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Rutgers
Edward J. Bloustein School of Planning and Public Policy

Duke Farms

Duke Farms Greenhouse: An Environmental Education Exhibit & Orientation Center

Prepared by

Lisa Avichal, Avonnét Bell (JD), Alison Kopsco, Michael Kwan, Emily Maciejak, Anna Quan

MCRP Candidates, 2019

Acknowledgements

Studio Team Members

Master in City and Regional Planning Candidates

Cecille de Laurentis (2020)
John Donadio (2020)
Eve Gabel-Frank (2019)
Robert Gates (2019)
Carrie Martin (2020)
Deanna Miller (2019)
Eric Schkrutz (2019)

Studio Advisors

Jeanne Herb, PhD
Marjorie Kaplan, PhD

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AJ Both, PhD
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Jean-Marie Hartman, PhD

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Michael Catania, MA, JD
Jon Wagar, MF
Nora DiChiara
Thom Almendinger, MS

Executive Summary

Our world is rapidly changing due to climate change, and Duke Farms has responded to this sobering reality through responsible and innovative environmental stewardship measures. Duke Farms is engaged in agricultural preservation, sustainable forestry, transforming areas into native meadows, and developing energy-efficient buildings and systems, always tying these efforts to educational opportunities for visitors. Duke Farms' current actions may have been a legacy from its previous owners. James B. Duke had always cared about public service. His daughter, Doris Duke, integrated this desire to serve the public with her lifelong interest in preserving flora, fauna and agriculture to produce greenhouse-enclosed gardens, each one portraying characteristics from a different part of the world.

In line with its mission to serve as the model of environmental stewardship in New Jersey and nation, Duke Farms has partnered with Rutgers University's Edward J. Bloustein School of Planning and Public Policy to repurpose the two-acre greenhouse complex, formerly known as the Gardens of the World. Duke Farms seeks to transform this complex into an environmental education exhibit and orientation center that guides school-aged children and other visitors in wisely responding to climate change through a variety of actions.

The objectives of the greenhouse complex are multiple-fold. It includes creating a hands-on experience for students and other visitors. Studies have shown that when students engage in physical activities, they can better understand the material (Institute for Learning Styles Research, N.d.). For example, if they experience climate change through multiple senses, they can retain the information for a longer period of time and share it with their peers and families. The education center will also serve as a building model that is energy-efficient and emits low carbon. Classes will be held at the educational center and be open to farmers and agricultural organizations; Duke Farms can contribute to the regional and national dialogues on issues, such as organic urban agricultural practices, cultivating healthy soils, and building according to LEED standards.

Yet another objective of the greenhouse educational center is to inform visitors of the importance of terrestrial carbon sequestration. Terrestrial carbon sequestration ("carbon sequestration"), the process by which plants, trees, wetlands and soils, naturally capture and store carbon, is critical in the race to decrease carbon emissions, especially when governments and other entities focus on how to maximize carbon sequestration in various ecosystems. To help its visitors learn more about carbon sequestration, demonstration and laboratory rooms will be created. Signage can engage visitors by asking them how they will apply what they have learned from the different exhibits.

Methodology

Site Visits

We conducted three site visits to Duke Farms in the winter/march of 2019. In our February meeting, we met Executive Director, Michael Catania, and Deputy Executive Director, Jon Wagar, learned about the history, mission, and programs of Duke Farms and toured the greenhouse complex. In our second visit, in March, we had a more thorough tour of the greenhouse complex, taking pictures and videos of the site and speaking with Michael about which features needed to remain or could be removed or replaced. In our third visit, we interviewed Duke Farms' Director of Programs, Nora DiChiara, about existing programming at Duke Farms and how the greenhouse educational complex could complement Duke Farm's existing mission, goals and programs. We explored topics, such as ADA-accessibility, transportation to and from the greenhouse educational center, and entrances to the center. We analyzed the strengths and characteristics of each room and considered the site's relationship to its surroundings.

Interviews

In addition to visiting the site and speaking with Michael, Jon and Nora, Michael also attended two of our studio classes and shared his knowledge about the site.

Relevant Documents

We received key Duke Farms documents related to the site, such as a 2002 report on the Duke Gardens Complex (Betty Bird & Associates), Duke Farms' Land Stewardship Plan (Van Clef, et al., 2017), and Duke Farms' Program Plan (2009). We received a scaled plan of the 2-acre greenhouse site. We also received additional reports, which included an ADA assessment of other parts in Duke Farms.

Best practices / successes in other greenhouses

We conducted research on historical greenhouses, greenhouse design and educational programming for the greenhouse education center.

Consulting with design and / other professionals

We consulted with multiple Rutgers professors, which ranged from greenhouse design experts, urban design professionals to experts in soil science and forestry. We spoke to Dr. A.J. Both, a greenhouse design and operation expert at the Department of Environmental Sciences at Rutgers University, acquiring an overview of best practices in passive heating/cooling techniques in greenhouses. We worked with design professionals, such as Juan Ayala, to understand how to design the interior layout as well as ensure an interesting and thoughtful relationship between the 2-acre greenhouse site and its surroundings. In our studio sessions, we also listened to various Rutgers professors present on topics of soil carbon sequestration, tree carbon sequestration, and life-cycle analysis.

Existing Conditions

Location

Duke Farms is located in the north-central portion of New Jersey in Hillsborough Township. The property consists of 1,000 acres. To the east and west, respectively, are Route 206 and Roycefield Road. To the north of Duke Farms is Route 202. Dukes Parkway West bisects the property from east to west. The greenhouse complex is located in the eastern portion of that property.

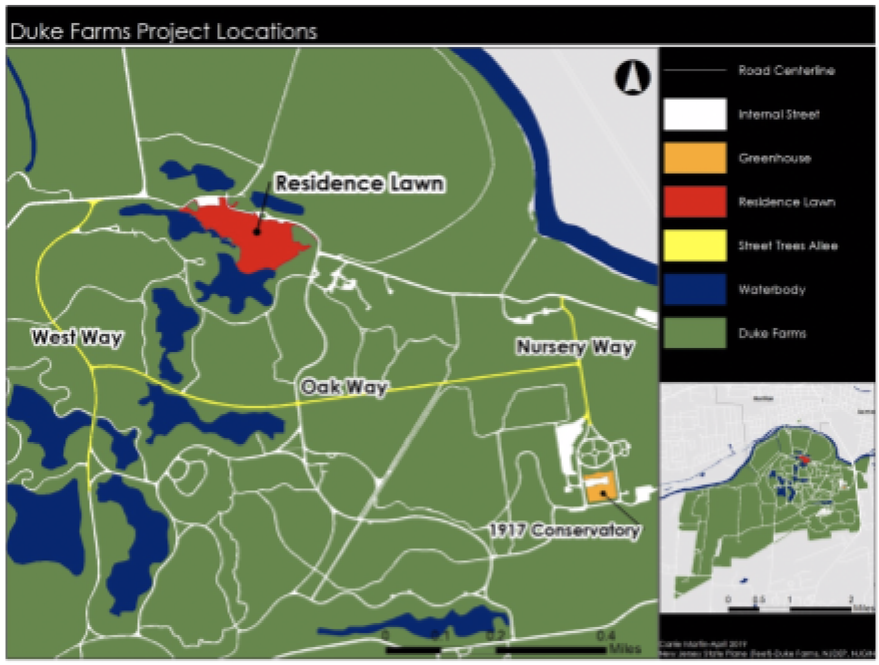

Figure 1. Site Overview

Once arriving at Duke Farms, visitors typically stop at the Farm Barn Orientation Center first, located 8/10 of a mile southwest of the greenhouse complex (See Figure 1). Directly west of the greenhouse complex is a parking lot, the Education Cottage containing classrooms and restrooms, the bikeshare tent, and Cottage 24. Northeast of the greenhouse complex are two more cottages, and southeast is one more cottage. North of the greenhouse complex is the sunken garden.

