MAKING CHANGE: Designing a new model for climate change interpretation and experimentation

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Abstract

Many people are aware of climate change, but have limited understanding of what climate impacts to expect, and what effects these impacts may have on their local environment. This uncertainty is often accompanied by frustration about the ambiguity of climate change as something that is intangible and therefore out of our control. With these concerns in mind, faculty in landscape architecture and horticulture in partnership with Cornell's botanical garden developed a project to make climate change impacts more visually and experientially available to visitors. The result was the installation of (to our knowledge) the nation's first interpretive "climate change garden" demonstration with the explicit intent of increasing visitor interest in and understanding of climate change.

Botanical gardens have an established record of data collection and research on plants and climate and are poised to share climate change knowledge with the public (Primack and Miller-Rushing, 2009). This paper outlines our process for defining an emerging garden genre, and how to link the science of climate change to a dynamic and compelling interpretive and demonstrative garden installation in a botanic garden setting. It describes the project as an installation of carefully selected planting beds embedded in both a high tunnel greenhouse (with degrees of control over temperature and precipitation) and an ambient open-air installation for comparison. It discusses lessons learned in combining experimental inquiry with interpretive design, while navigating the logistical constraints of crafting the right message for visitors to a garden of tomorrow within the opportunities and constraints of the world as it exists today.

Three overarching interpretive goals for the installation were crafted with the objective of affecting visitors' experiences and attitudes by a) informing visitors about climate change and what they can expect; b) physically demonstrating possible changes and impacts to plants so that visitors can understand them; and c) providing an interactive opportunity for visitors to interpret climate impacts by documenting their observations. This project also has a longer-term goal; as something of a "designed experiment" (Felson and Pickett, 2005, Felson and Pollack, 2010), the physical, botanical, and visitor experience data collected and observations made will be used to "tune" the installation's performance and impact, and may ultimately inform more significant experimental research investigations into resilient landscape planting selection and design (Hunter, 2011).

Introduction

Climate change is a complex phenomenon with far-reaching implications that are at once global and site-specific. Many people may have a conceptual grasp of climate change, but may not know what climate effects to expect in the region, and what impacts climate change may have on their day-to-day environment. As the urgency and significance of climate change continues to mount, new approaches are needed for interpreting and visualizing climate change with the public that are tangible and approachable beyond the abstract.

Botanical gardens have made longstanding contributions to climate change research, particularly with respect to temperature and its effects on the timing of plant flowering and leaf out by participating in phenological networks of botanical gardens, monitoring standardized plantings in phenological gardens, and studying and examining herbarium specimens and historical photographs (Primack and Miller-Rushing, 2009). In addition to research, botanical gardens have responsibility to share valuable information with the public about climate change and its impact on plants, ecosystems, and people (Primack and Miller-Rushing, 2009, Sellmann and Bogner, 2013). According to Dr. Casey Sclar, Executive Director of the American Public Garden Association, "Public gardens are uniquely positioned to be THE place to learn more about and EXPERIENCE climate change" (Lewis, 2012, p.5). Sclar adds that public gardens are places where visitors can make local connections to this global issue (Lewis, 2012).

Cornell University's botanical garden, Cornell Plantations, has a strong educational mission and a focus on contemporary botanical topics. It also enjoys a long-standing rapport with Cornell faculty, some of whom are leaders in climate science research. In 2011, the authors began exploring the possibility of designing and installing an interactive climate change demonstration garden within the botanical garden. At the time, no precedent for an interpretive 'climate change garden' existed, with the possible exception of phenological gardens, which are research installations of specific plant species for standardized comparison with other participating installations in an organized network (Primack and Ziller, 2009). Gardens such as The Chicago Botanic Garden, Wellesley College and others for example are participating in a program known as "The Floral Report Card" which offers citizen science opportunities for monitoring a garden of selected native wildflowers and grasses (Dunne, 2012, Project Budburst, 2015) Syracuse University also recently installed a climate change garden comprised of 34 different species of trees and shrubs, some native, some adapted to warmer climates. They plan to monitor the health and vitality of these plants over the course of years (Syracuse University, 2013). The American Public Garden Association's Youtopia program offers gardens and garden visitors information about climate change and possible solutions (Carlin, 2012). But Cornell Plantations was looking for something more demonstrative, interactive, and compelling. They were looking to find a way to "bring" climate change to a garden installation by allowing comparison between a present-day garden and a "garden of the future" influenced by aspects of a changing climate.

