? We now know that such things are possible -- that buildings can be designed to give more than they take." – David Orr



Photo 16 - - The Adam Joseph Lewis Center for Environmental Studies at Oberlin College. The curved roof is covered with photovoltaic panels, the atrium (center) is passively heated and cooled, and the Living Machine (right) helps purify the building's waste water.



Photo 17 – Interior view of the Lewis Center's Living Machine. The entrance from the building atrium is straight ahead in this photo. The auditorium is adjacent to this space (to the right). Note the use of vertical glazing and separate skylights (instead of continuous glazing as in a greenhouse). Image taken from Oberlin Website⁴

The building includes a small Living Machine™ (Photo 17), a nature-inspired waste water treatment plant, to process all greywater from the facility. The clean effluent from the Living Machine™ is recycled to flush toilets in the building and to help irrigate the

landscaping on site. A very similar (though larger) system will be proposed for use in the NW1 community as part of this thesis. Another example of this technology in current use is described in the Ethel M Chocolates precent study to follow. A more detailed description of the technology is given in Appedix A.

The Lewis Center building also demonstrates several other sustainable technologies, including photovoltaic energy systems, ground source heat pumps, fuel cells, daylighting, natural ventilation and passive solar heating, and sustainable materials use.

Although the greenhouse containing the Living Machine[™] is not really designed as a recreational space, it is a prominent element in the design (Photo 16). It fronts the building and is placed directly adjacent to the auditorium. It has been made visible from all of the buildings main circulation routes.

3.2 SOUTH BURLINGTON, VERMONT LIVING MACHINE

The importance of the South Burlington, VT facility (Photo 18) as a precedent is mostly technical, and in fact, no mention is ever made in the literature about its architecture. It demonstrates that the Living Machine™ technology is applicable at a scale comparable to that proposed for the NW1 community. The South Burlington facility processes 80,000 gallons per day (gpd) of industrial waste on site ⁵. The Living Machine™ is housed in a 8,000 square foot greenhouse. By comparison, it is estimated that the NW1 facility will have to process up to 300,000 gpd, requiring approximately 30,000 sq.ft. of greenhouse space (see Appendix B for calculations). All of the greenhouse space does not need to be in one building, however, and can be distributed across the site if desired.



Photo 18 – South Burlington VT Living Machine, with a capacity of 80,000 gpd demonstrates the application of this technology at a community scale. Note the utilitarian design of the space, but also the expansive greenhouse roof.

Although it is not a recreational space, the South Burlington precedent helps illustrate the nature of the space created by a larger facility. Although tours of the facility are offered,

the greenhouses are designed in a very utilitarian way. The challenge will be to make the space more suitable as a relaxing garden space.

3.3 WINTERGARDEN AT MILLENIUM CENTER, SHEFFIELD, ENGLAND

The Wintergarden designed for the Millenium Galleries in Sheffield, England (*Figure 17*), is cited here because of its dramatic arched form. It was designed by the firm of Pringle Richards Sharrat, and completed in 2001. The Wintergarden is a series of stepped glass vaults, supported by engineered wooden arches. The galleries that form the rest of the building's program form a series of vaulted spaces extending along an axis perpendicular to the axis of the garden vaults (see photo). Unlike some of the other precedents considered, this building appears to be built within a denser urban context, which is another important consideration in the thesis project.



Figure 17 – Wintergarden of Millenium Galleries in Sheffield, England. The rest of the program is separate from the garden space in this case. One interesting aspect of this design is the stepped arch profile. This creates some interesting possibilities for the greenhouses to be included in the thesis program. Images copied from Reference 6

3.4 INSTITUTE FOR FORESTRY & NATURE RESEARCH, WAGENINGEN, NETHERLANDS

This building, designed by Behnisch, Behnisch & Partner and completed in 1998 ⁶, is an interesting precedent for two reasons. For one, It uses the plants to help cool the building with natural ventilation; the two atrium spaces (see small plan in Figure 18) have been described as ‘two green lungs’ ⁷. The figure includes a rough sketch of the natural ventilation strategy. The other notable feature is the way the vegetation has been integrated with the interior structure (far right side of Figure 18). It almost appears that the building is an object inside the natural environment of the atrium, rather than being the enclosing element. The use of cantilevered and suspended walkways allow the occupants of the building to experience this indoor landscape without walking through the planted floor of the atrium itself.

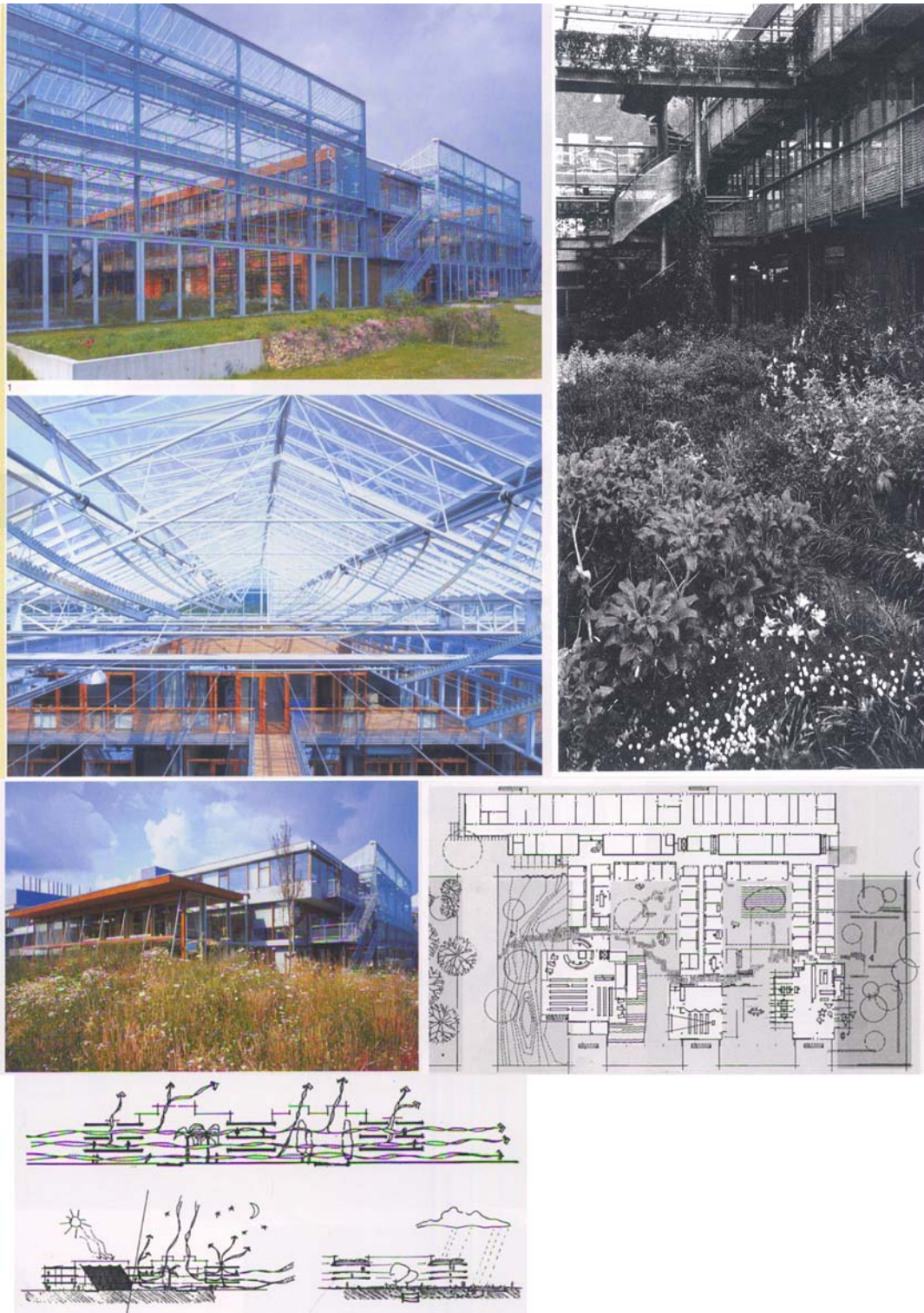


Figure 18 – Institute for Forestry and Nature Research, Wageningen, Netherlands. Like the South Burlington, VT facility, the building's envelop and atrium roof is extensively glazed, but manages to avoid overheating, apparently through the use of natural ventilation, water and plants. It is also worth noting that the building occupants are barred from direct access to the atrium floor in order to protect the plants. Office windows and walkways allow the occupants to enjoy the garden without walking through it.