Structure

The greenhouse complex itself occupies 2 acres and is comprised of 32 rooms and a root cellar. The following section includes an analysis of each room.

General Structural Notes

The floor is consistently concrete and stone throughout the complex, unless otherwise noted in a specific room's analysis. As the complex has gone mostly unused for about 10 years, the glass ceilings and walls are in state of disrepair. Unless otherwise noted below, the ceilings are generally the same condition by room. Throughout the complex's interior and exterior, there are no ADA-compliant entrances, stairs/ramps, or doorways.

Edwardian Garden / House 26

Situated in the northwestern-most corner of the greenhouse complex, the Edwardian Garden is about 40' by 35' and contains raised garden beds along the walls (Figure 2). Located in the center of the room is a an area enclosed by about 1 ½' brick wall. There are 3 doors in the room, one connecting to the Colonial American Garden, one on the south wall, and one on the north wall. The two exterior access doors are designated for staff use.

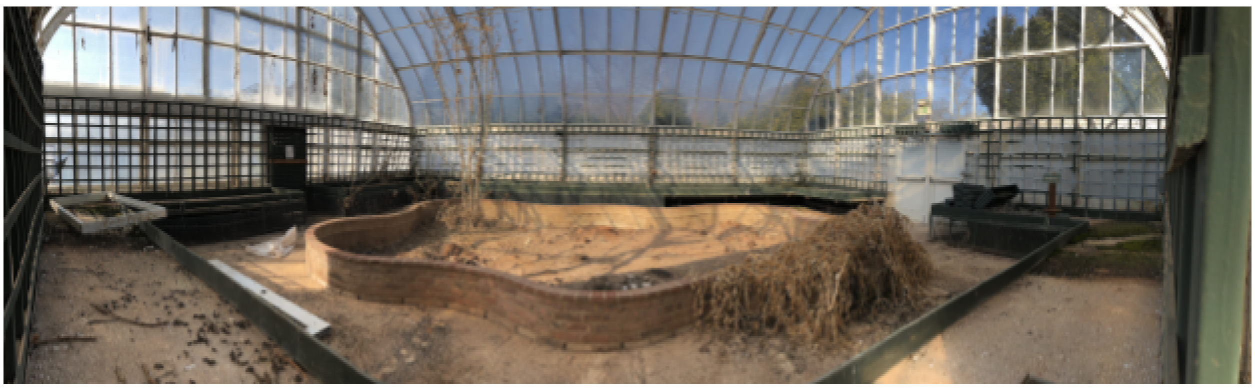

Figure 2. Edwardian Garden

Colonial American Garden / House 25

The Colonial American Garden connects the Edwardian and Italian Gardens. It is roughly 60' by 35' (Figure 3). Half-foot tall brick walls line a walkway from east to west with a large octagon shape in the center. Between the walkway and the exterior walls are garden beds. There are brick half-walls about 3' in height that cover pipes immediately along the exterior walls as well as the wall between the Colonial American and Italian Gardens.

Figure 3. Colonial American Garden

Italian Garden / House 24

The Italian Garden was once the main entrance to the complex (Figure 4). It is roughly 50’ by 100’. Its current use is bicycle and large gardening tools storage. Similar to the Colonial American Garden, there are balusters that hide pipes and plumbing along most of the walls. The foyer on the north wall is in extreme disrepair but according to representatives of Duke Farms, it is a priority to be fixed as it presents a high threat to safety. There are multiple statues throughout the area. There is a second entrance to the inner area of the complex on the south wall. In the center of the room is a small fountain. There are 2 fans on the ceiling for air circulation. The floor of this room is gravel and there are a few spots of overgrown plants.

Figure 4. Italian Garden

Semi-Tropical Garden / House 23

This room (Figure 5) is very similar in form and structure to the Colonial American Garden. Between the Semi-Tropical and Italian Gardens, however, there is no complete wall; instead, there are continuations of the previously mentioned balusters with a small entryway in the middle. The floor of this room is brick and in the center is a large square area, presumably for gathering. Currently, the only use of the room is storage of some concrete benches and planters.

Figure 5. Semi-Tropical Garden

Tropical Garden / House 22

The Tropical Garden is connected to the Semi-Tropical Garden and is the northeastern-most room of the complex (Figure 6). There is a doorway to the exterior on the north wall. This room is filled with uneven layers of soil and rocks, and contains what looks like what once was the beginning of a small stream, as there is a small rock bridge in the middle of the room. The current use of the room is storage of large plastic tubes.

The "stream" path continues down into House 22. The rock bridge drops down a few steps to another bridge, supported by cement blocks, that passes over a larger pond area. House 22 has no current uses and is mostly overgrown. The coverings over pipes along the walls are in disrepair

Figure 6. Tropical Garden

Indo-Persian Garden / House 16

Between the Indo-Persian Garden and House 22 are dividers reminiscent of the previous exotic use. Beyond the dividers are a series of three differently-elevated levels, all separated by the same dividers. The entire Indo-Persian Garden is about 125' by 20'. Along the wall of all three levels are decorative wall covers that hide pipes and plumbing along the wall.

The first area (Figure 7) contains a cement fountain in the center of the room, and four square cut-outs, each of which had 9 smaller fountains. There are small tracts, presumably for running water at one point, forming a cross in the first two rooms. This tract runs all the way from the first Indo-Persian level to the doorway between this room and the Japanese Garden.

The second level, about 2' below the first, has a cross of water tracts similar to the first level. This area has garden beds in place of where the first area had fountains. Additionally, this area has a small facade that looks as if it led to the center of the greenhouse complex at one point in time.

The third level (Figure 8) is the longest level of the Indo-Persian Garden, at just over 70'. There is a single water tract down the center of the room and 2 walkways on either side of that tract. Between the walkways and the walls are long areas. In these areas are multiple star-shaped gardens with gravel between each of them.

There is a small room at the end of the Indo-Persian Garden and before the Japanese Garden. This small room is not shown on the site plan.

Figure 7. Indo-Persian Room Levels 1 & 2

Figure 8. Indo-Persian Room Level 3

Japanese Garden / House 14

This room is the southeastern-most room in the greenhouse complex, forming an L-shape (Figure 9). This is a spacious room that is empty aside from scrap wood. The level of disrepair is a bit higher in this room, as there is a decent amount of wall coverings that are broken. There is a staff-accessible door on the eastern wall. There are some large boulders scattered throughout the room.

The terrain in this room is mostly flat near the entrance from the Indo-Persian Garden. There is a small bridge over a divot at the corner section of the room, and between that bridge and the Bamboo Room there are many large boulders. Similar to the Indo-Persian room, there is another facade reminiscent of a traditional Japanese building

Figure 9: Japanese Garden

Bamboo Room

The Bamboo Room is 2 steps down from the Japanese Garden. It is a small room, about 15’ by 25’. The walls and ceiling consist of trellises and the floor is an intricate stone pattern. The entryway to the Chinese Garden is a large circle.

