The Living Building at Georgia Tech

EcoLadder
Environmental Consulting LLC

Preliminary Design Considerations

Spring 2016

EcoLadder Environmental Consulting, LLC

943 Peachtree Street North East, Suite 1709

Atlanta, Georgia 30309

ACKNOWLEDGEMENTS

The preparation of the following report would not have been possible without a gratuitous amount of assistance and direction from a multitude of sources. EcoLadder is appreciative of the opportunity to be included in the initial design stages of such a high profile and widely visible project. The Living Building at Georgia Tech will serve as a pinnacle example of the environmentally friendly building efforts and innovations in the green engineering sector for the foreseeable future. Although this undertaking proved trying at times and required a high standard of excellence from all involved, it was truly those that provided support and guidance that made it coalesce into a single, cohesive document.

The full list of those that lent their time and offered insights would be extensive. However, certain persons deserve a mention before we present the body of our work. The following is a mostly comprehensive but by no means exhaustive accounting of the resources used during the creation of this study.

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EXECUTIVE SUMMARY

The Living Building Challenge outstrips all other building efficiency and wellness programs - LEED and similar systems only require certification based on theoretical, selective, and cost effective credits. Although these standards have created a thriving marketplace for building retrofits and environmental awareness, they fail to maximize usage of tools needed to classify buildings as truly sustainable. The Challenge bridges the gap between sustainable and regenerative structures by considering a more holistic and long term approach to this process. By requiring a one-year performance evaluation period before Certification is awarded, the Challenge ensures that the building is environmentally neutral or positive on a scale not often examined during initial start up.

EcoLadder has been tasked with providing the tools and knowledge needed to bring this project from the drawing board to reality. After careful consideration of the various components and individual aspects of the Challenge, Petals were separated thusly: those dominated by engineering constraints and those wherein architectural considerations were the limiting factor. Recommendations and preliminary feasibility assessments have been made for four of the seven required Petals most pertinent to the engineering side of design: Place, Materials, Energy, and Water.

Place

Preservation and revitalization of historically significant environmental features

Extension of existing urban agricultural programs and additional educational elements

Community engagement through added amenities catering to an enlarged clientele

Materials

Preferential use of recycled and salvaged materials

Selection of versatile building elements to ensure architectural freedom

Minimizing inherent but hidden embodied carbon contents

Water

Enhanced collection through naturalized catchment and diversion systems

Drought resiliency through increased cistern capacities

No-waste water balances through inclusion of composting and separation techniques

Energy

Solar production and storage that minimizes inefficiencies

Low pressure VAV HVAC system to reduce system loads

Increased worker productivity and comfort with naturalized lighting and ventilation

After examination of the available data and investigation of possible solutions and design alternatives, the premise of a Living Building on Georgia Tech's campus was determined to be feasible within the cost constraints provided. This is not to say that the project will be without its challenges and stumbling blocks; indeed there are too many unknowns at this point of the design to conclusively determine the viability of the proposal. However, the analyses performed within the scope of our work are promising - the generous donation from the Kendeda Fund provides the necessary capital to pursue the Living Building Challenge - and the initial designs contained herein provide a proof of concept for a Living Building at Georgia Tech.

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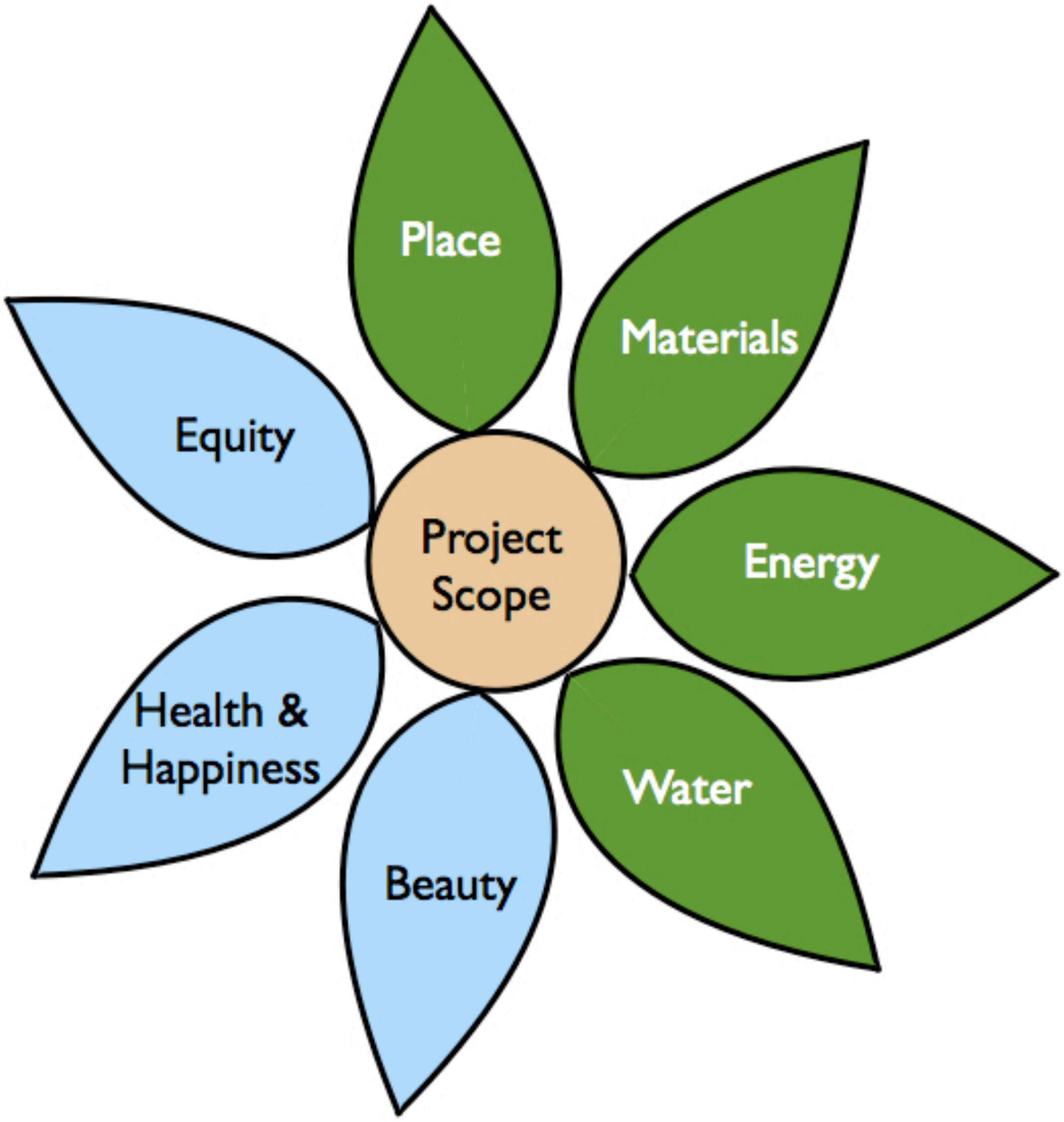


INTRODUCTION

The Georgia Institute of Technology continues to spearhead technological and humanitarian advancements in the South East. Embodied in the Georgia Tech Master Plan, many of these key concepts carry through to new construction, renovation of existing buildings, group initiatives and community engagement on the Institute's campus. Georgia Tech's Department of Sustainability ensures that environmental and ecological concerns are addressed in addition to the ergonomics of major construction. The campus' Stormwater Master Plan aims to mimic natural hydrologic functions on the campus despite the large amount of impervious surfaces that exist on and in the areas surrounding the Institute. Along with energy saving initiatives, waste reduction strategies, and paradigm changing imperatives, Georgia Tech keep's both short term environmental remediation and long term sustainability at the forefront of campus design.

As part of these sustainability efforts, the Institute is setting the standard for green infrastructure. Green efforts informing design shows itself in the planned Eco-Commons: a stretch of performance landscaping and green recreational space that spans the entirety of campus in the form of a 'Green Doughnut' indicated in Figure 1.1. This interlinked area provides stormwater management and initial water treatment while also functioning as both a passive and active activity area for students and campus visitors. Enhancing the beauty of campus while also providing functional utility, the planned Eco-Commons will be a centerpiece when describing the Institute's efforts: to provide sustainable solutions to urban design while integrating ecologically based and pedestrian accessible landscape.

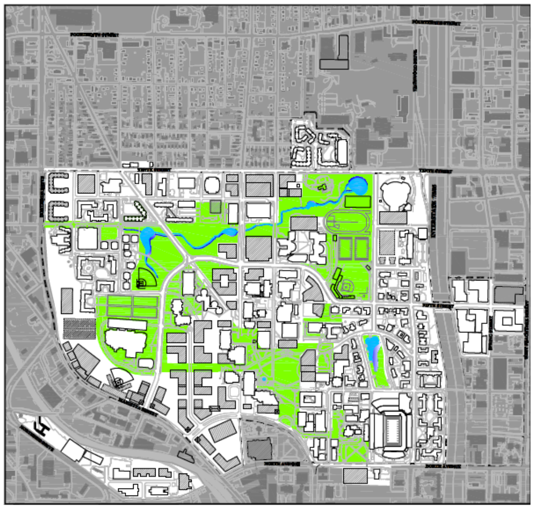


Figure 1.1: The proposed Eco-Commons, taken from the 2004 Master Plan

North Campus has been the focus of recent redevelopment efforts that include restoration components in addition to applying stringent building performance standards, such as the LEED and WELL certification programs. With nearly twenty existing structures meeting various levels of LEED certification, the Office of Capital Planning and Space Management (CPSM) has set its sights on an even more rigorous certification: moving from low-harm & no-harm or energy and environmentally neutral building to planning structures that actually function in mutually beneficial means with the local environment. This new standard of building design shifts the target from net zero to net positive impact, linking artificial structures with ecological processes in a way that enhances performance both at a systems level and for the patrons of the facility.

Providing a framework for the implementation of this new perspective on structure design is the Living Building Challenge (LBC). A product of years of interdepartmental and multidisciplinary cooperation, the International Living Future Institute has compiled a system for determining true environmental impact that considers a building not as a discrete structure, but holistically and in the frame of its local and regional surroundings. By taking into account the impact on the immediate surroundings as well as classifying systems into ‘Petals’ to further analyze the components of a ‘living’ building, the Challenge provides structure for an incredibly thorough investigation of all aspects of new construction. Figure 1.2 and the list below illustrate these Petals.

- **Place**
- **Water**
- **Energy**
- **Health and Happiness**
- **Beauty**
- **Equity**
- **Material**

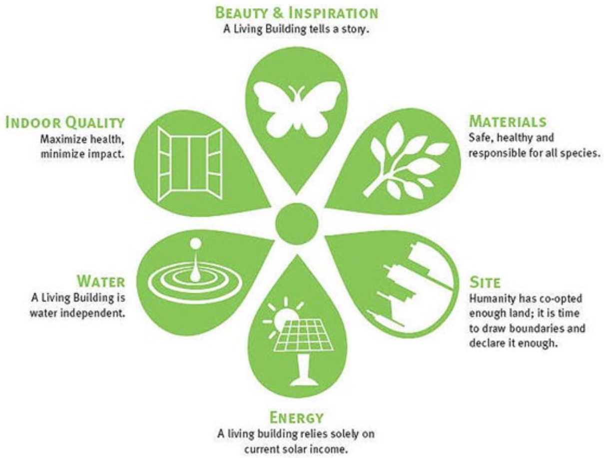


Figure 1.2: The seven discrete petals remain interconnected throughout building design and architectural considerations

Each of the Petals included in the Living Building Challenge address a specific aspect of building design, both from an architectural standpoint as well as from an engineering perspective. EcoLadder plans to provide both an overall feasibility analysis for those Petals containing more heavy engineering aspects and detailed design recommendations for the core components of these Petals. EcoLadder Environmental Consulting is tackling four of the Petals – Place, Materials, Energy & Water – each of which will play a deterministic role in the design and functionality of the proposed development as a truly ‘Living’ building. The specifics of the work covered by our firm will be covered in the Scope Section of this report.

The current Landscape Master Plan (published in 2004) has proposed an “Eco-Commons” to be developed in the northwest sector of campus. The goal of the Eco-Commons is to further the Institute’s goal of providing and maintaining a sustainable and practical urban environment within the Atlanta area. In the most recent update to the Landscape Master Plan, Georgia Tech aims to develop a green development zone that will run uninterrupted across the Institute’s campus. In November 2015, Georgia Tech received over $30 million in funding from The Kendeda Fund to add a Living Building to this green development. Of this donations, $18.6 million has been allocated for fixed construction costs with the remaining $11.4 million left for variable costs, such as labor and construction overhead. The planned location was determined for three primary metrics: encompassment by the planned Eco-Commons, opportunity for redevelopment, and access to solar energy.

1.1.1 Planned Redevelopment

The Engineered Biosystems Buildings (EBB) sector plan is a subsection of the Georgia Tech’s master plan. Last revised in 2013, the EBB sector plan aims to improve the many aspects of this section of campus, with a large focus on stormwater management and habitability, mainly through the implementation of an Eco-Commons green lawn. The key focus areas of the plan include:

- Eco-Commons & Eco-Commons Pond
- East-West Connector
- 8th Street Rain Gardens
- 10th Street Corridor

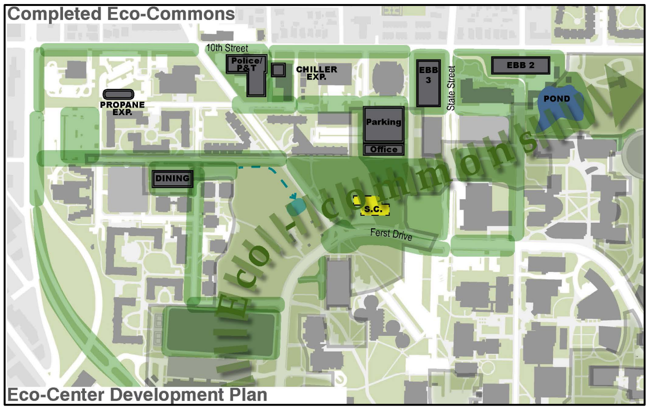


Figure 1.3: Initial redevelopment plans for the EBB sector, by the CPSM department at Georgia Tech

The EBB sector plan’s 1st stage includes the construction of the Engineering Biosystems Building on the northern edge of the sector, at the corner of 10th and State Street. The construction of this building was completed in 2015 and is open to the public. The second and third phases of the EBB sector involve the construction of two more EBB buildings adjacent to the current EBB building. In addition, the development of the Eco-Commons and the Eco-Commons pond is slated for development simultaneously. As most of the sector plans require a great deal of funding, money is a prime factor in determining if and when a certain phase of the plan gets implemented. Since the Kendeda fund has generously funded a large portion of the costs for the planned Living Building at the northeast intersection of Ferst Drive and State Street, the Living Building plan is the current focus of development in the EBB sector due to the recent contribution by The Kendeda Fund.

Not unfamiliar to high performance building standards, the Institute wishes to go beyond what is normally considered during an environmental impact evaluation & lifecycle analysis and perform a more comprehensive measure of the lifetime impact new construction will have on campus long term. The concept of a Living Building at Georgia Tech has been on the drawing board previously, but it hasn't been until recently that the funds to make such an initiative possible have been made available. Through a gracious donation by the Kendeda Fund, the Living Building at Georgia Tech is now more than an idea on paper. Pinned on the EBB sector plan simply as the "The Living Building at GT (Tentative)" until now, efforts to make this proposed edifice a reality have begun to move forward with the selection of Miller Hull in partnership with Lord Aeck Sargent (LAS) and various subcontractors to perform architectural and engineering services related to the project.

Figure 1.4: The Bullitt Center in Seattle, a similarly sized mixed used development that has received the Challenge certification. Photo by Nic Lehoux

The Living Building at Georgia Tech will be the first of its kind in the entire Southeast due to constraints that have made such regenerative structures difficult. Excessive heat and humidity in the summers pose a challenge for insulation and HVAC system design, while intermittent drought has caused problematic water shortages that create a major stumbling block for net zero water usage considerations. Overcoming these challenges is in effect the core of the problem with designing a feasible solution to the Living Building Challenge. The Institute is aiming for a Certified Living Building on campus, however even a Petal Certified structure would be a huge step forward for building design standards in Atlanta and the Southeast moreover. Figure 1.4, to the left, shows an example of a currently certified Living Building.

Student teams of architects and engineers have been presented with this problem both at the undergraduate and graduate level in an effort to curate creative and cutting edge solutions to the problems inherent to including high performance structures on campus. Meeting both these exacting codes and specifications while concurrently providing a comfortable and convenient multi-use space for students and staff is the predominant challenge associated with the Living Building project.

SITE OVERVIEW

The Institute is presented with a unique opportunity to embrace one of the most thorough and ambitious challenges available in the green building sector – above and beyond what LEED and similar no-harm building practices dictate, the Living Building Challenge sets an entirely new bar for people-place-building integration.

The adjacent Eco-Commons Lawn and moreover the Eco-Commons plan (Figure 1.5) as a whole are already in line with forward thinking green development. The Living Building at Georgia Tech would serve as a centerpiece and showroom for the accomplishments and advances made with this program.

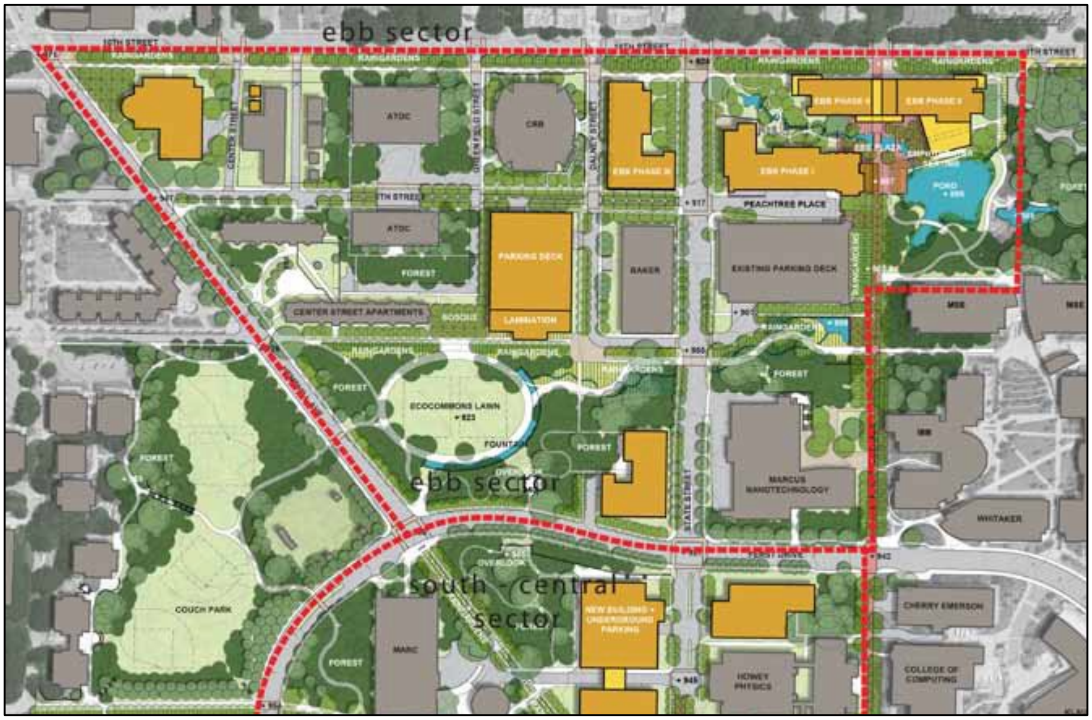


Figure 1.5: The existing EBB sector plan links greenspace throughout the North and West campus corridors

Stormwater management, water treatment, and responsible agrarian practices are all already under consideration for the EBB sector. Linking the Living Building's systems into these naturally-designed elements would ensure that this area of campus functions as a living, breathing space functional for both productivity and recreation.

The focus of this report is on the feasibility of locating a Living Building between the existing Marcus Nanotechnology Building that serves as the departmental headquarter for the Institute for Electronics and Nanotechnology at 345 Ferst Drive Northwest, and the current Greek Affiliated housing structure that stands at 401 Ferst Drive Northwest, depicted in Figure 1.6.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 1.6: Current site conditions as of February, 2016, showing the Eco-Commons potential area outlined in red

Much of the area proposed for renovation and redevelopment currently exists as a severely underutilized grey field, one of the larger remaining surface parking lots left on the Institute campus. Through a holistic approach in designing livability of this area, it will become more pedestrian friendly while contributing towards restoring and preserving the natural environment.

PROJECT SCOPE

The scope of this project was configured into two dependent categories: integration with the local environment while maintaining standards set by Georgia Tech's design & construction 'Yellow Book,' and major building systems. Broken down by Petal, our analysis includes aspects of each that are fundamental to achieving the Living Building Challenge.

Many of these bullet points are orchestrated in compliance with the Living Building Challenge's standards. They aim to integrate the existing and proposed systems inherent to the Eco-Commons Master Plan as well as the more specific functions included in the EBB Sector Plan with the goals and petals laid out by the Living Building Challenge.

Local Environment:

- Place Petal
    - Floor Area Ratio (FAR) Calculation
        - Living Transect determination
    - Limits to Growth
        - Flood map and landscape suggestions
    - Urban Agriculture
        - Percentage requirement based on FAR

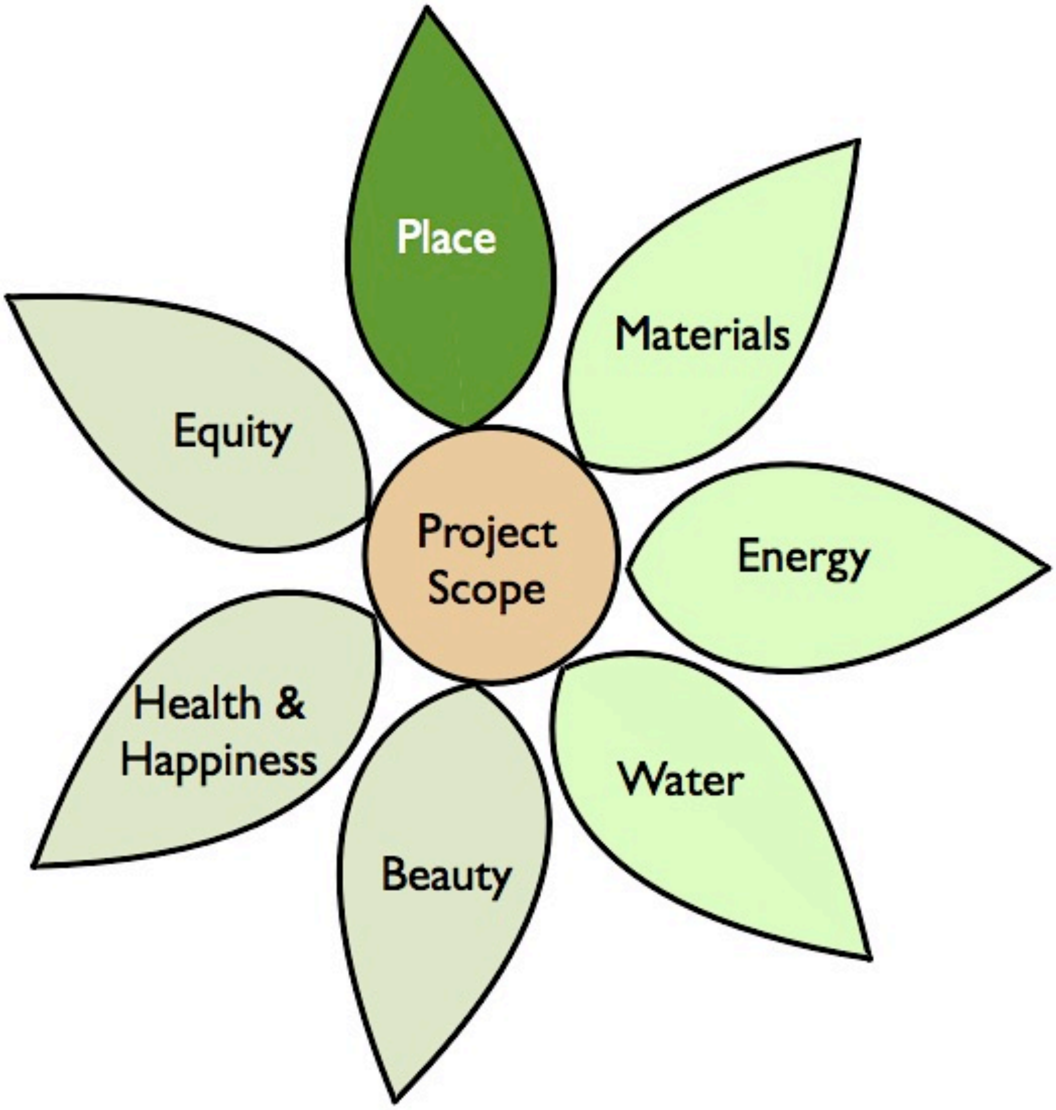
Building Systems:

- Materials Petal
    - Red List Compliance
    - Embodied Carbon Footprint
    - Responsible Industry
        - Sourcing salvaged materials
    - Living Economy Sourcing
        - Manufacturer locations map
    - Net Positive Waste
        - Construction waste diversion plan
- Energy Petal - 105% of annual energy needs provided locally
    - Renewable energy options and cost analysis
        - Projected loads, PV sizing, and storage systems
- Water Petal - 100% of project needs must be supplied by on-site
    - Water balance diagram
    - Stormwater calculations

2.0

The Place Petal

Site Situation



EXISTING CONDITIONS

Although much of the evaluated area is covered by surface parking lots, there are two buildings within the proposed Eco-Commons boundaries that are slated for deconstruction prior to redevelopment. The Gary F. Beringause Building that serves at the headquarters for the Georgia Tech Police department was opened in 1981, and 401 Ferst Drive, a Greek Housing structure, was built in 1942. Both of these structures, captured in Figure 2.1, satisfy the definition of 'Previously Developed' as outlined by the Place Petal Handbook for the Living Building Challenge, categorizing the area of interest as a greyfield.

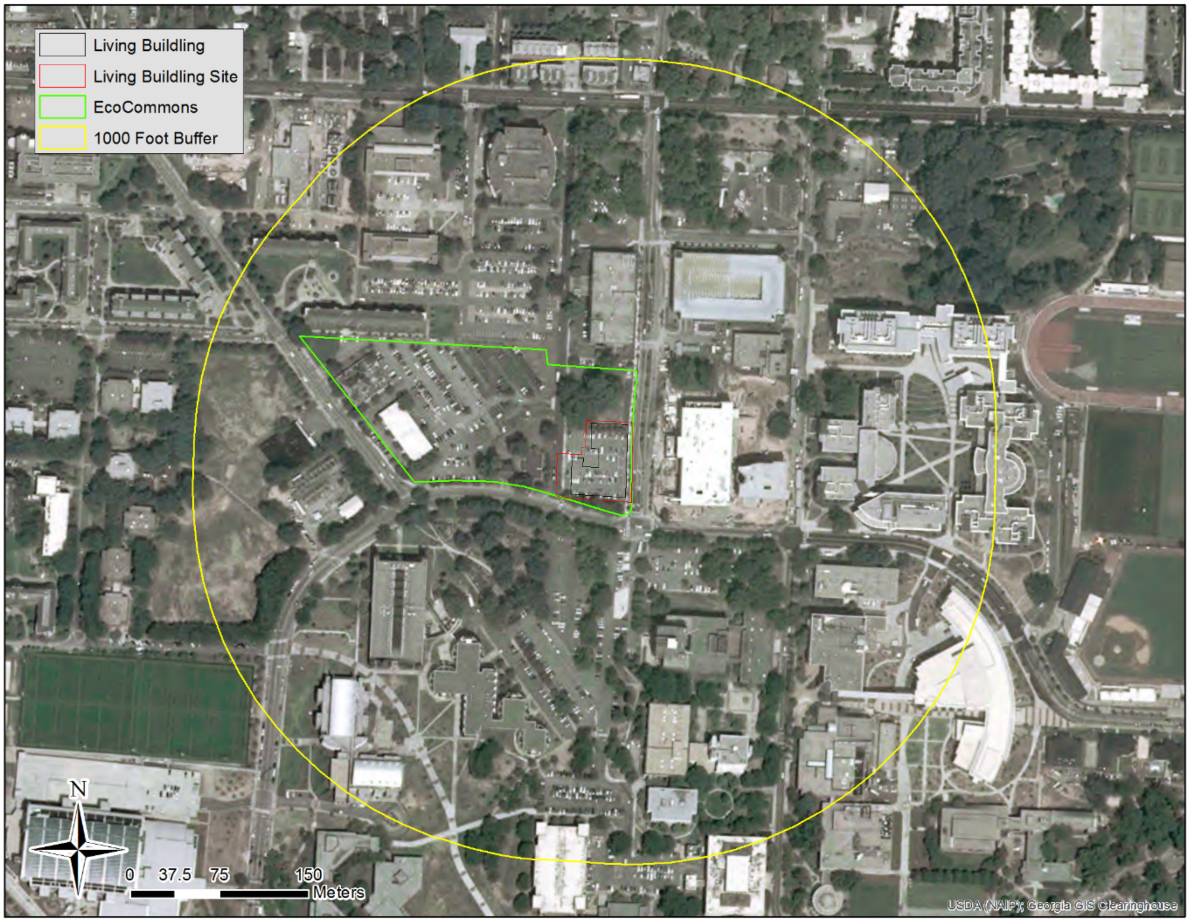


Figure 2.1: Imagery from 2007 showing the vicinity of campus with a 1000-foot buffer from the proposed building site

Redevelopment of this part of campus would have little effect on the operation of buildings and services not already planned for relocation due the disjointed nature of the area.