4 PROGRAM

4.1 DESCRIPTION OF PROGRAM ELEMENTS

1. GREENHOUSES

Daylit indoor spaces of different shapes and sizes, openness and intimacy, placed in relation to the functional elements of the infrastructure in such a way to inspire contemplation of the visitors role in the natural ecosystem. They should derive a sense of connectedness with nature, a responsibility to act in harmony with nature, and a sense of hope and joy that they CAN make a difference at the local level in building a sustainable future. The Greenhouse should be immediately accessible from the public entrance.

20,000 sq.ft. : Aerobic Treatment Tanks and Clarifiers, also known collectively in the context of this thesis as the “Water Gardens”, This includes sufficient spaces for circulation as part of guided and unguided tours.

8,000 sq.ft. : Decorative plantings, fountains, benches, open spaces.

*Not all 28,000 of this area needs to be housed in one building.

SUBTOTAL – 28,000 sq.ft.

2. MECHANICAL PLANT

10,000 sq.ft. : Closed Aerobic Tanks and Anoxic Tank (part of the tour).

1,000 sq.ft. : Centralized pumping machinery

500 sq.ft. : Electrical Inverter Equipment for Solar Array

250 sq.ft. : Engineer's Office

200 sq.ft. : Central monitoring and control room

150 sq.ft. : Gallery of control room for tours.

75 sq. ft. : Single occupant unisex rest room.

5% = 600 sq. ft. total : Circulation spaces

SUBTOTAL – 12,775 sq.ft.

3. AUXILLARY SERVICES BUILDING

3000 sq. ft. : Solid Waste Recycling Center

(including temporary storage of recyclable materials, sorting facility, and loading dock for transportation to final recycling facility).

4000 sq. ft. : Central Composting Center

(including temporary storage for community compostable material, facilities for reducing appropriate material for addition to digestion stream, storage for collected compost from community residences and sludge from Anaerobic

Reactor, facilities for transfer of compost to transport to nearest fertilizer processing plant.)

SUBTOTAL – 7,000 sq.ft.

4. VISITOR CENTER

An environmental education center where visitors and students can learn more about the system, its design, its operation, its goals and the implications to future development. This space should be easily accessible from the public entrance and provide immediate access to the tour route. It should be connected visually to the Greenhouse.

1500 sq.ft. : Atrium / Reception

(includes indoor component of Polishing Wetland)

500 sq.ft. : Gallery Space

(for artwork and text which people can inspect at their leisure).

2000 sq.ft. : Auditorium

(where groups of up to 100 visitors can be shown videos and hear oral presentations on the above subjects).

500 sq.ft. : Education Facility

(with computers that can be used by a relatively small number of individual visitors to view materials related to environmental design, data related to the operational state of the complex, etc.).

300 sq.ft. : Offices for education director and tour guides

(ideally the location of these offices would encourage daily interaction with the maintenance staff)

500 sq.ft. : Storage and support spaces associated with education

(for exhibits, printed materials, copiers, etc.)

250 sq.ft. total : Restrooms

SUBTOTAL – 5, 050 sq.ft.

5. OUTDOOR GARDEN

Outdoor paths that integrate the network of bioswales, the indoor spaces described above, and the rest of the community. The goal here is to make the infrastructure a positive part of peoples' daily lives as they travel from home to school, to the other recreational outdoor spaces (playgrounds, sports fields), to work, to the store, to the Metro and so on.

2000 sq.ft. : Polishing Wetland (outdoor component)

300 sq.ft. : Fountain / Well.

1000 sq.ft. : Plaza

(with benches, plantings – should be immediately accessible to restaurants and cafes occupying the ground floor of the apartments buildings on the street)

6. OUTDOOR SERVICE SPACE

4000 sq.ft. : Anaerobic Digester

(preferably earth sheltered but with access points for maintenance)

7. BIOSWALES

There are no square footage requirements here. They consist of a broad shallow ditch, with grasses planted along the bottom. Ideally, the swales would be planted with bushes and trees that would beautify it, discourage littering, discourage children from playing in it, and provide a refuge for wildlife.

8. DISTRIBUTED POWER GRID

Each of buildings in the community will include photovoltaic arrays. Electric energy from the panels will be converted to A/C power at the source and connected to the local power grid. The energy will be distributed throughout the local community. Ideally, any excess energy would be stored on-site for use later, making the community self-sufficient. This part, at least, might be foolish. As long as the existing electrical infrastructure does not require upgrading to handle the power, it would be wiser to use it to distribute the energy back to the entire municipal grid.

The design component of this thesis will include speculative designs for integrating solar panels with the apartments and single-family residences.

As part of the sustainable community design, some of the single family residences will be designed with composting toilets. The design implications of this on the house and the community will be explored as part of the thesis project as well.

4.2 AREA CALCULATIONS

Greenhouse *

Aerobic Treatment Tanks and associated service spaces	20,000
Garden spaces	8,000
<i>total</i>	<i>28,000</i>

Mechanical Building

Closed Aerobic Tank and Anoxic Tank	10,000
Pumping Equip	1,000
Inverters	500
Engineer's office	250
Control Room	200
Control Room Gallery	150
Circulation	600
Restroom	75
<i>total</i>	<i>12,775</i>

Auxiliary Services Building

Recycling	3,000
Composting	4,000
<i>total</i>	<i>7,000</i>

Visitors Center

Atrium	1,500
Gallery	500
Auditorium	2,000
Education Lab	500
Office	300
Restrooms	250
<i>total</i>	<i>5,050</i>

Garden (outdoor)

Wetland	2,000
Fountain	300
Plaza	1,000
<i>total</i>	<i>3,300</i>

Outdoor Service Space

<i>total</i>	<i>4,000</i>
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grand total **60,125**

total interior **52,825**

* - Area calculations for the greenhouse are based on similar Living Machine[™] systems built elsewhere, and on simple rules of thumb.

It is my goal to consider the entire life-cycle of the materials used in construction of the building, from cradle to grave or, better, from ‘cradle to cradle’ (borrowing a phrase from William McDonough). Because the design will not be defined to the point of construction documents and bill of materials, this accounting will necessarily be more qualitative, selecting materials that are recycled or sustainably harvested before constructed, and recyclable / reusable / biodegradable when they are ultimately taken out of service to this building.

5 DESIGN APPROACH

5.1 CONCEPTUAL DESIGN STRATEGIES

The basic design elements to be addressed in this thesis are:

1. Propose modifications to NCCI Master Plan to improve access to solar power and to better integrate the built and natural environments (water flow, pedestrian as well as vehicular traffic, etc.). Attempt to maintain the same overall human population (density) as suggested by the Master Plan (about 4,000).
2. Conceptual design of rowhouses to accommodate solar energy collectors, composting toilets, natural ventilation, under-house garage.
3. Conceptual design of apartment house to accommodate solar energy collectors, natural ventilation, underground parking, etc.

4. Integration of street network, pedestrian paths, courtyards, and bioswales to manage stormwater run-off.
5. Integration of NSRC building form(s) with its context (including landmarks offsite) and the flows that it must manage and tap into.
6. Detailed design of the NSRC building(s), focusing on the integration of the program elements, functional requirements, the architectural expression of the building, its visionary and inspiration missions.

5.2 ALTERNATIVE SITE PARTIS

The main site planning issues include:

1. the creation of greenways for:
 - a. circulation (pedestrian and vehicles) through the neighborhood
 - b. establishment of formal relationships between buildings, streets and landmarks
 - c. management of stormwater run-off
2. relationship of the NSRC building site to prominent landmarks on and off the site and to the greenways.
3. working with the natural flows of energy and water within the site.
3. integrating the NSRC building with the life of the community (cafes, restaurants, etc.).
4. creating a prominent entry space for the NSRC.

Figure 19 through Figure 22 show several sketches for alternative site strategies dealing with the issues above. The different strategies share some common characteristics, including broad greenways running north and south (some northwest to southeast) to reflect the overall hydrology of the site. Each scheme uses these greenways and other view corridors to create different hierarchical spaces and formal relationships between them.

In each site diagram, the hatched areas on the north and east edges are considered to be untouchable because of their historic significance. The lightly shaded areas in the middle of the western boundary marks the location of the school and recreation center, which will be assumed set. The arrows indicate major vehicular paths through and around the site. They also define important relationships with the Metro station, Capitol Dome and other landmarks in the larger community.