Many devices have been used to approximate the anticipated effects of climate change in scientific research, including phytotron growth chambers, greenhouses, open top chambers, infrared heating and other techniques. Some of these techniques however can be costly, logistically challenging or have limited interpretive potential. High tunnels (steel frames with clear plastic films stretched over them) can be erected over growing plants, utilizing radiant energy to increase air temperature with relatively low cost. In temperate environments, these structures are used to extend the growing season at both ends through protection from low temperatures and allowing early plantings and late season harvests. Currently, about 1 million ha of high tunnels cover vegetable, flower and fruit production areas of China, and it is estimated that 150,000 ha of protected cultivation is practiced in winter around the Mediterranean region (Jiang et al., 2004; Castilla and Montero, 2008). In the United States, use of high tunnels for crop production has recently received a major boost through a federal program that partially subsidizes high tunnel acquisition by farmers (NRCS, 2014).

High tunnels lack the precise environmental controls of expensive greenhouses, but are nevertheless able to influence temperatures experienced by plants to levels projected for our changing climates by trapping heat generated from solar radiation and regulating temperatures via ventilation. The structure also sheds rain, and thus allows the user to select the watering regime inside through irrigation. More mechanized high tunnels with exact temperature control and equipment that manipulates air CO2 concentration have been used by scientists to explore the combined effects of important climate change variables on crop performance (e.g. Dias de Oliveira et al., 2013). While less-equipped high tunnel setups cannot emulate projected climate change effects as comprehensively and accurately as these more expensive setups, we saw the potential for a lower-tech setup to provide an interpretive and demonstrative environment for visitors to experience the possible impacts of certain anticipated climate change effects, notably those of projected shifts in temperature and/or precipitation patterns on vegetation, as a means for engaging visitors in a dialogue about climate change. There were a few environmental limitations of the high tunnel, such as reduced air movement and differences in day and night temperatures, that would not be typical of climate change effects, but we judged that these limitations would not be major factors in plant growth during the season and refrained from specifically interpreting these limitations during the pilot season.

Cornell Plantation's interest in a dynamic and interpretive climate change installation paired with international-level expertise in high tunnel-based horticultural research and other expertise at Cornell led to a series of partnerships exploring the design and installation of (to our knowledge) the nation's first climate change demonstration garden. This investigation was based on two basic research questions: a) How might we define a climate change garden and its characteristics as an interpretive and demonstrative installation?; and b) How might a high tunnel be used in a climate change garden to interpret climate change effects? In this paper we describe our process for defining our own climate change garden project, our investigation into the materials and methods for siting such an installation, our initial observations, and the complexities and lessons learned from such an installation as we chart our course forward.

Approach

A grant by the Toward Sustainability Foundation in Spring 2014 catalyzed an interdisciplinary effort to envision, design and install an interpretive climate change garden at Cornell Plantations. During the course of its development, it became evident that this project would be a dynamic exercise- one of iterative design, construction and learning- where the results would be unique and possibly the first of its kind. To begin, we had to first define for ourselves what a climate change garden actually is. While a climate change garden can generally be defined as a garden installation with a combination of plants and other materials with an overall climate-based theme, there can be much more embedded within it. We surmised that there are four fundamental influences that drive the design of a climate change garden: the designer and her capacities as space-maker and generator of conceptual intent, the garden space with its locational opportunities and constraints that impact the potential of the project as a composed and intentional landscape, the visitor as an observer and interpreter of space and meaning, and finally climate change itself as a present and future agent of change within the garden. While the first three are certainly not unique to project development, particularly in interpretive settings, climate change, as an arbiter or force of change that is both global and local, is unique for the physical conditions it dynamically defines as well as the revelatory interpretive opportunities it can provide.

To define our own vision for a climate change garden, we posed the following six questions. Those endeavoring to design their own climate change gardens may also want to consider these questions in order to optimize their own project.

What are the regional impacts of climate change?

A specific understanding of climate change and its projected impacts on climate in the project region provide the basis for design. Whether the garden will actively engage these impacts or address them more passively, knowing what can be anticipated with climate change is critical for moving a design concept forward. State-level models that make specific predictions for climate change in regional locations throughout a given state may be available, and if not, national assessments like the 2014 National Climate Assessment Development and Advisory Committee Report (Melillo et al, 2014) provide multistate-level assessments of climate change effects and impacts that may provide enough resolution to anticipate changing climate patterns.

What is the intent of the garden?

Fundamentally, the purpose of the garden must be clear and evident to the designer and the visitor. For example, is the primary intent to collect scientific data on climate change as an experimental design, or will it be about interpreting these effects for visitors? Are there other objectives? How are these objectives exclusive of one another, or not?

What is the message you intend to send your visitors?

Climate change will upend many aspects of our environment and our lifestyle. Its impacts can be dramatic, confusing, frightening, and/or controversial for those who confront it. The intent or purpose of a garden, as it is experienced by the visitor, ultimately sends a message to visitors who must process this information and make something of it. Is this message one of hope, concern, or despair? Is it about information, understanding, or action?

How will the garden communicate this message?

A garden as a landscape is essentially the medium of the climate change garden designer. What combination of landform, vegetation and structure will be used to communicate your intent and how? How will dynamic and static elements come together to tell "the story" you intend to share? How will the design of the garden, both in terms of selection of garden elements as well as their spatial arrangement, facilitate this story and impact visitor perception? Will the garden be a display, interactive, or even more engaged?