EXISTING CONDITIONS

Satellite imagery from 2007 (Figure 2.2) shows the lack of greenspace and overall low density of this sector of campus. High resolution imagery was not available for this time period. Replacing the large surface parking lots with further mixed used educational space and a green area that provides water retention and early filtration would be a marked improvement in the ecological functionality of the locality. In addition, the planned Eco-Commons lawn adds valuable recreational space that can be used for both passive and active pursuits.

Figure 2.2: Satellite imagery from 2007 illustrating the prevalence of asphalt paving throughout the property

Due to the largely residential nature of the immediate vicinity, replacing surface parking with an adjacent high density multi-level parking deck and utilizing the available space for greenery and recreational facilities would strengthen the close-knit community feel of the area and serve to break up the expanse of concrete and asphalt that is endemic to urban Atlanta.

EXISTING STRUCTURES

Two buildings currently stand within the area of interest for this project. Both were occupied and fully operational before December 31, 2007 as required for the ‘Previously Developed’ designation laid out in the Living Building Challenge standards. Figure 2.3 below satisfies this Documentation requirement.

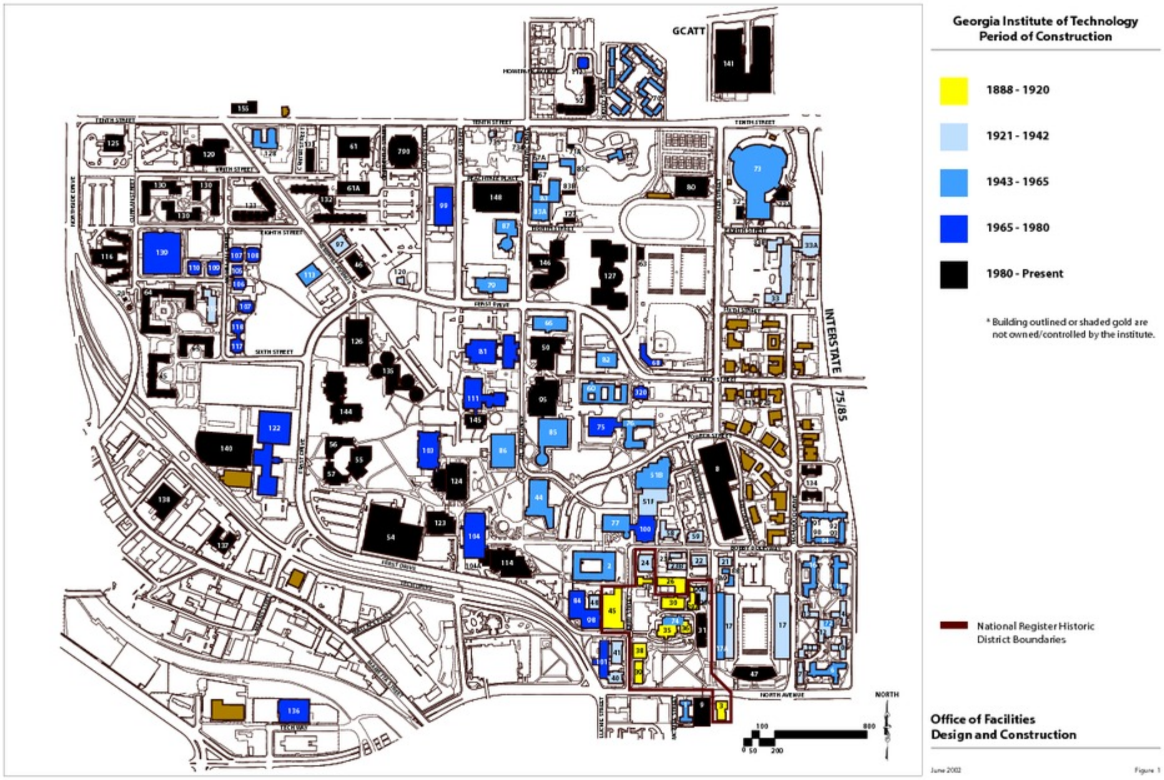


Figure 2.3: Construction planning documents from 2002 showing both the Beringause (46) and the Greek Housing (120) buildings by construction period

The Beringause building, the current police headquarters, was built and occupied in 1981, undergoing renovation in 2009. The current EBB Sector plan has the police headquarters relocated to the corner of 10th Street NW and Hemphill Avenue. The Greek affiliated housing is slated for demolition along with the current police station. This building (401 Ferst Drive) was constructed in 1942, with occupancy beginning in 1967. The structure has not been renovated since initial construction. Figures 2.4-2.6 show these buildings as they look currently.

EXISTING STRUCTURES

Figure 2.4: An aerial view of the current site conditions. Increasing parking density is fundamental to the renovation plans outlined in the EBB sector plan

Georgia Tech Capital Planning & Space Management

Figure 2.5 (left): Alpha Phi Omega, Gamma Zeta Chapter building as viewed from Ferst Drive looking Northeast

Figure 2.6 (right): The Gary F. Beringause Building serving as the Georgia Tech Police Department's headquarters, viewed from Hemphill Avenue looking East

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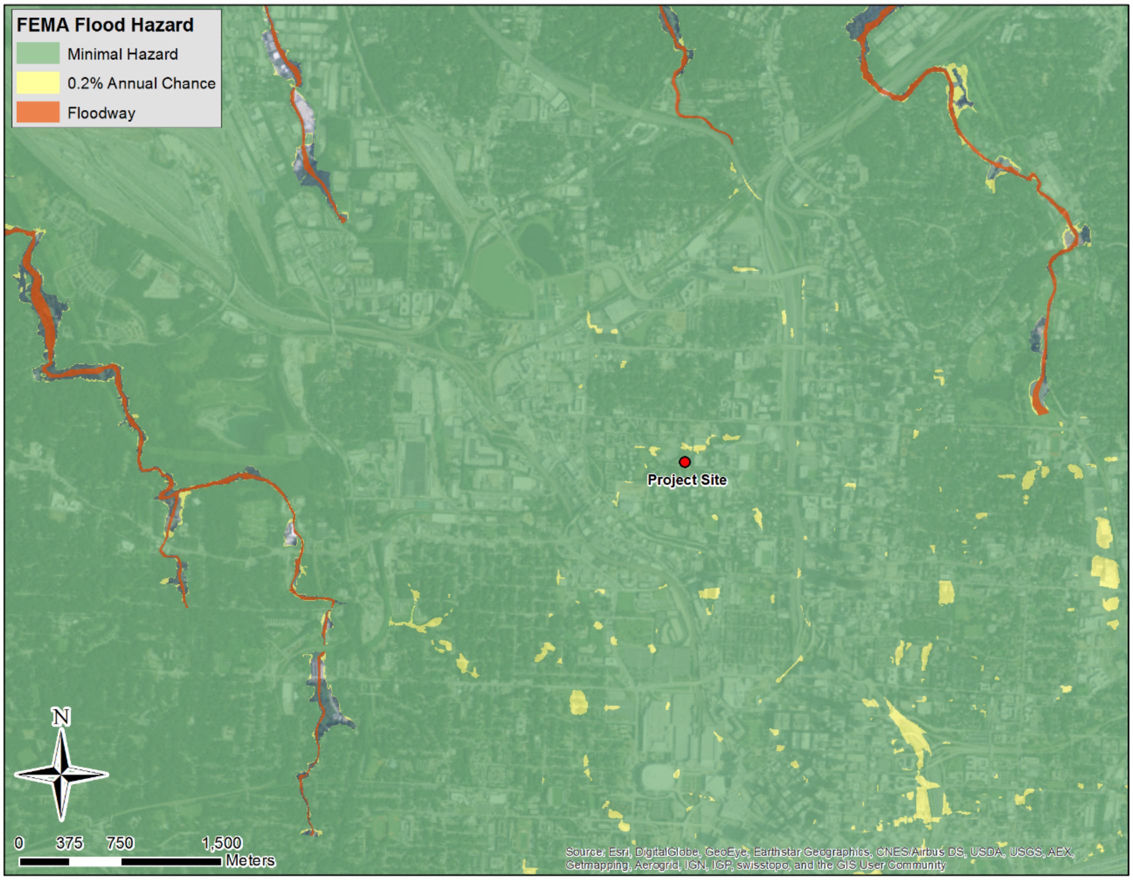
FLOOD HAZARD

As per the Living Building Challenge Documentation requirements for the Place Petal, Limits to Growth Imperative (I01-2), an analysis of the potential flood hazards was conducted for the building site and project area moreover. Although the available information pertaining to the flood hazard of low risk sites such as the area for the proposed Living Building is not particularly fine grained, it is enough to verify that the location of interest resides in a minimal flooding hazard zone. Within this extent there are small areas that have been documented with a 0.2% chance of annual flooding hazard, still well below the Living Building Challenge Standard of avoiding 100-year flood zones, a 1.0% annual chance of flooding. Figure 2.7 satisfies this requirement.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 2.7: Overview of the nearest FEMA designated Floodways – areas that are considered 100-year flood zones

The nearest flooding zone to the proposed building location is approximately 2.35 kilometers in distance, with additional floodways between 2.5 and 2.75 kilometers away.

FLOOD HAZARD

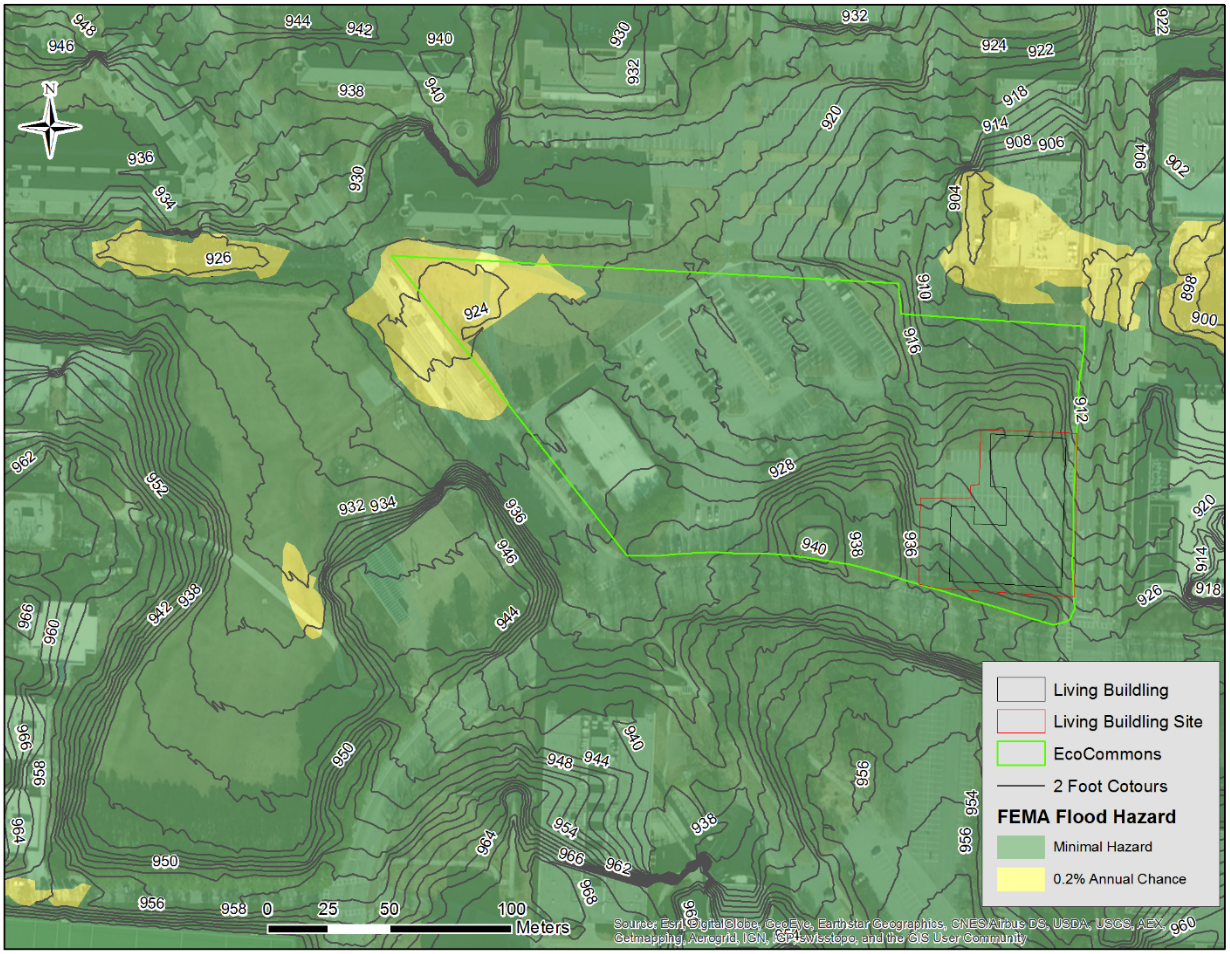
Considering the more immediate vicinity of the proposed building location reveals an area of 0.2% annual chance of flooding present in the Northwest corner of the project boundary. Figure 2.8a shows the flood hazard for the Eco-Commons area.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 2.8a: FEMA classification of the flooding hazard in the vicinity of the proposed building site

The Stormwater Master plan has already provided solutions for dealing with surface runoff throughout this sector, including a naturalized retention and detention infiltration area at the West edge of the project boundary. In addition, diversion to a larger pond further East of this extent is planned through the inclusion of a manufactured streambed near the North edge of the surface parking lot occupying proposed Living Building location. This stream bed follows the path of a historic stream in alignment with revitalizing the natural ecosystem throughout the area.

When viewing the site and the FEMA flood area map with a topographic overlay, (Figure 2.8b) the cause for certain points' designation as other than minimal hazard becomes more apparent. The relatively low lying sections of the property are subject to a non-negligible annual chance of flooding.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 2.8b: Two foot topographic contours overlaid with the FEMA flood hazard map illustrate probable areas of accumulation

Special consideration will be needed when designing the catchment systems for this area. Strategically placed bioswales and other low height but dense ground cover should be used to prevent excessive runoff velocities, while diversion systems should account for the probable variation in water collection due to elevation differences throughout the site. Proper collection for the site's planned cisterns in addition to efficient diversion to the larger EBB retention pond is necessary to ensure adequate drainage of the Eco-Commons Lawn and surrounding locality.

LANDSCAPE NARRATIVE

Figure 2.9: Renderings of the vegetation dense Eco-Commmons corridor, specifically the bioswales proposed to border the Eco-Commmons Lawn. Courtesy of GT CPSM

The landscape adjacent to the Living Building at Georgia Tech's project area is part of a larger campus landscape planning sector, the Eco-Commmons. The existing landscape conditions on the site include some native plants as part of the campus' urban landscape theme, light tree cover and small shrubbery alongside pedestrian sidewalks. The site is composed predominantly of greyfield and otherwise underutilized land. Preliminary geotechnical analysis based on boring samples from across the site conducted by Professional Service Industries Incorporated indicate that little to no pollutants exist in concerning quantities, pointing to the absence of chemical or other industrial spillage. These results allow redevelopment to move forward without any prerequisite site remediation.

Georgia Tech's Capital Planning and Space Management (CPSM) department has developed a comprehensive landscape plan (Figure 2.9) for the Eco-Commons sector, which include various plant and tree types that fit within Georgia Tech's urban landscape theme. Georgia Tech is home to over 100 species of trees. The Eco-Commons will add further variety and increased biodiversity across campus, with interconnected pedestrian pathways and corridors designed to work in tandem with new landscaping.

Figure 2.10: Existing naturalized hydrologic features in the EBB sector

The plant typologies and planting strategies outlined in the Landscape Plan and CPSM's EBB Sector Plan take into consideration available sunlight, tree canopy cover near pedestrian areas, and also optimal plant selection to minimize stormwater runoff while adding native or non-invasive plant typologies that can be easily managed.

Georgia Tech uses various natural systems (Figure 2.10) to reduce potable water consumption for landscape maintenance in consideration of intermittent drought and other regional climate challenges. Some of these natural systems such as rain gardens, bioswales, and bioretention cells, provide both stormwater drainage management as well as educational opportunities to students from various disciplines on campus.

LANDSCAPE PLAN

A detailed landscape plan is necessary to ensure proper assimilation of the building with its surroundings while still achieving the highest level of Imperative and campus standard compliance. By knowing the existing Eco-Commons plant and vegetation compositions, the Living Building at Georgia Tech can be in better harmony with native flora. Georgia Tech has a clear and comprehensive list of standards for Eco-Commons operations, which will be heavily utilized in the Place Petal. Looking into the Campus Master Landscape and the EBB Sector Report in particular, EcoLadder was able to analyze the existing and future tree canopies, hydric planting, and recommended plants and planting methods.

A schematic of the existing and future tree canopy is pictured in Figure 2.11. As shown, there are currently small amounts of tree cover in the Eco-Commons, but will soon be expanded by the addition of many new trees and flora.

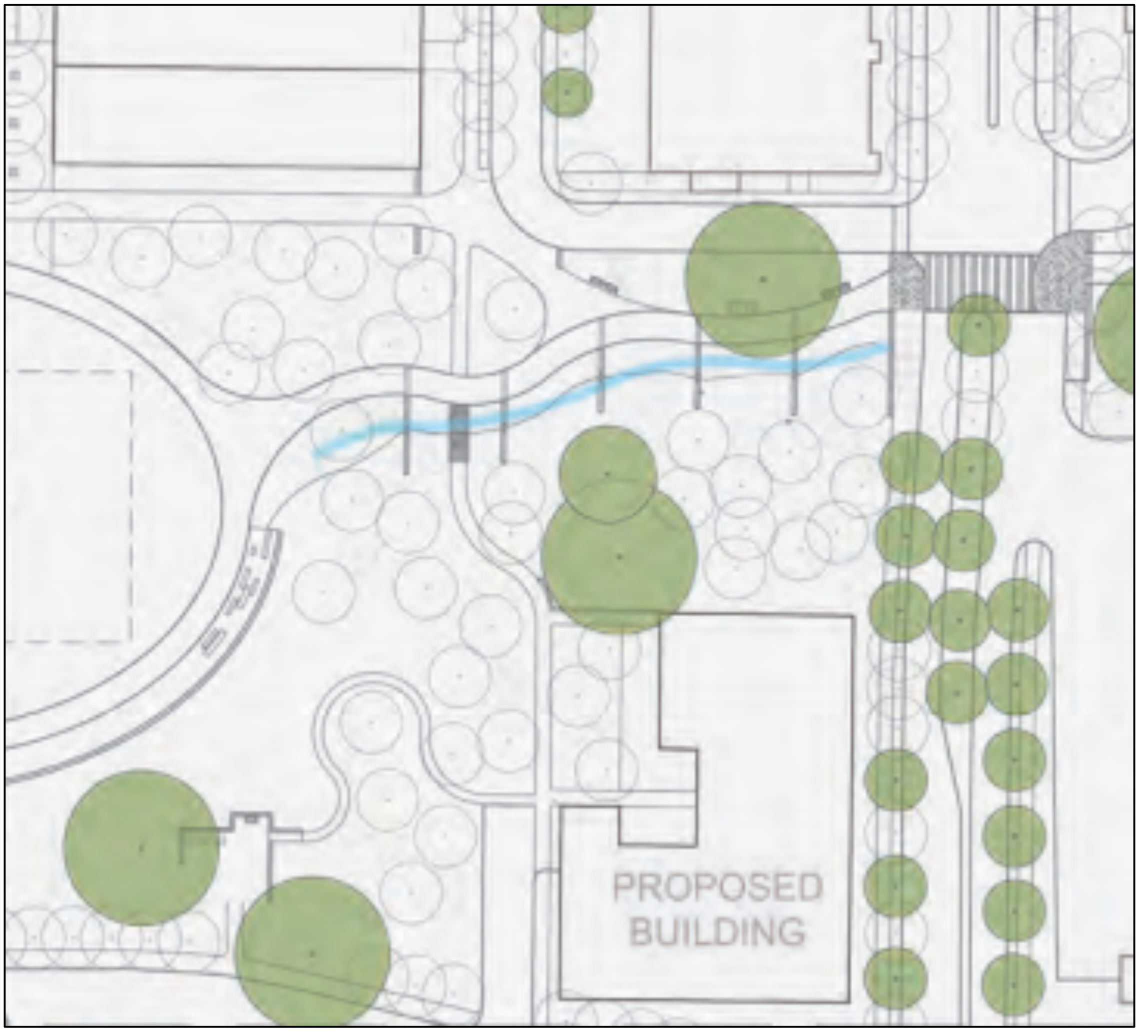


Figure 2.11: Green circles depict the existing tree canopy while transparent circles depict future canopy (Sourced from EBB Sector Report)

The immediate area surrounding the Living Building at Georgia Tech will be comprised mostly of mesic and xeric plants, which include upland and dense forest regions as depicted in Figure 2.12 and Figure 2.13. The upland forest refers to the trees that dominate the hillside and stabilize steep slopes. These species are planted densely and range in size from 5-gallon saplings to 2' caliper trees. A "dense" forest in this case is achieved with the maximum amount of plant species and an average tree spacing that varies between 10-30 feet. A combination of upland typology and vegetation density will give a better understanding of planting.

As previously mentioned, the area of land proposed for the Living Building has a unique landscape from other areas in the Eco-Commons - therefore requiring a different plant community. Since the building is oriented on corner of Ferst Drive and State Street, this area will feature plants from the "State Street- Eco-Commons Threshold" depicted in Figure 2.14 on the next page. These plants have been selected from the Georgia Tech Landscape Master Plan based on their native and naturalized properties and ability to thrive in this type of environment.

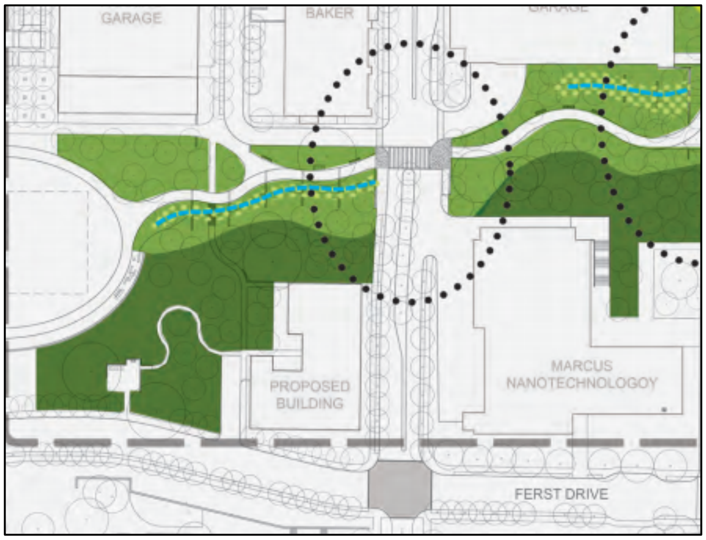


Figure 2.12. The dark green area surrounding the building area encompasses mesic and xeric planting of upland and forest areas (Sourced from EBB Sector Report)

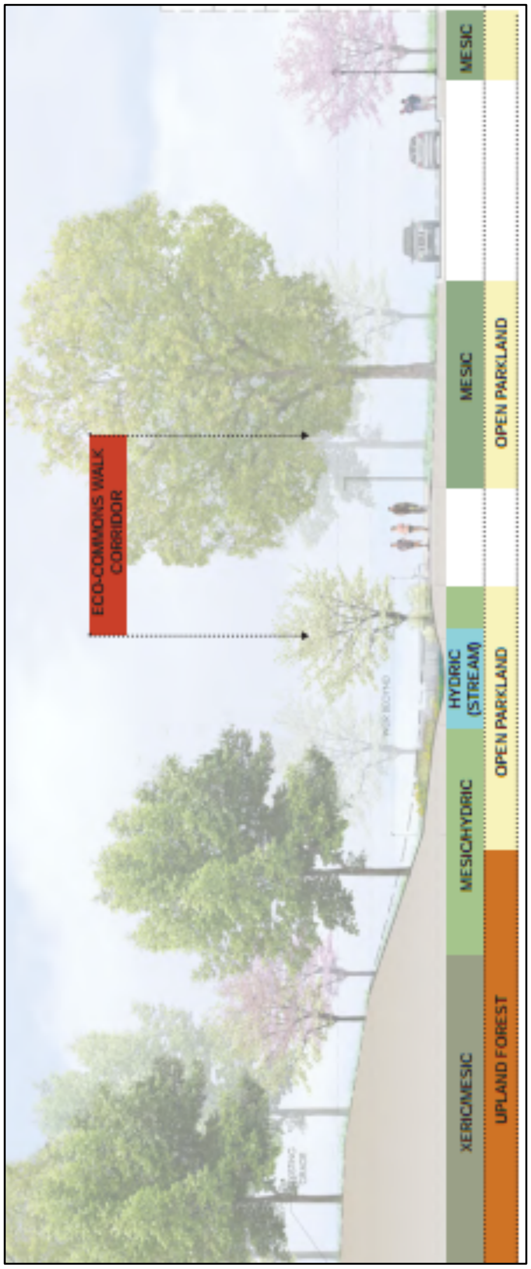
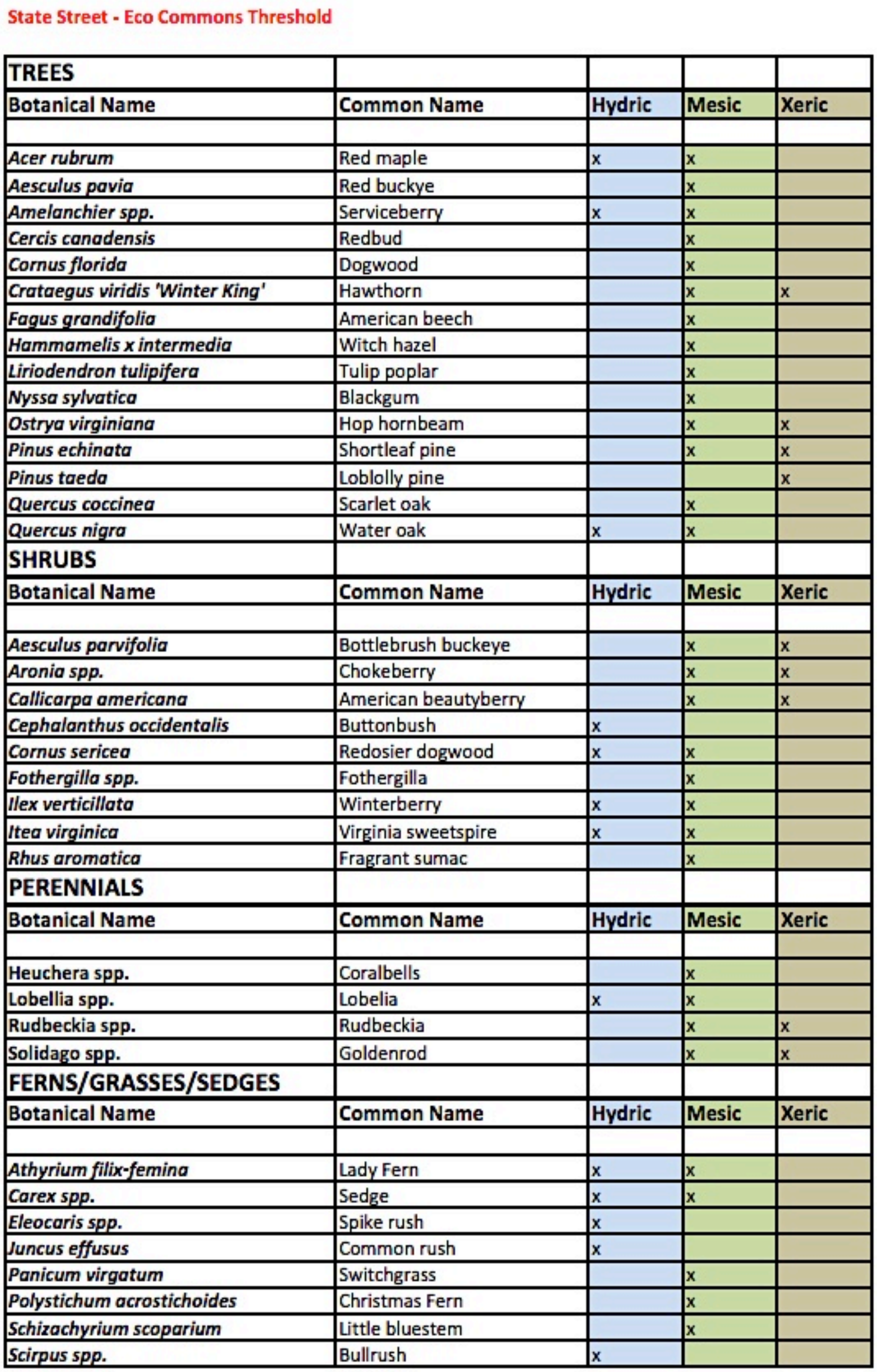


Figure 2.13. Illustrates the upward slope and vegetation associated with the upland forest (Sourced from EBB Sector Report)



State Street - Eco Commons Threshold

TREES				
Botanical Name	**Common Name**	**Hydric**	**Mesic**	**Xeric**
Acer rubrum	Red maple	x	x	
Aesculus pavia	Red buckye		x	
Amelanchier spp.	Serviceberry	x	x	
Cercis canadensis	Redbud		x	
Cornus florida	Dogwood		x	
Crataegus viridis 'Winter King'	Hawthorn		x	x
Fagus grandifolia	American beech		x	
Hammamelis x intermedia	Witch hazel		x	
Liriodendron tulipifera	Tulip poplar		x	
Nyssa sylvatica	Blackgum		x	
Ostrya virginiana	Hop hornbeam		x	x
Pinus echinata	Shortleaf pine		x	x
Pinus taeda	Loblolly pine			x
Quercus coccinea	Scarlet oak		x	
Quercus nigra	Water oak	x	x	
SHRUBS				
Botanical Name	**Common Name**	**Hydric**	**Mesic**	**Xeric**
Aesculus parvifolia	Bottlebrush buckeye		x	x
Aronia spp.	Chokeberry		x	x
Callicarpa americana	American beautyberry		x	x
Cephalanthus occidentalis	Buttonbush	x		
Cornus sericea	Redosier dogwood	x	x	
Fothergilla spp.	Fothergilla		x	
Ilex verticillata	Winterberry	x	x	
Itea virginica	Virginia sweetspire	x	x	
Rhus aromatica	Fragrant sumac		x	
PERENNIALS				
Botanical Name	**Common Name**	**Hydric**	**Mesic**	**Xeric**
Heuchera spp.	Coralbells		x	
Lobellia spp.	Lobelia	x	x	
Rudbeckia spp.	Rudbeckia		x	x
Solidago spp.	Goldenrod		x	x
FERNS/GRASSES/SEDGES				
Botanical Name	**Common Name**	**Hydric**	**Mesic**	**Xeric**
Athyrium filix-femina	Lady Fern	x	x	
Carex spp.	Sedge	x	x	
Eleocaris spp.	Spike rush	x		
Juncus effusus	Common rush	x		
Panicum virgatum	Switchgrass		x	
Polystichum acrostichoides	Christmas Fern		x	
Schizachyrium scoparium	Little bluestem		x	
Scirpus spp.	Bullrush	x		

Figure 2.14: Planting standards on State Street and their associated typology (Sourced from EBB Sector

2.7.1 Supportive Climate

According to the Georgia Farm Bureau, “Georgia is blessed with a climate that allows tremendous opportunities for farmers.” With average temperatures ranging from highs of 90°F and lows of 30°F, along with consistent regional rainfall of about 50 inches per year, Georgia’s climate provides some flexibility to the project’s potential urban agriculture solutions. Despite an encouraging average annual rainfall, Atlanta struggles with intermittent droughts, which pose further constraints on the Water Petal. The project area provides open space and the means to take advantage of the sunlight and rainfall as well due less intensive urban development in the area. With a very strong existing agricultural infrastructure combined with the availability of diverse soils and crops, there are a lot of options for urban agriculture solutions.