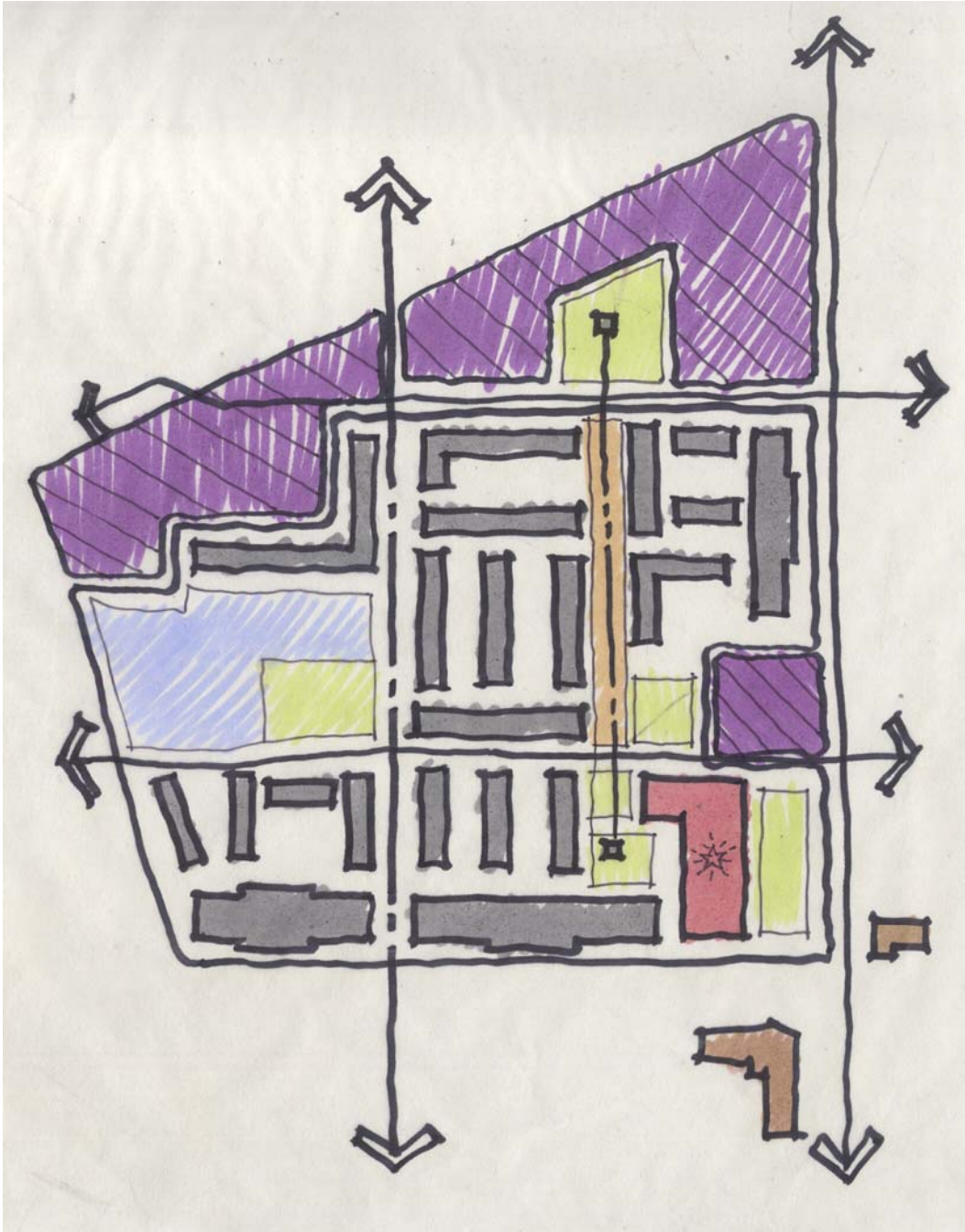


Figure 19 – Site Scheme 1: small urban squares anchor both ends of the single strong N-S axis defined by the bioswale. The NSRC engages the southern square on one side and North Capitol Street on the other. A small greenspace defines the natural connection between Mt Airy Church on North Capitol and the bioswale / greenway. This placement gives the NSRC a strong presence on K Street and North Capitol Street. The square on the north and the bioswale / greenway's north terminus help 'capture' visitors approaching from the Metro station.

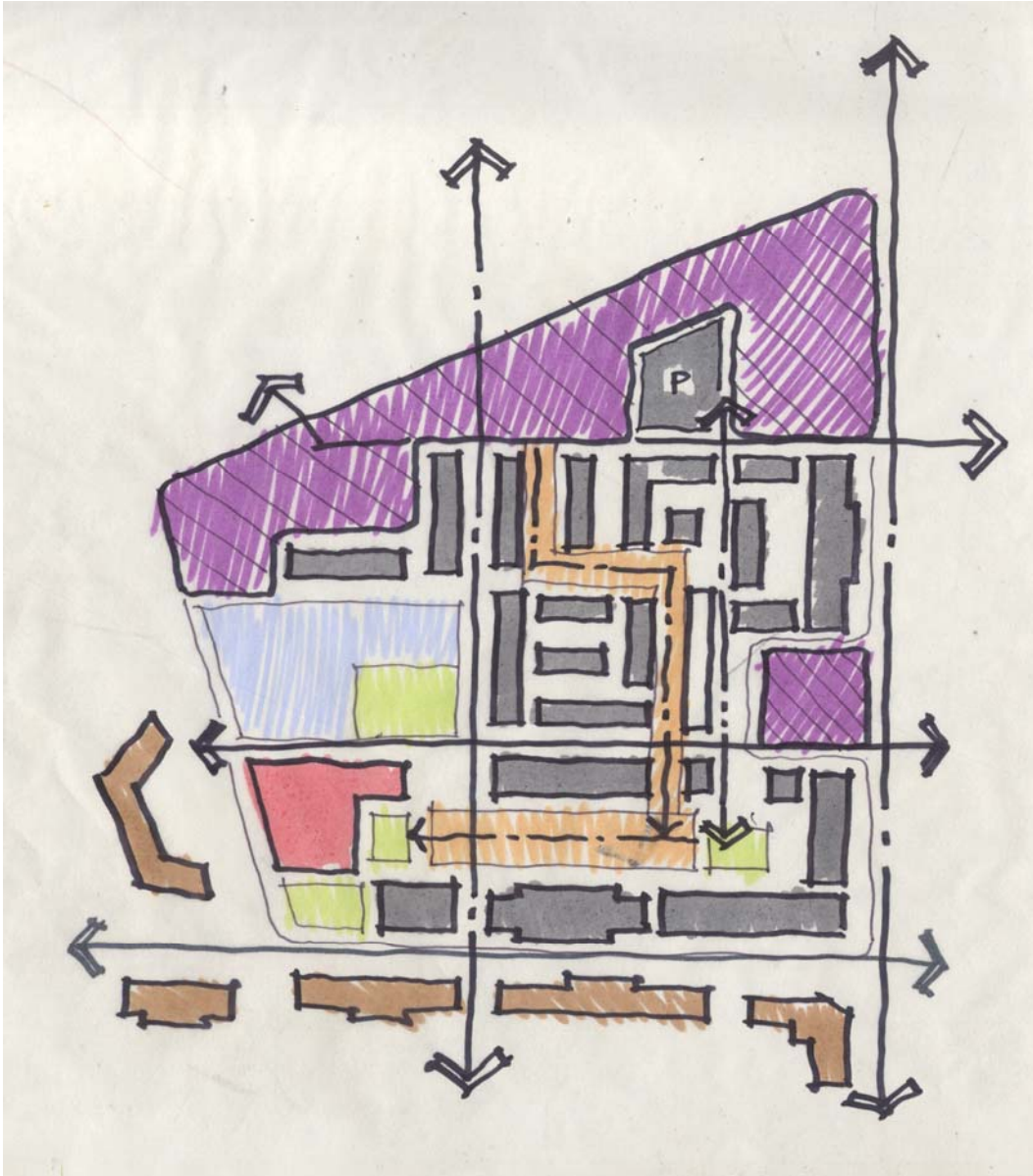


Figure 20 – Site Scheme 2: the bioswale / greenway weaves through the site, ending on a long green that connects to the NSRC. The NSRC addresses New Jersey Avenue and K Street, and is adjacent to the school, making its educational value more visible.