Who are the visitors to the garden?

Different types of visitors will have different sets of interests and knowledge of climate change. Their personal lives and priorities will vary. The purpose of their visit to the botanical garden-at-large- why they are at the botanical garden- will also be different. A persons' relationship to the issue of climate change, as something that affects us all collectively and each of us individually, will ultimately be a different experience for everyone. By anticipating who the garden visitors may be and their interests in the garden, we can better tune the experience of the installation so its message is more clear, legible, and relevant to visitors.

Will the garden by climate-dynamic or static, and at what temporal scale?

As an exercise in revealing the future, the site is consistently subject to a fourth dimension- time. How might a garden be designed with an eye toward the future, under the conditions of today? While all gardens are necessarily dynamic, how might the agency of climate change be best anticipated, represented, or interpreted for the benefit of the project?

Defining our approach

In defining our project, we answered these questions through the course of multiple meetings, conversations, and email dialogues. For the region of our project location in Ithaca, NY, the anticipated effects of climate change are well studied. Statewide, New York is projected to experience increases in total annual precipitation. Much of this precipitation increase may be in winter and precipitation may slightly decrease in late summer or early fall, though seasonal projections have greater uncertainty than annual projections (Horton et al, 2014). In New York's Southern Tier Region 3 where the project is located, increases are projected in annual precipitation of +4 to +10% by the 2050's and +6 to +14% by the 2080's) (Horton et al, 2014). Although these annual increases may seem relatively incremental, larger increases in the frequency, intensity, and duration of extreme precipitation events are projected (Horton et al, 2014). By the end of the century statewide, the number of drought events is likely to increase during the warm months, though with relatively high uncertainty (Horton et al, 2011). Increases in average annual temperatures are also expected statewide. In New York's Southern Tier Region 3, mid-range projections indicate increases in average temperature of +4.4° to +6.3° F by the 2050's and +5.7° to +9.9° F by the 2080's (Horton et al, 2014). A greater frequency and duration of heat waves (three or more consecutive days of maximum temperatures at or above 90 degrees F) is also projected (Horton et al, 2014).

We knew early on that while our garden would possess aspects of scientific interest and investigation, it would be primarily interpretive in its intent. We were concerned about visitors' general unfamiliarity with climate change and its projected impacts on the region, and wanted to send a message that was both bold and unequivocal: that climate change is coming, it will have impacts, and those impacts will affect our local environment and daily life. While we understood this message could be daunting for visitors, our intent was to share with visitors what climate change phenomena are projected for the region, so that the notion of climate change, as a large-scale process all-too-often defined in the abstract, would seem immediately relevant and visible to the visitor.To do so, we were looking for a way to demonstrate the impacts of climate change in a comparative setting, so that aspects of climate change could be contrasted with current conditions. While basic high tunnel equipment could not provide an actual simulation of all climate change factors, it could provide reasonable control over average temperature, high temperature extremes associated with heat waves, and extremes in precipitation. We hypothesized that manipulation of these environmental factors associated with climate change in a high tunnel environment would significantly impact plant survival and vigor, indicating possible future climate impacts. A demonstration of these impacts could open a dialogue about climate change where visitors might be interested in learning additional information about climate change, and perhaps how to mitigate and adapt to its effects.

Based on surveys of visitors to Cornell Plantations, we knew that many visitors to the garden have an interest in gardening and horticulture, so demonstrating climate change impacts through plant response seemed an appropriate strategy. We also wanted the project to be dynamic, high impact, and constantly changing, so that these visitors could return to the garden multiple times during the season in order to view and interpret different impacts. Finally, we further sought to provide a way for visitors to interact with the installation, so that they could make their own observations of impacts first-hand, develop conclusions, share them, and take ownership of that understanding. This final point had the secondary purpose of providing feedback to us on the effectiveness of the installation in providing knowledge about climate change in an interpretable and useable format for visitors, so that we could continue to refine and tune it.

Materials and Methods

Site design layout

The climate change garden design concept was developed in Winter 2014 and was installed in May 2014. The project was composed of a garden area inside of a high tunnel, on which some measures of environmental control would be imposed (primarily temperature and irrigation), and another identical garden area directly outside of the high tunnel that was subject to ambient environmental conditions. In this initial season, the objective was to create a moderately warmer environment in the high tunnel, similar to average temperature increases projected for this location in the 2050's. We located the garden in the southeast corner of Plantations' Sustainable Backyard Garden so that beds inside and outside the high tunnel had equal and adequate solar access for comparative growing conditions. The high tunnel itself consists of a steel frame unit of 24' length, 20' width, and 12' height, and was covered with a 0.15 mm thick translucent polyethylene plastic skin. Solar energy penetrated this skin and warmed the inside of the tunnel. Ventilation and temperature control was achieved by gable-end vents and sides that could be rolled up or down based on the desired environmental conditions.