Chinese Garden / House 13

The Chinese Garden is on the opposite side of the complex from the Italian Garden and is roughly 25’ by 140’ (Figures 10 and 11). Upon leaving the Bamboo Room, on the left is a large group of boulders, some of which are cemented together. There is a zig-zagging bridge over an area that was once filled with water. In the center of the room against a wall is a decorative overhang over the pathway. Directly across from that overhang is a massive overgrowth of bamboo which covers a door with exterior access.

There is another bridge on the other side (Figure 11) of the overhang that arches over the water area. The pathway from the end of that bridge to the deck on the other side of the room is being invaded by the bamboo mentioned earlier. In the water area on this side is a large boulder formation. There is minimal space for plants in the corners of the room as well as along the south wall where the bamboo is intruding.

Figure 10. Chinese Garden viewed from Bamboo Room

Figure 11. Chinese Garden viewed looking towards Bamboo Room

Desert Garden / House 4

This room is located 4 steps up from the Chinese Garden. It is roughly 20’ by 60’ (Figure 12) and provides exterior access on the west wall. There is a door that once allowed access to the Succulent and English Garden areas, but it is blocked off. This room contains some rocks but has the most potential for leveling, as it is mostly uneven soil and one large overgrown plant.

Figure 12. Desert Garden

Figure 13. English Garden

Succulent Room & English Garden / House 3

This room is roughly 22' by 115' (Figure 13). The Succulent Room is closed off, but the English Garden room is being used for storage of wheelbarrows, lawnmowers, bicycles, and other equipment. There is a garage door on the north wall of this room.

Potting Shed

This is the most-utilized structure in the greenhouse complex (Figure 14). Duke Farms workers utilize this shed as storage for tools. There is an office in the building as well as two restrooms. The greenhouse complex security system is centralized here. There is also a basement. There are workbenches and shelving units throughout the building. If needed, there is Internet access here.

Figure 14. Potting Shed

Houses 1, 2, 17, & 18

Houses 1 and 2 connect the potting shed to the English Garden, and houses 17 and 18 connect the potting shed to the Indo-Persian Garden as well as Houses 16, 19, 20, and 21. They are used as storage rooms.

Houses 16, 19, 20, & 21

These houses connect the Semi-Tropical Garden and the Japanese Garden and are used for storage.

Houses 9 & 10

These houses are attached to the potting shed and are frequently used for preparing plants for placement in other portions of the property. A concern that was raised by Duke Farms representatives was that the roofs in these houses are fairly low and must have heating in them to account for snow accumulation (Figures 15 and 16).

Figure 15. Potting Area

Figure 16. Potting Area

Innovative Precedents & Recommendations

Principles and Objectives

The goals of this environmental education center is to reduce carbon emissions and energy usage and inform visitors about carbon sequestration. The center will focus on demonstrating native species and other characteristics that reflect Duke Farms' work in other parts of its property. The center will emphasize hands-on learning for visitors of all ages. Last but not least, the greenhouse complex will accommodate schools by providing accessible and comfortable spaces for students to gather indoors and outdoors.

Innovative Precedents

Reducing carbon emissions and energy needs

Figure 17. Phipps Conservatory

Duke Farms has a head start in creating its environmental education center that is energy-efficient and decreases carbon emissions, because it transformed its historical orchid conservatory into a LEED-Platinum certified building in 2011. The Orchid Conservatory, which was built before the two-acre greenhouse complex, now operates with radiant floor heating and condensing boilers. It also captures and reuses rainwater to water the plants within the conservatory through the misting system. The conservatory has also replaced its windows to be double-pane insulated glass, which will protect the building from excessive heat or cold.

Another example of a historical greenhouse that has decreased its carbon footprint is Phipps Conservatory, which was built in 1893 (Phipps, N.d.). It has reduced the historical conservatory's energy usage and carbon emissions in a variety of ways, which includes strategically placing and growing plants. For example, plants that require similar conditions will be placed in the most optimal areas together, thereby decreasing labor and energy costs. Other strategies include re-glazing the windows and white-washing the greenhouse before the summer (Figure 17). For its lighting needs, Phipps has transitioned to LED lights. To decrease water inefficiencies, it has replaced outdated irrigation systems and fixed leaking in water fountains.

Focus on native species and environments that exist in Duke Farms

Located in Bergen County (Englewood, NJ), Flat Rock Brook also contains an environmental education center, but we most admired its Native Habitat Gardens (Figure 18), which consists of more than seventeen micro ecosystems and variety of native plants and flowers and integrates educational signs through its gardens. It is similar to Duke Farms in using its education signage to encourage visitors to apply their experiences in the Native Gardens to their homes and communities (Flat Rock Brook, N.d.).

Figure 18. Flat Rock Brook Nature Center

Hands-on Learning

A leader in hands-on learning for children is the New York Botanical Garden, specifically Everett Children's Adventure Garden (Figures 19 and 20), a 12-acre area that features a variety of

Figure 19. NY Botanical Garden

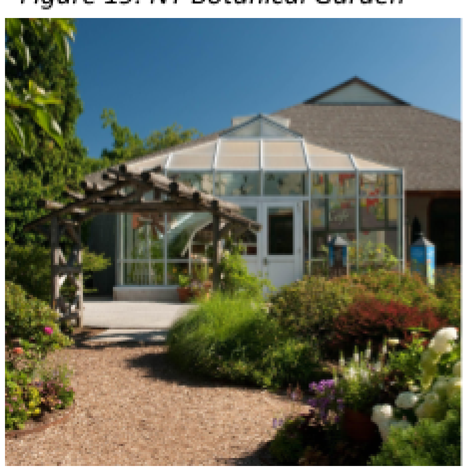

Figure 20. NY Botanical Garden

environments, such as a woodland and meadow. A highlight of this garden include its ability to attract children to explore the gardens through its playful features (e.g. a shrub that has been trimmed into the shape of a worm). In addition, children can engage in science activities that are set outdoors.

Schuylkill Center, which is in Philadelphia, PA, has come up with another approach to hands-on learning. As a leader in creating environmental art, Schuylkill uses art to encourage the public to engage in environmental stewardship. Art displays are displayed both indoors and outdoors. Schuylkill Center's leadership in developing environmental art challenges its visitors' conceptions of the environment as an entity remote from them; its synthesis of environmental features and artwork makes the argument that similar to how environment and art are integrated, so its visitors should consider the integration of the environment and environmental concerns in their daily lives. Also, through art, Schuylkill can explore topics in a compelling way that other more standard approaches could not. For example, through this art installation, "Welcome Home" by Vaughn Bell (Figure 21), visitors can become more emotionally and mentally invested in the importance of preserving native species, because they understand how important it is to have their own homes.

Figure 21. "Welcome Home" by Vaughn Bell.