Figure 21 – Site Scheme 3: in this plan, the NSRC is sited on the north axis of the bioswale / greenway network. This gives it a much more direct connection to the greenway, fills a void in the fabric of the neighborhood (currently occupied by a swimming pool) and makes the facility much more of a gateway element to the community. On the other hand, the NSRC is now less visible from the major thoroughfares, and also puts it at a higher elevation than most of the rest of the neighborhood (which means that waste water would have to be pumped uphill). Minor axis greenways connect across the site as tributaries for stormwater runoff. This cross axis may tend to divide the community too much. The strong N-S axis is interesting here, but the drawbacks seem to override that.

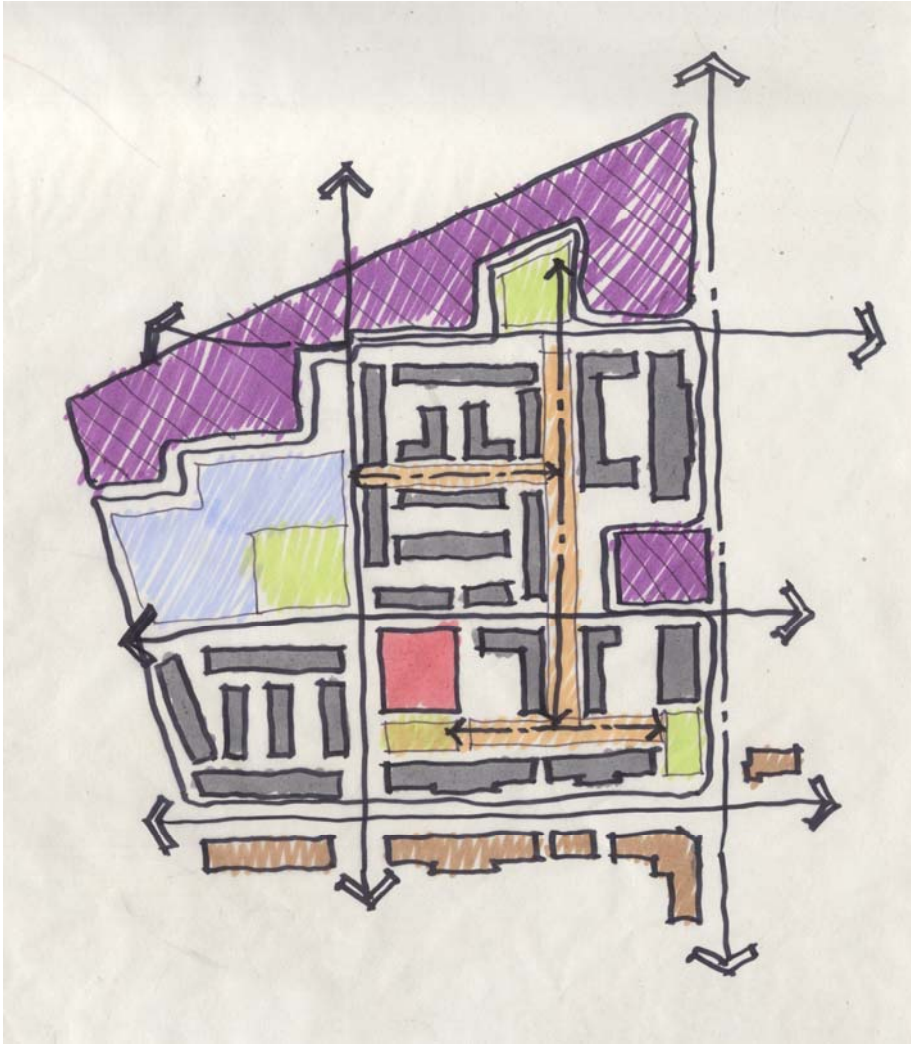


Figure 22 – Site Scheme 4: this site strategy is similar to the others described above. It is distinct in siting the NSRC in the middle of the neighborhood rather than at the edge. This makes the building almost entirely the ‘property’ of the neighborhood, rather than a public attraction. It still offers the potential for a visual connection to the NAR LEED building south of the site along First Street. It also addresses the school diagonally. This semi-private site within the neighborhood may defeat some of the educational value of the building by making it hard for visitors to find.

It appears that the strong north-south axial greenway with only minor tributary flow channels, and some sort of strong cross axis (east-west) across the south of the site was the most effective site plan. The NSRC might be located at either end of the major axes, or at their intersection. It might also allow its form to extend out into the community along these axes. These ideas are explored in more detail in the section below dealing with building form.

5.3 BUILDING FORMS

Several alternative parti's for the building form were explored. One functional consideration that drives several of the forms is that the process of waste water treatment involves a linear series of tanks, and that these tanks need access to sunlight. Several of the schemes extend the greenhouses holding the tanks out into the landscape. Others outline the more centralized parts of the building using the greenhouses . Still others simply stack the greenhouses to create a more solid mass for the building. The forms explored here are generally linear and not curved, although there is no reason that they could not be.

One issue to be considered here is the surrounding context, which has not really been defined as yet. Some of the sketches from the NCCI Master Plan given a conceptual form to the buildings that might be built, but there is nothing sacred about these conceptual sketches. Indeed, they will probably have to be modified to some extent for solar power anyway. If there is a natural form to the NSRC that might inform the design of the surrounding buildings, then that option should be explored. Additional analysis into the connection between the NW1 buildings and the greater context of NOMA should be undertaken. The historical context of the site and the sensibilities of the residents will also have an impact.

I have come to favor the idea that some of the greenhouses can be distributed throughout the neighborhood and provide point source water treatment. The remainder of the flows will be handled at the NSRC.

6 DEVELOPMENT OF FINAL DESIGN

6.1 SITE DESIGN

Continuing to work with the idea of using the constructed wetlands to reinforce axial relationships across the site, I decided to create a network of parks that would connect various entry points into the community and help visitors to discover the NSRC. This is illustrated in Figure 23. The greenway running north and south, located on the east side of the site is conceived of as a constructed wetland for handling stormwater, as is the greenway running east and west and located near the south edge of the site. These public greenways are connected to a series of private and semi-private garden spaces, including rooftop gardens. The greenways are occupied by ‘lanterns’, which are actually greenhouse structures for a distributed network of Living Machines™ (see Figure 24); the round ‘lantern’ in the northwest corner is a water tower. The decision to distribute half of the total water treatment function to machines throughout the community was driven partly by this concept of creating markers, and partly by preliminary massing studies that showed the NSRC beginning to overshadow its surrounding context (Mt Airey Church) if all waste processing for the community was located in a single facility.