2.7.2 Harvest Plan

Georgia Tech’s diverse community allows for various harvesting plans and distribution for students on campus, while also providing educational opportunities. Georgia Tech Dining Services has initiatives to provide students with fresh, local, and sustainable food, and already uses honey harvested from on campus bee farms (Figure 2.16), herbs from a small garden at the Wenn Student Center, and the Georgia Tech Farmer’s Market. There are also various urban agriculture and localism efforts in Atlanta that aim to connect communities with local produce in their urban center. Figure 2.15 shows a potential planter box configuration.

All this considered, the infrastructure of Georgia Tech and various success-stories and case studies in the greater Atlanta area create various opportunities for consistent harvesting and utilization of crops.

Figure 2.15: Harvestable planter boxes for urban agricultural needs

2.7.3 Recommendations

The project's required urban agriculture requirement is 6,375 square feet, or the equivalent of 60% of the project roofing. Considering the Energy Petal and other possible limitations such as a smaller roof design, EcoLadder recommends Scale Jumping as defined by the Challenge and using a space adjacent to the building or within the Eco-Commons dedicated to urban agriculture.

One possible option for produce would be bee farming, which is already implemented at Georgia Tech with existing infrastructure for harvesting and distribution. Studies from the Research and Education Garden at the University of Georgia provide a laundry list of optimal native flower and plant species for bee farming and other insects.

Figure 2.16: Bee harvesting though the Urban Bee Project

TRANSECT DEFINITION

The location of the Institute in relation to the downtown core of Atlanta and moreover the metropolitan area in which the campus resides makes for an interesting fundamental choice in the designation of a Living Transect for the project. The Transect designation will affect multiple aspects of the project, most importantly height limitation and indirectly the amount of edible urban agriculture that will be required on site. Example Transects are depicted in Figure 2.18.

Two possible Transect definitions could be applied to the Living Building at Georgia Tech depending on the definition of the project area. The Transect is determined through a simple ratio: gross square footage of building area divided by the total project area. This Floor Area Ratio (FAR) determines the necessary project area dedicated to agriculture, therefore limits the amount of area that could be used for systems that satisfy other Petal Challenges: namely the Net Energy Positive and Net Water Zero initiative. The project area includes not only the building footprint area of disturbance, but also any remote (but connected) area used to satisfy Challenge Imperatives. In addition, the construction staging area used as well as conveyance area used for hydrologic diversion.

With this calculation posing such a foundational and pivotal point in the project design, special care must be taken to choose the Transect that will best meet the needs of the building while still satisfying Challenge Imperatives. The Institute's campus is unique in that it remains a traditional college grounds while also being located adjacent to Midtown Atlanta and in close proximity to the urban core of Downtown Atlanta. As such, the ability to be designated as Living Building Transect L3 (Village or Campus Zone) or L4 (General Urban Zone) presents itself; dependent on the amount of land used during construction and the selected height of the eventual Living Building at Georgia Tech. An L4 designation would lead to 20-25% of the project area being used for crop production, while the L3 definition requires at least 30% of the total area to be used for the same purpose.

Figure 2.17: A graphic representation of Transects as defined by Duany Plater-Zyberk & Company

Keeping these figures in mind while considering the additional limitations placed on area use by the Water and Energy Petals, it would be beneficial to leave as much of the building's roof area available for energy production through photovoltaics as possible. Some Imperatives can be satisfied through Scale Jumping, which would alleviate some of the pressure in energy production posed through certain Transect designations.

2.8.1 Transect L3 – Village or Campus Zone

Perhaps most in the spirit of the Challenge would be the L3 transect title - indeed the Living Building will be residing on a college campus. However, due to space limitations in addition to the previously planned uses for the Eco-Commons field of development, the amount of space needed for edible crop planting would exceed that which would be feasible for the current vision outlined in the EBB sector plans.

For the L3 Transect, a maximum FAR of 0.49 is listed with a minimum FAR of 0.1. Using the entire area of the Eco-Commons outlined in Figure X and the 42,500 gross square foot target given by the existing Living Building Program Documentation, a FAR of 0.15 results. The area needed for agriculture at this figure exceeds 100,000 square feet, a sizeable amount of the available area.

2.8.2 Transect L4 – General Urban Zone

With a FAR limitation of 0.5 to 1.49, this Transect allows for between 28,500 and 85,000 square feet of project area. A four story Living Building (the minimum height requirement for this Transect designation) leaves at most nearly 75,000 square feet of available project area and a minimum of nearly 18,000 square feet. The smaller of the two values would leave less than 8000 square feet available for construction and conveyance, but would still be feasible. Table 2.1 following summarizes the FAR bounds and resulting available square footage.

Figure 2.18: Comparison of the agriculture requirements between an L3 and L4 Transect designation

Table 2.1: Comparing unallocated usable space after Transect selection

Transect	Minimum Agriculture Requirement	FAR Bound	Allowable Project Area*	Agriculture Area* Requirement	2 story Remaining Area*	3 story Remaining Area*	4 story Remaining Area*
L3	35%	0.10	425000	148750	255000	262083	265625
		0.24	177083	61979	93854	100938	104479
	30%	0.25	170000	51000	97750	104833	108375
		0.49	86735	26020	39464	46548	50089
L4	25%	0.50	85000	21250	-	-	53125
		0.74	57432	14358	-	-	32449
	20%	0.75	56667	11333	-	-	34708
		0.99	42929	8586	-	-	23718
	15%	1.00	42500	6375	-	-	25500
		1.49	28523	4279	-	-	13620

* All areas provided in square feet.

2.8.3 Transect Recommendation

With the previously stated goal being to maximize the project are while minimizing urban agriculture requirements, the obvious inflection points occur at the bounds of each Transect FAR limits. Within each Transect, there are further dichotomies for the minimum required percentage of land used for agriculture. Holding the Living Building gross square footage constant, Figure 2.19 illustrates the Imperative requirements at these intersections. Minimizing the agriculture requirement through selecting an L4 Transect designation would only prove to be effective if the project area is minimized. The potential for optimization lies at either end of a FAR bound, in a four-story building placed at the proposed location, a FAR of 1.0 would show maximum benefits.

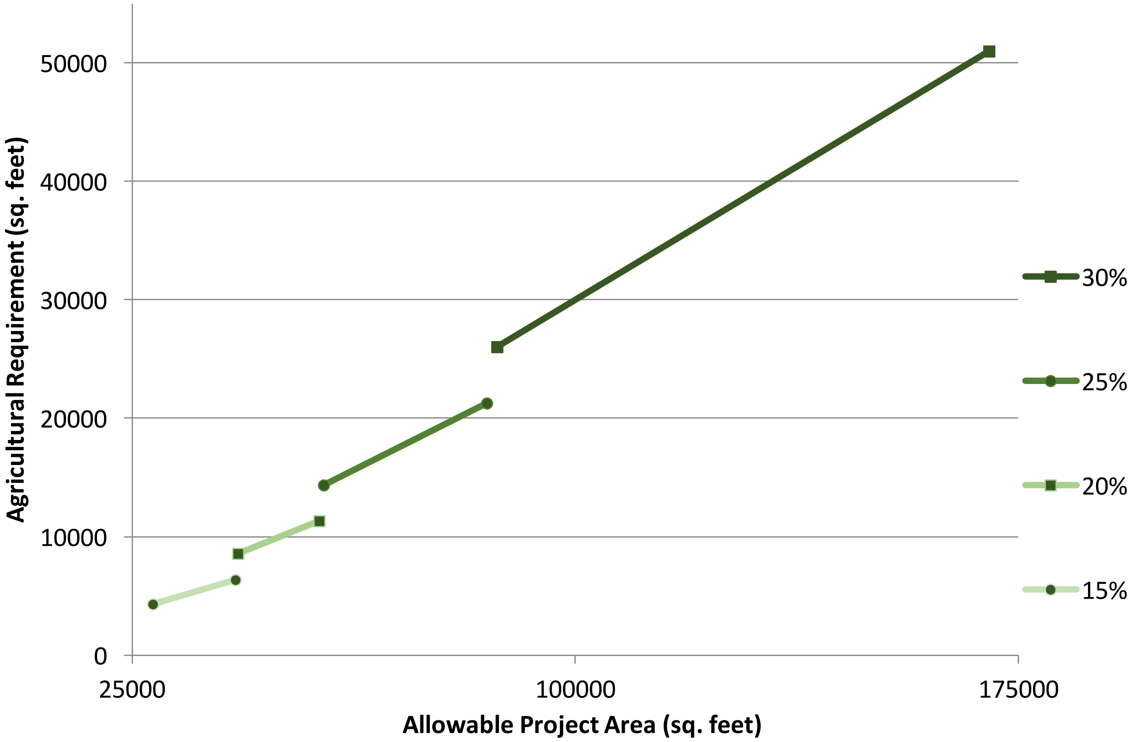


Figure 2.19: The resulting step function from the Living Building Challenge's linear relation between project area and building square footage for a structure in the L4 Transect

Since the specific site area has not been determined yet, and cannot be determined until more concrete plans are obtained for the building, an accurate FAR cannot be established. In addition, the Living Building Challenge allows for the site area to be variable and adjusted to the projects need. An FAR of 1.0 would place the Living Building needing an urban agriculture requirement of 15% (of the project site total). This FAR would result in an L4 transect, requiring a four story structure. Architects are free to design large open floors for the lower stories, while creating smaller upper stories that can open up into the roof garden spaces that are planned, making great use of extra roof space.

The intent of the Place Petal and its Imperatives is to prevent new construction and development from disturbing the natural environment. Instead, focusing on integrating more densely populated multi-use complexes within existing ecosystems and revitalizing historical natural networks is paramount during design and construction. The Living Building should work in harmony with its local environment; broad swaths of impermeable surfaces and artificially constructed landscapes need to be avoided. Maximizing the performance of the landscape for hydrologic diversion, urban agriculture, and human enjoyment is key to the Place Petal.

Limits to Growth:

Part of the preliminary site selection and design is ensuring that no natural hazards exist to threaten the longevity of the building. Constructing on flood plains is prohibited, save for the highest density Transect designations. The site must meet the Previously Developed requirements – it is the goal of the Challenge to convert grayfield and brownfield sites into community centers that offer communal amenities to the surrounding neighborhoods. Listed among the Imperatives is the protection of sensitive ecological areas. Historically, developments have altered areas like wetlands, lowlands, and floodplains to meet the needs of the planned construction with little regard for the impact on wildlife and hydrology. By ensuring that such areas are not compromised by new development and alternatively are rejuvenated to best perform their original function, a return to historically optimal functions of these projects is possible.

The land on which the proposed Living Building will be built has experienced a large degree of artificial landscaping in the form of lot leveling – these efforts have disrupted the original water flow through the sector, leading to occasional flooding of the intersection of Hemphill Avenue & Fest Drive and the Couch Park Fields. The inclusion of manufactured bioswales and streambeds in the Landscape Master Plan has already addressed some of these issues, while planned and existing rainwater collection cisterns help to alleviate the potential for flooding during storms. By integrating the Living Building's water systems with these available water sinks and construction additional capacity for rain and stormwater catchment, the Building can further act to attenuate runoff that would be diverted to the Eco-Commons Pond behind the President's House. Treatment and use of this collected water is discussed in the Water Petal recommendations section.

Urban Agriculture:

Satisfying the Urban Agriculture requirement of the Petal is dependent on the project's Transect Designation. Less dense Transects require a smaller percentage of agriculture, although all designations allow for the possibility of Scale Jumping. The remaining percentage of the roof space not used to meet the solar energy needs that is subsequently outlined in the Energy Petal will be used to house the green roof. Urban agriculture that will not fit on roof will be scale jumped to the nearby Eco-Commons. Vertical gardens will also contribute to this percentage of on-site urban agriculture. Figure 2.20 displays a vertical gardening technique that can utilized in the exterior commons at the base on the building.

Figure 2.20: Example of a vertical garden

Atlanta already subscribes to many progressive ideals regarding the inclusion of urban agriculture: a multitude of local farmer's markets and regional supplier outlets currently exist to curb the dependence on the global food market for those that choose to pursue the Live-Work-Eat local attitude. Georgia Tech presently hosts a small vendor market for local growers and produces, and has an in-house program to facilitate the transition to this paradigm: the Urban Honey Bee Project provides hands-on educational experiences with local agriculture advancement and should act as a model for the manner in which urban agriculture at the Living Building is presented to both students and the public. Deriving lessons on sustainability from effective programs such as this should be cornerstone to the implementation and distribution of food products sourced on campus.

Habitat Exchange:

The Habitat Exchange Imperative of the Petal calls for the preservation or rehabilitation of wildlife environments in the vicinity of the development. Habitat fragmentation in urban settings is rampant and can be combated by including densely vegetated and connected Forrest zones within the property boundaries.

Georgia Tech's CPSM has provided initial planting schemes to make the transition from heavily trafficked pathways and local commute routes to less accessible naturally-functioning areas seamless. Utilizing these schemas during the landscape planning for the Living Building should maintain constancy with existing development throughout the EBB sector. This can all be put in place in addition to the purchase of Habitat Offsets as required by the Challenge.

Human Powered Living:

The more architecturally focused inclusions of this Petal pertain to advancing and promoting the carless commute possibilities for patrons of the building. The Living Building at Georgia Tech aims to be the hub of the walking, running, and biking community associated with the entire campus & beyond, as well as the local Eco-Commons. The building is conveniently placed on the path of the Institute's 'Pi Mile,' as well as in close proximity with the Beltline entrance at Piedmont Park, making the Living Building a destination for runners and bikers who need access to water fountains, rest stations or storage and service for bikes (Figure 2.21).

Recent years have shown the Campus's biking infrastructure to be lacking. Overcrowded bike racks lead to bikes being locked to handrails and fences, often blocking pedestrian walkways. Planning not only for the 15% occupancy capacity goal set by the Challenge but for additional bike parking to be used by other office and residential structures in the surrounding area can diminish logistical issues associated with the increase in non-traditional transportation modes. Providing amenities that cater to these commuters such as showers and covered bike parking further enhance the Human Powered Living themes presented by the Challenge. In addition, the new parking structure in the adjacent Eco-Commons should provide ample outlets for EV charging as well as supplementary covered bicycle and moped parking areas.

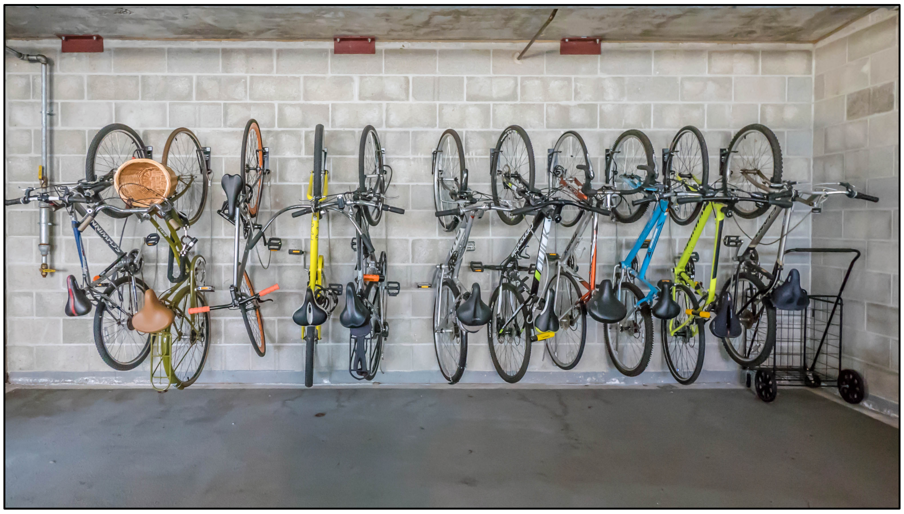
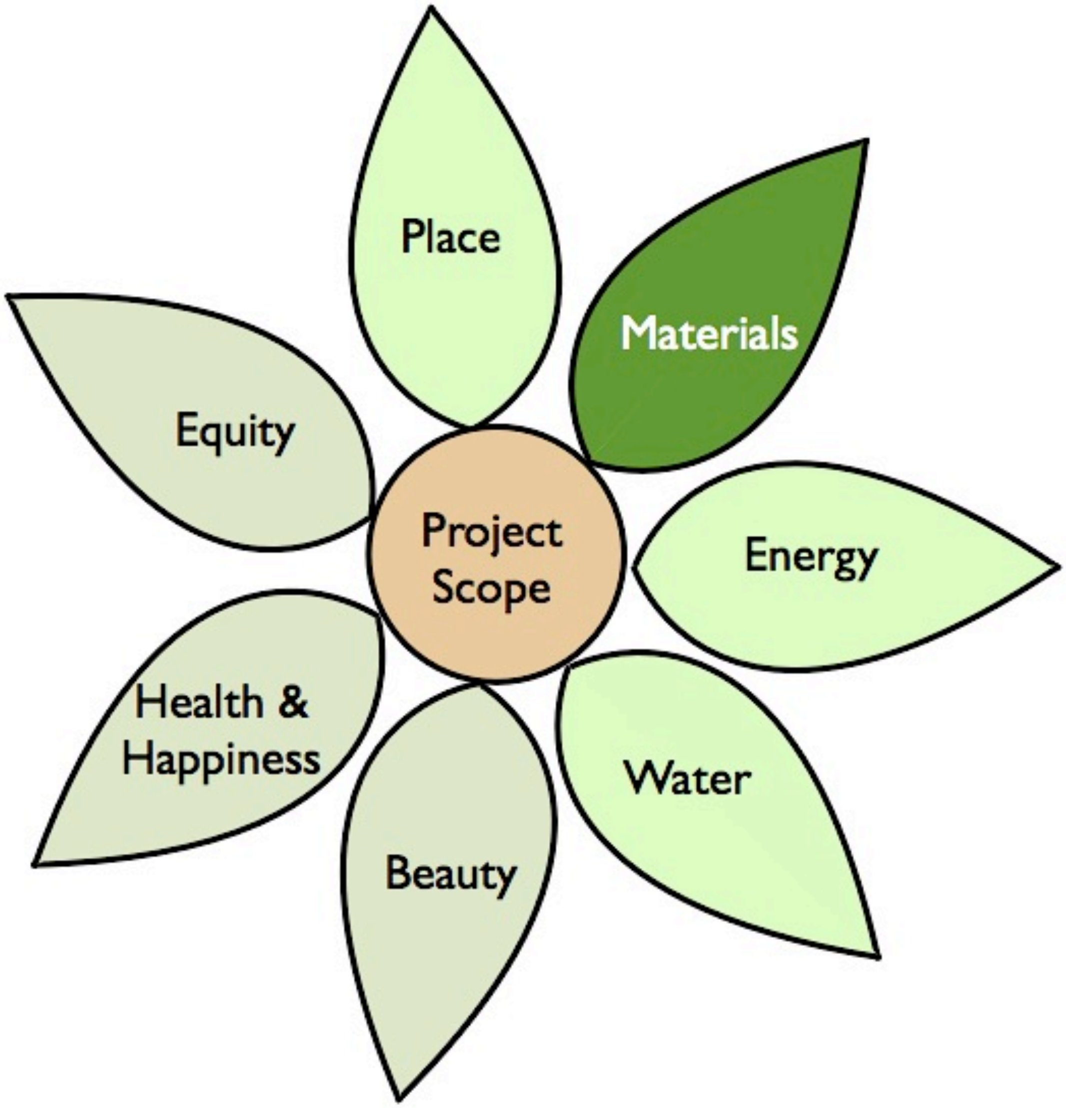


Figure 2.21: The effective use of vertical bike storage.

3.0

The Materials Petal

Core Components



Contained within the Materials Petal are five Imperatives that define and describe the limitations placed on materials sourcing and properties from manufacturing to disposal. The Imperatives are as follows:

I10 - Red List

All materials used from bulk raw construction elements to furnishings and furniture may not contain red list compounds, with various exceptions in place to facilitate achievability.

I11 - Embodied Carbon Footprint

The total carbon impact incurred during construction must be accounted for through a carbon offset; it is therefore in the best interests of the project to minimize this carbon footprint through the use of mitigation tactics and responsible sourcing techniques in materials procurement.

I12 - Responsible Industry

A major component of the Living Building Challenge is the advocacy for improved labelling standards and manufacturing processes to eliminate Red List containing components. Included in this imperative is Declare labelling program usage requirement based on total building area as well as the petitioning of companies not currently using the Declare standard to adopt the labelling method.

I13 - Living Economy Sourcing

Constraints are placed in the form of geographical areas from which certain percentages of materials may be obtained. In addition, the human factor of construction in the form of labor and consultants is also geographically limited.

I14 - Net Positive Waste

Focused on the entire lifespan of the project, plans must be formed for responsible disposal of construction waste in addition to the inclusion of salvaged materials during the construction phase. This amount is determined by the gross square footage of the building.

RED LIST COMPLIANCE

It is the duty of those undertaking the Challenge to ensure that Red List compounds and chemicals are avoided in all materials used in the construction of the Living Building. This constraint effectively forces the phasing out of known toxic, harmful, or carcinogenic compounds common to the manufacturing and construction industries. Figure 3.1 shows current industry standards for toxic and hazardous material labeling. The full Red List as of version 3.0 of the Challenge has been included for reference.

Figure 3.1: Typical shorthand labeling format representing major categories on which chemicals are evaluated

- Alkylphenols
- Asbestos
- Bisphenol A (BPA)
- Cadmium
- Chlorinated Polyethylene and Chlorosulfonated Polyethlene
- Chlorobenzenes
- Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs)
- Chloroprene (Neoprene)
- Chromium VI
- Chlorinated Polyvinyl Chloride (CPVC)
- Formaldehyde (added)
- Halogenated Flame Retardants (HFRs)
- Lead (added)
- Mercury
- Perfluorinated Compounds (PFCs)
- Polychlorinated Biphenyls (PCBs)
- Phthalates
- Polyvinyl Chloride (PVC)
- Polyvinylidene Chloride (PVDC)
- Short Chain Chlorinated Paraffins
- Wood treatments containing Creosote, Arsenic or Pentachlorophenol
- Volatile Organic Compounds (VOCs) in wet-applied products

To satisfy the Documentation requirements for Red List Compliance, 100%* ingredients lists from the manufacture, Declare product information, or other complete and full disclosure forms (MSDS, GH SDS, etc.) are required.

*Exceptions apply for proprietary ingredients to a limited extent.

SOURCING CONSTRAINTS

In the interest of promoting local economy growth and minimizing carbon releases due to transportation of goods, geographical limitations are imposed in the form of percentage of construction budget. Sourcing constraints in addition to a hard limit for the distance from which consultants and labor may be sourced (excluding highly specialized expert consultants, see Exceptions) are also imposed. Figure 3.2 depicts the overall sourcing boundaries.

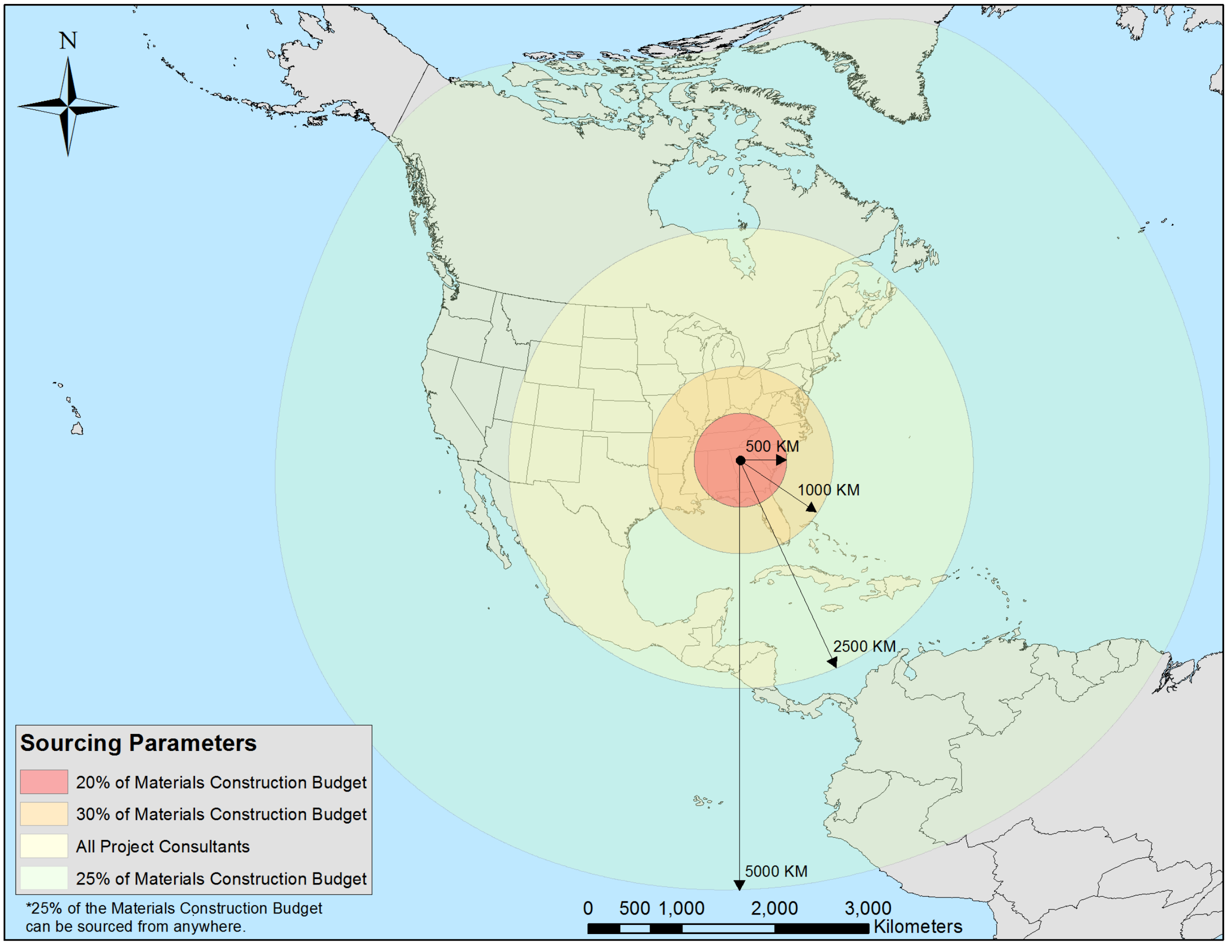


Figure 3.2: Geographical representation of the limits on supplier distance from the project site

Atlanta offers an advantageous location for sourcing of materials and human resources in that it is effectively the transportation hub of the south. Numerous rail yards can be utilized to minimize transportation costs and carbon release that would be incurred were a large amount of bulk materials moved to the site by flatbed diesel vehicles. The relatively close proximity of granite and stone mining sources and timber harvest land make both attractive options for substructure, foundation, and superstructure components.