Accessible and comfortable spaces

Given that the environmental education center will attract many school-aged children, our proposed design would meet functional needs (e.g. providing spaces for students to gather to eat and learn) but also provide other benefits. For example, the classroom and gathering spaces would be created from recycled material, especially those that are local or regional,

Figure 22. Potawatomi Conservatories, South Bend, Indiana

in order to decrease carbon emissions from transportation (Kirsch Center, 2007). This could serve as another form of hands-on education and helping students and visitors understand that environmental stewardship does not need to be compartmentalized as a trip to Duke Farms but can be activated in their daily routines and purchasing habits. Another guiding theme for the proposed concept is highlighting beauty through design and organization of the space. Some of the greenhouses, such as the Italian Greenhouse, are awe-inspiring because of its spaciousness, expansive and wide-arching roofs, and numerous clear window panes. We would like to design spaces that emphasize the existing beauty of the greenhouses.

Recommendations

We created two design options (Figures 23 and 24), which differ in the number of inner greenhouses we keep. In Option A, four inner greenhouses are removed between the potting shed and the former Chinese Garden to allow for more courtyard space. In Option B, only two inner greenhouses in the same area are removed to allow for some courtyard space while maximizing classroom or lab space. The rationale for removing several of these inner greenhouses in both options is that the inner greenhouses, especially those not adjoining the potting shed, have roofs that are not in the best conditions and subject to cracks. The current practice is to use propane heaters to melt snow from the inner greenhouse roofs, which requires substantial amounts of energy. The two options have the same phasing with the exception of the demolition of varying structures in Phase 1.

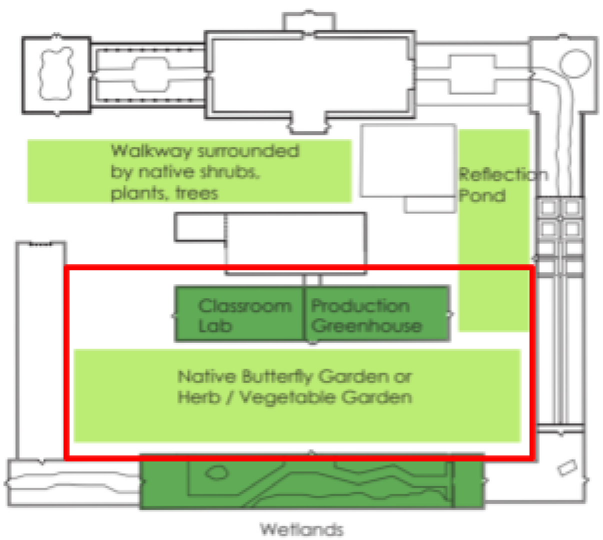

Figure 23. Option A: More courtyard, fewer classrooms

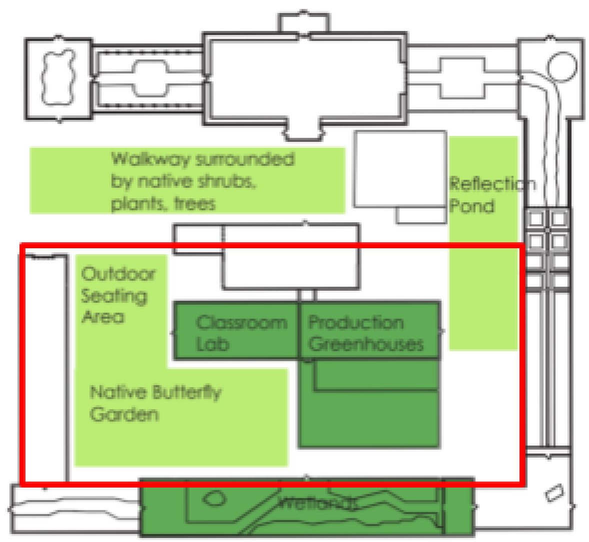

Figure 24. Option B: More classrooms, less courtyard

Phase 1

Demolish several inner buildings, create a new entrance, expand bathrooms in the Potting Shed, and develop a seating and gathering space in greenhouse complex.

Figure 25. Phase 1

In this phase (Figure 25), certain inner greenhouse buildings will be demolished; these greenhouses do not have as much historical and cultural significance as the exterior greenhouse buildings, which served the public for more than forty years. Because of this distinction, the proposed concept is consistent with Hillsborough's local ordinance on historic preservation. The purpose for removing the interior greenhouse structures is to make space for amenities that would benefit the visitors to the center. Once the specified inner greenhouses are removed, there will be space for outside seating, gardens, and courtyards. The removal of these greenhouses will also facilitate circulation through the outside areas of the greenhouse complex that does not currently exist.

The proposed concept envisions an entrance in addition to the official entrance across from the Sunken Garden. The new entrance will be the area between the former Edwardian Garden and English Garden. This is a natural entrance due to its proximity to the Visitor's Center and to the parking lot.

Because the site will serve many students, the bathrooms in the Visitor's Center will not be sufficient or safe, as the Visitor's Center is beyond the confines of the greenhouse complex. Thus, the potting shed will serve as a site for bathrooms and offices. It is in a central location in the greenhouse complex and will be ADA-accessible.

The student seating and gathering area will be in the former English Garden due to its smooth and even surface and simple greenhouse design. We envision sets of tables installed in this greenhouse that would operate as communal areas. This seating and gathering area would serve as a passive learning opportunity as students sit and eat at tables that use eco-friendly materials. One possibility is removing the bamboo from the former Chinese Garden room and constructing chairs and tables from the bamboo. A few signs will be dispersed through this greenhouse to disclose the environmentally-friendly characteristics of the room.

Phase 2

Transform Italian Garden as the Welcome Center, build spaces for hands-on learning, develop a zen garden and prepare the underground soil room.

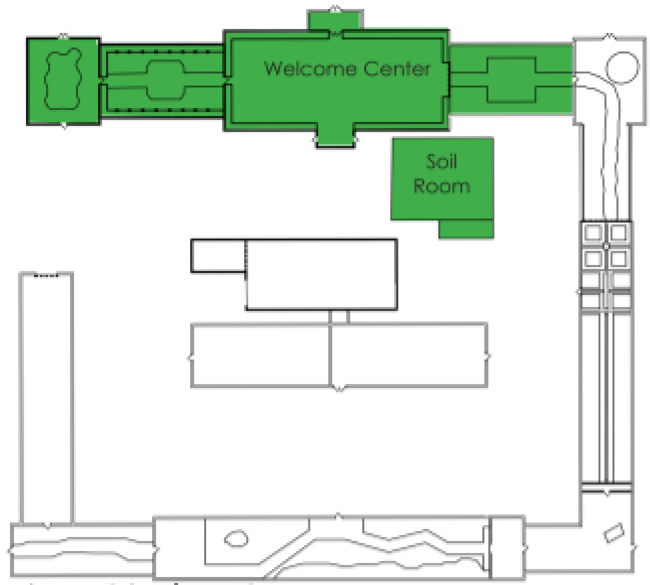

Figure 26. Phase 2

In this phase, the former Italian Garden, the most auspicious building in the entire complex, will serve as the official Welcome Center. We envision a colorful, playful display in the center of the space. There would also be a check-in desk and some seating. These features will not clutter the greenhouse in order to allow the beauty of the building and its relation to the outside shine forth. A ramp will be attached to the southern side of the building for ADA compliance.

The rooms adjacent to the Welcome Center will become hands-on learning or demonstration spaces. Possible themes for these spaces include designing a shrub exhibit and explaining the importance of the shrub undergrowth or creating a native meadows display and reflecting on its ability to sequester carbon and attracting birds and bees. Another option is turning one of these rooms into plots in which students can propagate native seeds and bring some of them home to plant in their own home or community gardens.