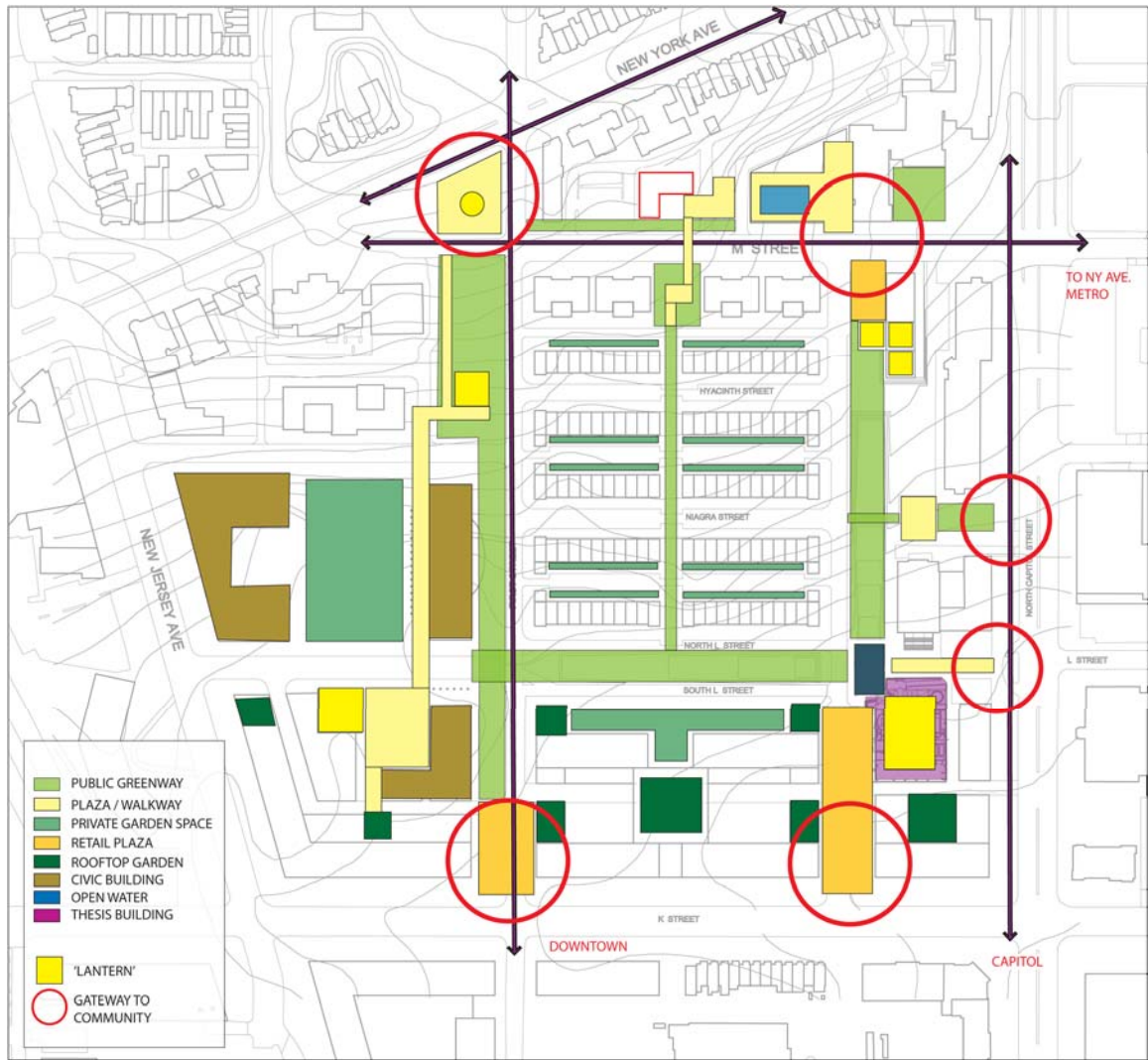


Figure 23 – Diagram of greenway network and how it is intended to connect entry points (gateways) to important elements of the community.

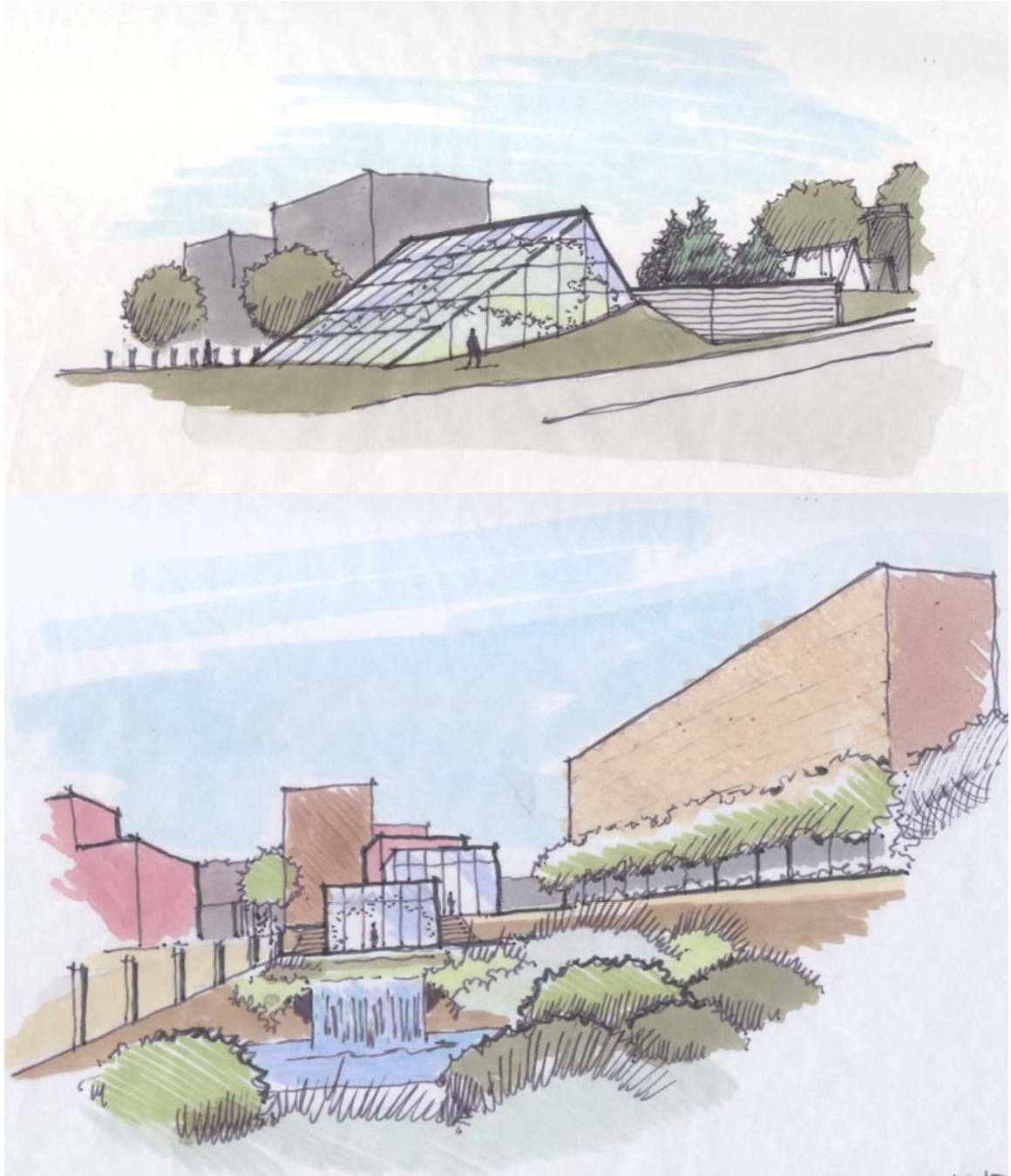


Figure 24 – Sketches of Living Machine ‘lanterns’ located throughout the community.

The constructed wetlands converge on the site for the NSRC, located in the southeast corner of the site. These wetlands were designed to be compatible with DC’s urban context (see Figure 25). The edges of the wetland were made absolutely straight and lined by roads (the new L Street and Half Street), creating a kind of grand boulevard.

Several sitting spaces line the edge of the wetlands also, providing locations for people to interact with the natural beauty of the wetlands. There are grassy areas with a gradual slope along the border for people to sit or walk. In addition to the cat tails, bulrushes and other wetland species used to help filter the water, the wetlands would be strategically enhanced by plantings of more ornamental native plant species that can help to ‘civilize’ the wetlands further. People are prevented (or at least discouraged) from walking through the heart of the wetlands by low (3-4 ft walls) with plantings in front of them (possibly including thorn bushes).