Six 4'x6' raised planting beds were constructed of 2"x6" black locust planks within each of the garden areas and filled with soil amended with manure compost at a ratio of two parts soil to one part compost. Identical plant species were planted in each of the six beds in the planting areas both inside and outside of the high tunnel, so that all aspects of plant layout- plant species, form, numbers, their spacing and their arrangement- within the beds was identical inside and outside the high tunnel so that visitors could make comparative observations about the differences in plant conditions both inside and outside the tunnel. See Figure 1 for an illustration of the project plan. Figure 2 and Figure 3 provide photo views of the installation.

When selecting plants for each of the beds, we wanted to demonstrate impacts of changing environmental conditions on plant survival, phenology, and vigor both inside and outside the tunnel. We knew that many plants- landscape plants, garden plants, perennials, and members of New York native plant communities- will be subject to the impacts of climate change. What we didn't know was how individual species would respond to changing environmental variables. We chose a broad spectrum of species to include in the beds to develop our understanding of how different plants would react to climate change-associated variables and show visitors the effect of climate change on each. Each of the six beds had a unique organizing theme. For example, Bed 1 held plants that we anticipated would grow well inside the tunnel while not so well outside of the tunnel, while Bed 2 was composed of plants adapted to regions that we anticipated would grow well outside the tunnel but not so well inside the tunnel. Other beds had specific themes or types of plantings, including landscape, vegetable garden and native plants beds, each harboring a selection of plants that we anticipated would have a mixture of discernable reactions to climate change. Table 1 provides a description of each of these beds and the species placed within them.

Environmental controls and data collection

At the outset of the project, it was unclear to us precisely how the tunnel would perform in emulating aspects of climate change and how plants would respond to these variables. Therefore we limited manipulation of the environmental variables to just average temperature within the tunnel, and sought an average temperature increase similar to future climate change projections for the 2050's. We controlled temperature by opening the gable vents and keeping the sides open for most of the growing season. Temperatures inside and outside the tunnel were monitored by temperature sensors linked to a weather station (Onset Computer Model U30 Hobo), with sensors placed at 10 cm and 28 cm depth in the soil, and 122 cm above ground. The aerial sensors were protected from the sun by a shading screen. A quantum sensor measured photosynthetically active radiation (PAR) in the tunnel during the growing season. We chose to provide comparable bed irrigation adequate for growth, and not to experiment with the effects of either drought or excess water this first season. Beds in the tunnel were watered by hand twice weekly, and the outside beds were watered when needed to also keep them comparatively well hydrated.

Plant data collection

To monitor the performance of plants inside and out of the tunnel, growth rates were measured by determining plant heights with a meter stick, dates of fruiting were noted, and the yields of ripe fruits were counted where applicable. Photos from all beds were periodically taken from set locations. No other indications of plant phenology were taken this season.

Interpretation and visitor data collection

The overarching goal of this project was to share the story of climate change with visitors to Cornell Plantations through the lens of a garden, and explore how to best convey it. Prior visitor surveys indicated that those visiting Plantations have a strong interest in