The former Edwardian Garden would be converted into a zen garden or a display of community activities and projects taking place around Somerset County. The former option would help students and other visitors engage in rest even in the midst of a hectic school field trip. The latter could include rotating displays of projects from local school children or environmental initiatives throughout the county. It would be a showcase room that contributes to the regional dialogue on environmental stewardship.

The root cellar will be turned into a soil exhibit. Maximizing soil organic carbon is one of the key cost-effective options for mitigating climate change. More carbon resides in the soil than in the atmosphere and all plant life combined. There are 2,500 billion tons of carbon in soil compared with 800 billion tons in the atmosphere and 560 billion tons in plant and animal life. However, the world's cultivated soils have lost between 50 and 70 percent of their original carbon stock. An important question that the soil exhibit would ask visitors is how to create conditions so that soils sequester maximum amounts of carbon. The soil exhibit will be ADA-accessible and utilize some form of wheelchair lift.

Figure 27. World Soil Museum, Netherlands

Above the root cellar, the concrete platform, which serves as a visual termination point, would be covered with pots of plants and flowers or an attractive and thought-provoking environmental art installation (Figure 27).

Phase 3

Re-create a stream, design a climate change or life-cycle analysis exhibit, establish the decomposition room and the tree nursery or lawn conversion room.

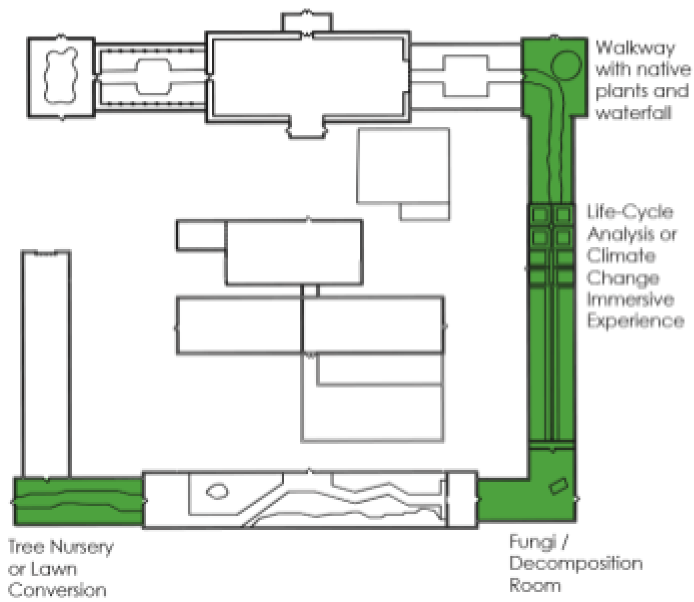

Figure 28. Phase 3

Some of the boulders from the former Tropical Garden room will be removed to create clear and safe walkways. Rubbish and weeds will be removed. The rock formations in this room indicate that a stream once existed. The proposed plan reintroduces this feature.

The former Indo-Persian Room, which comprises of two square spaces and a much longer room, could be an interactive exhibit that either focuses on climate change or life-cycle analysis. For example, one room could be dedicated to learning more about the causes and effects of climate change (Figure 29). Another room could be a sensory experience of climate change, in which students' five senses are engaged. "What does climate change look, smell or taste like?"

Figure 29. Immersive climate change experience (Boston Museum of Science)

These questions would encourage students to view climate change not so abstractly. For the long room, one half of the walkway could depict a challenge of climate change and the other side of the walkway could depict potential responses to that challenge. Another possibility is engaging in environmental art and having each star-shaped plot in the long room focused on its individual art exhibit or having a larger art display that spans many plots. To turn these rooms into an exhibit that demonstrates the life-cycle analysis and encourages visitors to think through their purchasing decisions, the rooms could portray the life-cycle analysis of different resources that exist in Duke Farms and how those resources are turned into products that could be subsequently recycled.

The "Decomposition: Fungi in Action Room" would be in the former Japanese Garden and would showcase the role of soils and fungi in sequestering carbon and removing toxins from the soils (Figures 30 and 31). Researchers are beginning to understand that fungi may be the most pivotal and

Figure 30. EEM fungi like the Amanita mushroom help soils store more carbon (Colin Averill)

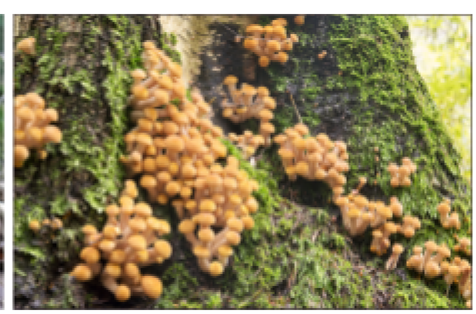

Figure 31. Honey Fungus (Boston University)

important actor in keeping and decomposing carbon in the ground (Bücking, 2015). Plots in the Decomposition Room can allow visitors to physically inspect the texture of soils (should they wish) that are rich in fungi and the plants that grow out of them, while comparing plots without them.

In our proposed Lawn Conversion room, which would be in the former Desert Garden, visitors can compare the differences between a typical grass lawn and lawns with native perennial beds and groundcover. They can learn the basics of converting their home lawn and how to address challenges they may encounter. Visitors will be taught how soil quality increases fungi and the amount of carbon stored in their simple lawn.

Alternatively, a Tree Nursery room concept can highlight native trees and how they sequester carbon. Visitors can be taught basic tree planting and maintenance techniques. Like the Lawn Conversion room, visitors can observe how soil quality increases tree growth and carbon capture due to increased fungi.

Phase 4

Construct a wetlands indoors, create classrooms, labs and production spaces, design courtyards, gardens and pond (Figure 32).

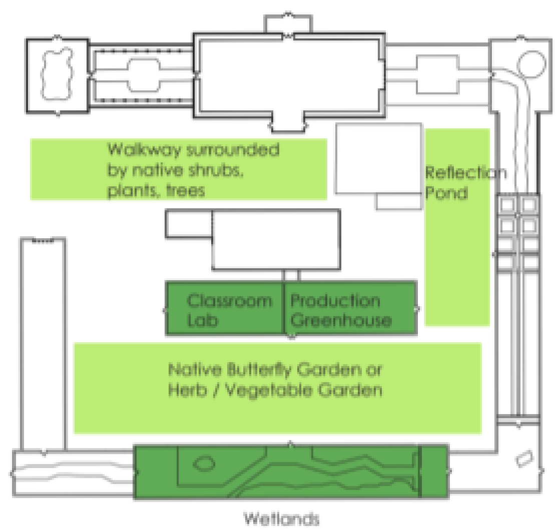

Figure 32. Phase 4

The former Chinese garden will have clean water, and the bamboo will be removed. This room will introduce visitors to wetland functions, which includes water purification and removal of pollutants. The wetlands area will contain native plant species. The educational displays can describe how wetlands also sequester carbon.