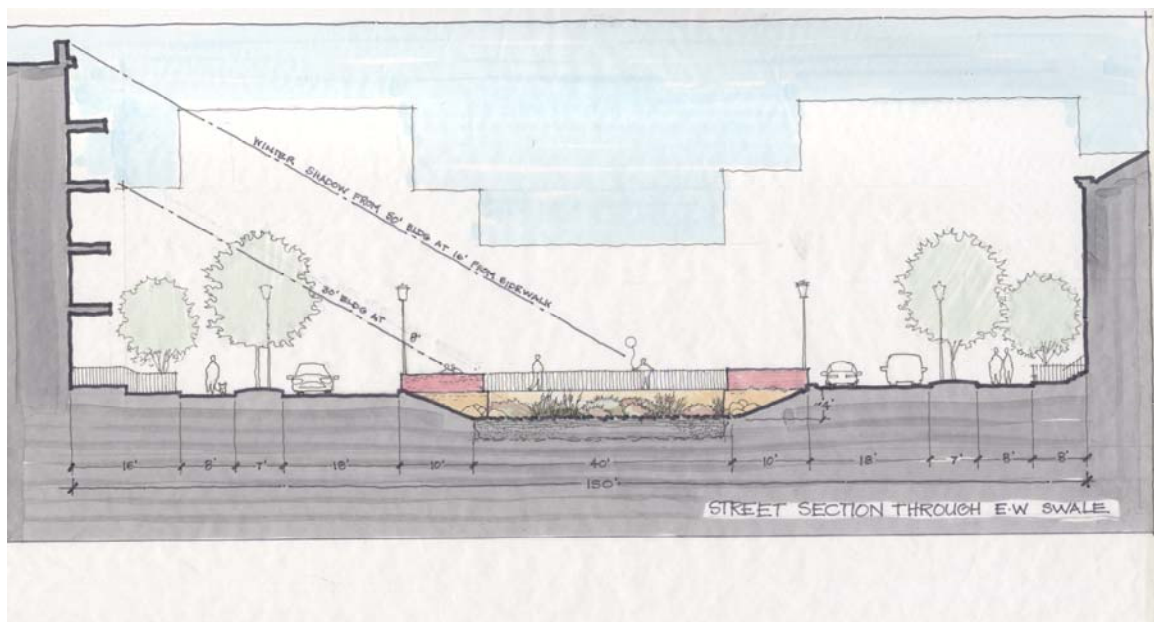
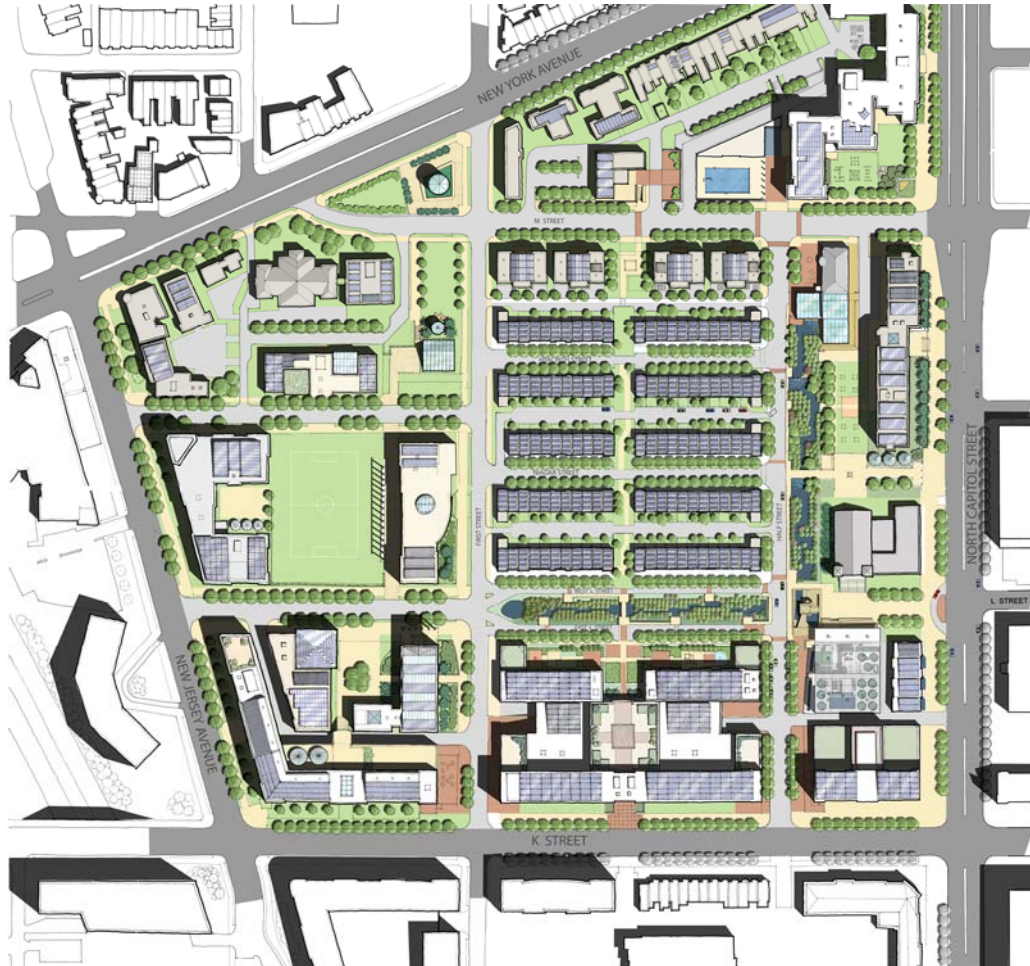


Figure 25 – Street section through E-W wetland.

From the greenspace network diagram and this concept for the wetlands, the full site plan shown in Figure 26 was generated. In addition to the greenways, wetlands, lantern and NSRC, this plan gives a glimpse of the intent for solar power generation (the way the rooftops are populated by solar arrays). The townhomes in the middle of the site have been reordered to provide better solar access, not only for solar arrays, but for passive solar heating and daylighting. Because the wetlands displaced some of the townhomes

proposed by the NCCI Waster Plan, I have added some mid-rise (3-5 story) apartment buildings on the north and south edges of the site's core in order to accommodate a population similar to that suggested in the Master Plan (about 4000 people).



*Figure 26 – Rendered Site Plan for the Community
(north is up in this plan, as with others incl. in this report)*

6.2 BUILDING DESIGN

The essential design goal for the Neighborhood Solar Regeneration Center (NSRC), beyond meeting the requirements set forth in the program and accommodating the Living Machines™, was to make the process of water purification clear to visitors (without exposing them to anything too unappetizing). A secondary goal was to connect the NSRC to the streetlife envisioned for the K St corridor.

The final design of the building elevates the garden (containing the living machine) above the other program elements on heavy concrete columns. The garden is terraced and steps down and around to form a loop (see Figure 27). Untreated waste is piped into a settling tank under the plaza. The liquid is pumped up into the garden and then flows down through the Living Machine™ and ends up back at the plaza, where it flows down into a fountain basin in full view of passers by. During warm weather, the water is also allowed to run from scuppers on the building's western façade, where it is captured in a basin and runs back to the plaza; this water feature is intended to help guide and draw people from the street scene on K Street to the entrances of the building (see Figure 26). From the plaza fountain basin, the water is pumped into the wetlands where it helps keep the plants alive in times of drought, and there it is filtered further and allowed to soak into the ground. The form of the terraces therefore reflects the cycle of water purification.

The entire terrace structure is contained within a separate enclosure that is solid below (with window openings into the interior spaces) and translucent above. The glass top for the garden is supported by a grid of street columns and trussed arches (Figure 28, Figure 29, Figure 31, and Figure 31). The glass is translucent rather than transparent in most

locations to help control solar heat gain in the summer. The glass roof of the building is also covered with Built-In Photo-Voltaic (BIPV) cells. These small solar panels are spaced to allow