As the Living Building project remains in preliminary design stages, detailed estimates for the amounts of materials needed to complete the project are unavailable. Until further design decisions regarding the final shape and size of the building are made, along with resolutions as to aesthetic considerations, recommendations regarding material use must be made on a unit basis. After further details have been solidified, it may become apparent that attractive materials will not scale properly to meet the needs of the final design. Substitutions must then be made to maintain cost feasibility of the project.

At this stage of design, life cycle assessment tool use must be limited pending further information. Carbon calculations made on this unit basis will remain valid throughout the lifespan of the system.

3.3.1 Concrete

Concrete is an unavoidable constituent of the Living Building at Georgia Tech. Substitution of poured and cast in place concrete for footings and pilings proves difficult, however for other above ground components that are commonly poured in place, block and mortar construction can prove to be less impactful to the structure's carbon footprint. See Table 3.1 for an overview of the concrete components that generally contribute the most to embodied carbon content.

Table 3.1: Overview of the sources of Carbon in commercial concrete

Material	**Embodied Energy** (MJ/kg)	**Embodied Carbon** (kg CO2/kg Material)
General Concrete	0.95	0.130
General Aggregate	0.10	0.005
General Sand	0.10	0.005
General Cement	4.60	0.830

Values from Hammond and Jones

For the assemblies that absolutely must utilize poured in place concrete, the inclusion of supplementary cementitious materials and recycled components for the aggregate has become an accessible and largely non-cost-prohibitive practice in the green building industry. Fly ash sourced from Georgia's coal fired power plants, purchased slag cement from neighboring states that have closer proximity to smelting facilities, or silica fume concrete could all be utilized in the construction of the Living Building to minimize the embodied carbon footprint resulting from mold-formed structural elements. Table 3.2 contains comparison values for the energy and carbon tradeoffs that are achieved through the use of supplementary cementitious materials.

Utilizing recycled aggregate for the needed concrete substructure would also work towards satisfying the Net Positive Waste component of the Materials Petal. Many commercially available concrete sources already include recycled aggregate in the mixing process. The Living Building could choose to go a step further and make use of the potentially recycled aggregate that will be made available by the demolition of the existing Georgia Tech Police Department Headquarters and the vast surface parking lots that will be removed to make way for the Eco Commons. Sourcing of recycled material from such close proximity to the construction site would prove to be a unique aspect of the building. Concrete block and other bricks could also be repurposed form the small building at 401 Ferst and used for landscaping purposes or other nonstructural curtain wall components.

Table 3.2: Carbon Values for common variations and constituents of concrete

Material	**Embodied Energy** (MJ/kg)	**Embodied Carbon** (kg CO2/kg Material)
Concrete by Proportions		
1:1:2	1.39	0.209
1:2:4	0.95	0.129
1:3:6	0.77	0.096
1:4:8	0.69	0.080
Prefab Concrete	2.00	0.215
Cementitious Materials		
Portland Cement, Wet Kiln	5.90	0.909
Portland Cement, Dry Kiln	3.30	0.718
Fiber Cement	10.90	2.110
Soil-Cement	0.85	0.140
Fly Ash, 25% Replacement*	3.52	0.620
Fly Ash, 50% Replacement*	2.43	0.420
Slag, 25% Replacement*	3.81	0.640
Slag, 50% Replacement*	3.01	0.450

*Substitution is made considering Portland Cement
Values from Hammond and Jones

Mixing ratios of concrete are determinate to the strength of the resulting material, and as such mixtures with lower carbon content can absolutely not be substituted for higher strength ratio mixtures solely to serve the purpose of embodied carbon reduction. Instead, reducing the carbon content of the final mixture for a necessarily strong structural pour can be achieved through the use of supplementary cementitious materials such as blast furnace slag or fly ash. Although the obvious contender for carbon reduction in the above table is soil-cement based on the low carbon content, it is unsuitable for structural applications in the same manner that fly ash and slag are in that it does not provide the high compressive strength values generally desired from concrete utilization.

3.3.2 Stone and Brick

Embodied carbon can be difficult to calculate for non-homogenous materials such as naturally sourced stone and rock, as the constituents undergo many physical and chemical changes during the igneous stage of formation. It should be noted that stone is not considered a renewable resource on a human time scale; any intuition that it is more natural or green than synthetic compounds has little to no truth behind it. Stone can also prove to be a more difficult material to incorporate structurally, as there is often much less uniformity to the material matrix when compared to brick or concrete. Although these other materials may have inclusions and variations of constituent density within their matrix, these abnormalities make up a far lesser percentage of the overall material when compared to stone, which may have large veins or pockets of differing composition throughout that is not always visible at the surface. However, stone or brick may be a prime choice for facades and other smaller load bearing features. Table 3.3 below offers a brief comparison of the embodied carbon intrinsic to various stone components, as well as evaluating the amount of carbon contained in different forms of manufactured brick. Concrete blocks have been included in this section, as they were determined to be closer in resemblance to these building materials in form, function, and construction methods than poured concrete as outlined in the previous section.

Table 3.3: Embodied energy and carbon as CO2 for stone and brick elements

Material	**Embodied Energy** (MJ/kg)	**Embodied Carbon** (kg CO2/kg Material)
Bricks		
Baked Clay Brick	3.00	0.220
Facing Brick	8.20	0.520
Limestone Brick	0.85	-
Concrete Blocks		
8 MPa Concrete Block	0.60	0.061
10 MPa Concrete Block	0.67	0.074
12 MPa Concrete Block	0.71	0.080
13 MPa Concrete Block	0.81	0.098
Autoclaved Aerated Block	3.50	0.28 - 0.375
Stone		
General	1.00	0.056
Granite	0.10 - 13.90	0.006 - 0.781
Limestone	0.30	0.017
Marble	2.00	0.112
Shale	0.03	0.002
Slate	0.10 - 1.00	0.006 - 0.056

Values from Hammond and Jones

Stone and to some extent manufactured bricks have the added benefit of being reusable without an energy intensive recycling process involved. More often than not, cut stone used previously for structural purposes can be utilized again if care is taken in the demolition of the previous structure. Removal of existing cementitious materials or grout work can be accomplished through chemical means or manually if uniformity in appearance is desired. Brick and stone both can be sourced from nearly on site in the case of the demolition of the small building at 401 Ferst Drive, with no transportation based carbon use incurred.

3.3.3 Timber

Wood as a bulk material offers the advantage of being both sustainable and immediately replaceable on a human time scale. None of the other materials common to standard residential and commercial construction can be considered renewable on the same level as wooden components. Timber and other fibrous compounds also maintain an advantage in being one of the lowest carbon contributors, although this position varies based on the sourcing routes and types of lumber used. Georgia has one of the largest percentages of remaining timber land of any of the contiguous states: nearly 70% of the states land cover is forested. Atlanta itself has been nicknamed ‘ The City in a Forest’ due to the heavy tree canopy that remains even in the heavily developed urban core. Maintaining this title has been a unifying cause for many conservationists and green construction industries. Responsibly sourced timber from intentional harvest plantations helps to prevent further reduction of the existing forested land in the state. Indigenous to the Southeast, softwood pine is fast growing and useful for low rise construction projects or more superficial members in larger structures. Table 3.4 provides a brief comparison of standard wood and wood pulp products in terms of their carbon content.

Table 3.4: Overview of timber and engineered wood products common carbon content

Material	**Embodied Energy** (MJ/kg)	**Embodied Carbon** (kg CO2/kg Material)
General Timber	8.50	0.46
Sawn Hardwood	7.80	0.47
Sawn Softwood	7.40	0.45
Glue Laminated	12.00	0.46
Plywood	15.00	0.098

Values from Hammond and Jones

In addition to locally sourcing any wood or wood products needed during the construction of the Living Building, trees that are removed to make way for site preparation could be utilized as either chipped ground cover or contribute to starting composting bins to reduce waste transport. It is also possible to relocate trees that have been condemned due to new construction to other areas on campus if no on-site location is suitable, though care must be taken when moving mature trees not to damage the root structure. Even with caution, excavating and replanting rooted trees can lead to serious and often irreparable damage to the organism.

Different species of wood can be considered sustainable at varying levels as the speed of growth, density of growth (amount of harvestable specimens per land area), nutrient & water requirements, and processing & treatment techniques can fluctuate vastly between fast growing high-density species such as bamboo and slow growth hardwoods such as oak varieties.

3.3.4 Glass

The glass used in construction of the Living Building must be chosen carefully according to its insulative and reflective properties. Unlike traditional construction wherein interior walls have a sheet rock layer in front of layers of insulation and structural members that are again hidden by a curtain wall or other form of façade, large panes of glass offer little insulation comparatively. Double or triple paned windows have become more common as a form of reducing energy usage in new construction or retrofitting operations due to their more favorable insulation over single pane windows. These techniques are easy and relatively cheap to implement on residential projects where windows are sectioned. In larger scale construction, where designs may call for exceedingly large panes of glass for aesthetic purposes, the use of multi-paned or other sealed window elements can prove to be a large expenditure. See Table 3.5 below comparing some of the insulative properties between single pane and more advanced insulation formatting of windowpanes. Although multi-pane configurations prove to be more energy efficient due to their thermal conductivity, they do represent an increase in the one time embodied carbon associated with construction.

Table 3.5: Comparison of insulation properties represented by U-factor, with various Emittance (E) levels

Glazing Type	Aluminum Frame, No Thermal Break	Aluminum Frame, Thermal Break	Wood or Vinyl Frame, Insulated Spacer
Single Glass	1.3	1.07	(n/a)
Double Glass, 1⁄2-inch air space	0.81	0.62	0.48
Double Glass, E=0.20, 1⁄2-inch air space	0.7	0.52	0.39
Double Glass, E=0.10, 1⁄2-inch air space	0.67	0.49	0.37
Double Glass, E=0.10, 1⁄2-inch argon space	0.64	0.46	0.34
Triple Glass, E=0.10, 1⁄2-inch argon spaces	0.53	0.36	0.23
Quadruple glass, E=0.10, 1⁄4-inch krypton spaces	(n/a)	(n/a)	0.22

Based on 3-ft-by-5-ft windows. U-factors vary somewhat with window size.
Table taken from Department of Labor and Economic Growth Publicationand the 1993 ASHRAE Fundamentals Handbook

The carbon embodied in common glass is relatively high compared to other bulk construction elements aside from metals and insulation, and increases with toughened glass or otherwise further specialized and engineered products. The use of acrylic products or other advanced plastics in place of traditional glass may be beneficial in terms of cost and longevity, however these polycarbonate products work counter to the goal of reducing embodied carbon. Table 3.6 below provides an overview of the variance in embodied carbon between common types of glass and glass constituents.

Table 3.6: Comparison of embodied energy and carbon for glass-based compounds

Material	**Embodied Energy** (MJ/kg)	**Embodied Carbon** (kg CO2/kg Material)
General Glass	15.00	0.85
Toughened Glass	28.00	1.27
General Sand	0.10	0.005
Acrylic Paint*	61.5	3.39

Data sourced from Hammond and Jones and the Australian Government in partnership with the Institute for Sustainable Futures
*PMMA suspended in water is used as an approximation for PMMA sheeting; actual values for embodied carbon would be much higher than presented

As mentioned previously, the selection of the proper type of glass for the needs of the building will be dependent on the energy usage requirements and dependency on passive solar heating designs. Large glass curtains and panes have been proposed for the building in preliminary designs and will most likely be present in the final designs submitted for construction. The benefits of natural lighting and passive heating will probably be favored over the amount of carbon that will be contained in these members, making the glass utilized in construction one of the largest sources of carbon that will need to be considered when meeting the Imperatives dictating the purchase of carbon offsets. With this in mind, minimizing the embodied carbon of the selected glass should be a priority if the goal of minimal expenditures for carbon offsets persists.

3.3.5 Insulation

Proper insulation selection during the design and construction phase will contribute directly to the feasibility of a net zero energy building. Energy use, as discussed in the relevant section, is an inseparably intrinsic property that influences design aspirations and cannot be ignored. Since many proposed designs include a large percentage of the building exterior existing as glass panes, there will exist a limited area of the building that requires traditional insulation as a raw material.

Ensuring maximal heat retention during the winter months in addition to heat dispersion during the warmer seasons is paramount to occupant comfort, and although no explicit guidelines exist for determining the levels of temperature variation that is considered acceptable in the final design, general rules of thumb have been established for maintaining a comfortable working environment that provides for a temperature range and maximum deviation from thereof. Many different types of insulation materials are available on the current market, and the standard fiber glass insulation found in residential projects is far from the only option when selecting a material to provide the desired thermal properties for a new construction project. Table 3.7 covers a variety of possible materials that would be suitable for insulation between interior rooms and floors, and could also be applied to exterior walls where necessary.

Table 3.7: Overview of the carbon intrinsic to common insulation materials found in commercial construction project

Material	**Embodied Energy** (MJ/kg)	**Embodied Carbon** (kg CO2/kg Material)
General Insulation	45.00	1.86
Celluar Glass	27.00	-
Cork	4.00	0.19
Fibre Glass or Glass wool	28.00	1.35
Flax	39.50	1.70
Mineral Wool	16.60	1.20
Rockwool or Stone wool	16.80	1.05
Paper wool	20.17	0.63
Wood Wool Board	20.00	0.98
Polyurethane	72.10	3.00
Expanded Polystyrene	88.60	2.50

Data sourced from Hammond and Jones

It is apparent that natural insulation materials contain less embodied carbon in the form of carbon dioxide, however these materials often do not provide the same thermal insulative properties as their engineered counterparts.

Since insulation material will be included in smaller scales than other bulk construction materials, sacrifices made here in the interest of maintaining energy efficiency would not be as harmful to the goal of minimizing embodied carbon as selections made for other materials like poured concrete and metals.

3.3.6 Steel and Aluminum

Steel and other metals used as structural elements provide multiple advantages over typical load bearing wooden trusses and beams or precast concrete members. Steel offers a much greater structural strength, requiring less mass of material to effectively accomplish similar design tasks. The greatest area of benefit when considering the carbon footprint of the Living Building is the ability to include many-times recycled steel. Wooden members must be utilized as is if they are to be salvaged, and concrete offers little to no immediate recycling potential as a structural material. Steel members salvaged from the demolition projects in the immediate vicinity would further complete the Net Zero Waste Imperative while saving on cost of new materials and lowering the embodied carbon footprint.

Based on existing conceptual models of the Living Building at Georgia Tech, steel would offer the greatest ability to meet the expectations of large open spaces and minimal blockage of sunlight infiltration through the roof and walls due to structural elements. Keeping this in mind, the final design plans will undoubtedly call for large amount of structural steel members in the form of beams, girders, joists, and columns. The total amount of steel used in the project will depend on the grade chosen and its engineering properties. Selection of a material that is capable of supporting the loads in the design while also remaining low carbon can be accomplished through the use of certified recycled steel where possible, as the savings in embodied carbon over virgin steel can be more than fivefold. Table 3.8 contains values for the embodied energy and carbon as CO2 for common steel elements. It can be seen that the use of recycled steel material will substantially lower the embodied carbon content across the board.

Table 3.8: Virgin and recycled steel embodied carbon contents

Material	**Embodied Energy** (MJ/kg)	**Embodied Carbon** (kg CO2/kg Material)
General Steel	24.40	1.77
General Virgin Steel	35.30	2.75
General Recycled Steel, 42.7%	9.50	0.43
Recycled Engineering Steel	13.10	0.68
Virgin Section Steel	36.80	2.78
Recycled Section Steel	10.00	0.44

Data sourced from Hammond and Jones

An alternative to steel in the fabrication industry is aluminum, prized for its lighter weight and similar strength to the more common steel alloys that are used. Although not recommended as a replacement for all steel applications, aluminum can provide high strength, low volume members for bridging large spans where steel may not be optimal. Aluminum has similar recyclability to steel, although often recycled content is used in lower ratios to virgin material when compared to the amount of recycled content found in steel members. This leads to higher embodied carbon contents on a unit mass basis, but as aluminum is less dense than steel the two have similar amounts of embodied carbon on a volumetric analysis. A comparison of the embodied carbon found in iron and aluminum products is found in Table 3.9 below.

Table 3.9: Embodied carbon for common aluminum production methods compared to iron

Material	**Embodied Energy** (MJ/kg)	**Embodied Carbon** (kg CO2/kg Material)
General Iron	25.00	1.91
General Aluminum	155	8.24
General Virgin Aluminum	218	11.46
General Recycled Aluminum	28.8	1.69
Virgin Cast Aluminum	226	11.70
Recycled Cast Aluminum	24.5	1.35
Virgin Extruded Aluminum	214	11.20
Recycled Extruded Aluminum	34.1	1.98
Virgin Rolled Aluminum	217	11.50
Recycled Rolled Aluminum	27.8	1.67

Data sourced from Hammond and Jones

The benefits that aluminum offers when compared to steel are numerous, including more workability, less weight, intrinsic anti-corrosive properties, and a variety of aesthetic components that vary depending on the production method. Both metals have their respective applications in building construction and both will assuredly be present in the designs issued for construction of the Living Building. Both materials are readily available with recycled content, further reducing the carbon footprint of the project. In addition, if care is taken during the demolition of the existing Police Department building at the corner of Hemphill and Ferst, the possibility of immediate reuse of steel members is present. The reuse of these components would further the goals of reducing the carbon footprint of the building, the Living Economy Sourcing Imperative, and the Net Zero Waste Imperative by minimizing the amount of virgin material that is wasted during construction.

3.3.7 Other Materials

The materials outlined in this section are far from comprehensive when considering all of the elements that will be included in the construction phase of the project. The Materials Petal calls for the Imperatives to apply to all phases of the building life and all of the materials contained within, including interior furnishings and purchase package assemblies. Conducting a comprehensive analysis of the embodied carbon that will be contained in the building components at this stage of the design process would likely have little accuracy when compared to the final product. A more detailed report outlining the carbon content of all materials will be required from the firm that supplies the designs for construction, and should be more easily accomplished while simultaneously creating the Materials Tracking Tables that are a requirement for this Petal.

In the interest of providing the most exhaustive investigation possible at this point in the project's development, additional materials that will likely be utilized have been included in a less detailed fashion. Table 3.10 presents some of the expected carbon amounts that will be contained in other areas of the project.

Table 3.10: Embodied carbon found in other construction materials

Material	**Embodied Energy** (MJ/kg)	**Embodied Carbon** (kg CO2/kg Material)
Asphalt	2.60	0.045
Road Pavement	2.41	0.14
Virgin Brass	80.00	4.39
Recycled Brass	20.00	1.1
Bronze	77.00	4.1
Carpet	74.40	3.89
Nylon	67.9	3.55
Rubber	67.5	3.91
Ceramic Tile	9.00	0.59
Virgin Copper	70	3.83
Recycled High Grade Copper	17.5	0.96
Virgin Lead*	49.00	2.61
Recycled Lead*	10.00	0.53
Linoleum	25.00	1.21
Expanded Perlite	10.00	0.52
Expanded Vermiculite	7.20	0.52
Paint	68.00	3.56
Paperboard	24.80	1.32
Gypsum	1.80	0.12
Plasterboard	6.75	0.38
General Plastics**	80.50	2.53
Tin	250.00	13.70
Zinc	61.90	3.31

Data sourced from Hammond and Jones
*Added Lead violate Red List Imperative
** Certain Plastics (PVC, PVDC) violate Red List Imperative

3.4.1 Calculations

The Athena EcoCalculator was used to calculate the embodied carbon of the materials used in the construction of the proposed Living Building. This tool was listed by the Living Building Challenge as an approved embodied carbon calculator. The purpose of the embodied carbon analyses was to provide a rough order of magnitude estimate for the total embodied carbon of the building. The EcoCalculator takes inputs in square feet: the buildings dimensions were estimated according to rule of thumb guidelines. The total building area, provided as 42,500 square feet, was divided into three intermediate floors and a basement. Each floor was assumed to be 10,625 square feet based on symmetry. The walls of the foundation and each story were assumed to be 12 feet tall. The building's dimensions were assumed to be 125 feet wide by 85 feet long and 48 feet tall, including the basement. It was assumed that there were 40 columns per floor and each column would take up 4 sqft of space, with a height of 12 feet each. Eight beams per floor were assumed, being 2 feet wide and 85 feet long. The foundation slab was assumed to be 4 inches thick. The building's footings were assumed to be 1 yard deep, and each column would have one footing, summing to 160 cubic yards of concrete total for the footings. When considering the windows of the building, it is known that the building will require ample natural light to fulfill both architectural considerations as well as requirements set by the LBC. In order to ensure that these standards were incorporated in the embodied carbon calculations, the exterior walls were assumed to be 70% windows, with the rest of the wall being the building's façade. The materials used for the walls, windows, roof, and other parts of the building were chosen based on their feasibility for use in a commercial building as well as their embodied carbon. EcoLadder recognizes that this calculator makes multiple assumptions for the building's size, but these uncertainties are justifiable as the building is in the preliminary stage of the design process. Interior walls were not considered since the exact layout of each floor is still in its design phase. Three embodied carbon analyses were performed: a best, worst and mid-tier case. This ensures that a variety of possible options are considered during the design phase. Table 3.11 shows a summary of the embodied carbon and energy results for the three analyses. The fully detailed analysis for each of the three cases and their environmental impacts can be found in the Appendix.

Table 3.11: Summary of Embodied Carbon and Energy Calculations

Assembly	Total Area (sqft)	Total Fossil Fuel Consumption (MJ)			Total Global Warming Potential (tons CO2eq)		
		Best	Mid-Tier	Worst	Best	Mid-Tier	Worst
Foundations & Footings	15665	1,258,151	1,258,151	1,324,992	137.09	137.09	151.10
Columns & Beams	6080	235,819	336,425	699,776	22.36	17.38	54.86
Intermediate Floors	31875	2,923,703	2,632,853	4,907,048	216.00	268.41	488.22
Exterior Walls	4536	455,188	523,652	1,160,735	43.54	48.94	101.42
Windows	10584	2,630,781	3,916,284	5,219,714	268.52	352.17	468.04
Roof	10625	2,144,310	1,957,786	3,005,497	104.46	83.82	194.36
	Total	9,647,955	10,625,154	16,317,764	791.96	907.81	1458.01

Table 3.12: Material Composition for Each Analysis

Foundations & Footings	**Best Case**	**Mid-Tier Case**	**Worst Case**
Foundation Wall	Concrete Block	Concrete Block	Cast-in-place concrete
Foundation Slab	4" Poured Concrete Slab	4" Poured Concrete Slab	4" Poured Concrete Slab
Footing	Poured Concrete Footing	Poured Concrete Footing	Poured Concrete Footing
Columns & Beams			
Non-Load Bearing Walls	Precast Concrete Column/ Precast Concrete Beam	WF column/WF beam	Concrete column/Concrete beam
Intermediate Floors	Open-web Steel Joist w/ concrete topping	Precast Double T w/ concrete topping	Suspended concrete slab
Exterior Walls			
Cast-in Place Concrete	Stucco Cladding	Brick Cladding	Steel Cladding
Windows	Vinyl-clad Wood	Vinyl	Aluminum
Roof	Precast hollow-core concrete	Precast Double T	Suspended concrete slab

*WF=Wide Flange

Table 3.12 on the shows a list of the various materials used in each calculation. These materials were chosen based on practicality and embodied carbon amounts. The materials used are just suggestions and should not be used as the only considerations for the Living Building as there are a variety of possible materials that can be used in the shell, core and superstructure. Figure 3.3 shows a visual comparison of the embodied carbon for each analysis broken down in by each building assembly.

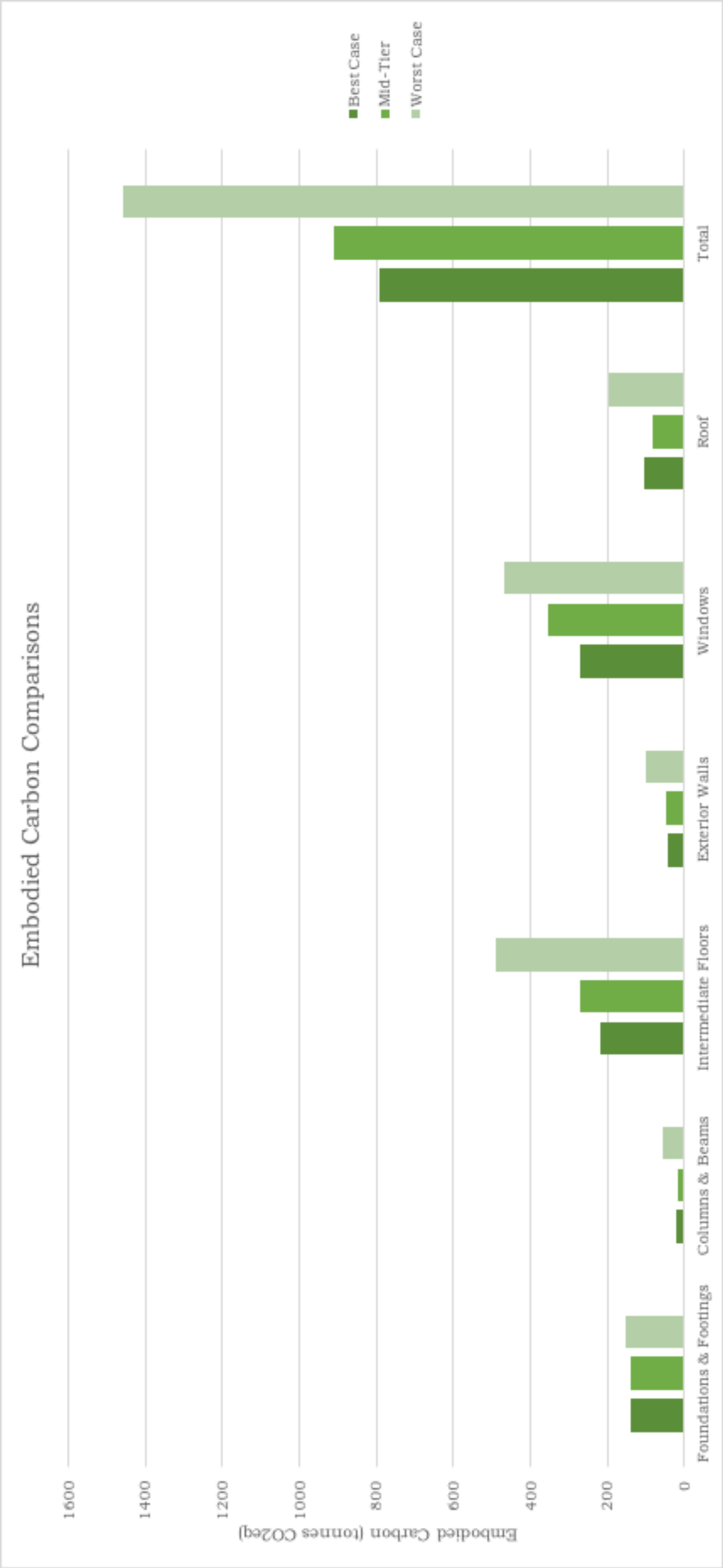


Figure 3.3: Comparisons for embodied carbon for 3 different scenarios

3.4.2 Offsets

Fly ash can be used as a substitute for cement in certain proportions, but not as a full substitute. Depending on the amount of fly ash that can be used, a significant cost savings and reduction in embodied carbon can be achieved. An unreinforced cubic yard of concrete costs roughly $80-100, with reinforcement increasing the price. Fly ash can reduce the cost of concrete by 10-20% depending on the percentage fly ash replacement. Table 3.13 shows an example cost break down for the cementitious contents of concrete and the reduction in price achieved using fly ash. The table shows about a 13% reduction in cost though fly ash substitution. It should be noted that the cost of concrete varies widely, and an accurate estimate of concrete cost for the building is difficult to obtain at this stage of the project life.

Table 3.13: Comparison of cost savings through fly ash substitution

	Cement Only		Cement with Fly Ash	
	Weight (lb/cy)	**Cost**	**Weight (lb/cy)**	**Cost**
Cement ($.03/lb)	517	$15.51	390	$11.70
Fly Ash ($.012/lb)	0	$0.00	150	$1.80
Total	517	$15.51	540	$13.50

As for embodied carbon, a 25% replacement of fly ash can reduce carbon content by 10-20% depending on how much cement is used in the concrete mix. Additionally, blast slag can be used as another supplementary cementitious material to further reduce the embodied carbon. Tables 3.14 and 3.15 below show the difference in embodied carbon in kilogram of CO_2 per kilogram of concrete for various percentages of fly ash and blast slag. This reduction in embodied carbon will help reduce the amount of carbon that needs to be offset by the building though its initial one-time offset.