The inner greenhouses that are south of the potting shed will be divided into classrooms, labs, and production and educational spaces. The classrooms and labs will be in one or two of the wider greenhouses adjoining the potting shed. Classes will be held at the educational center and be open to community members, farmers and agricultural organizations. Duke Farms can thus contribute to the regional and national dialogues on issues, such as organic urban agricultural practices and cultivating healthy soils. The remaining inner greenhouse could be a production space, which could be a space to grow plants before transplanting them somewhere on the property. The space could also be used as an example of innovative urban farming techniques, which includes hydroponics and variations of vertical farming (e.g. having plats or boxes of vegetables above others).

The open spaces that have been created by removing several inner structures can be public gathering spaces that increase the natural ventilation of the site. The proposed concept will be designed with local native plants and vegetation. It will comprise a mixture of walkways (some form of pervious surface that complements the rest of Duke Farms), gardens, green spaces, seating areas and perhaps, a pond. The gardens can be interactive educational sites, where children get their hands dirty by planting their own local native plants and flowers or organic vegetables.

Maintenance and Energy Recommendations

Passive Heating and Cooling Strategies

The costs of heating, cooling and lighting the greenhouses should be significantly decreased compared to previous greenhouse use as the Gardens of the World. Given the proposed greenhouse concept, we do not anticipate significant lighting costs since most visitors and staff will be using the facility during the day. We anticipate significantly decreased cooling needs, since our concept does not require supporting exotic plants but cultivates native species that can thrive under the existing weather conditions.

Our proposed concept would utilize well-proven passive cooling and heating techniques. To facilitate passive cooling, shading can be used to decrease the amount of heat that comes into greenhouses. These curtains would contain woven material and openings to allow warm air to rise and leave the greenhouse. To reduce the heat that becomes absorbed by the greenhouse, the building can be "whitewashed" or painted at the beginning of the growing season around late May or early June. This would block half or more light that comes in and would last until the summer. One challenge is trying to paint the greenhouse's nooks and crannies. Another method is re-glazing, which entails placing glass that reflects infrared light and some UV light. However this method can be very expensive. Another technique is evaporative cooling, which can be done through a mechanical ventilation method. Air enters one side of the greenhouse, encounters a wet pad that cools the air, and then travels through the greenhouse interior and is removed from the greenhouse by fans on the other side of the greenhouse. A natural evaporative cooling method entails a high-pressure fog system in a growing area, which generates fine water droplets or mist (Both, 2019).

During the evening, the building may require some heating, especially during the winter. Passive heating techniques could save costs. One technique is installing two curtains, one over the other. The first curtain is used to provide shade and to block out heat, while the second prevents heat from escaping during the night. One caveat is that there must be sufficient vertical room for the two curtains, as they have to be horizontally draped from one side of the greenhouse to the other (Both, 2019). Tall trees cannot reach the roofs of the greenhouse.

Lighting

The greenhouse receives an adequate amount of sunlight during the day. However, if the greenhouse receives nighttime or evening visitors, it may require additional lighting sources to enhance safety, mood or aesthetics. If lighting is needed for plants, white LED light could be beneficial because it provides a spectrum that plants need. LED lights could also be placed close to plants compared to traditional high-pressure sodium lamps. However, LED lights are more expensive (ranging from $500 - $2000 each).

Water

The eastern side of the greenhouse has a water drainage system extending from the north to south of the building, which can support the proposed Wetlands greenhouse concept in the former Chinese Garden.

A underground water storage tank can be placed near the greenhouse. It can recycle water from inside the greenhouse through irrigation and condensation. For our proposed concept, the tank would support watering needs for the demonstration plots, the proposed Lawn Conversion or Tree Nursery and the Wetlands room. Outside the greenhouse, the water tank would capture rainwater by having a clean roof and making sure all downspouts are connected to the tank. However, this would require high maintenance. The water features require staff to manage pumps, pipes and leakages, and the water also needs to be treated and filtered.

Biofuels

To support energy needs, we propose the use of biomass which can be sourced from other areas of Duke Farms and the surrounding community. Biomass could be from wood, waste wood, switchgrass and miscanthus (also known as Elephant grass). As noted in the Duke Farms Land Stewardship Plan, biomass would also include grass pellets from mowing fields dedicated to grassland bird habitat. One of the main challenges of relying on biofuels is maintaining reliable sources.

Directions for Future Research

Further research should be conducted on the costs and benefits of repurposing the greenhouse complex as an energy-efficient, low-carbon emitting environmental education center. Duke Farms needs to integrate ADA compliance into its plans. Many of the doorways and greenhouse rooms are not accessible to people with physical disabilities. One idea is to apportion a part of the greenhouse complex to be ADA-accessible, such as the wing of the greenhouse complex that contains the majestic Welcome Center (former Italian Garden).

Another matter for Duke Farms to consider is whether it should open the Duke Farms entrance adjacent to Route 206, so buses and school-related vehicles can directly travel from Route 206 to the environmental education center without going through the Farm Barn Orientation Center.

In terms of historic preservation, Duke Farms needs to adhere to Hillsborough's local ordinance pertaining to historic preservation, §188-109 Historic Zones, Historic Sites and the Historic Preservation Commission, which follows the Secretary of the Interior's Standards for the treatment of historic properties. Our proposed concept would keep the historically and culturally significant exterior greenhouses while removing the interior greenhouses that are in poor conditions.

In addition, Duke Farms needs to work with Hillsborough's Building Department to identify the number of sprinklers required per room and the maximum number of occupants per room.

Conclusions

Leaders within Somerset County and beyond can learn about the innovative practices at Duke Farms. For example, Somerset County's Green Leadership Hub, which comprises municipalities' environmental teams, county staff, and the nonprofit, Sustainable New Jersey, held a walking tour of Duke Farms to learn about the sustainable technologies and practices employed at the Farms. The participants also brainstormed how to implement such strategies in municipalities (Somerset County Green Leadership Hub, 2017).

Through expanded research and experimentation with best practices in soil management and fungi applications, Duke Farms can significantly increase the amount of carbon sequestered on its property. Soil research, management expertise and knowledge about native plant and fungi species can also guide other landowners and planners on best practices to help more regions achieve net-zero or possibly negative zero emissions goals. Duke Farms can further facilitate this effort by funding additional staff, fellowships or scholarships for those interested in pursuing soil science or regenerative agriculture research. According to the "4 per 1000" Initiative, there are 570 million farms in the world and more than 3 billion people living in rural areas that could help implement these practices.