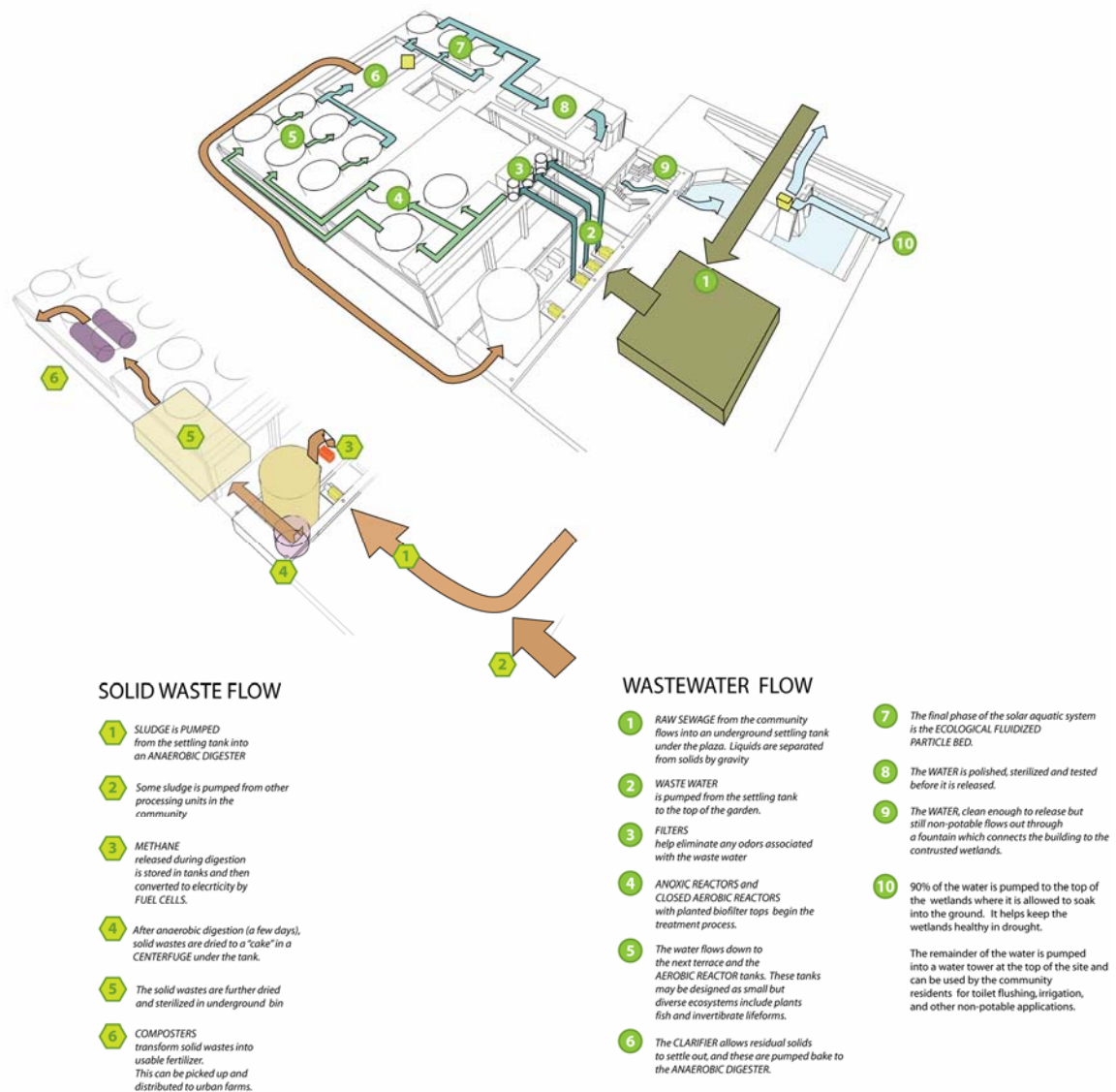


Figure 27 – Basic configuration of the garden terraces that support the Living Machine™ and auxiliary components.

ample light to pass between them. They will help to create a dappled pattern of sunlight, evoking the image of a canopy of trees. The power from these cells, as the leaves of a tree, will provide a significant fraction of the power needed to operate the facility. The

corners of the box and the northern façade are transparent, allowing views into the garden from strategic viewpoints along K Street and from the entry plaza at North Capitol Street.

The twin arched form of the roof (not identical twins) define the separation of upper and lower terraces, and form a central valley that captures half of the rainwater from the roof into a prominent downspout and scupper that create a dramatic presence on the building's west façade. The arched forms have a slightly industrial appearance to them, reflecting the mechanical function of the building as well.

The skin below the level of the garden on the east, south and west sides is solid, constructed from reinforced CMU with a layer of rigid insulation and a cultured stone rainscreen on the outside. The rainscreen has a mottled terracotta finish, reflecting the materials used in the Mt Airey Church nearby and reminiscent of industrial buildings of the past.

The public procession begins at the plaza fountain where the wetlands intersect (the northwest corner of the building). Visitors can walk up through the lightwell in the center of the terraces, into the lower garden or up through the machine into the upper garden. At both locations, there are spaces to sit and relax, enjoy a cup of coffee and a book, and reflect on the surrounding garden. A stairway connects the upper and lower gardens, forming a loop that parallels the flow of the water as it is purified. Catwalks with translucent glass floorplates divide the upper and lower terraces, provide elevated views

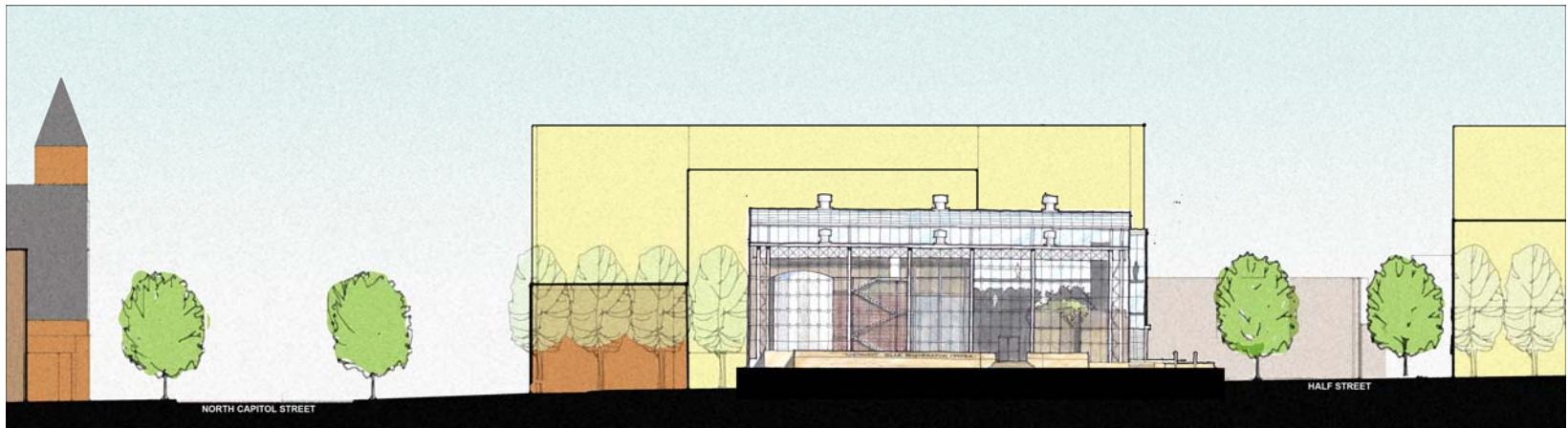


Figure 28 – North Elevation of NSRC Building with context.



Figure 29- West Elevation of NSRC Building with context

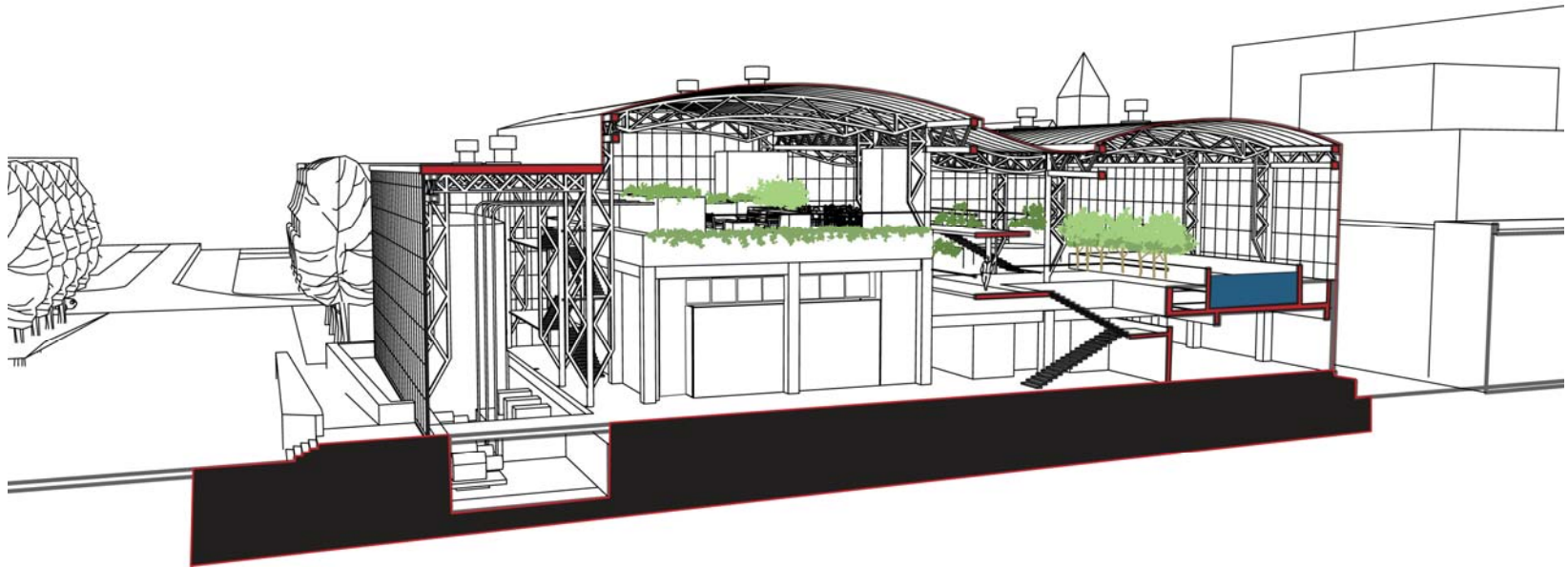


Figure 30 – Section perspective cut from north to south through terrace interior light court.