Table 3.14: Carbon savings by percentage of fly ash substitution

	0% Fly Ash	25% Fly Ash	50% Fly Ash
GEN 1	0.095	0.077	0.058
RC 30	0.153	0.12	0.087
RC 35	0.161	0.126	0.091
RC 40	0.169	0.132	0.096
PAV1	0.145	0.114	0.083

*GEN = General
*RC = Reinforced Concrete
*PAV = Pavement

Table 3.15: Carbon savings by percentage of blast furnace slag substitution

	0% Blast Slag	25% Blast Slag	50% Blast Slag
GEN 1	0.095	0.078	0.061
RC 30	0.153	0.122	0.092
RC 35	0.161	0.129	0.096
RC 40	0.169	0.135	0.101
PAV1	0.145	0.116	0.088

3.4.3 Carbon Offset Cost

Part of the Challenge is to offset the carbon produced by construction, including all materials, through a one-time carbon offset purchase. The Challenge provides a variety of options for suppliers of CO_2 offsets. One suitable company is TerraPass, offering multiple carbon offset solutions at an affordable cost. TerraPass offers businesses the ability to offset 1 metric ton of CO_2 for $13.12 as of April 2016. For this project, the materials will have an CO_2 emission equivalent of between 791 and 1458 metric tons according to initial estimates. Table 3.16 shows the cost projections for the carbon offset necessary for the materials shown in the best, mid-tier, and worst cases based on Athena EcoCalculator models.

Table 3.16: Incurred costs of carbon offsets due to material selections

	Metric Tons of CO2 Equivalent	Cost
Best Case	791.96	$10,390.57
Mid-Tier Case	907.81	$11,910.42
Worst Case	1,458.01	$19,129.03

RECOMMENDATIONS

Concrete will most likely be a large component of the Living Building, as it is cheap to manufacture, easy to form, and has low embodied carbon. Although pre-cast concrete has many advantages over site-poured concrete, site-poured concrete should be used to help promote architectural freedom. In addition, supplementary cementing materials should be used in the cement mix when allowable. Examples of supplementary cementitious materials include fly ash and blast furnace slag. Supplementary cementitious materials both change the properties of the concrete and lower the embodied carbon of the mix.

Steel is the backbone for almost all modern commercial building and as such will play a crucial role in the Living Building in providing both structural support as well as a modern look. Recycled steel should be used as much as possible to reduce the embodied carbon of the building. In addition, aluminum is a widely used material for its aesthetics and high strength to weight ratio. Although aluminum has a very modern look, it should be avoided as it has a very high embodied carbon amount. Forming virgin aluminum is a very energy intensive process that leads to a large embodied carbon footprint. Alternatives to aluminum should be used when possible.

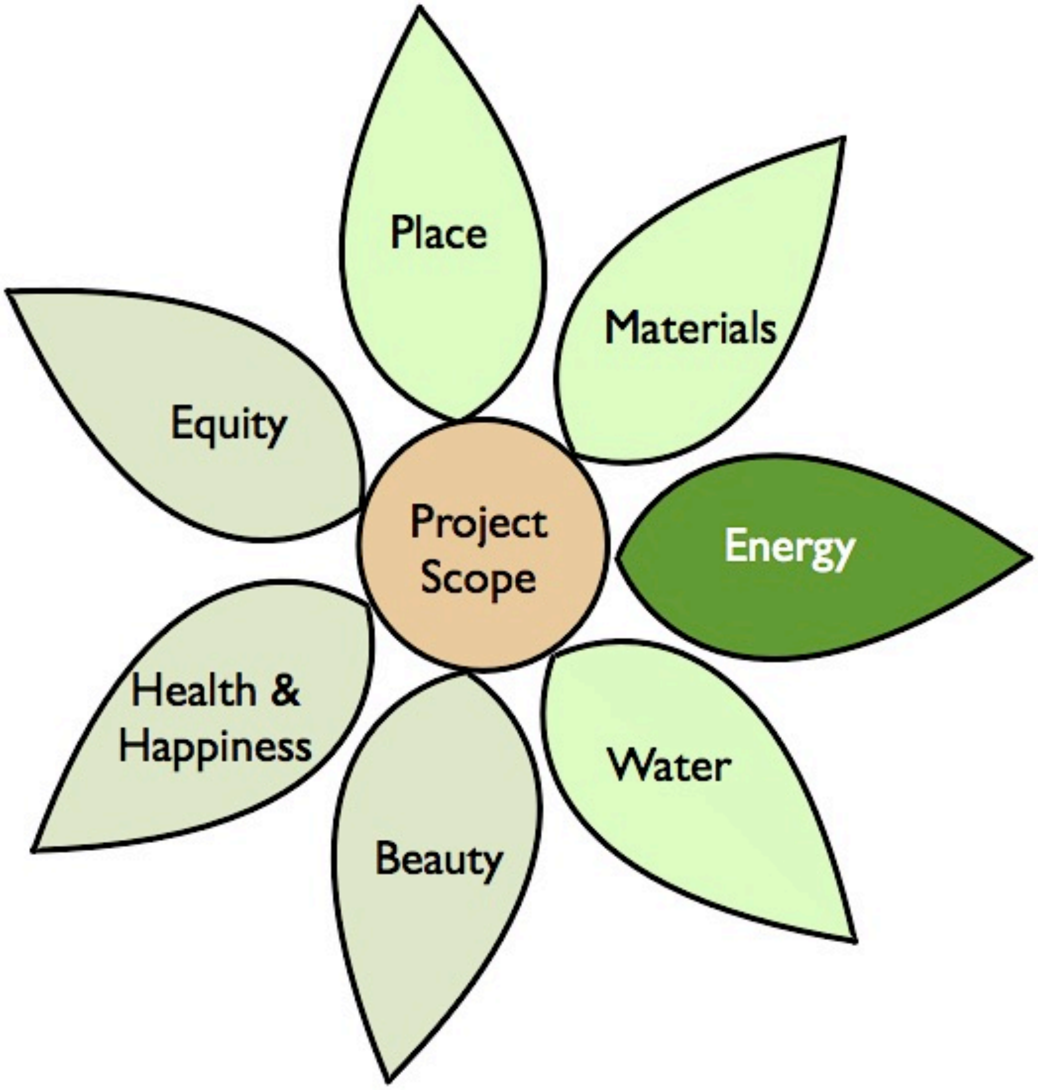
Most importantly, recycled materials should be chosen over new materials in order to reduce the overall embodied carbon for the building. Wood is a great choice due to its low embodied carbon, small sourcing distance, and variety of possible uses: it can be shaped in many different ways to leave room for architectural freedom. Bricks should be used for the façade of the building when possible, to keep the building in the same style as the rest of the brick campus.

Other materials including insulation and piping should be carefully studied to ensure that they are Red List compliant. It is recommended that recycled plastics be used in the building to further reduce its impact on the environment. One suggestion is that copper pipes be used instead of PVC pipes for increased durability and recyclability of the material while also satisfying the Red List compliance Imperative.

4.0

The Energy Petal

Ensuring Efficiency



A building of this caliber was only a dream until recently. This building challenge is so rigorous that only 8 certified projects have been achieved in the entire United States, none of which located in the Southeast. EcoLadder will once again push the envelope of sustainable design by working through energy production barriers such as extreme heat, humidity, and intermittent droughts that have previously plagued environmentally sustainable construction projects in this region.

4.1.1 Renewable Energy Selection and Explanation

Solar and geothermal renewable energy systems were both carefully considered for on-site energy production based on the building's geographic location and site conditions. The geothermal system, which would harness the Earth's thermal differences for energy production, was quickly ruled out due to the deep digging requirement, initial land destruction and lack of sufficient energy production. Geothermal properties could, however, possibly be used to supplement or replace energy intensive HVAC systems. The renewable energy system that was selected for this project was a photovoltaic solar system. This method was deemed the best solution to conventional sources of energy production that meet the Living Building Challenge design constraints of non-combustible renewable energy source. Not only was solar power the most cost effective energy source, it was best suited for Georgia's climate and landscape. Solar energy was the most practical approach: it is fairly easy to install, has a short payback time, and is the least destructive to the environment. Capturing the sun's energy entirely on-site will provide 100% of the buildings energy needs as well as an addition 5% to meet the net positive energy requirement. This approach will eliminate the need for a connection to the utility grid making the entire building self-sufficient. Figure 4.1 shows a potential solar array on the Living Building.

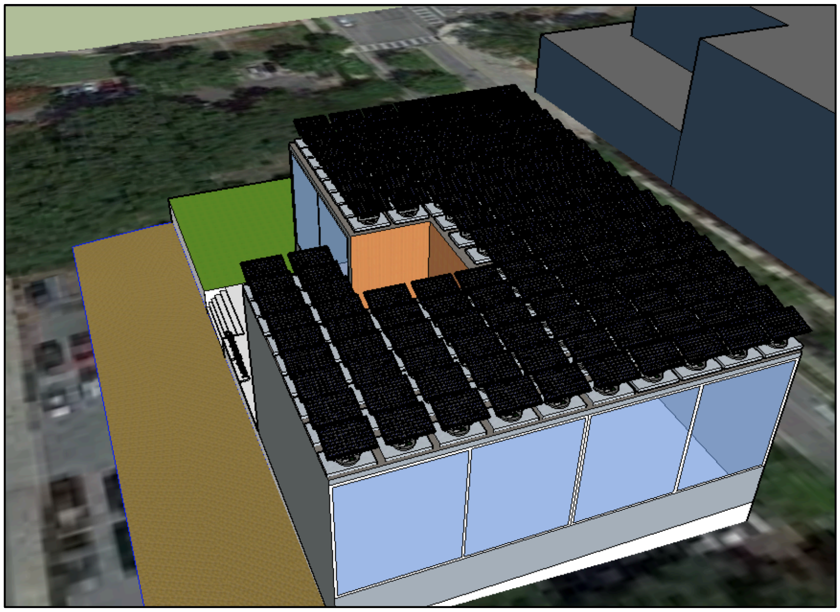


Figure 4.1: A modular solar panel array on the roof would provide energy for the building

4.1.2 Building Performance Estimates

The Living Building at Georgia Tech is especially unique because not only will it be large in size and house hundreds of people daily, it will consume far less energy than a building of comparable size and function. To assess a building's energy performance, the Energy Use Intensity or EUI, is used. The EUI is a building efficiency measure that calculates the annual energy used per square foot of building space and is the most common way to reveal building efficiency. A low EUI signifies efficient energy performance, while a higher EUI represents room for energy improvements. Ideally, the Living Building at Georgia Tech will have an EUI around 20, which is rare for a building this size. Just to understand how impressive this EUI is, if a school of 50,000 square feet consumes 7,500,000 kBTU's of energy, it would have an EUI of 150. Yearly, the Living Building at GT would need to consume 850,000 kBTUs or 249,000 kWh per 42,500 square feet to meet the 20 EUI goal. A typical K-12 school that is most similar with this building challenge has a median EUI of 114 kBTUs/ft^2 as calculated by the ENERGY STAR portfolio manager. The Living Building will have an EUI almost 6 times smaller than the education sector median EUI. A low EUI is only made possible by reducing convention energy consumption methods like space heating and continuous electrical usage. Building materials, natural heating & cooling for thermal control, natural lighting & ventilation, and dry labs are just a few examples of the techniques EcoLadder proposes for use to reduce the annual energy consumption throughout the building.

4.1.2.a Occupancy Calculations

Occupancy loads were estimated to get an idea of how many people will utilize the building at peak hours and at typical operational hours. These occupancy figures were used for load calculations and later used in the Water Petal estimates. These calculations were derived based on the space breakdown of the building, shown in Table 4.1. This table shows the room-by-room breakdown for the proposed space, its use, and the amount of square footage allotted. The full table of the proposed space breakdown with the max and ideal occupancy can be viewed in the Appendix. The remaining occupancy numbers were estimated based on fire code regulations. Table 4.2 combines data taken from Table 4.1 to estimate occupancy for the remaining spaces.

Table 4.1: The space breakdown based on type and total floor area

Space Component		Space Type	Total Sq. Ft.
Instructional Space	Classrooms	Auditorium	3000
		Classrooms	3000
		Seminar Rooms	1200
		Breakout/Group Study Rooms	720
		Classroom Support	240
	Class Laboratories	Computational/Biology ClassLab	2400
		ClassLab Staff and Support	600
	Design Studio Instructional Space	ClassLab/Maker Space	900
		ClassLab Staff and Support	450
Student/Community Center		Center	1500
		Center support Areas (storage, catering kitchen, etc.)	750
		Quiet Study Areas	600
		Collaboration/Innovation Learning Area	750
		Peer to Peer/Project Based Learning Studios	300
		Small Team Study Room	280
Research and Industry Partnership Component		Computational/Light Biology Res. Lab	1800
		Lab Support	600
		Lab Staff	600
		Faculty Office	280
Multipurpose/Exhibit Space/Event Support		Multipurpose/Exhibit Space/Event Support	1800
Lobby/Display Area and Kiosks		Lobby/Display Area and Kiosks	300
Office Space		Center- Director's Suite (office, reception, waiting)	600
		Office- Related Programs Support Staff	450
		Office- Building Manager/Support Staff	300
		Open Office	240
		Student Work Stations	72
		Break Room/Copy/Storage/Files	240
		QEP Activities (Office Space, reception, waiting)	600
		Office	450
		Open Office	160
		Student Work Stations	72
		Break Room/Copy/Storage/Files	240
		Structural, Mechanic, Elec. Data, Toilets, Stairs, Custodial (Unassigned)	16,996
		Gross Floor Area:	42,490

Table 4.2: The max and ideal occupancy based on space type and total floor area

Space Component		**Space Type**	**Total Sq. Ft.**	**Max Occupancy**	**Ideal Occupancy**
Instructional Space	Classrooms	Auditorium	3000	125	100
		Classrooms	3000	100	75
		Seminar Rooms	1200	32	25
		Breakout/Group Study Rooms	720	12	8
		Classroom Support	240	4	2
	Class Laboratories	Computational/Biology ClassLab	2400	80	40
		ClassLab Staff and Support	600	10	2
	Design Studio Instructional Space	ClassLab/Maker Space	900	15	2
		ClassLab Staff and Support	450	7.5	2
Student/Community Center		Center	1500	150	25
		Center support Areas (storage, catering kitchen, etc.)	750	12.5	1
		Quiet Study Areas	600	10	10
		Collaboration/Innovation Learning Area	750	12.5	8
		Peer to Peer/Project Based Learning Studios	300	10	8
		Small Team Study Room	280	5	5
Research and Industry Partnership Component		Computational/Light Biology Res. Lab	1800	60	30
		Lab Support	600	10	2
		Lab Staff	600	10	2
		Faculty Office	280	3	1
Multipurpose/Exhibit Space/Event Support		Multipurpose/Exhibit Space/Event Support	1800	180	10
Lobby/Display Area and Kiosks		Lobby/Display Area and Kiosks	300	30	10
Office Space		Center- Director's Suite (office, reception, waiting)	600	6	2
		Office- Related Programs Support Staff	450	5	1
		Office- Building Manager/Support Staff	300	3	1
		Open Office	240	3	1
		Student Work Stations	72	12	10
		Break Room/Copy/Storage/Files	240	2	1
		QEP Activities (Office Space, reception, waiting)	600	6	2
		Office	450	6	1
		Open Office	160	2	1
		Student Work Stations	72	12	10
		Break Room/Copy/Storage/Files	240	2	1
			Totals:	937.5	399

Occupancy estimates were completed in accordance with max occupant numbers set by fire standards. This includes assumptions such as 30 square feet person in classrooms, 10 square feet per person for lobbies or open areas, and 100 square feet per person for office space. These values were chosen in accordance with recommendations made by the National Fire Protection Association. Study rooms and smaller support centers were assumed at 60 square feet per person. Some spaces like student work and study stations were manually modified to account for smaller sized cubicles. Any non-integer value was rounded up to the nearest whole number. Maximum occupancy was determined to be 938 persons with all rooms full and in continuous use throughout the day. Ideal occupancy accounts for a more realistic estimation of individuals in the building when all rooms are being used, but not at peak capacity. This takes into considerations classes, lobbies, and offices not at full occupancy, but full study rooms. This was determined to be 400 persons. Figure 4.2 shows a potential visual occupancy breakdown of the Living Building.

Figure 4.2: A conceptual model of the building proposed by LAS and Miller Hull

4.1.2.b Load Calculations

The goal of 105% net positive renewable energy will only be made possible with unique design considerations. The diverse building space will house roughly 10 full time employees with patrons consisting mostly of students and faculty arriving throughout the day. Not only will students and professors come to the Living Building for class, but the space will also foster other learning environments such as group collaboration, seminars, hang-out commons, and study space. These diverse settings will drive the occupancy numbers higher. As class times and occupancy varies with time, the usage will vary as well.

Since the building is designed to be as eco-friendly as possible, some of the luxuries that students take for granted in normal buildings on campus will need to be reduced in order to meet energy usage goals. This includes compromising on excessive amounts of public desktops and TVs and fewer hours of operations. This might include the building having limited weekend hours open to students and less than 12-hour daily operating hours. Load estimations proved difficult to accurately calculate due to the limited amount of design details provided. Many assumptions had to be made to overcome the lack of solid detail in this regard. One of the energy efficient considerations pertained to the use of laboratory classrooms. Traditional labs consume large amounts of energy because they require heat, gas, and water. The labs used in the living building are all “dry” labs, meaning that the labs will consist of physical, hands on learning. Biology, ecology, geology, and computational chemistry are a few examples of the types of the labs that should be implemented. These types of laboratories don’t require complex systems, materials, or resources.

In order to accurately size the PV solar system, the electrical and mechanical loads were estimated based on the number of kilowatt hours needed to power a building with a similar space breakdown. Sixty percent of the building, or 25,500 square feet, will be used for instructional space including classrooms, labs, and a community center, as well as faculty research labs, event space, and office space. The remaining 40% or 17,000 sqft. of the building space is unassigned and to be used for areas like mechanical closets, staircases, bathrooms, and custodial storage.

Like occupancy, the loads varied based on the type of space, which were classified into similar categories: classroom, assembly, office, or other. Since each type of space varies in energy usage, the average light power density, equipment power density, and peak plug loads were calculated with their respective wattage per square foot as specified by the Department of Energy. These three intensity components were used to predict the ideal load of the total space shown in table 4.3. The full peak and ideal load tables can be viewed in the Appendix, which show lighting power density, equipment power density, and peak loads multiplied by the total space square footage by wattage per square foot in order to obtain the total wattage. Continuous building operation, which assumes a 7-day week and 12-hour operating day, was calculated in kilowatt-hours of energy consumption per day and per year (1,742 and 627,168 kWh, respectively). Not only would this system be much larger than the allotted roof space, it would be incredibly expressive to buy and install. These values are simply not feasible and are not practically achieved. The ideal loads in kWh per day and year were calculated to be 383 and 137,868 kWh respectively. This estimate takes into consideration shortened hours of operation and only weekday use. Many spaces like the auditorium, classrooms, labs, and study spaces assume non-continuous use, which in most cases was 4-6 hours instead of 12. The amount of energy needed to power the building was only made possible based on the ideal load, as the peak load requirement was not feasible. Instead, more realistic hours of operation and usage were used to size the system. The ideal energy usage per day was determined to be 383 kWh/day and this value was then used to size the PV array.

Table 4.3: Ideal loads based on space breakdown

Space Component		Space Type	Total Sq. Ft.	kWh/day	kWh/year
Instructional Space	Classrooms	Auditorium	3000	26.57	9698.57
		Classrooms	3000	26.57	9698.57
		Seminar Rooms	1200	10.63	3879.43
		Breakout/Group Study Rooms	720	6.38	2327.66
		Classroom Support	240	2.13	775.89
	Class laboratories	Computational/Biology ClassLab	2400	21.26	7758.86
		ClassLab Staff and Support	600	5.31	1939.71
	Design Studio Instructional Space	ClassLab/Maker Space	900	7.97	2909.57
		ClassLab Staff and Support	450	3.99	1454.79
Student/Community Center		Center	1500	11.57	4223.57
		Center support Areas (storage, catering kitchen, etc.)	750	6.11	2229.11
		Quiet Study Areas	600	19.54	7133.14
		Collaboration/Innovation Learning Area	750	12.21	4458.21
		Peer to Peer/Project Based Learning Studios	300	4.89	1783.29
		Small Team Study Room	280	9.12	3328.80
Research and Industry Partnership Component		Computational/Light Biology Res. Lab	1800	15.94	5819.14
		Lab Support	600	2.66	969.86
		Lab Staff	600	2.66	969.86
		Faculty Office	280	9.12	3328.80
Multipurpose/Exhibit Space/Event Support		Multipurpose/Exhibit Space/Event Support	1800	6.94	2534.14
Lobby/Display Area and Kiosks		Lobby/Display Area and Kiosks	300	4.63	1689.43
Office Space		Center- Director's Suite (office, reception, waiting)	600	19.54	7133.14
		Office- Related Programs Support Staff	450	14.66	5349.86
		Office- Building Manager/Support Staff	300	9.77	3566.57
		Open Office	240	7.82	2853.26
		Student Work Stations	72	2.35	855.98
		Break Room/Copy/Storage/Files	240	3.91	1426.63
		QEP Activities (Office Space, reception, waiting)	600	9.77	3566.57
		Office	450	14.66	5349.86
		Open Office	160	5.21	1902.17
		Student Work Stations	72	2.35	855.98
		Break Room/Copy/Storage/Files	240	3.91	1426.63
		Structural, Mechanic, Elec. Data, Toilets, Stairs, Custodial	16,996	72.84	26586.60
			Totals:	382.97	139783.63

4.1.2 Site Photovoltaic Calculations

EcoLadder had to evaluate many different factors in sizing the PV panel array based on the usable area on the roof in consideration of the percentage of urban agriculture required dictated by the floor-to-area (FAR). The total capacity of the solar system takes into account usage of 60% of the total roof space which equated to 6,375 ft^2 of the total roof area of 10,625 ft^2. The remaining percentage of the energy needed to sufficiently power the building was scale jumped to the nearby planned Eco-Commons parking deck.

The building's orientation is a critical design recommendation. Building height and positioning are two factors that have the potential to obstruct the solar cells from receiving the maximum amount of solar insolation with the rising and setting of the sun. The sun will rise on the building's East, over State Street NW, and set in the West towards Hemphill Avenue with maximum solar energy captured during midday when the sun is directly above the building. The number of sun hours will vary with time of day and season. In Table 4.4, the daily average solar insolation values are provided in $kWh/m^2/day$. This daily radiation was plotted versus the month to show how the peak hours change with season in Figure 4.3.

Table 4.4: National Renewable Energy Laboratory (NREL) average daily radiation by month

Month	Daily Radiation (kWh/m2/day)
January	2.62
February	3.37
March	4.54
April	5.78
May	6.04
June	6.4
July	6.04
August	5.45
September	4.87
October	4.06
November	2.87
December	2.36
Average	4.54

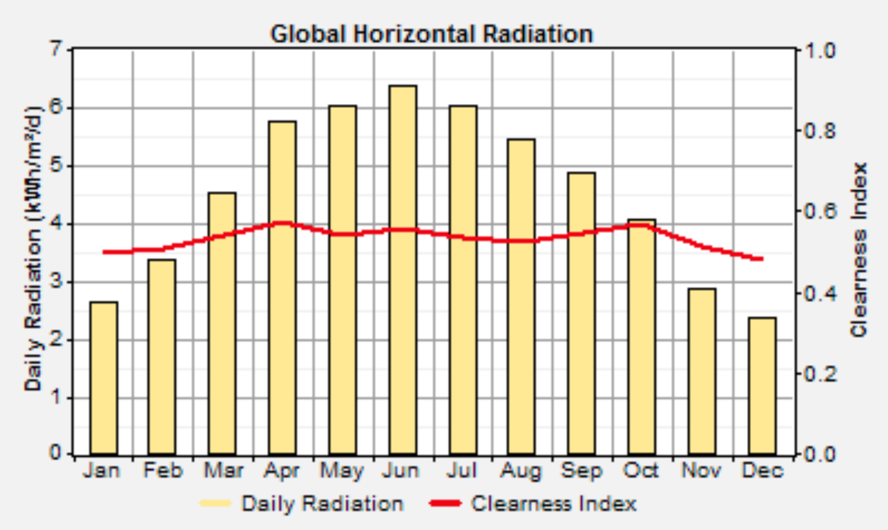


Figure 4.3: The plotted NREL average daily radiation versus the month

Since the amount of peak sun hours varies with the time of year, the photovoltaic panels were sized based on the lowest amount of daily average solar insolation in December at 2.360 hours of peak sunlight. This number is the average number of hours that the sun will shine on the building given its longitude and latitude in Atlanta, Georgia. In the winter, the system will be running at full capacity to capture the maximal amount of sunlight since the number of sun hours is so low: this was the strictest design limitation required to meet the building's winter needs. During the summer hours, the system will not be used at full capacity since the sun will provide more hours of direct sunlight and will provide excessive amounts of energy. The Living Building can use this excess energy in the summer to meet the buildings net positive energy goals as well as provide energy to other buildings in the vicinity.

A dual axis solar tracker was best for the Living Building at GT because it has the ability to move on a 2-axis system to follow the sun's movement throughout the day. While single axis trackers pivot on one axis to track the sun, facing East in the morning and West in the afternoon, a dual axis tracker follows the sun in both azimuth and elevation that keep the sun's rays normal to the module surface at all times when the solar energy is available. Capturing the maximum amount of solar insolation depends largely on the solar azimuth (Figure 4.4), or the compass direction of sunlight that varies with latitude and time of year, and the solar zenith angle, which is the altitude of the sun as a function of time, day number, and latitude.

Figure 4.4: The angle of sunlight affects the conversion rate of PV cells

Figure 4.5 depicts the potential shading that the Living Building at Georgia Tech will receive. This sketch takes into account the height of the Marcus Nanotechnology building to the East and the eventual tree height of the densely populated tree landscape to the west of the building that comprises the Eco-Commons. The Nanotechnology building and the Living Building will both stand four stories tall. Using the Institute's EBB Sector Plan, the surrounding tree heights will range from 20 ft. to 110 ft. tall. The obstacles present on either side of the building will slightly limit the amount of sun received during the early morning and late evening of the day.

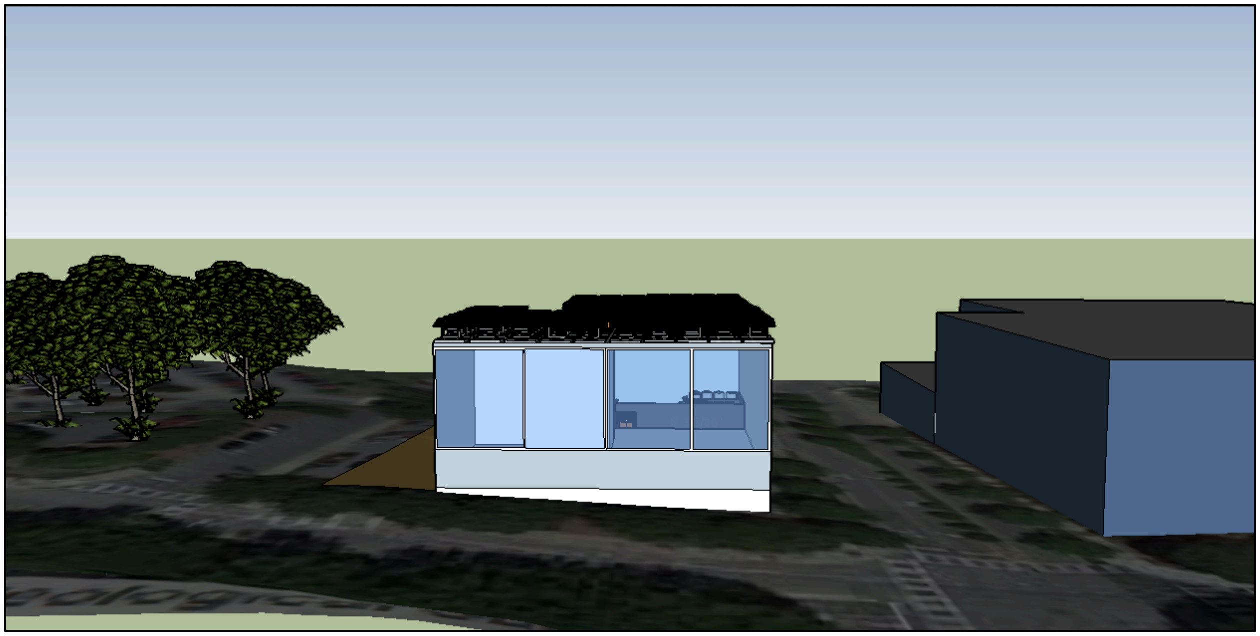
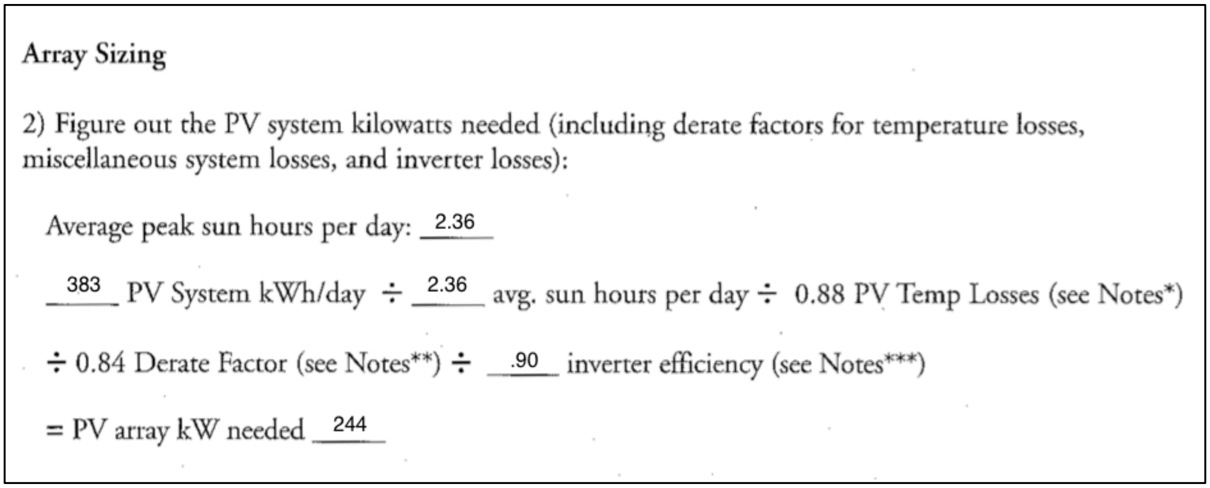


Figure 4.5 The Living Building in relation to the Nanotechnology building and the adjacent trees

Taking loads, climate, site conditions, and inefficiencies into consideration, EcoLadder was able to conclude that the Living Building at Georgia Tech would need a south-facing 244 kW system to sufficiently power the building during the short winter hours. Figure 4.6 shows the PV sizing method from the Solar Energy Institute used to scale the system based on the lowest daily kWh load of 2.36 kWh/day in December.