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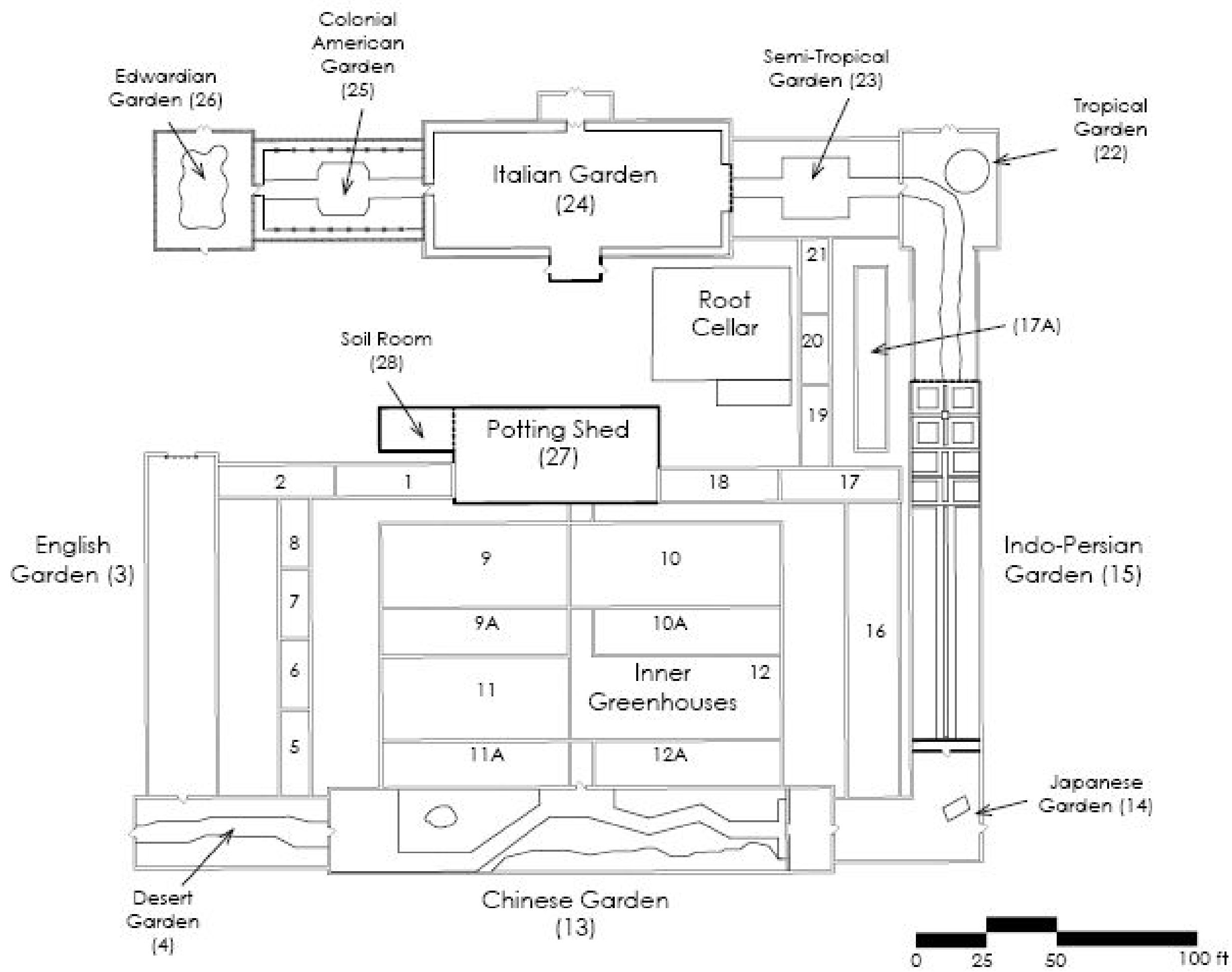
Appendix A: Floor Plan Map with Former Names of Greenhouse Room and Identifying Numbers



Appendix B: Soil, Fungi, and Sequestration

Science Behind Soils and Fungi

To reinforce and validate the educational lessons that Duke Farms shares to its visitors, and to demonstrate the sequestration potential of these practices, we propose that Duke Farms creates demonstration plots with “before and after” effects of land management and sustainable agricultural practices. Visitors will be able to witness how these best practices affect plants, grasses, shrubs and the composition of soils.

For example, the proposed “Decomposition: Fungi in Action Room” can showcase the role of soils and fungi in sequestering carbon and removing toxins from the soils. Soil organic carbon is one of the key cost-effective options for mitigating climate change. More carbon resides in the soil than in the atmosphere and all plant life combined. There are 2,500 billion tons of carbon in soil compared with 800 billion tons in the atmosphere and 560 billion tons in plant and animal life (Ontl & Schulte, 2012). However, the world’s cultivated soils have lost between 50 and 70 percent of their original carbon stock (Schwartz, 2014).

While research has been done on how plants, various microbial decomposers (such as earthworms and bacteria) and soil minerals affect carbon pools in the ground, researchers are beginning to understand that fungi may be the most pivotal and important actor in keeping and decomposing carbon in the ground (Bücking, 2015). Specifically, scientists are examining organisms named mycorrhizal fungi which colonize a plant’s or tree’s roots. They gain nourishment from plants while helping their hosts to absorb water and nutrients from the soil. Mycorrhizal provides a number of benefits, including increases in the following: soil resistance, nutrient absorbing surface and uptake, and storing phosphate (Bücking, 2015). About 80-90% of known plant species contain mycorrhizal fungi. Ecto and ericoid mycorrhizal fungi (EEM), found in trees, contain 70% more carbon vs soils with arbuscular (AM) fungi. EEM fungi produce more nitrogen-degrading enzymes, which allow them to extract more nitrogen from the soil, and outcompete soil microbes which slows their ability to decompose dead plant matter and return carbon to the atmosphere (Walsh, 2014). AM fungi occur in the roots of herbaceous plants and trees, while EM fungi occur on numerous tree genera, including those found in the nursery and landscape (Kleczewski, et. al., 2019).

Demonstration Plots

Plots in the Decomposition Room can allow visitors to physically inspect the texture of soils (should they wish) that are rich in AM or EM fungi, and the plants that grow out of them, while comparing plots without them. Visitors should also note differences in plant or shrub growth. Duke Farms can also test commercially available mycorrhizal products to increase mycorrhizal volume in its soils or plant growth. Research between various products has already been conducted by South Dakota State University on the differences between fungal products on plant growth and fungi volume.

In our proposed Lawn Conversion room, visitors can compare the differences between a typical grass lawn and lawns with native perennial beds and groundcover. They can learn the basics of converting their home lawn and how to address challenges they may encounter. Visitors will be taught how soil quality increases AM fungi and the amount of carbon stored in their simple lawn.

Alternatively, a Tree Nursery room concept can integrate elements from our studio class's "Tree Group" project, highlighting native trees and how they sequester carbon. Visitors can be taught basic tree planting and maintenance techniques. Like the Lawn Conversion room, visitors can observe how soil quality increases tree growth and carbon capture due to increased EM fungi.

How Soils Can be Improved

Fortunately, scientists already have a strong understanding of how to begin maximizing sequestration of carbon in the soils, which begins with promoting soil health. What tends to increase soil health includes no-till or conservation tillage, cover or relay crops, diverse crop rotations, perennial crops, organic fertilizers, crop residue retention, integrated pest management, and mulching/cultural weed control tactics (Lehman, et al., 2015). There are also practices to avoid, such as applying inorganic phosphorus or nitrogen, which lowers respiration in the soil and has adverse effects on fungi (Bücking, 2015). According to the French-led initiative "4 per 1000", an international effort to promote carbon farming, practices that should be promoted include agroforestry and keeping farmland together. During COP21 of the UN Framework on Climate Change, stakeholders voluntarily committed to promoting soil carbon enhancing agricultural practices.

It is important to place the role of soils into perspective. According to biologist and fungi expert Jennifer Talbot at Boston University, "The amount of carbon coming out of soil is roughly 10 times larger annually than the amount of carbon coming out of human processes on land. So these pools, if they are perturbed even slightly, could have an enormous impact on the carbon cycle and on climate change (Moran, N.d.). So, it is imperative to focus on all of the processes and organisms that keeps carbon below the ground.