Figure 31 – Aerial View of the NSRC with context shown (ends of constructed wetlands are at left and bottom of this view)

of the garden, terminate on a bay that gives visitors a view of the wetlands to the west, and also act as a path of emergency egress.



Figure 32 – Sketch of interior space showing the Lower Garden viewed from the Upper Terrace catwalk.

The garden space will be mechanically ventilated to help keep it cool in the summer. In the winter, much of the heating can be done by passive solar income, but the garden space can also be heated through ducts in the raised floor of the garden. The garden will not be air conditioned otherwise, but the other program spaces (the auditorium, education lab, offices and service spaces) can be. These areas will be separated from the unconditioned space of the garden. It is likely that the garden space will be used by people (other than visitors taking a tour of the facility) primarily in the fall, winter and spring. It is easy to imagine hosting community functions and other gatherings in the beauty of the indoor garden. In the summer, any outdoor space in Washington DC is

generally too warm and humid for most people to feel comfortable. Even so, the conditioned spaces will still be useful for meetings and educational tours).

7 CONCLUSIONS

In order to live more sustainably, it is important that begin to adopt a more sustainable infrastructure, one that works in cooperation with nature. It is essential that people begin to understand the infrastructure that sustains them and how their actions impact the environment as well. This thesis project begins to explore the design issues involved with integrating a decentralized, holistic and sustainable infrastructure into our urban neighborhoods. It seeks ways to celebrate that infrastructure rather than making it invisible. I do not claim to have answered all of the questions or solved the problems associated with making such an infrastructure a reality, but I hope this project will help start a discussion in the design community aimed at doing just that.

This project has proposed the creation of a largely self-sufficient energy and waste treatment infrastructure within a community of approximately 50 acres, and with a population of about 4000 residents. One of the first questions we should ask ourselves as the discussion continues is ‘what is the minimum and maximum appropriate size of community to apply this conceptual framework?’ The design proposed in this thesis project created indoor garden spaces in close proximity to the Living Machine™ water purification tanks, and sought to create a garden-like interior space. What other forms can we envision to weave facilities such as this into our communities? What are the legal and social issues involved? This is just the beginning of an exciting debate that will include the general public, policy makers, engineers and, of course, architects. It is my hope that this discussion will help lead us into a new era of technology and design focused on living well, but within the capacity of the Earth to sustain us all.

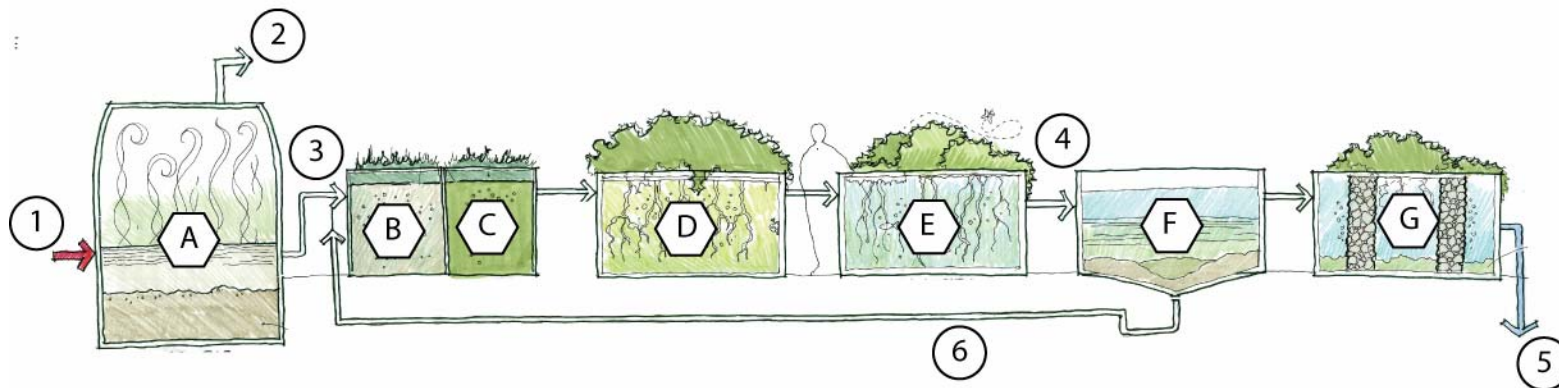
APPENDIX A – INTRODUCTION TO LIVING MACHINES™

Living Machines™ is a proprietary version of what some call ‘solar aquatic systems’.

There is nothing particularly proprietary about the basic technology and anyone can build such a system if they have the experience. Living Machine™ systems are also marketed under the company name Dharma Living Systems. Market research suggests that this is the only company that has built waste water treatment plants for relatively large commercial applications. Most of the other examples of this technology are used as educational aids alone, built by teachers and their students.

Nearly all of the available literature on such systems is in reference to Living Machines™ installations, but most of the technical details on tank sizes, flow rates, plant species, temperature, light and humidity levels, materials and so on appear to be considered trade secrets of a sort. Repeated attempts to contact Dharma Living Systems for information have failed thus far. By cross referencing several different papers, it has been possible to establish some sizing guidelines for the systems – each 10,000 gallons per day of waste water to be processed by the system requires approximately 1000 sq. ft. of floor area for the tanks. In the paragraphs below, the basic idea behind the system, their physical form and operating principals are discussed.

The basic configuration of the Living Machine™ is shown in below. Wastewater flows through a series of cells or tanks, each performing a specific function.



COMPONENT

- A - Anaerobic Digester
- B - Anoxic Reactor
(w. planted biofilter cover, actively aerated water)
- C - Closed Aerobic Reactor
(w. planted biofilter cover, active aeration)
- D & E - Open Aerobic Reactors
- F - Clarifier
- G - Ecologic Fluidized Bed.

WASTE MATERIAL

- 1. - Raw Sewage Input
- 2. - Methane Gas Output (can be converted to energy)
- 3. - Liquid Waste with some suspended solids
- 4. - mostly purified water
- 5. - purified water (non-potable, but can be used for irrigation, washing cars/walks and other non-potable uses)
- 6.- Settled sludge from clarifier and fluidized bed can be fed back to the anoxic reactor.

Figure 33 – Solar Aquatic (“Living Machine”) Schematic

Anaerobic Reactor –

Untreated sewage flows into this tank, which is an airless, lightless environment.

Microbes breakdown the solids, reducing their mass by up to 75%. Ultimately, the remaining solids need to be cleaned out periodically. These solids can be dried, sterilized, composted and then used for fertilizer (if desired).^{5, 8}

The liquid component of the waste is separated out and sent to the next tank in the series.

Anoxic Reactor –

Promotes floc-forming and denitrifying microorganisms. Active (mechanical) aeration of the liquid ensures that aerobic conditions exist in the reactor, as well as assisting mixing of the fluid.^{5, 8}

This tank is generally closed at the top by a planted biofilter.

Closed Aerobic Reactor

Intended to reduce biochemical oxygen demand (BOD – a measure of the waste levels remaining in the water) within the water to a low level, further remove odorous gases and promote nitrification.^{5, 8}

The closed aerobic reactor is also covered by a planted biofilter. Active aeration is also used here.

Open Aerobic Reactor

Reduces BOD to better than secondary levels (clean non-potable water) and completes the process of nitrification.^{5, 8}

These reactors have free-surface of water; plants are held by racks above the surface of the water. Their roots help promote the purification process, filtering the water and providing surface area where other agents can work. These tanks may host more complex ecosystems including fish and snails.

Clarifier

This is essentially another settling tank where residual solid can settle out and be sent back to the anoxic reactor (or digester) for continued processing.

The surface of the water is typically planted with duckweed to prevent algae formation.^{5, 8}

Ecological Fluidized Bed

This tank provides final polishing of the waste water before it leaves the machine.

It is comprised of an annular bed of crushed rock through which the water is circulated (typically by an air-lift pump). The rock media acts as a filter, and provides surface area where microorganisms can attach and help consume the remaining waste. A small amount of solid matter does collect in the bottom of the

tank and must be removed periodically (to be processed along with the biosolids from the anaerobic digester).^{5, 8}

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- 2 Office of Deputy Mayor for Planning and Economic Development, “Northwest One Master Plan – Draft 11-11-05”,
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- 4 Adam J. Lewis Environmental Study Center – Oberlin College website – www.oberlin.edu/ajlc/ajlcHome.html
- 5 U.S. EPA, 2004, Wastewater Technology Fact Sheet – Living Machine.
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