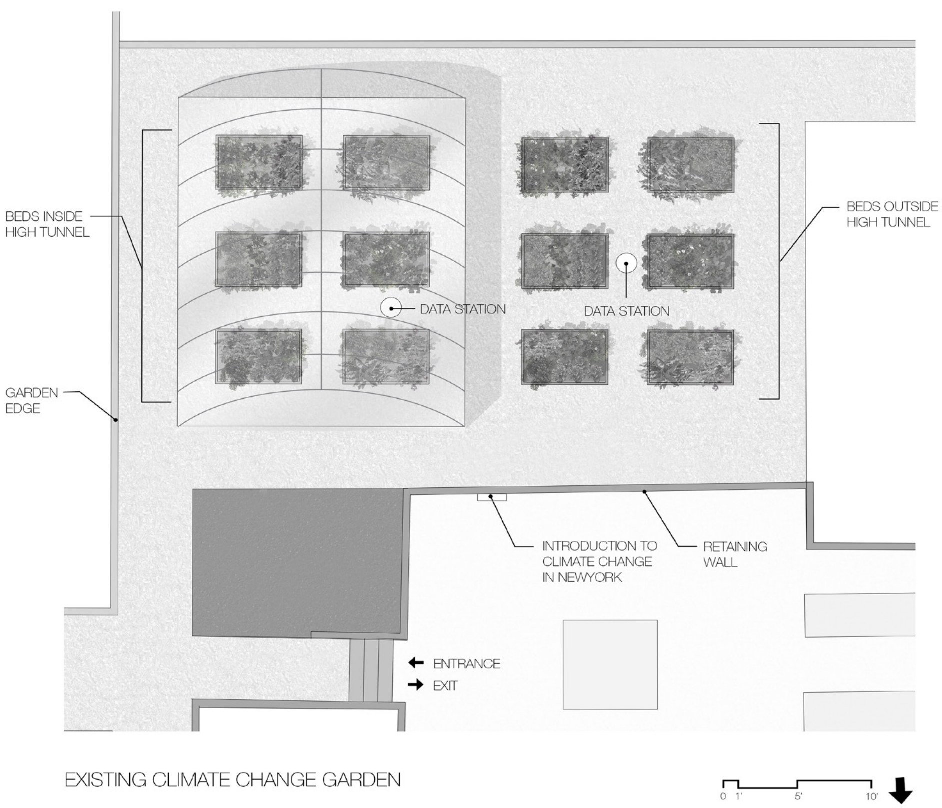

Figure 1. Plan for the 2014 climate change garden. (Morouj Akbar, MLA '15)

Figure 2. Photo of the 2014 climate change garden installation. The outside beds are in the foreground. (J. Cera)

Figure 3. Photo of the 2014 climate change garden installation. The inside beds are in the foreground. (J. Cera)

horticulture and gardening. The climate change garden is located in a section of the botanical garden that is home to Plantations' vegetable garden, and a teen environmental education garden called the "Sustainable Backyard". Additionally, the teen program used the climate change garden to support their understanding of climate change principles.

We knew that it would be necessary to introduce the garden and the topic of climate change to visitors; to do this we installed a kiosk that included an introductory sign along with a brochure that included a visitor survey and small pencils. The sign introduced fundamental aspects of climate change- extreme fluctuations in temperature and precipitation, as well as longer-term changes in climate conditions in the region. It also invited visitors to observe, compare, and take note of how well plant species grew inside and outside the tunnel. The available brochure outlined specific climate change projections for the region in greater depth, and stated that while the high tunnel can't provide an actual comparison of the differences between today's environmental condition and anticipated future conditions, it can approximate some of the effects of climate change projected for the region including extended periods of higher temperature and drought. Intended as a take-home piece, the brochure also directed readers to Cornell's climate change website, a clearinghouse of reputable sources about climate change as well as citations for climate change effects and predictions about climate change.

A detachable visitor survey was also included in the brochure. We had two main objectives for the survey a) to provide an interactive opportunity for visitors to make and record observations about the plants and b) to gather baseline information about what visitors would like to know about climate change. There were five questions on the survey, two were rating questions using a Likert scale and three were open-ended questions. We asked visitors to "rate the overall condition of the plants in each bed. 5=excellent; 1=poor" for the beds inside and outside the high tunnel. Following the rating questions, visitors were asked to provide open-ended responses, "use this space to add any specific observations." We then asked, "Which plants did you see growing better INSIDE the high tunnel? What are the difference that you see?" and asked the same question for plants OUTSIDE the high tunnel. The final question simply asked, "What would you like to know about climate change?" We expected the survey would take approximately 10 minutes for visitors to complete. Our intent for the open-ended questions was that visitors' responses would provide us with objective baseline data about what our visitors knew and wanted to know about climate change. We were hesitant to provide answer choices so as not to bias visitors' observations or to restrict their answers to what additional information about climate change they might like to have. Visitors were invited to leave the completed survey in a box provided on the introductory kiosk.

In addition to the introductory sign and the brochure, each bed was labeled with a description of the types of plants in the bed using the bed descriptions in Table 1. Finally, a Cornell University student intern was employed by Cornell Plantations over the summer months to care for and interpret the garden to visitors. This intern often spoke with visiting tour groups, visitors, and students about the garden and its intent, and shared the interpretive messages outlined above. She recorded her visitor observations and interactions in a journal and shared her observations with staff during and at the end of the season.

Initial Observations

Our first year was primarily an initial investigation into the process of designing, installing, and maintaining an interpretive climate change garden. However we did make some preliminary observations, both qualitative and quantitative, that inform our lessons learned from this process and the steps we plan to take moving forward.

Environmental Controls

In this first, mainly observational season, tunnel ventilation was not severely restricted and the air and soil temperatures were only modified to a small extent by maintaining some ventilation through tunnel sides and roof vents (Table 2). Over the growing season, daytime air temperatures were only 3.4°F higher in the tunnel, and overall, the difference was only 1.5° F. Soil temperatures fluctuated less, but showed a similar overall difference. In comparison, a 3.5°F increase in temperature was on the low end of the average annual temperature increase projected for the Ithaca Southern Tier region in the 2050's due to climate change by the latest projections available at the time of the study (Rosenzweig et al, 2011). Since initiating the project the mid-range projection for change in temperature by the 2050's has been revised upward to between +4.4 to +6.3°F (Horton et al, 2014). Finally, comparative readings inside and outside the tunnel with a line quantum sensor (Model LI-191SB, LICOR, Lincoln NE) in early October established that the high tunnel structure reduced incident PAR (Photosynthetically Active Radiation) by 29%.