According to the "4 per 1000 Initiative", the quantity of carbon contained in the atmosphere increases by 4.3 billion tons every year, largely due to human activities, deforestation, forests and the oceans. In comparison, the world's soils contain 1500 billion tons of carbon. The Initiative calculates that theoretically, an annual increase of the world soil carbon stock by 0.4% would be larger than the 2015 annual increase in CO_2, which means the increase would completely offset annual carbon emissions from human activity. By sharing and applying best practices in soil management, Duke Farms can help the world achieve that annual 0.4% reduction.

Assuming that Duke Farms can achieve an annual 0.4% increase in soil organic carbon, this would have significant effect over time, assuming trees are able to survive and do not reach a threshold in the amount of carbon stored. Here are some calculations using the baseline CO_2 capture estimates from our studio's "Street Trees" team, which proposed adding 433 new trees, which would sequester an estimated 7,344,549 pounds of carbon.

Table 1: Change in carbon sequestration with 0.4% increase per year in soil capture

	Year 5	**Year 10**	**Year 20**	**Year 50**	**Year 100**
Additional increase in carbon (lbs)	148,071	299,127	610,436	1,622,525	3,603,492
% carbon vs. baseline year	2%	4%	8%	22%	49%

If there is an annual increase in the soil capture of 0.4% for 100 years, the carbon sink of the original 433 trees will be increased by nearly 50%, which is the equivalent of adding 216 trees. In 50 years, the total carbon sink is 22%, the equivalent of adding 95 trees.

By focusing on the long-term carbon potential of soils, Duke Farms can increase carbon stored in the ground despite land use constraints (for example: we cannot plant trees and meadows everywhere) and not growing beyond its current boundaries of 2700 acres.

One important point is that it is possible that soil may become saturated and will not sequester carbon at these predicted rates (Nayak, et al., 2019). The 4 per 1000 Initiative estimates carbon accumulation in soils would continue 20 to 30 years after the implementation and maintenance of good practices. So, it is important to distinguish between different types of fungi for their carbon capture potential. As mentioned EEM fungi can capture 70% more carbon than AM fungi. One example is the Amanita mushroom, of which there are more than 12 species found on Duke Farms, according to the Mushroom species list in the Duke Farms Stewardship Plan. There is also evidence that some soil organisms and fungi species such as suillus fungi can decompose organic matter which increases the amount of carbon stored (Moran, N.d.). By better understanding the symbiotic relationships between fungi, plants and the carbon cycle we can maximize carbon that is kept underground.

Table 2: Duke Farms Mushroom Species List includes 12 Amanita mushrooms

Appendix L. Duke Farms Mushroom Species List			
Duke Farms Stewardship Plan			
Genus	**species**	**group**	**comment**
Chlorociboria	aeruginascens	asco	
Chlorosplenium	chlora	asco	
Daldinia	concentrica	asco	
Diatrype	stigma	asco	
Hypocrea	gelatinosus	asco	
Hypocrea	sulfurea	asco	
Hypomyces	chrysospermus	asco	
Mollisia	sp.	asco	
Peziza	badioconfusa	asco	
Plasmopara	viticola	asco	
Scutellinia	scutellata	asco	
Scutellinia	sp	asco	
Ustulina	deusta	asco	Now Kretzschmaria
Xylaria	polymorpha	asco	dead man's fingers
Agaricus	augustus	basidio	The Prince
Amanita	cf cokeri	basidio	
Amanita	cf elliptosperma	basidio	
Amanita	citrina	basidio	
Amanita	flavoconia	basidio	
Amanita	flavorubens	basidio	
Amanita	fulva	basidio	Tawny Grisette
Amanita	muscaria	basidio	
Amanita	onusta	basidio	
Amanita	rubescens	basidio	Blusher
Amanita	sp. 36	basidio	
Amanita	unknown	basidio	
Amanita	vaginata	basidio	Grisette
Armillaria	tabescens	basidio	
Auricularia	auricula	basidio	
Bjerkandera	adusta	basidio	
Boletus	bicolor	basidio	
Boletus	edulis group	basidio	
Boletus	pulverulentus	basidio	
Boletus	rubellus	basidio	
Cantharellus	lateritius	basidio	Smooth Chant.

To reach not only net-zero emissions goals, but broader negative-emissions goals for the region, Duke Farms must have a strong understanding of its soils systems to maximize the amount of carbon stored and to support organisms which can decompose carbon, to keep soils from reaching a carbon saturation point.

To measure carbon sequestration in soils, there are some current and emerging methodologies described in a May 2019 report (Nayak, et. al). In addition, there are methods to estimate the amount of mycorrhizal fungi found in the roots, such as counting spores extracted from soil, soil propagules enumeration, plant root colonization.

Appendix C: Historic Preservation Regulations

Although not listed at the National or State level of the National Register of Historic Places (NRHP), the entire site of Duke Farms is considered to be a historic place at the local level, preserved the jurisdiction of the Hillsborough Historic Preservation Commission. Being designated a historic site, even at the local level, still holds Duke Farms to historic preservation regulations such as the local ordinance which follows the Secretary of the Interior's Standards for the treatment of Historic Properties.

Duke Farms has pursued a difficult challenge in preserving such a historic site with important links to the past and ensuring that the cultural heritage and architectural integrity as well as the historic resources that make up New Jersey continue to be sustained; Duke Farms was one of the few 2015 Historic Preservation Award recipients for their Vision Plan that lays out the transformation of Duke Farms for the future. Their dedication was demonstrated in the first phase of the plan, an adaptive reuse of the Farm Barn into the Welcome Center and with the second phase, renovating the grand structure, the 1899 Orchid Conservatory Greenhouses; the foundation even did so in such a way that promotes environmental stewardship, as demonstrated in the energy efficient lighting, rainwater collections for reuse, and bioswales and rain gardens, both buildings are LEED-platinum certified.

However, another historic greenhouse complex in need of restoration resides on the property. The once beloved Gardens of the World complex consists of 32 greenhouse structures including the grand Italian Garden. The complex was completed in 1917 and still exists as a true reflection of the time period and Duke Farms' history over 100 years later. Gardens of the World was opened in 1964, however, in 2008 as Duke Farms evolved and shifted their mission from displaying plants to modeling environmental stewardship, the complex closed to the public because it was no longer feasible considering it was not aligned with the environmental sustainability that the foundation wanted to demonstrate. That being said, the complex was never intended to be closed for good, but rather temporarily until a more sustainable use of the greenhouses could be constructed. This project aims to transform the historic structures into an educational center to teach climate change and the environmental stewardship they practice. In doing so, Duke Farms intends to achieve an adaptive reuse of these historic structures.

It is our understanding that Duke Farms is already aware of the lengthy process that comes along with rehabilitating historic structures and that any work done to the structure will need to go to the Historic Preservation Commission for approval on building and construction permits before anything can move forward, even before going to the Planning Board; knowing this, we also understand that Duke Farms wants to demolish as little as possible, as it is likely the structures would fall apart if moved. We have done our best to keep the historic integrity intact and keep the structures as true to their original form as possible. With that being said, we understand that local ordinance, §188-109 Historic Zones, Historic Sites and the Historic Preservation Commission, need to be considered throughout this beginning process. The section of the local ordinance we felt were most pertinent to the project is *Section D. General Conditions and Procedures.*