Array Sizing

2) Figure out the PV system kilowatts needed (including derate factors for temperature losses, miscellaneous system losses, and inverter losses):

Average peak sun hours per day: 2.36

383 PV System kWh/day ÷ 2.36 avg. sun hours per day ÷ 0.88 PV Temp Losses (see Notes*)

÷ 0.84 Derate Factor (see Notes**) ÷ .90 inverter efficiency (see Notes***)

= PV array kW needed 244

Figure 4.6: The worksheet used to size the array based on the daily kWh.

A 244 kW system took into account PV temperature losses, derate factor, and inverter inefficiency. PV temperature losses assumed a factor of 0.88 to account for temperature losses in realistic situations, which assumes daytime ambient temperature of 68 degrees Fahrenheit. The derate factor of 0.84 took into account system losses including the acceptable ranges for module production tolerance, module mismatch, wiring losses, dust and soiling losses, shading, and age of the system. The inverter efficiency used a value of 0.90 as a conservative estimate. Figure 4.7 shows a rendering of the Living Building with a south facing solar array. Due to Atlanta's positioning in the Northern Hemisphere, south facing panels is the best positioning for capturing the most sunlight.

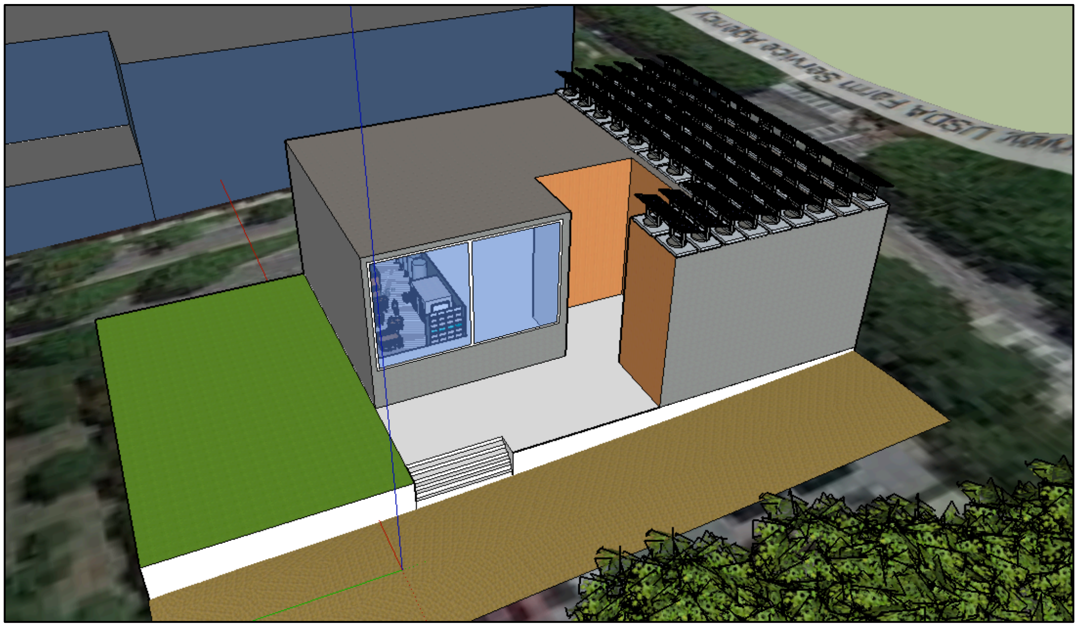


Figure 4.7: This rendering shows south facing panels taking up only a percentage of roof space

4.1.3.a *Sizing Requirements and System Expectations*

The total roof space needed to fit a 244 kW PV array was found to be 1,626 square meters using the equation shown below. This is based on the assumption that each panel has dimensions of two square meters, 320-watt productivity, and a total solar irradiance of 1000 watts per square meter.

$$Panel\ Efficiency = \frac{Panel\ Output}{Total\ Solar\ Irradiance} = \frac{320\ W}{2000\ W} = .16\ or\ 16\%$$

$$Area\ Needed = (PV\ Size) * \left(\frac{1}{panel\ efficiency}\right) * \left(\frac{1}{Total\ Solar\ Irradiance}\right)$$

$$Area\ Needed = (244\ kW) * \left(\frac{1}{0.16}\right)\left(\frac{1}{1000}\frac{m^2}{W}\right) = 1{,}626\ m^2$$

Sixty percent of the roof area (588 m^2) was selected to fulfill the urban agriculture requirement by allowing for additional green roof. This puts the percentage of on-site energy use at about 40% of the total solar array. The remaining 60% of the system (Figure 4.8) will be placed at the adjacent Eco-Commons parking deck. From preliminary estimates, the size of this parking deck roof will be nearly 1.5 times the size of the Living Building footprint. This deck size will allow the remaining energy needs to be placed on the parking deck, justified by the scale jumping Exception.

Figure 4.8: The adjacent parking deck roof that will house the remaining PV array

The system expectations are revealed by the energy production and demand estimate table in Table 4.5, showing the ability of the system to meet the 105% energy production LBC standard by tracking the building performance over the course of a year. This table records the differences between the monthly-modeled energy production and the energy demand to find the total annual difference. Not only did the building sufficiently provide 105% of the requirements, but also the table clearly demonstrates that the array will largely exceed the energy demand. The projected annual total energy production is 268,875.7 kWh, while the required amount is 139,783.6 kWh yearly. The smallest difference occurs, as expected, in December. The modeled production and demand are almost even because the system was sized at the lowest sun hours in this month. To combat the winter heating loads combined with the already low energy production, energy efficient building management techniques and appliances will be used to reduce loads within the building. Reducing the winter loads through natural lighting, window shading, battery storage, and effective use of thermal control will create a more positive producing gap between the modeled energy production and consumption during this time. Load calculations that vary with the number days in the month can be found in the Appendix. During the summer when the system is producing more than enough energy to power the building, the extra energy can be sent to nearby buildings within the Eco-Commons. The EUI per month varied with the number of days in the month ranging between 0.861 and 0.953. The yearly EUI was 11.22. This EUI meets the design goal of an EUI of 20 or under.

Table 4.5: Monthly predictions for energy production and demand

Performance Period	Performance Month	1	2	3	4	5	6
	Actual Month	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May.*	*Jun.*
	kWh						
Energy Production	Photovoltaics (location 1)	13,184.31	15,317.30	22,846.09	28,147.73	30,394.35	31,167.04
	Total Energy Production	13,184.31	15,317.30	22,846.09	28,147.73	30,394.35	31,167.04
Energy Demand	Lighting Power Density	4,363.44	3,941.18	4,363.44	4,222.69	4,363.44	4,222.69
	Equipment Power Density	3,407.78	3,077.99	3,407.78	3,297.85	3,407.78	3,297.85
	Plug Loads (Peak)	4,100.81	3,703.96	4,100.81	3,968.53	4,100.81	3,968.53
	Total Energy Demand	11,872.03	10,723.13	11,872.03	11,489.07	11,872.03	11,489.07
EUI	**Project Energy Use Intensity (EUI)**	0.953	0.861	0.953	0.922	0.953	0.922
	Energy Storage						
Modelled (optional)	Modelled energy production	13,184.31	15,317.30	22,846.09	28,147.73	30,394.35	31,167.04
	Modelled energy demand	11,872.03	10,723.13	11,872.03	11,489.07	11,872.03	11,489.07
	Predicted delta	1,312.28	4,594.17	10,974.06	16,658.66	18,522.32	19,677.97

Performance Period	Performance Month	7	8	9	10	11	12	Annual Total
	Actual Month	*Jul.*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	
	kWh							
Energy Production	Photovoltaics (location 1)	30,394.35	27,425.37	23,716.17	20,430.64	13,976.47	11,876	127,818.94
	Total Energy Production	30,394.35	27,425.37	23,716.17	20,430.64	13,976.47	11,876	127,818.94
Energy Demand	Lighting Power Density	4,363.44	4,363.44	4,222.69	4,363.44	4,222.69	4,363.44	25,899.16
	Equipment Power Density	3,407.78	3,407.78	3,297.85	3,407.78	3,297.85	3,407.78	20,226.80
	Plug Loads (Peak)	4,100.81	4,100.81	3,968.53	4,100.81	3,968.53	4,100.81	24,340.31
	Total Energy Demand	11,872.03	11,872.03	11,489.07	11,872.03	11,489.07	11,872.03	70,466.27
EUI	**Project Energy Use Intensity (EUI)**	0.953	0.953	0.922	0.953	0.922	0.953	5.657
	Energy Storage							
Modelled (optional)	Modelled energy production	30,394.35	27,425.37	23,716.17	20,430.64	13,976.47	11,876	127,818.94
	Modelled energy demand	11,872.03	11,872.03	11,489.07	11,872.03	11,489.07	11,872.03	70,466.27
	Predicted delta	18,522.32	15,553.34	12,227.10	8,558.61	2,487.40	4	57,352.67

BATTERY RESILIENCY

Battery resiliency must be used in order to back up 15% of the daily lighting load and up to one week of the refrigeration load as required by the Living Building Challenge. These constraints will be utilized on days when peak sun hours are minimal in less than ideal weather conditions like rainy and cloudy weather. Table 4.6 represents the lighting power density based on floor space and total wattage-hours that lighting will require. The sum for the lighting energy demand was calculated to be 141 kWh/day, which is almost 40% of the total demand requirements under the worse case scenario when natural sunlight is not available. To meet LBC requirements, this total lighting load sum was then multiplied by .15 to find 15% of the daily lighting load needed to size the battery components. This was calculated to be 21.1 kWh/day in instances where energy from the PV array would not be available.

Battery backup required to fulfill refrigeration loads up to one week was not a major concern for the system scaling. The Living Building at Georgia Tech will only have one small catering/miscellaneous kitchen as well as multiple miniature refrigerators in offices for full time employees. This percentage of refrigeration was very minor in comparison to the other plug loads. Common refrigerators will consume nearly 1.6 kWh of energy per day. Since the building will only house a small number of full time employees in the offices, larges amount of refrigeration will not be needed. An extra 7 kWh per day is a conservative estimate to add the overall battery operating needs. This addition puts the total battery backup requirements at around 28 kWh per day.

Battery specifications were highly important to enable the system to meet these PV design goals. Tesla energy was selected for the battery system that will power the building when the sun is not shining. This Powerwall system will be wall mounted rechargeable lithium-ion batteries, that have 6.4 kWh of energy storage capacity each. This system will be located in the basement, away from common areas. Five of these wall mounted units will be sufficient and will far exceed the requirements to meet the 15% of the daily lighting load and up to one week of refrigeration loads. Figure 4.9 above shows two of these battery wall mounts. Current battery systems are bulky and expensive in maintaining. Tesla batteries are sleek, relatively inexpensive, and require minimal maintenance. Given its pristine reputation and proven capabilities, Tesla battery innovative technology will be a design consideration that Eco Ladder is happy to recommend.

Figure 4.9. Two Powerwall battery systems.

Table 4.6: The total lighting load in kWh/year

Space Component		**Space Type**	**Total Sq. Ft.**	**kWh/day**	**kWh/year**
Instructional Space	Classrooms	Auditorium	3000	10.29	3754.29
		Classrooms	3000	10.29	3754.29
		Seminar Rooms	1200	4.11	1501.71
		Breakout/Group Study Rooms	720	2.47	901.03
		Classroom Support	240	0.82	300.34
	Class Laboratories	Computational/Biology ClassLab	2400	8.23	3003.43
		ClassLab Staff and Support	600	2.06	750.86
	Design Studio Instructional Space	ClassLab/Maker Space	900	3.09	1126.29
		ClassLab Staff and Support	450	1.54	563.14
Student/Community Center		Center	1500	6.86	2502.86
		Center support Areas (storage, catering kitchen, etc)	750	2.04	743.04
		Quiet Study Areas	600	6.51	2377.71
		Collaboration/Innovation Learning Area	750	4.07	1486.07
		Peer to Peer/Project Based Learning Studios	300	1.63	594.43
		Small Team Study Room	280	3.04	1109.60
Research and Industry Partnership Component		Computational/Light Biology Res. Lab	1800	6.17	2252.57
		Lab Support	600	1.03	375.43
		Lab Staff	600	1.03	375.43
		Faculty Office	280	3.04	1109.60
Multipurpose/Exhibit Space/Event Support		Multipurpose/Exhibit Space/Event Support	1800	4.11	1501.71
Lobby/Display Area and Kiosks		Lobby/Display Area and Kiosks	300	2.74	1001.14
Office Space		Center- Director's Suite (office, reception, waiting)	600	6.51	2377.71
		Office- Related Programs Support Staff	450	4.89	1783.29
		Office- Building Manager/Support Staff	300	3.26	1188.86
		Open Office	240	2.61	951.09
		Student Work Stations	72	0.78	285.33
		Break Room/Copy/Storage/Files	240	1.30	475.54
		QEP Activities (Office Space, reception, waiting)	600	3.26	1188.86
		Office	450	4.89	1783.29
		Open Office	160	1.74	634.06
		Student Work Stations	72	0.78	285.33
		Break Room/Copy/Storage/Files	240	1.30	475.54
		Structural, Mechanic, Elec. Data, Toilets, Stairs, Custodial	16,996	24.28	8862.20
			Totals:	140.76	51376.04

SYSTEM COSTS

Cost estimates were based on the 244 kW sized PV array and 5 Tesla batteries. The PV array and battery assumed industry-pricing standards. The solar panels alone sell at approximately $1 per watt and the installation fees associated with it sell at roughly $2.5 per watt. Installation prices include installation labor, engineering fees, and other overhead. Combining these prices puts the PV array at $244,000 for the panels and $610,000 for the associated installation costs. The PV array totaled to cost $854,000. The Tesla battery system will cost $3,000 for one 6.4 kW system. Five of these batteries will sell at $15,000. The industry standard for PV installation was also used for the battery pricing. For every kilowatt-hour of load requirements, $2.5 were needed for installation, wiring, and overhead purposes. The additional installation costs were priced at $80,000. Totaling the battery prices and the installation, the sum was derived to be $95,000. The overall system pricing, which includes the PV array and the battery system, was totaled to be $949,000.

$$Total\ System\ Cost = (PV\ Paneling + PV\ Installation) + (Batteries + Battery\ Installation)$$

$$Total\ System\ Cost = (\$244{,}000 + \$610{,}000) + (\$15{,}000 + \$80{,}000) = \$949{,}000$$

These pricing estimates are very reasonable for a system this size. Through the generous Kendeda funding, EcoLadder was able to recommend technology on the forefront of the industry. Although slightly more expensive than traditional systems, the higher pricing equates to a more efficiently sized system that experiences less inefficiency losses. EcoLadder uses the most common pricing standards that are equivalent with the most up to date and innovative technologies. Other methods for energy efficient components are cheap in comparison. A few of these recommendations for energy efficiency will be discussed in more detail in the overall Energy Petal Recommendations section. A part from energy recommendation, the PV array will be one of the most expensive expenditures in the entire building. The higher PV pricing is justified by other Petal requirements that will only cost a fraction of total energy costs.

The system was sized for a non-optimal load case and didn't include energy efficiency recommendations for the initial ideal load or pricing calculations. With the addition of these recommended systems, the building will reduce the amount of energy lighting, mechanical equipment, and plug loads contribute to the overall energy consumption. EcoLadder has compiled an extensive list of techniques and control systems that the Living Building at Georgia Tech can implement year round to ensure the building's demands have been met. In situations where sunlight is lost for long periods of time, the building will still be able to meet its consumption needs. The ideal loads were calculated without the use of energy efficient systems like thermal control and building management technology. Taking these high performance measures into account, the building will be able to save massive amounts of energy in unique ways.

Thermal Control:

Space heating and cooling is one of the most energy intensive features of any building design. When natural systems are not available for thermal control, HVAC energy will be provided from a central system. The HVAC system will be based on a low pressure variable air volume system (VAV), creating primary conditioned air which can be pulled on a room-to-room basis depending on need. This low pressure VAV system can be up to 30% more efficient than a traditional duct-to-duct system. In addition, a centrally located HVAC system will allow faster heating and cooling through the reduced amount of ductwork. A "duct sock" is one alternative to conventional metal ductwork systems in large open areas. This sock will hang from the ceiling and has the benefit of increased diffusion of air throughout the space without additional energy input.

Natural methods for reducing loads and energy consumption will also be heavily implemented. Passive solar techniques will best achieve natural thermal control (Figure 4.10). Considerations like thermal mass and natural lighting & ventilation are highly recommended because they are simple, require minimal maintenance, and provide optimal comfort. Utilizing the laws of thermodynamics, thermal mass will be achieved through materials and insulation where energy can be absorbed, stored and later released helping preventing rapid temperature fluctuations. Many of the materials used in the embodied carbon analysis were run assuming that 70% of the building's shell was constructed with windows.

To further reduce energy lost to space heating and cooling, a combination of natural lighting and ventilation is used. Natural lighting is maximized through tall and large windows that allow more light in a space. The combination of natural lighting hitting these panels, tinted windows, and air sequestering can be a huge source of energy efficiency and reduce the space & heating loads while optimizing ventilation. Effective use of partially shaded, vinyl-lined, and glazed windows will shade the interior space from exterior heat during the summer and warm the building during the colder seasons. Partially shaded windows are made possible by exterior façade paneling and louvers. These panels can be computer automated to tilt, meeting ideal sun angle and maximizing sunlight transmission into the structure. Another unique way that passive solar will be used includes the surrounding tree heights. Deciduous trees, which are already slated for planting in the landscape narrative, allow solar radiation through their bare crown during the winter and provide shading in the summer.

A rooftop down draft chimney can be used not only to filter pollen and other air contaminants, but also sequester outside warm air for use within the building. In the lower parts of the building, 'the stack effect' is a technique that will be used to achieve efficient airflow throughout. Air will flow in through the bottom of the building, up, and out to maximize the natural air current. Radiant flooring will allow the hot or cool air to move across floors. Radiant flooring can be adjusted based on the individual's comfort through the use of a flooring 'plemns'. These systems are an excellent choice for large spaces needing infiltration where air heating is not effective.

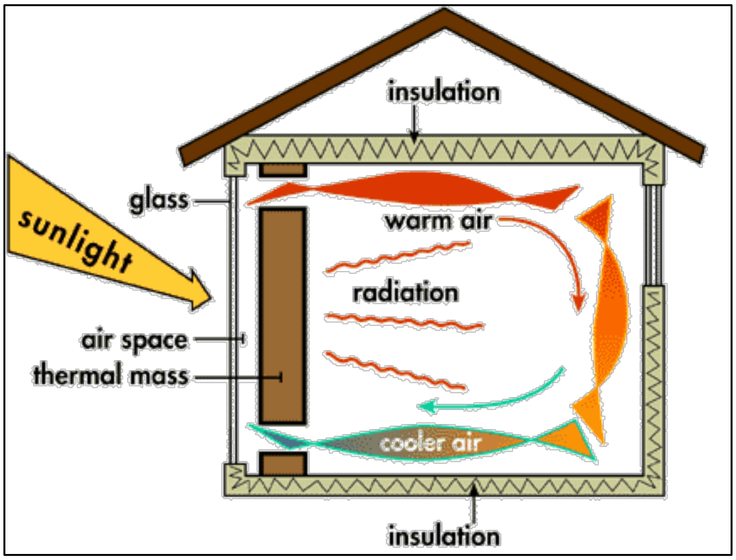


Figure 4.10: A basic passive solar system utilized throughout the building

In more recessed parts of the building where natural lighting is not directly accessible, the use of lighting tubes will be implemented. Lighting tubes use the refraction of the sun's light to direct the natural sunlight to hard to reach places surrounded entirely by concrete or other non-penetrable materials. Lighting tubes are placed on the roof and only require minimal amounts of roof space. These tubes are incredibly effective in resembling traditional light bulbs; studies now show that the use of natural lighting can increase worker productivity in these spaces. When the sun is not readily available at any point in the day, energy efficient light bulbs will be powered by the battery system. EcoLadder recommends the use of T-5 fluorescent bulbs. These lights give off a cool white light and can last up to 32 years before needing replacement when used appropriately. Although they contain mercury, there is a Red List exception for small electrical components.

In addition to providing air condition capabilities from the PV array, EcoLadder recommends a smaller scaled geothermal energy system beneath the building. This renewable energy source was not enough to meet the original energy demands of the building, but is still an effective measure to meet other demands. Geothermal energy utilizes the temporal gradient between Earth's surface and interior, which can be harnessed as an air heating or cooling source. Geothermal wells can be as shallow as 15 feet below the surface where a constant temperature can be found. By leveraging these temperature differences, thermal energy can be used to either heat or cool the building via the displacement air supply or heat domestic hot water pumps to further reducing energy loads.

Building Management Systems:

To maximize energy efficient systems within the building, we recommend the use of a building management system. The most optimal building performance can now be achieved through automatic control systems that monitor HVAC, ventilation, censored lighting, fire and security, water, refrigeration, and solar positioning. To make these systems work in orchestration with each other and as smoothly as possible, EcoLadder recommends the use of a third party consultant to install and track performance over time. A company such as SmartCore operates on a cloud-based system where controls can be set automatically according to a schedule or manually throughout the day to meet load requirements. At a very reasonable price, performance monitoring can be utilized to effectively measure current trends. These trends can be tracked and analyzed to help with reducing energy consumption and building upkeep. For instance, during the night when the building loads are low, the system will run automatically at the lowest capacity and can kick on an hour before the first employee is scheduled to arrive in the morning. Further retrofits can be added during the one-year performance period to assure Energy Petal requirements are met.

Other Recommendations:

EcoLadder recommends that all the PV energy be stored in DC current, and converted to AC current when needed in the building's grid. PV energy from the Living Building roof and nearby parking deck roof can be combined into one central system that provides the electricity needs for the building. One exception for the use of AC current in the building is lighting. Lighting for the building can be run on separate lines that are DC only. While DC lighting can increase the complexity of the system, the energy saved from not having it to convert to AC can be a significant savings in terms of energy efficiency. In addition, the DC grid can be used to provide occupants USB charging stations for mobile devices, further increasing efficiency. By creating a separate grid that is DC, large amounts of energy can be saved that is normally lost in the conversion from DC to AC and then back down.

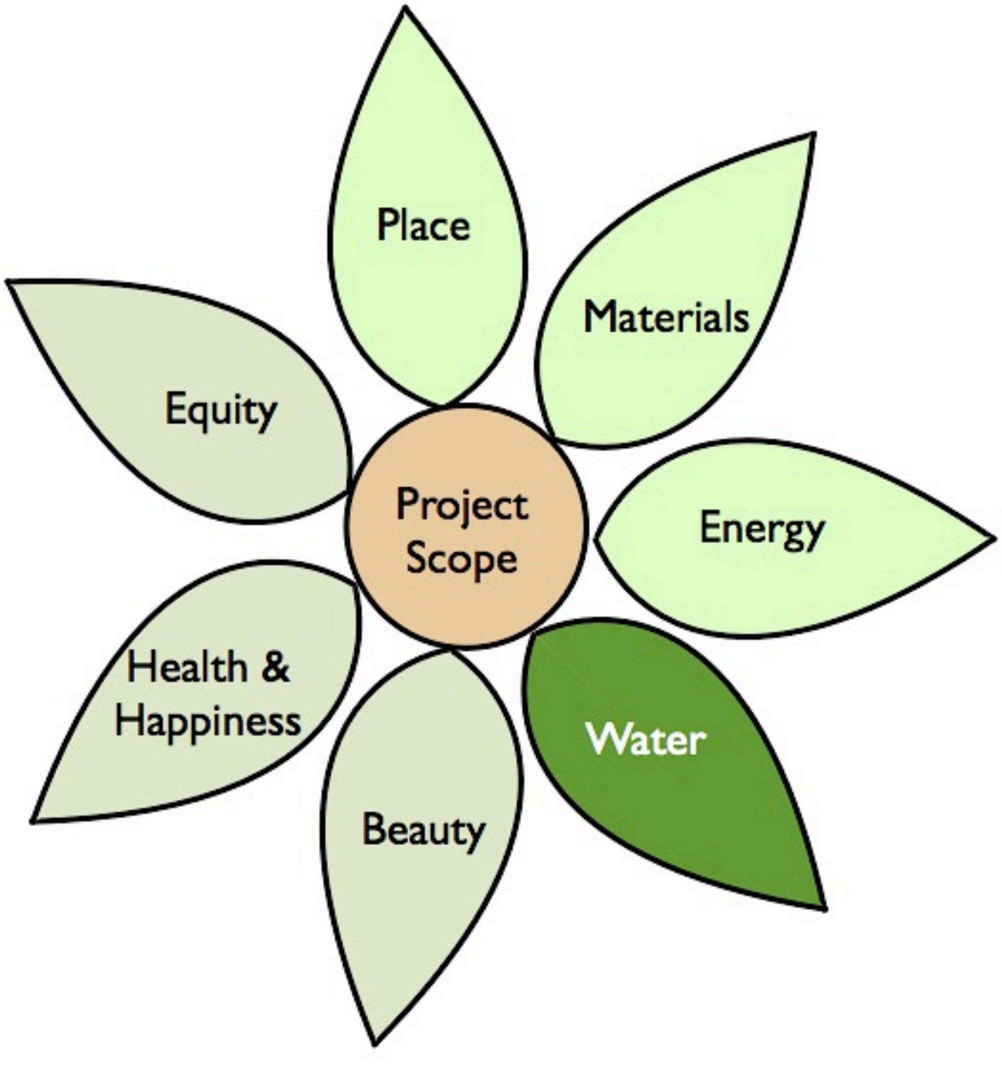
As mentioned by ENERGY STAR, 30% of total energy consumption in commercial buildings is wasted. The Living Building will strive to drive this waste percentage number down so that minimal losses and maximal utilization of energy efficient techniques will occur. EcoLadder estimates that between 20 to 25% of the energy consumption lost through waste can be completely avoided, which will result in an equal reduction of the ideal building load. This would decrease the previously calculated ideal load from 383 kWh/day down to almost 300 kWh/day. Over the course of a year, the sum of these energy savings will be crucial in achieving 105% energy performance.

Through the use thermal control, building management systems, and other modifications, a building that was thought to have a distance chance of success is a realistic possibility.

5.0

The Water Petal

Weather and Waste



The Living Building Challenge has developed the Water Petal to achieve net zero water usage from natural sources. Mimicking the surrounding ecology's natural systems and recycled water treated onsite by non-chemical means within a closed loop system lays the framework for this Petal. Using historical data and existing infrastructure in addition to items from Georgia Tech's Stormwater Masterplan, EcoLadder approximated the annual water consumption from building operations, required monthly water capture, treatment & storage needs, and provided various recommendations to meet treatment and efficiency standards.

5.1.1 Fixture Water Usage Calculations

Occupancy numbers for the Living Building were used by our team to develop estimates of the building's water consumption. Based on US Averages and a CPSM provided figure of 10 full-time employees, water usages for various fixtures in the building have been estimated using data from Kohler's Commercial Water Calculator. Results tabulated in Table 5.1

5.1.2 Urban Agriculture Water Requirement Calculations

Calculations were made for providing urban agriculture space with 1-1.5 inches of soil moisture over our required urban agriculture area of 6,375 ft^2. Considering the water requirements of a typical garden soil porosity of 0.6 extrapolated over a year, urban agriculture water needs for the project would be 187,000 gal/year.

5.1.3 HVAC Water Requirement Calculations

Water usage was estimated using water consumption data for a 100,000 ft^2 office building in Fresno, California, normalized for the size of the Living Building at Georgia Tech. All water requirement calculations are illustrated in Table 5.1 with consumption values per day, month and year listed for each particular fixture.