Plant response

Given the moderate conditions in the tunnel, most plants showed some increase in plant growth. In particular, the plants adapted to warm climates showed the greatest growth stimulation, but growth stimulation was also observed in those that would normally do best in a temperate environment. At this stage of the project, we did conclude however that a comparative high tunnel setup such as this installation has the potential to elicit differences in plant response inside and outside the tunnel by manipulating environmental variables inside the tunnel. We would assume that in another growing season, in which a more restricted ventilation would raise air temperatures for the temperate crops to above their optimum, temperate crops would grow less well in the warmer environment.

Design layout and interpretation

From a design layout standpoint, we were seeking a comparative experience for the visitors to the garden. Visitors were attracted to the introductory sign for the Climate Change Garden and tended to read it and take a brochure. While we anticipated that visitors would view the garden comparatively, not all visitors actively did so unless prompted by staff or intern. The garden layout was unstructured in terms of its sequencing, and some visitors visited the high tunnel while not visiting plants

Bed Number	Best Description	Bed Species
Bed 1	Plants in this bed have adapted to grow in warmer regions and should grow well inside the high tunnel but not so well outside of the high tunnel.	okra, peanuts, cotton, Malibar spinach, cowpea (long bean)
Bed 2	Plants in this bed are adapted to grow in this region, but as the climate in this region continues to warm, these plants may no longer grow well here.	Lettuce, Spinach, Radish, Calendula, Torenia
Bed 3	Plants in this bed grow well here in the warmer months, but cannot survive in winter. Some plants may survive the winter inside the high tunnel.	Canna, Eucomis, Musa, Fig, Gladiola, Acidantera, Agapanthus
Bed 4	These are popular landscape plants used in urban and residential settings. These plants have been specifically selected to see which will grow well in the high tunnel.	Lagerstroemia, Camellia, American Holly, Hydrangia, Phygelius, Abelia
Bed 5	Plants in this bed are found in native plant communities Upstate New York. Plants have been selected to see which will grow well in the high tunnel.	Ilex glabra (Inkberry), Symphorocarpus spp (Snowberry), Monarda fistulosa (wild bergamot), Ilex verticillata (deciduous holly), Veronicastrum spp. (Culver's root),
Bed 6	This bed has a variety of pepper plants known to have a longer growing season similar to conditions in the high tunnel. Some vegetable crops may grow better here as the growing season gets longer in this region.	long season peppers

Table 1. Bed descriptions and species lists for the six beds included both inside and outside of the tunnel in the 2014 installation. (J. Cera)

	Air temperature, °F		Soil temperature at 4 in.	
	Outside	Inside	Outside	Inside
Day	72.6	76.0	67.7	69.2
Night	59.6	59.6	67.3	68.5
Overall	65.2	66.7	67.5	68.8

Table 2. High tunnel air and soil temperatures between June 26 and Oct. 7, 2014. (Rodekohr, 2014)

growing under ambient conditions, or viewed them in ways that made them difficult to compare. When they did walk through the garden, many appeared hesitant to enter the high tunnel without explicit instruction or permission to do so. Once invited by staff or the intern, visitors would enter. We speculated whether the unstructured, free-roaming nature of the garden made it challenging for visitors to learn key information, make observations, and interpret them in a way that would be most meaningful to them. Visitor feedback told us that a basic choreography of experience would be more helpful.

There were also interpretive lessons learned from a planting design standpoint. When visitors did view the garden comparatively, sometimes the phenological differences between the plants were subtle to the untrained eye. This was partly due to the fact that we intentionally limited the environmental variation between the gardens inside and outside the high tunnel to a moderate increase in average temperature (rather than temperature or precipitation extremes for example). However even with modest temperature interventions (slightly warmer inside the high tunnel than out) visitors were able to detect differences between the plants inside and outside the tunnel. When asked to rate the overall condition of the plants, visitors and survey respondents generally provided higher ratings to the overall condition of the plants inside rather than outside the tunnel.

We had over thirty species and cultivars of plants in the installation, and while we hoped that grouping them in theme-based beds would assist in organizing observable changes for viewers, processing all of the plant effects over that many species was likely too daunting for the typical visitor. Also some of the species used were perhaps not typically familiar to visitors and may have caused some visitors to focus on plants they were interested in for their own gardens, or just for the plants' interesting qualities. Many visitors for example gravitated toward Bed #3 which displayed tropical plants.