Table 5.1 Annual Building Water Consumption Estimates for Fixtures, HVAC, and Urban Agriculture

Annual Building Water Consumption		**Gallons/day**	**Gallons/month**	**Gallons/year**
Fixtures	**Showers**	300.00	9,000.00	109,500.00
	BioLabs	15.00	450.00	5,475.00
	Breakrooms	15.00	450.00	5,475.00
	Bathroom Sink Faucets	200.00	6,000.00	73,000.00
	Urinals	720.00	21,600.00	262,800.00
	Toilets	1,152.00	34,560.00	420,480.00
HVAC Water Consumption		913.89	27,416.66	333,569.34
Urban Agriculture		512.33	15,583.33	187,000.00
Total Building Consumption		3,828.22	115,059.9	1,397,300.00

ANNUAL RAINWATER CALCULATIONS

Rainwater was assumed to be collected from the whole roof, a total of 10,625 square feet. EcoLadder assumed a roof capture system with 90% efficiency, with losses expected in evaporation and infiltration into rooftop soil for planter boxes. The water will be captured from the roof though the gutter system and funneled to the grey water treatment system and then to the potable water cistern in the basement of the building.

As part of Georgia Tech's Stormwater Masterplan, various infiltration spaces have been planned to provide water to the Eco-Commons and Living Building sector. EcoLadder used approximate infiltration surface areas of raingardens and other rainwater capture space equivalent to 3.2 acres (139,392 sq ft), which is well exceeded by the Eco-Commons (Sector 6) and Infiltration Area (Sector 9A) as outlined in the Georgia Tech Stormwater Masterplan. Rainwater capture and infiltration were calculated using the equation below and the estimates of Rooftop Capture and Raingarden Capture provided in Table 5.2.

*Water Supply = Rainfall Rate (in) * Area (in^2) * 0.00432899 gallons/in^3 * 90%*

Table 5.2 Average Monthly Rainfall and Rainwater Capture Estimates

Month	Jan	Feb	Mar	Apr	May	Jun
Avg Rainfall* (in)	4.20	4.67	4.81	3.36	3.67	3.95
Rooftop Rainwater Capture (gal)	25,036.30	27,838.00	28,672.60	20,029.10	21,877.00	23,546.10
Raingarden Capture (gal)	328,457.20	365,213.10	376,161.70	262,765.80	287,009.00	308,906.20
Month	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Avg Rainfall* (in)	5.27	3.90	4.47	3.41	4.10	3.90
Rooftop Rainwater Capture (gal)	31,414.60	23,248.00	26,645.80	20,327.10	24,440.20	23,248.00
Raingarden Capture (gal)	412,135.60	304,996.00	349,572.30	266,676.00	320,636.80	304,996.00

Using these numbers, we can see that on a monthly average, combined Rooftop and Raingarden Capture numbers exceed the Living Building's usage consumption. The lowest month of rainfall, April, provides over 280,000 gallons of rainwater in capture, which exceeds the Living Buildings approximate 115,000-gallon water consumption. Taking into consideration added efficiencies and water saving technologies, which have been outlined in EcoLadder's recommendations, even less raingarden capture, space may be required for water supply.

Buildings in warmer climates suspect to wet years and periods of drought typically require one third of the potential annual rainwater capture volume in cistern storage. This estimate is based on cistern capacity calculation standards in Albuquerque, New Mexico, which experiences heavier droughts than Atlanta. From Table 5.3, the required cistern capacity for rooftop rainwater capture in the Living Building is approximately 100,000 gallons and for the raingarden capture in the Eco-Commons Area approximately 1,300,000 gallons.

Table 5.3 Required Cistern Size for Annual Rainwater Capture

	Annual Rainwater Capture (gal)	Required Cistern Size (gal)
Rooftop	296,322.80	98775
Raingarden	3,887,525.70	1295842

5.3.1 Water Balance Diagram for Graywater Treatment

EcoLadder studied three different system alternatives with various treatment routes. These water balance diagrams each indicate overall flow of water in and out of the building. The system shown in Figure 5.1 is a traditional approach to water treatment: blackwater and graywater from the building may be treated in a combined system or separately. Water balances typically contain separate processes for grey and blackwater treatment due to various code requirements for recycling black wastewater.

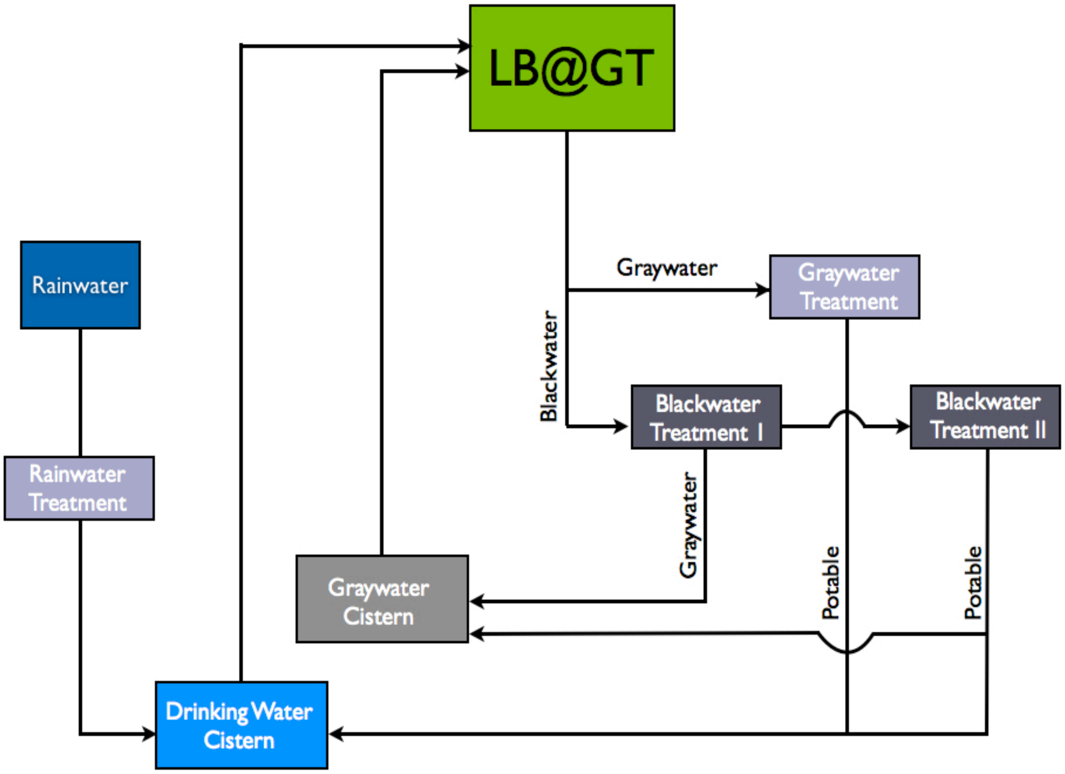


Figure 5.1: Water balance diagram with separate graywater treatment

5.3.2 Water Balance with Urine Separation

The system shown in Figure 5.2 illustrates a system with urine separation, which reduces blackwater treatment system loads. This is accomplished using urine-diverting or waterless toilets, which will allow for separate outflows of solid and liquid waste. By splitting these two streams, more water can be designated as graywater for reuse in non-potable applications instead of blackwater that must be treated before being released from the closed loop system as effluent.

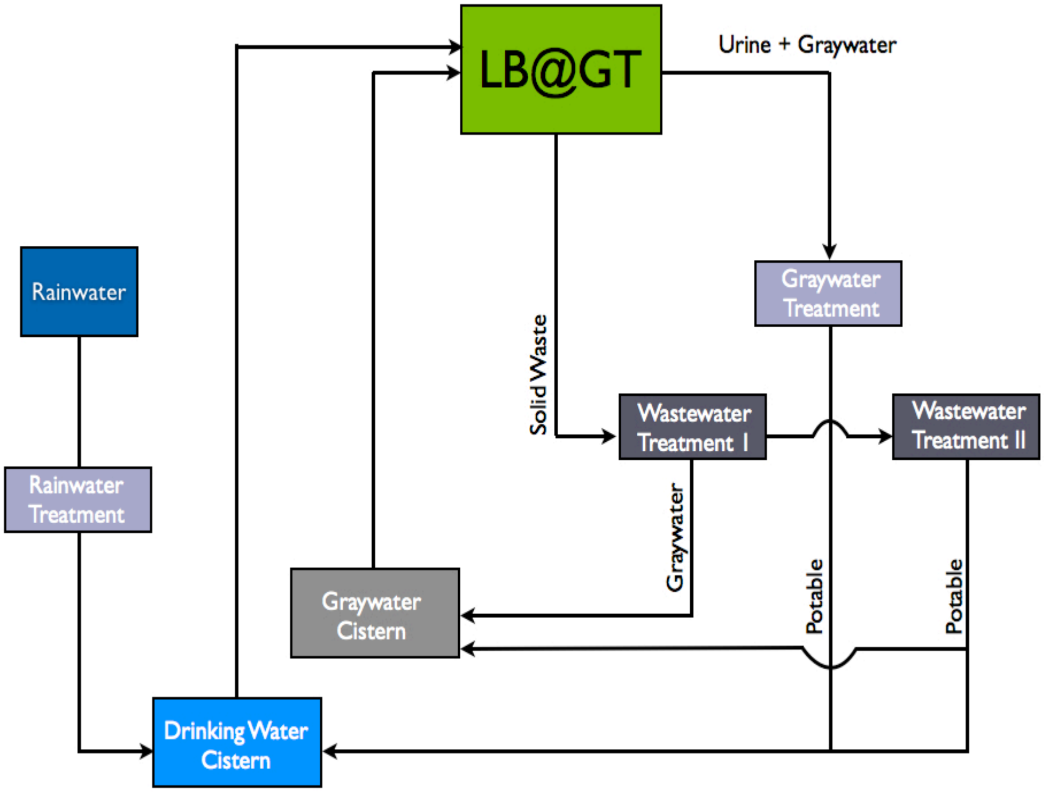


Figure 5.2: Water balance diagram with urine separation system

5.3.3 Water Balance with Urine Separation and Composting Toilets

The system shown in Figure 5.3 utilizes composting toilets to eliminate the need for blackwater treatment systems by separating solid waste and storing it within a composting system. Equipped with negative air pressure ventilation systems, the system helps to maintain indoor air quality. Storage of solid waste at a large scale adds some unique risks; however, composting toilet systems developed by Clivus Multrum can theoretically fulfill the capacity needs for stadiums, and have been used in Living Building projects of similar scale to the Living Building at Georgia Tech. When used in conjunction with urine separation strategies, the maximum amount of water can be maintained in the closed loop. This methodology minimizes waste effluent while also providing nutrient rich compost that can be utilized in agriculture not intended for human consumption.

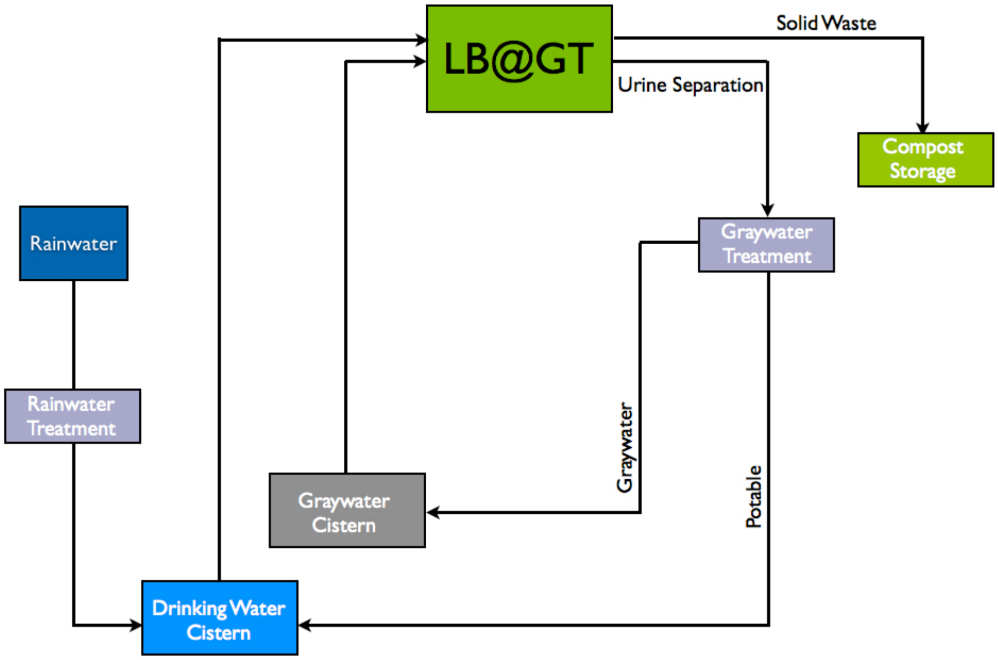


Figure 5.3: Water balance diagram with urine separation and composting toilet systems

TREATMENT SYSTEMS

Captured Rainwater must undergo non-chemical treatment and purification prior to being used for potable outlets. The Living Building Challenge recommends utilization of UV disinfection, which requires additional exception paperwork due to use of Red-List materials in UV treatment systems. Chlorine can be utilized for final treatment with residual disinfecting properties, but must be removed at fixture outlets.

Potable water, once used in the building, may be recycled through either graywater or blackwater treatment systems. Georgia Tech's CPSM plans of utilizing an off-site blackwater treatment facility adjacent to the Living Building and Eco-Commons area may require additional exception documentation. This near-site facility would be implemented as a lamination to the new parking structure in the EBB sector.

CPSM outlines various graywater and blackwater treatment solutions in the Stormwater Masterplan that are non-chemical and acceptable by LBC standards, such as simulated tidal wetlands and hydroponic technologies as illustrated in Figures 5.4 and 5.5.

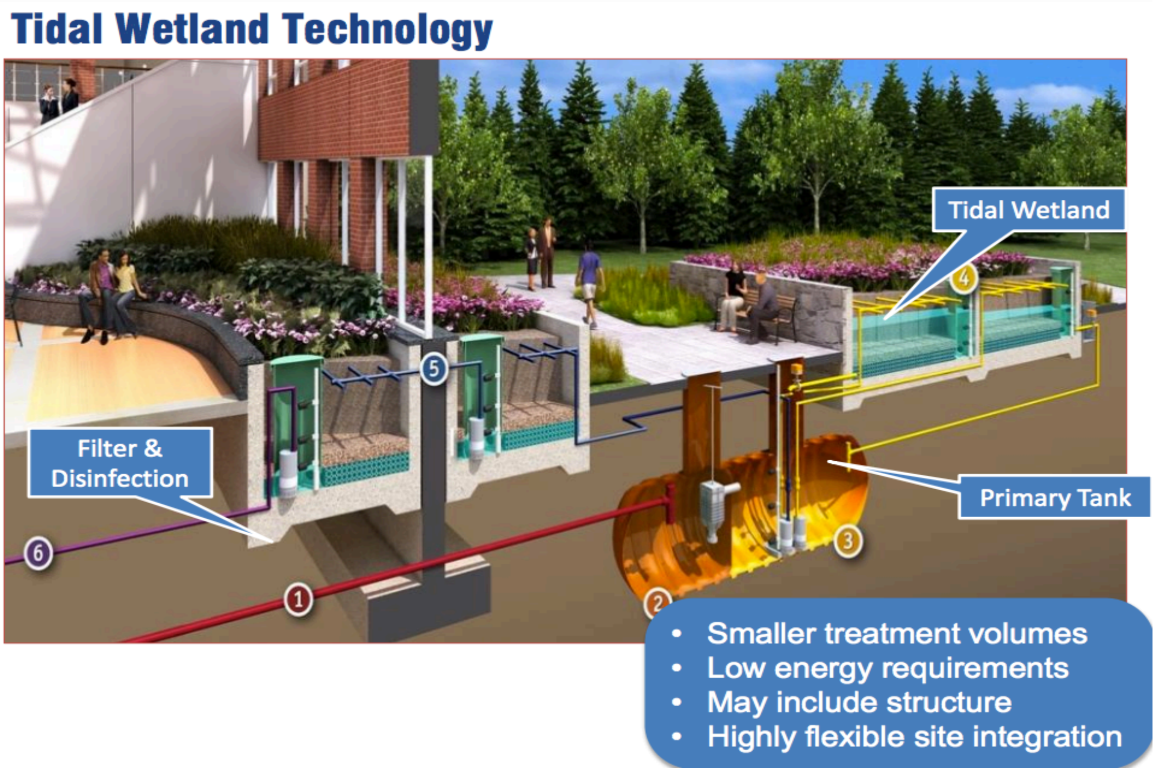
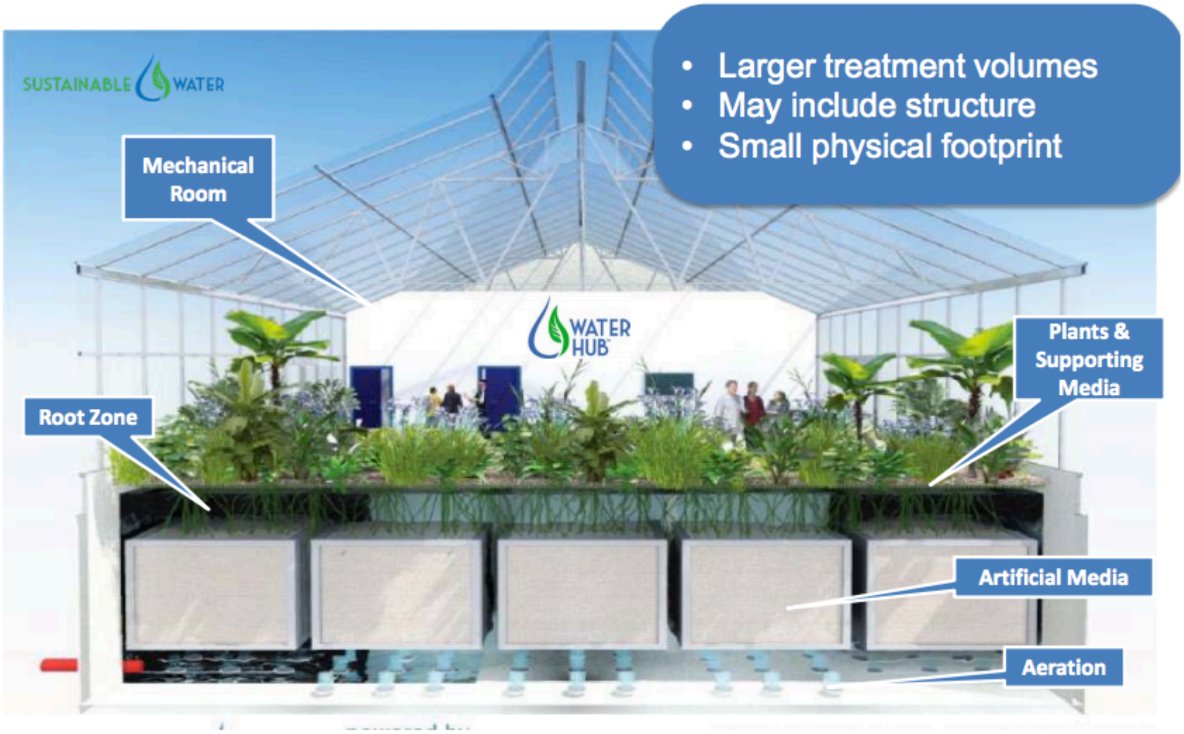


Figure 5.4: Tidal wetland technology for blackwater treatment

Hydroponic Technology



- Larger treatment volumes
- May include structure
- Small physical footprint

Figure 5.5: Hydroponic technology for blackwater treatment

These treatment methods may help fulfill additional requirements for the Urban Agriculture Imperative and Place Petal.

From the estimated values, the Living Building can feasibly source all of its water consumption needs from recycled water and captured rainwater. These values may decrease or be within closer reach to accurate predictions after further study of rainfall patterns near the proposed site. Studying rainwater infiltration at selected sites, such as the rain garden, and increased water consumption efficiency within the Living Building may help overcome these limitations. In order to meet LBC's requirements for the water petal and to reduce overall water consumption, we at EcoLadder are providing various recommendations for landscaping and building systems to increase porous surface areas for rainwater infiltration. Water table recharge concerns, although not currently at the forefront in the southeast, may become problematic for the Proctor Creek Watershed. Looking to California as a possible future outcome for the current 'Water Wars' paints a bleak picture when accounting for the rapid population growth in the Metro Atlanta region.

Eco-Commons and Landscaping

In order to reduce storm surge in the Eco-Commons area, retain stormwater on site, and provide groundwater recharge, it is important for the Living Building and its surrounding area to implement wetlands and bioswales. Wetlands and bioswales can help prevent water from entering the sewer system by allowing rainwater to be filtered and collected before runoff enters municipal water systems. Wetlands and bioswales can be utilized by the Living Building as an additional source of water since these sources will be cleaner than general rainwater. This technique has the additional effect of reducing load on the graywater treatment system. Figure 5.6 illustrates an example of a bioswale system attached to a pedestrian and bike pathway.

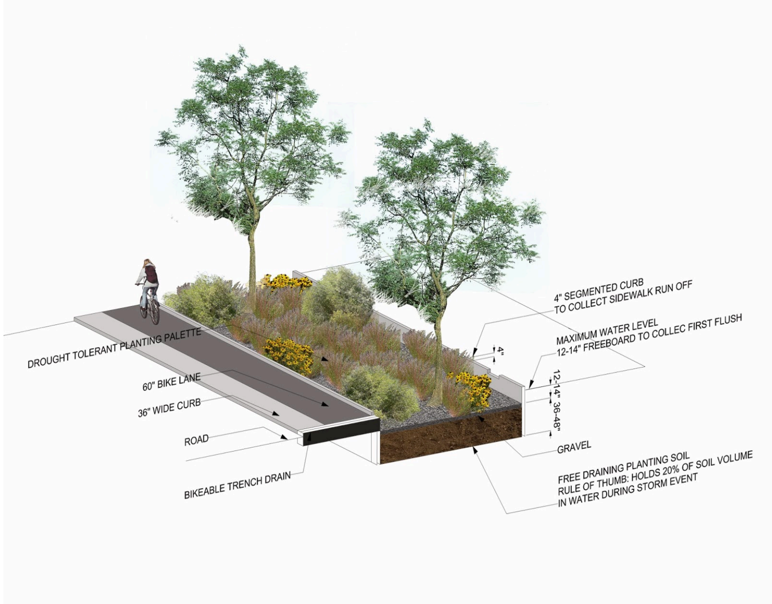


Figure 5.6: Sidewalk Bioswale System

Various paved surfaces used around the Eco-Commons area and Living Building can be optimized for groundwater infiltration and collection by using pervious paving techniques. These techniques can be applied to pedestrian pathways, bike paths, low traffic parking lots, service lanes and other paved surfaces. Another advantage of using pervious paving is the filtration of suspended solids and pollutants in the rainwater.

Plants are a crucial component of both wetlands and bioswales. EcoLadder suggests using the "Guidelines for Establishing Aquatic Plants in Constructed Wetlands" produced by the U.S Department of Agriculture as a reference when choosing effective plants for constructed wetlands and swales. In addition, utilization of plants native to the Atlanta area can reduce landscape maintenance needs and return the current environment to its most natural state. Healthy and established plant communities play an indispensible role in the hydrologic cycle through their contribution of evapotranspiration by enabling liquid water to be moved from the soil to the atmosphere. EcoLadder suggests using horsetail reeds, giant bulrush, and giant cutgrass in the wetland and bioswales created for the Living Building and its surrounding area, as they are effective and primary plants in Georgia's wetlands.

Building Management System & Suggested Equipment

In order to reduce the total amount of water used by the structure, a building management system is essential in keeping the project as efficient as possible. For water specifically, there are many different solutions that can be implemented to reduce water use. Some suggestions include low flow fixtures, automated landscape irrigation, waterless urinals, and composting toilets.

In addition to fixtures that use less water, monitoring is key to ensuring water usage is kept at a sustainable level. Monitors for the cisterns and treatment systems will also ensure that water levels are consistent and excess water can be drained when levels are high. Similarly, water can be conserved during periods of low rainfall or drought. Monitoring also helps find inefficiencies in the system and makes finding leaks and other troublesome issues in the plumbing system more straightforward. Monitoring allows the building manager to see patterns in building water use, facilitating tracking and planning efforts that can be utilized in maximizing system efficiency while minimizing losses.

A building management system may also be extremely beneficial in documenting the 12-month review period. The building management system may also extend to HVAC system management while incorporation of sensor-triggered lighting and air conditioning may further increase the efficiency of those systems, and reduce overall water usage.

Composting Toilets

Clivus Multrum Incorporated is one of the industry's leaders in closed-loop graywater treatment and composting toilet system implementation, having designed and installed systems on multiple Living Building projects in the United States in addition to other projects similar or larger in size than the Living Building at Georgia Tech. With this in mind, EcoLadder recommends utilizing these systems if the financial cost is lower than implementing blackwater treatment systems. Figure 5.7 shows a basic schematic of the system from Clivus Multrum's website.

HVAC Solutions for Water Use Reduction

Typical methods of reducing water use in HVAC systems involve reducing evaporation and loss of water within water cooling towers, and using alternative sources of water, such as recycled graywater or a blend with soft water. Many of these methods are outlined in the Journal of Fluids Engineering and are industry standards for efficiency in these types of systems.

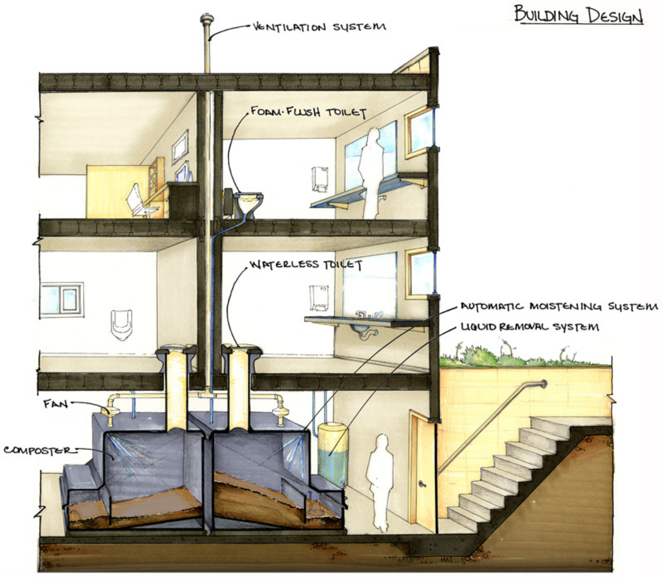


Figure 5.7: Foam flush toilets can be used on higher floors where waterless will not suffice.

Thermosiphon and Passive Solar Water Heating

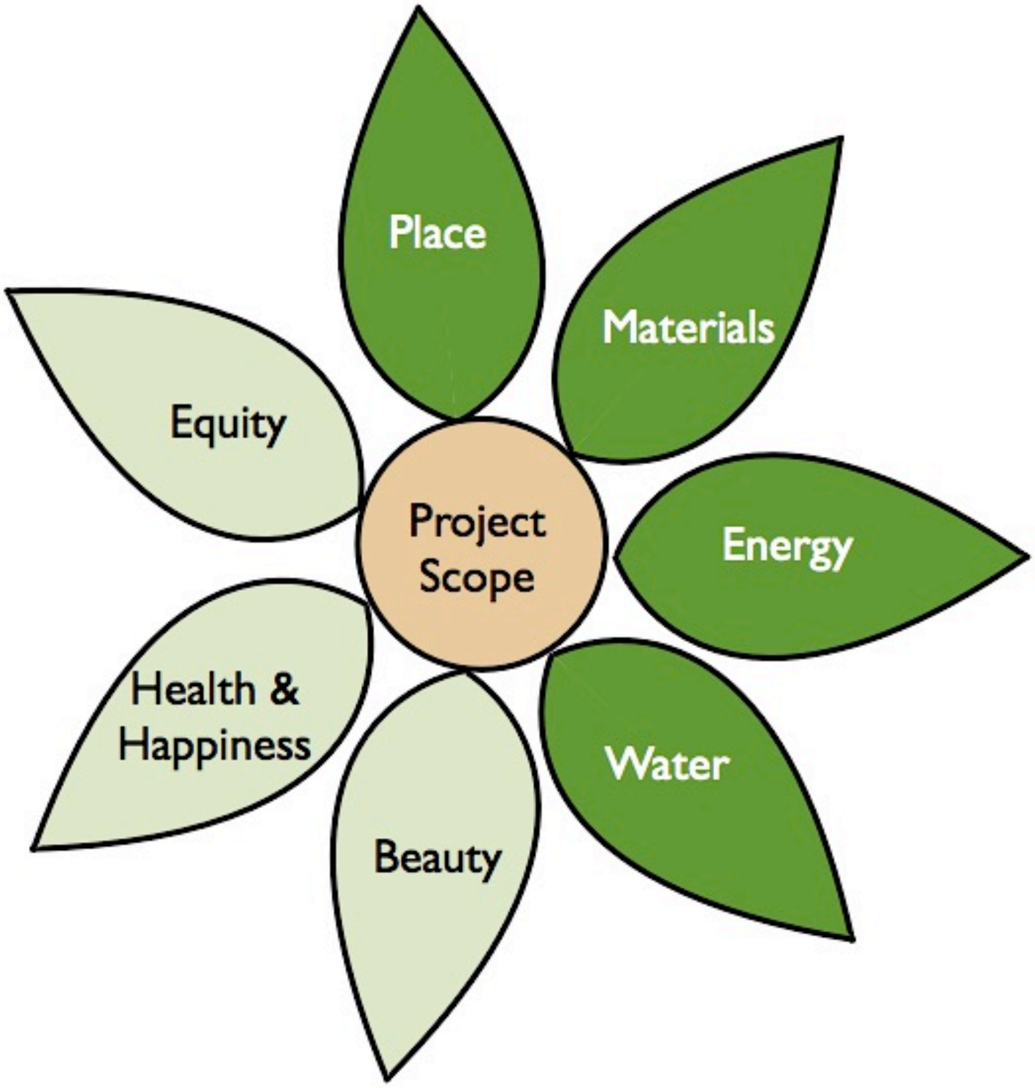
A thermosiphon or passive solar water heating system can provide hot water to the building without adding energy stress to the building's PV array. Many subcontractors provide installation and lifetime maintenance for these systems, and the cost benefits are even more profound in warmer climates.

Feasibility

The water systems chosen may also begin the 12-month review period with a one-time filling of cisterns with municipal water. This allows for a gradual implementation of rainwater capture and collection by sustainably sourced water cisterns stored in the basement of the building. With added efficiencies in water use, the building's total water needs can be feasibly met with sustainably sourced water. Cost of the systems can vary depending on the size of infiltration capture and choices of added water efficiency systems, which may have variable cost-benefit ratios. These ratios are too complex to determine without more information on the building's shape and final design; however, in examining other case study projects and their incorporation of many of the listed recommendations, EcoLadder is confident the scaling of these systems can meet the Living Building's needs within reasonable financial means.

6.0

Conclusions



Place

The return to a more naturalized environment through innovative and fully explored landscape design is central to the Place Petal. Integration of the building's water systems with existing water distribution infrastructure will be beneficial to both the Water Petal net zero usage requirement and the architectural considerations found in the Place Petal. The usage of naturalized stormwater attenuation features can alleviate flooding issues with this sector of campus.

Existing Urban Agriculture efforts on campus and in the Atlanta area moreover should serve as a guide for the implementation of an effective agricultural plan at the building site. Making use of this educational opportunity has the ancillary benefit of advancing localism attitudes that are necessary for the shift to true sustainability in infrastructure design.

Making the building and the Eco-Commons area that surrounds it an attractive place for both work and recreation is necessary to fully integrate the Living Building with its local environment; proper facilities for alternative commute options is not only required by the Challenge, but also by current conditions on campus in regards to biking amenities.

Materials

Embodied carbon should be reduced as much as possible when choosing the building materials. Recycled metals such as steel & aluminum, and supplementary cementitious materials can be easily used to lower the embodied carbon. The aesthetics and architectural design of the building are vital in creating educational appeal to the general public and conveying the goal of setting new sustainable development standards in the Southeast. In order to achieve this, a large degree of architectural freedom must be retained, and thus materials that can achieve this freedom must be utilized.

Despite the advantages of cost and ease of erection for pre-cast concrete, cast-in-place concrete would allow a much larger degree of freedom with a minimal impact on cost and labor expenses. Finally, wood should be the material of choice for the Living Building. Wood is a carbon neutral, eco-friendly, and cheap material that is readily found in the southeast. Wood would be a great choice for extensive implementation for the Living Building.

OVERALL RECOMMENDATIONS

Energy

EcoLadder estimates that nearly 20-25% of the energy traditionally lost to space heating and cooling can be saved with energy efficient systems. While there were numerous smaller energy efficiency considerations previously outlined, the most important recommendation for reducing energy consumption loads utilized passive solar techniques. Thermal control will be achieved through thermal mass insulating materials combined with natural ventilation and lighting to provide the system with the highest level of comfort and energy efficiency. Large, tinted windows with controllable outside louvers ensure the maximum amount of natural sunlight penetrates the occupant space. Optimal ventilation levels will be achieved through utilizing natural air currents, radiant floors, external hot air sequestering, and low-pressure variable air volume.

EcoLadder recommends a small-scale Geo-thermal system dug below the building grounds for an added source of conditioning the displacement air supply and heating domestic hot water pumps. While this system was not enough to meet the building's overall electricity loads, it can still be utilized as an important natural energy cooling and heating source.

A building management system is recommended to allow building systems to be automatically regulated for high building performance. This control system will regulate electrical systems and HVAC, at both peak hours of operation and non-occupied times. To avoid energy losses in the PV array, DC lighting will be used for a portion of the energy in the Living Building sourced from the parking deck PV array.

Water

EcoLadder recommends the use of pervious paving to allow for improved stormwater infiltration, groundwater recharge, and collection in the Eco-Commons area in conjunction with bioswales and other natural runoff control measures outlined within the Georgia Tech Stormwater Masterplan. To treat stormwater, hydroponic treatment facilities or an artificial tidal wetland system can be implemented adjacent to the building or within the Eco-Commons area. CPSM has outlined preliminary plans to add a blackwater treatment system lamination to a new parking deck structure in the EBB sector, which may require additional documentation to receive approval for the Living Building's purposes.

In order to reduce overall water consumption within the building, various systems such as composting toilets, pulsed-power HVAC units, and Building Management Systems can be implemented. The water balance performed by Eco-Ladder illustrates that net-zero water usage is feasible although further design considerations must be taken into account as the water needs of the building may be dependent on the shape, occupancy estimates, and HVAC loads.

CLOSING REMARKS

EcoLadder was founded in 2013 as a small and disadvantaged business enterprise whose employees share a common dedication to environmental responsibility, sustainable design, and the implementation of safe and effective business practices. In just three short years, EcoLadder has grown from taking on smaller environmentally focused projects to what is now one of the most highly sought after projects in all of Atlanta. The tremendous growth of the company has been a product of extraordinary hard work combined with exceptional client relations to ensure the delivery of the most satisfactory sustainable designs. EcoLadder is honored to work with such a prestigious Institute and innovation building standard.

EcoLadder has utilized this expertise in green building construction to recommend the most sustainable solutions possible for the Living Building Challenge. Not only will the construction of the Living Building at Georgia Tech set a precedent for regenerative building construction, it will change the way individuals interact with a building and the natural environment. Traditional buildings solely focus on a space for gathering, but this building will facilitate much more. Students and faculty will now have the opportunity to interact, learn, and thrive in an environment that is not only comfortable and welcoming, but conducive to increased productivity through immersion in a more naturalized work environment.

The Living Building at Georgia Tech is an ambitious project, involving a medley of systems working in full synchronization to further enhance the building environment. EcoLadder was focused on a base-level feasibility analysis of a Living Building on campus. After our analysis, EcoLadder believes that the Living Building is an attainable goal for the Institute. Of the four Petals that were analyzed, each was concluded to be feasible in its initial consideration. Despite many of the design details and as of yet unknown limitations, the results from our work are promising.

The Materials that create the building have embodied carbon that needs to be offset in order to meet the Challenge. After an embodied carbon calculation for the materials of the building, it was found that the offset of embodied carbon could be purchased at an affordable cost. Since the design of the building is still in preliminary stages, it is impractical to perform an in-depth cost feasibility analysis on the full scope of materials needed in order to provide more than a rough order of magnitude estimate for the total cost of the building. Labor costs were not considered in this preliminary examination, as there remains a portion of the Kendeda donation reserved for these outlays.

The Petals that will be hardest to achieve are the Water and Energy Petals. The Water Petal faces significant challenges when it comes to treating and reusing black and grey water without the use of chemicals. Although this treatment is possible, treatment on this scale is hard to accomplish. The residual disinfection that chlorine and other chemicals provides is not an element provided by UV disinfection, though if chemicals were used in treatment they must be removed at the fixture - applying these dechlorination filters at every effluent point is considered in a Petal Exception, however it could easily prove to be cost prohibitive at this scale.

CLOSING REMARKS

As this is both a commercial and educational building, its energy requirements are fairly substantial. Providing the energy needs for the building without any connections to the grid while ensuring the building maintains the ability to stay 'lit' 24/7/365 is a major challenge for the project. An extensive solar array will be required, spanning both the rooftops of the Living Building and an adjacent parking deck. The design and reliability of these systems is crucial to the Living Building becoming a reality at Georgia Tech. Although these systems are tough to design, they are feasible with the right level of detail and attention.

Costs are a crucial factor in creating a building that satisfies the Living Building Challenge. Costs are highly variable, especially at this early stage of design. In many instances, the Challenge would prove to be cost prohibitive for those wanting to construct buildings to these standards and may in fact turn away potential pursers of the Certification. Buildings that do not meet the overall Challenge requirements for full certification should still be considered for Petal Certifications, as these areas of building technology are not without merit. There exists a large gap between the demands of a LEED Platinum certification and completing the Living Building Challenge that may prove to be economically impractical for widespread adoption of the Challenge for some time to come. A program that bridges these two standards and offers more attainable goals for building owners and stakeholders would do more to promote sustainable thinking. Setting goals that some would consider unrealistic runs the risk of alienating the construction industry at large and can diminish efforts that would otherwise improve efficiencies that although do not satisfy the high criterion of the Challenge still have environmental benefit.

7.0

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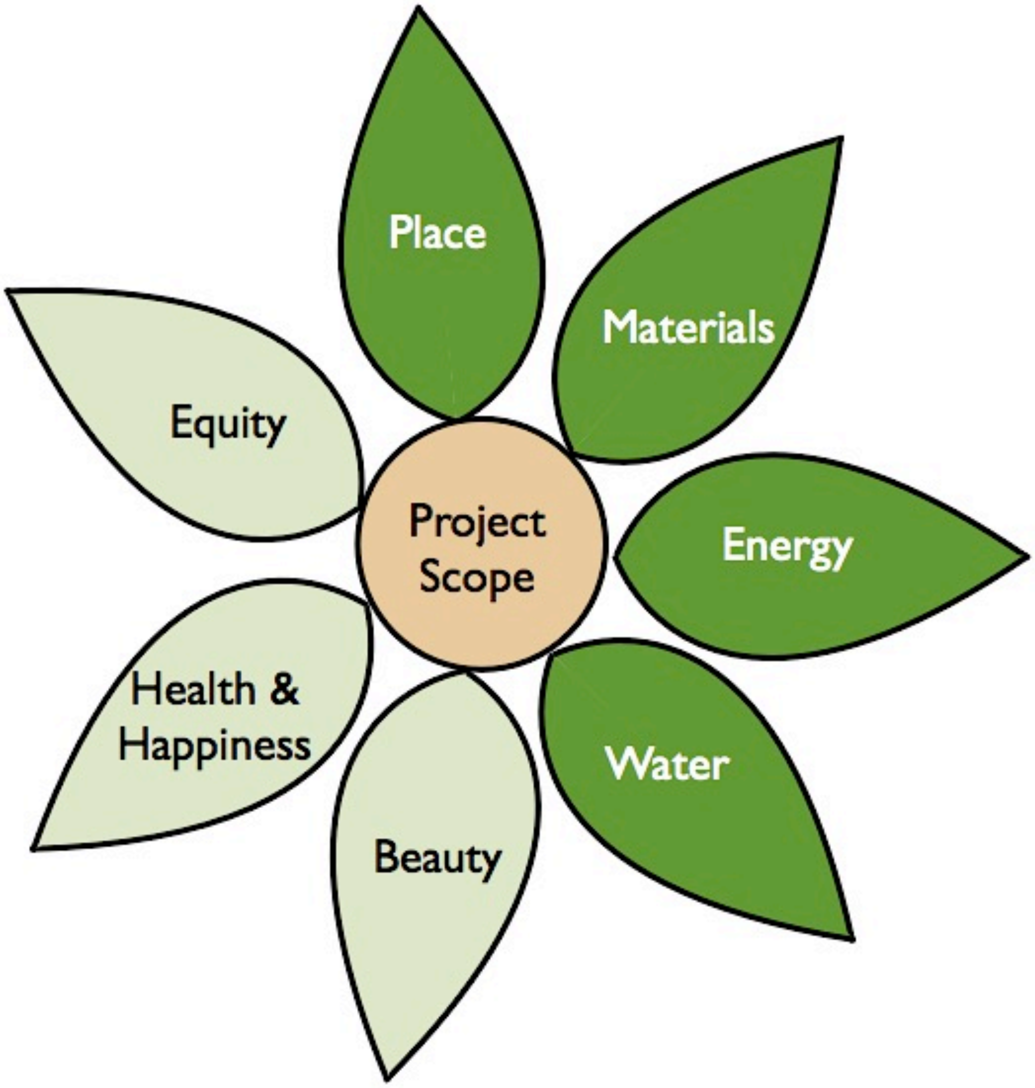

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Best Case

ENVIRONMENTAL IMPACT SUMMARY

ASSEMBLY	Total area	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	Human Health Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg NOx eq) TOTAL
Foundations & Footings	15,665	1,258,152	137	34,880	457	31,793	1,063	7,393
Columns & Beams	6,080	235,820	22	5,699	38	6,778	89	898
Intermediate Floors	31,875	2,923,703	216	59,297	734	90,541	614	7,789
Exterior Walls	4,536	455,188	44	11,449	157	8,177	386	2,570
Windows	10,584	2,630,781	269	143,327	5,215	74,163	929	22,072
Interior Walls	0	0	0	0	0	0	0	0
Roof	10,625	2,144,311	104	39,128	337	26,091	698	8,716
TOTALS		9,647,956	792	293,780	6,939	237,543	3,780	49,438

Mid-Tier Case

ENVIRONMENTAL IMPACT SUMMARY

ASSEMBLY	Total area	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	Human Health Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg NOx eq) TOTAL
Foundations & Footings	15,665	1,258,152	137	34,880	457	31,793	1,063	7,393
Columns & Beams	6,080	336,426	17	6,021	26	20,353	0	618
Intermediate Floors	31,875	2,632,853	268	70,978	862	50,558	1,560	14,698
Exterior Walls	4,536	523,652	49	16,164	152	8,011	390	2,513
Windows	10,584	3,916,285	352	174,590	5,306	88,460	1,908	23,499
Interior Walls	0	0	0	0	0	0	0	0
Roof	10,625	1,957,787	84	27,471	270	12,792	577	3,521
TOTALS		10,625,155	908	330,104	7,072	211,966	5,498	52,243

Worst Case

ENVIRONMENTAL IMPACT SUMMARY

ASSEMBLY	Total area	Fossil Fuel Consumption (MJ) TOTAL	GWP (tonnes CO2eq) TOTAL	Acidification Potential (moles of H+ eq) TOTAL	Human Health Criteria (kg PM10 eq) TOTAL	Eutrophication Potential (g N eq) TOTAL	Ozone Depletion Potential (mg CFC-11 eq) TOTAL	Smog Potential (kg NOx eq) TOTAL
Foundations & Footings	15,665	1,324,992	151	38,340	521	30,727	1,272	8,293
Columns & Beams	6,080	699,777	55	15,502	150	31,952	302	2,413
Intermediate Floors	31,875	4,907,048	488	130,940	1,826	131,905	3,689	28,846
Exterior Walls	4,536	1,160,736	101	33,212	276	29,673	1,346	4,245
Windows	10,584	5,219,715	468	361,165	6,787	90,930	2,213	37,076
Interior Walls	0	0	0	0	0	0	0	0
Roof	10,625	3,005,497	194	57,227	705	46,214	1,578	10,813
TOTALS		16,317,765	1,458	636,384	10,264	361,402	10,400	91,686

Space Component		Space Type	Given Occupancy (People)	Quantity	Avg. Sq. Ft.	Total Sq. Ft.	Space Classification	Max Occupancy	Ideal Occupancy
Instructional Space	Classrooms	Auditorium	125	1	3,000	3000	Classroom	125	100
		Classrooms	50	2	1,500	3000	Classroom	100	75
		Seminar Rooms	16	2	600	1200	Classroom	32	25
		Breakout/Group Study Rooms	6	2	360	720	Classroom	12	8
		Classroom Support	N/A	1	240	240	Classroom	4	2
	Class Laboratories	Computational/Biology ClassLab	N/A	2	1,200	2400	Classroom	80	40
		ClassLab Staff and Support	N/A	2	300	600	Classroom	10	2
	Design Studio Instructional Space	ClassLab/Maker Space	N/A	1	900	900	Classroom	15	2
		ClassLab Staff and Support	N/A	1	450	450	Classroom	7.5	2
Student/Community Center		Center	N/A	1	1,500	1500	Lobby	150	25
		Center support Areas (storage, catering kitchen, etc)	N/A	1	750	750	Office	12.5	1
		Quiet Study Areas	N/A	1	600	600	Office	10	10
		Collaboration/Innovation Learning Area	N/A	1	750	750	Office	12.5	8
		Peer to Peer/Project Based Learning Studios	N/A	1	300	300	Office	10	8
		Small Team Study Room	N/A	2	140	280	Office	5	5
Research and Industry Partnership Component		Computational/Light Biology Res. Lab	N/A	2	900	1800	Classroom	60	30
		Lab Support	N/A	2	300	600	Classroom	10	2
		Lab Staff	N/A	1	600	600	Classroom	10	2
		Faculty Office	N/A	2	140	280	Office	3	1
Multipurpose/Exhibit Space/Event Support		Multipurpose/Exhibit Space/Event Support	N/A	1	1,800	1800	Lobby	180	10
Lobby/Display Area and Kiosks		Lobby/Display Area and Kiosks	N/A	1	300	300	Lobby	30	10
Office Space		Center- Director's Suite (office, reception, waiting)	N/A	1	600	600	Office	6	2
		Office- Related Programs Support Staff	N/A	3	150	450	Office	5	1
		Office- Building Manager/Support Staff	N/A	2	150	300	Office	3	1
		Open Office	N/A	3	80	240	Office	3	1
		Student Work Stations	N/A	2	36	72	Office	12	10
		Break Room/Copy/Storage/Files	N/A	1	240	240	Office	2	1
		QEP Activities (Office Space, reception, waiting)	N/A	1	600	600	Office	6	2
		Office	N/A	3	150	450	Office	6	1
		Open Office	N/A	2	80	160	Office	2	1
		Student Work Stations	N/A	2	36	72	Office	12	10
		Break Room/Copy/Storage/Files	N/A	1	240	240	Office	2	1
							Totals:	937.5	399

Space Component		Space Type	Quantity	Avg. Sq. Ft.	Total Sq. Ft.	Space Classification	Lighting Power Density (W/sf)	Equipment Power Density (W/sf)	Plug Loads (peak) (W/sf)	Total Watts	Use (hrs/day)	Use (days/week)	wh/day	kWh/day	kWh/month	kWh/year
Instructional Space	Classrooms	Auditorium	1	3,000	3000	Classroom	1.2	1	0.9	9300	12	7	111600	111.6	3348	40734
		Classrooms	2	1,500	3000	Classroom	1.2	1	0.9	9300	12	7	111600	111.6	3348	40734
		Seminar Rooms	2	600	1200	Classroom	1.2	1	0.9	3720	12	7	44640	44.64	1339.2	16293.6
		Breakout/Group Study Rooms	2	360	720	Classroom	1.2	1	0.9	2232	12	7	26784	26.784	803.52	9776.16
		Classroom Support	1	240	240	Classroom	1.2	1	0.9	744	12	7	8928	8.928	267.84	3258.72
	Class Laboratories	Computational/Biology ClassLab	2	1,200	2400	Classroom	1.2	1	0.9	7440	12	7	89280	89.28	2678.4	32587.2
		ClassLab Staff and Support	2	300	600	Classroom	1.2	1	0.9	1860	12	7	22320	22.32	669.6	8146.8
	Design Studio Instructional Space	ClassLab/Maker Space	1	900	900	Classroom	1.2	1	0.9	2790	12	7	33480	33.48	1004.4	12220.2
		ClassLab Staff and Support	1	450	450	Classroom	1.2	1	0.9	1395	12	7	16740	16.74	502.2	6110.1
Student/Community Center		Center	1	1,500	1500	Assembly	1.6	0.9	0.2	4050	12	7	48600	48.6	1458	17739
		Center support Areas (storage, catering kitchen, etc)	1	750	750	Office	1.9	1.3	2.5	4275	12	7	51300	51.3	1539	18724.5
		Quiet Study Areas	1	600	600	Office	1.9	1.3	2.5	3420	12	7	41040	41.04	1231.2	14979.6
		Collaboration/Innovation Learning Area	1	750	750	Office	1.9	1.3	2.5	4275	12	7	51300	51.3	1539	18724.5
		Peer to Peer/Project Based Learning Studios	1	300	300	Office	1.9	1.3	2.5	1710	12	7	20520	20.52	615.6	7489.8
		Small Team Study Room	2	140	280	Office	1.9	1.3	2.5	1596	12	7	19152	19.152	574.56	6990.48
Research and Industry Partnership Component		Computational/Light Biology Res. Lab	2	900	1800	Classroom	1.2	1	0.9	5580	12	7	66960	66.96	2008.8	24440.4
		Lab Support	2	300	600	Classroom	1.2	1	0.9	1860	12	7	22320	22.32	669.6	8146.8
		Lab Staff	1	600	600	Classroom	1.2	1	0.9	1860	12	7	22320	22.32	669.6	8146.8
		Faculty Office	2	140	280	Office	1.9	1.3	2.5	1596	12	7	19152	19.152	574.56	6990.48
Multipurpose/Exhibit Space/Event Support		Multipurpose/Exhibit Space/Event Support	1	1,800	1800	Assembly	1.6	0.9	0.2	4860	12	7	58320	58.32	1749.6	21286.8
Lobby/Display Area and Kiosks		Lobby/Display Area and Kiosks	1	300	300	Assembly	1.6	0.9	0.2	810	12	7	9720	9.72	291.6	3547.8
Office Space		Center- Director's Suite (office, reception, waiting)	1	600	600	Office	1.9	1.3	2.5	3420	12	7	41040	41.04	1231.2	14979.6
		Office- Related Programs Support Staff	3	150	450	Office	1.9	1.3	2.5	2565	12	7	30780	30.78	923.4	11234.7
		Office- Building Manager/Support Staff	2	150	300	Office	1.9	1.3	2.5	1710	12	7	20520	20.52	615.6	7489.8
		Open Office	3	80	240	Office	1.9	1.3	2.5	1368	12	7	16416	16.416	492.48	5991.84
		Student Work Stations	2	36	72	Office	1.9	1.3	2.5	410.4	12	7	4924.8	4.9248	147.744	1797.552
		Break Room/Copy/Storage/Files	1	240	240	Office	1.9	1.3	2.5	1368	12	7	16416	16.416	492.48	5991.84
		QEP Activities (Office Space, reception, waiting)	1	600	600	Office	1.9	1.3	2.5	3420	12	7	41040	41.04	1231.2	14979.6
		Office	3	150	450	Office	1.9	1.3	2.5	2565	12	7	30780	30.78	923.4	11234.7
		Open Office	2	80	160	Office	1.9	1.3	2.5	912	12	7	10944	10.944	328.32	3994.56
		Student Work Stations	2	36	72	Office	1.9	1.3	2.5	410.4	12	7	4924.8	4.9248	147.744	1797.552
		Break Room/Copy/Storage/Files	1	240	240	Office	1.9	1.3	2.5	1368	12	7	16416	16.416	492.48	5991.84
		Structural, Mechanic, Elec. Data, Toilets, Stairs, Custodial	Unknown	Unknown	16,996	Other	1	1	1	50988	12	7	611856	611.856	18355.68	223327.44
													Totals:	1742.1336	52264.008	635878.764

Space Component		Space Type	Quantity	Avg. Sq. Ft.	Total Sq. Ft.	Space Classification	Lighting Power Density (W/sf)	Equipment Power Density	Plug Loads (peak)	Total Watts	Use (hrs/day)	Use (days/week)	wh/day	kWh/day	kWh/month	kWh/year
Instructional Space	Classrooms	Auditorium	1	3,000	3000	Classroom	1.2	1	0.9	9300	4	5	26571.43	26.57	797.14	9698.57
		Classrooms	2	1,500	3000	Classroom	1.2	1	0.9	9300	4	5	26571.43	26.57	797.14	9698.57
		Seminar Rooms	2	600	1200	Classroom	1.2	1	0.9	3720	4	5	10628.57	10.63	318.86	3879.43
		Breakout/Group Study Rooms	2	360	720	Classroom	1.2	1	0.9	2232	4	5	6377.14	6.38	191.31	2327.66
		Classroom Support	1	240	240	Classroom	1.2	1	0.9	744	4	5	2125.71	2.13	63.77	775.89
	Class Laboratories	Computational/Biology ClassLab	2	1,200	2400	Classroom	1.2	1	0.9	7440	4	5	21257.14	21.26	637.71	7758.86
		ClassLab Staff and Support	2	300	600	Classroom	1.2	1	0.9	1860	4	5	5314.29	5.31	159.43	1939.71
	Design Studio Instructional Space	ClassLab/Maker Space	1	900	900	Classroom	1.2	1	0.9	2790	4	5	7971.43	7.97	239.14	2909.57
		ClassLab Staff and Support	1	450	450	Classroom	1.2	1	0.9	1395	4	5	3985.71	3.99	119.57	1454.79
Student/Community Center		Center	1	1,500	1500	Assembly	1.6	0.9	0.2	4050	4	5	11571.43	11.57	347.14	4223.57
		Center support Areas (storage, catering kitchen, etc)	1	750	750	Office	1.9	1.3	2.5	4275	2	5	6107.14	6.11	183.21	2229.11
		Quiet Study Areas	1	600	600	Office	1.9	1.3	2.5	3420	8	5	19542.86	19.54	586.29	7133.14
		Collaboration/Innovation Learning Area	1	750	750	Office	1.9	1.3	2.5	4275	4	5	12214.29	12.21	366.43	4458.21
		Peer to Peer/Project Based Learning Studios	1	300	300	Office	1.9	1.3	2.5	1710	4	5	4885.71	4.89	146.57	1783.29
		Small Team Study Room	2	140	280	Office	1.9	1.3	2.5	1596	8	5	9120.00	9.12	273.60	3328.80
Research and Industry Partnership Component		Computational/Light Biology Res. Lab	2	900	1800	Classroom	1.2	1	0.9	5580	4	5	15942.86	15.94	478.29	5819.14
		Lab Support	2	300	600	Classroom	1.2	1	0.9	1860	2	5	2657.14	2.66	79.71	969.86
		Lab Staff	1	600	600	Classroom	1.2	1	0.9	1860	2	5	2657.14	2.66	79.71	969.86
		Faculty Office	2	140	280	Office	1.9	1.3	2.5	1596	8	5	9120.00	9.12	273.60	3328.80
Multipurpose/Exhibit Space/Event Support		Multipurpose/Exhibit Space/Event Support	1	1,800	1800	Assembly	1.6	0.9	0.2	4860	2	5	6942.86	6.94	208.29	2534.14
Lobby/Display Area and Kiosks		Lobby/Display Area and Kiosks	1	300	300	Assembly	1.6	0.9	0.2	810	8	5	4628.57	4.63	138.86	1689.43
Office Space		Center- Director's Suite (office, reception, waiting)	1	600	600	Office	1.9	1.3	2.5	3420	8	5	19542.86	19.54	586.29	7133.14
		Office- Related Programs Support Staff	3	150	450	Office	1.9	1.3	2.5	2565	8	5	14657.14	14.66	439.71	5349.86
		Office- Building Manager/Support Staff	2	150	300	Office	1.9	1.3	2.5	1710	8	5	9771.43	9.77	293.14	3566.57
		Open Office	3	80	240	Office	1.9	1.3	2.5	1368	8	5	7817.14	7.82	234.51	2853.26
		Student Work Stations	2	36	72	Office	1.9	1.3	2.5	410.4	8	5	2345.14	2.35	70.35	855.98
		Break Room/Copy/Storage/Files	1	240	240	Office	1.9	1.3	2.5	1368	4	5	3908.57	3.91	117.26	1426.63
		QEP Activities (Office Space, reception, waiting)	1	600	600	Office	1.9	1.3	2.5	3420	4	5	9771.43	9.77	293.14	3566.57
		Office	3	150	450	Office	1.9	1.3	2.5	2565	8	5	14657.14	14.66	439.71	5349.86
		Open Office	2	80	160	Office	1.9	1.3	2.5	912	8	5	5211.43	5.21	156.34	1902.17
		Student Work Stations	2	36	72	Office	1.9	1.3	2.5	410.4	8	5	2345.14	2.35	70.35	855.98
		Break Room/Copy/Storage/Files	1	240	240	Office	1.9	1.3	2.5	1368	4	5	3908.57	3.91	117.26	1426.63
		Structural, Mechanic, Elec. Data, Toilets, Stairs, Custodial	Unknown	Unknown	16,996	Other	1	1	1	50988	2	5	72840.00	72.84	2185.20	26586.60
													Totals:	382.97	11489.07	139783.63

Month	Days in Month	Daily Radiation (kWh/m2/day)	kW Array Size	PV Temperature Losses	Derate Factor	Inverter efficiency	kWh/day	kWh/month
January	31	2.62	244	0.88	0.84	0.9	425.30	13184.31
February	28	3.37	244	0.88	0.84	0.9	547.05	15317.30
March	31	4.54	244	0.88	0.84	0.9	736.97	22846.09
April	30	5.78	244	0.88	0.84	0.9	938.26	28147.73
May	31	6.04	244	0.88	0.84	0.9	980.46	30394.35
June	30	6.4	244	0.88	0.84	0.9	1038.90	31167.04
July	31	6.04	244	0.88	0.84	0.9	980.46	30394.35
August	31	5.45	244	0.88	0.84	0.9	884.69	27425.37
September	30	4.87	244	0.88	0.84	0.9	790.54	23716.17
October	31	4.06	244	0.88	0.84	0.9	659.05	20430.64
November	30	2.87	244	0.88	0.84	0.9	465.88	13976.47
December	31	2.36	244	0.88	0.84	0.9	383.09	11875.94
						Totals:	8830.66	268875.76