One of the methods by which we had hoped to have this garden be an interactive experience was for visitors to use the provided survey to rate the plants and provide comments about their performance. Over the course of the season (May – September) we distributed 100 brochures in a box attached to the introductory sign. Of those, 9 surveys were returned. We hypothesize that the layout of the garden contributed to the lack of returned surveys (it is likely that visitors did not exit the garden the same way they entered thereby bypassing the survey return box) and that the survey itself inhibited completion and submission. One objective of the survey was to provide an interactive way for visitors to observe the plants inside and outside the tunnel, and as stated earlier making the observations may have been difficult and therefore visitors may not have felt able to provide ratings. The open-ended nature of many of the questions, while seemingly a good way to gather baseline, objective feedback from visitors may also have inhibited completion. Finally, having the survey attached to a take-home brochure may have influenced the return rate in that visitors simply took the brochure home not realizing there was a survey. For the surveys that were returned, the rating questions were answered by all respondents, 1 respondent answered all the open-ended questions and 3 others provided answers to the observation open-ended questions. Only one respondent gave feedback on what they would like to know about climate change.

Lessons Learned

Based on our experiences in this initial materials and methods investigation we see the following opportunities to improve the interpretive experience and impact of the climate change garden.

Simplify plant diversity and variation

There are opportunities to focus the way that information is shared in the garden so that it is more apparent to visitors. Climate change can have varying and diverse impacts on plant vigor, and differences in phenologic expression may not be immediately obvious to observers. Conversely, diverse responses that are unorganized visually can also be difficult to interpret for the typical viewer. This can be addressed by reducing the number of species (and their corresponding response diversity) used in an installation. This legibility could be further improved by arranging individuals of the same species together in groups, such that plant phenological effects will be more visually significant in the garden landscape.

From a project development standpoint, we benefitted greatly from observing variation in phenological expression for a diversity of plant species and types in the first year, and the conclusions we've drawn from these observations will be very useful for choosing new plant palettes moving forward. By reducing the number of species and their corresponding response diversity moving forward, we should be able to make effects on plant phenology more interpretable to the user. Using plants that may be familiar and readily identifiable to the visitor may also improve interpretability.

Choose plants by their message

Many visitors will be observing the possible effects of climate change for the first time when visiting the garden. The plants chosen and their phenologic expression have a profound effect on the message sent by the entire garden. Some plants respond more significantly to climate change-associated environmental effects than others, and exhibit pronounced phenological effects. Plants are your messengers- their relative susceptibility or resilience to environmental effects and how they exhibit phenologic effects (e.g. accelerated growth, senescence, altered bloom time, stress-related disease) will directly impact what a visitor takes away from the installation. For our case, as we continue to run trials in the garden we may also find that certain plants demonstrate phenologic responses to climate change factors in ways that are more evident to the viewer. Rather than exaggerating the impacts of climate change on plant response, these effects should be readily evident and visible, preferably throughout the growing season. Therefore choosing the right plants is critical. Over time we anticipate tuning the plants in the installation to optimize for plant phenologic expression, survivability, and productivity and their corresponding interpretive messages.

Amplify the impact of the installation

For our first season, we limited the environmental variables in the tunnel to better understand how the tunnel would perform, and how plants would respond. While the phenologic effects were evident for many species, the absence of environmental extremes associated with climate change may have had a relatively muted effect on plant response. This made the effects on plants subtle and sometimes difficult to discern for viewers. Beginning next year we will be adding extremes in temperature and precipitation (e.g. periods of excess irrigation, drought and/or heat waves) and may also increase the average daytime temperature in the high tunnel, which we hypothesize will have more pronounced effect on plant phenologic expression, survivability, and productivity.

Strengthen visibility of cause and effect

The climate change garden is a dynamic and ever-changing system, and environmental conditions and their effects are changing constantly. We feel 'current events' in the garden could be more easily shared to enhance the impact and interactivity of the installation. Strategically positioned bulletin boards, white boards or other similar devices could post environmental effects underway like heat waves or excessive irrigation, and highlight any readily observable impacts on plants. This could be further reinforced by placing highlighted "tags" near plants that are currently expressing responses to such effects. These improvements would improve visibility by enhancing the cause-and-effect linkages between changing environmental variables and their impacts on plant phenology and/or survival. It would also improve the dynamic nature of the garden, so that visitors visiting the garden repeatedly during the season can readily observe new phenomena.

Choreograph the user experience

While most people have heard of climate change, its effects on regional climate may not be known to visitors, and its impacts on plants are even less so. Therefore, to begin an interpretive climate change garden installation must be fundamentally educational. When comparative interpretation and feedback is also sought from visitors, sequencing the visitor experience may help communicate the intent of the garden and improve the quality of visitor experiences in the garden.

Improve the feedback loop

Providing opportunities for visitors to make overall and specific observations about the garden and plants and asking them to share those with staff will give visitors the chance to be an active participant rather than a passive observer in the garden. Through the use of bulletin boards and highlighted "tags" along with opportunities for visitors to leave their own observations on the bulletin boards, we hypothesize that such interactivity may help reinforce the messages being shared. We will also benefit from this feedback by learning how visitors interpret and respond to conditions in the garden. Providing a survey, separate from a take-home brochure, with more directed questions and answer choices, and a survey depository at the end of the garden sequence may provide for increased completion and submission of the survey.

Redesigning the garden

Based on our observations this year, we plan to redesign the project for greater impact. While the basic layout of the beds and high tunnel will not change, the redesign will overhaul the climate-associated environmental effects displayed in the garden, plant selection and composition, visitor interpretive experience, and visitor survey data collection.

Environmental controls

With the high tunnel in place and average baseline temperatures established from the 2014 season, we propose to use the high tunnel to more closely demonstrate the cumulative effects of climate change by adding significant variation in temperature and precipitation extremes associated with climate change. For example we will simulate discrete periods of high temperature, drought and/or flood by not venting the greenhouse and withholding water or over-irrigating to demonstrate impacts of such effects on the plants. We may also increase the average daytime temperature in the high tunnel to approach the mid-range of the increased average annual temperature increase predicted for the area in the 2050's, +4.4 to +6.3°F (Horton et al, 2014).

Plant selection and composition

To increase the accessibility and visibility of the climate change message, in 2015 we will install just two overall plant categories instead of six for the beds inside and outside the tunnel. Three beds will contain food crop plantings, each with a limited selection of vegetable and grain varieties that are likely to demonstrate changes in growth, development, productivity, and survival based on temperature and precipitation patterns. We intend to use the grain varieties to help us interpret possible impacts of climate change on our staple foods, many of which are derived from grains; commonly grown garden vegetables that visitors may find in their own gardens will be used to help visitors recognize the possible local impacts of climate change. The remaining three beds inside and outside the tunnel will contain nectar resource plants. These plants, many of them native, will be grouped into three different typical bloom times- early, middle, and late season. The intent of this part of the installation is to demonstrate how climate change-associated variables may bring about differences in bloom time, resource abundance or other phenological expression. Plants for both bed types will be selected so that visitors returning to the garden will be able to observe different conditions and effects throughout the course of the growing season.

Visitor interpretive experience

The current layout of the high tunnel and the associated outdoor beds will remain in place; however the visitor's experience of the garden will be enriched and improved by a new pattern of circulation that coordinates movement through the site with an unfolding interpretive message. See Figure 4 and Figure 5. Five stations will be set up throughout the garden, each with interpretive signage and an opportunity for visitors to dial a phone number on their mobile phone to learn more:

1. *Introduction* - We will provide a clear point of entry for the garden. At this entry point there will a new set of stairs and entryway installed to provide access to the entrance of the garden. There will be a sign introducing the garden, with information describing the science of climate change, the goals of the garden, a map, and instructions for interacting with the installation.

2. *Garden of Today* – This station will introduce the two main groups of plants (food crops and nectar resource plants), why they were chosen, and plant characteristics of interest to observe in the garden beds outside the tunnel.

3. *Wayfinding and Transition*- This stop will provide a place for staff to highlight particular plants of interest, for visitors to record their observations, and to direct visitors to the next station.

4. *Garden of the Future* – This stop will remind visitors of the predicted effects of climate change, identify current climate conditions inside the high tunnel (higher average temperatures than the "Garden of Today" as well as acute temperature and irrigation events), and specific plant characteristics to observe inside the tunnel.

5. *Conclusions and Additional Resources*– After visitors exit the high tunnel they will approach a final interpretive stop where themes will be reinforced, and visitors will have a chance to share their observations, thoughts and conclusions. We anticipate collecting visitor's observations with a white board on the kiosk at the final stop with specific questions and prompts for visitors to share. An improved visitor survey will be provided at the garden's entrance with clear instruction for completing it during the visit, revised questions for ease of answering, and a clear place to return the survey at the end of the visit. Resources for additional learning will be shared including a webpage dedicated to the garden that users may visit to learn about the current goings-on at the garden for their next visit. Opportunities for visitors to both reduce their carbon footprint and adapt to climate change will also be shared.

Finally within both the outside and inside garden beds project staff will use eye-catching focused information tags to draw visitor attention to particular plant characteristics, impacts of note, and to convey additional interpretive messages. The tags will be moved periodically as project staff observe events worth sharing with visitors to help amplify the intended interpretive experience in the garden.

Visitor survey data collection

To improve the onsite survey we will begin by conducting an online pre-survey with a wider audience and hold several focus groups to help us understand people's knowledge of climate change, its impact on plants, and how the climate change garden might help them understand these topics better and be compelled to action. We will use the data from the pre-survey and focus group sessions and consult with climate change communications experts at Cornell to craft a better onsite survey. In addition to the onsite survey we will provide several opportunities for visitors to leave their observations directly in the garden on white boards and on focused information tags that staff and visitors can write on. At the final interpretive stop another white board will give visitors a final chance to share their feedback. The surveys and observations made by visitors on the white boards and the focused information tags will be recorded by staff as visitor response data.

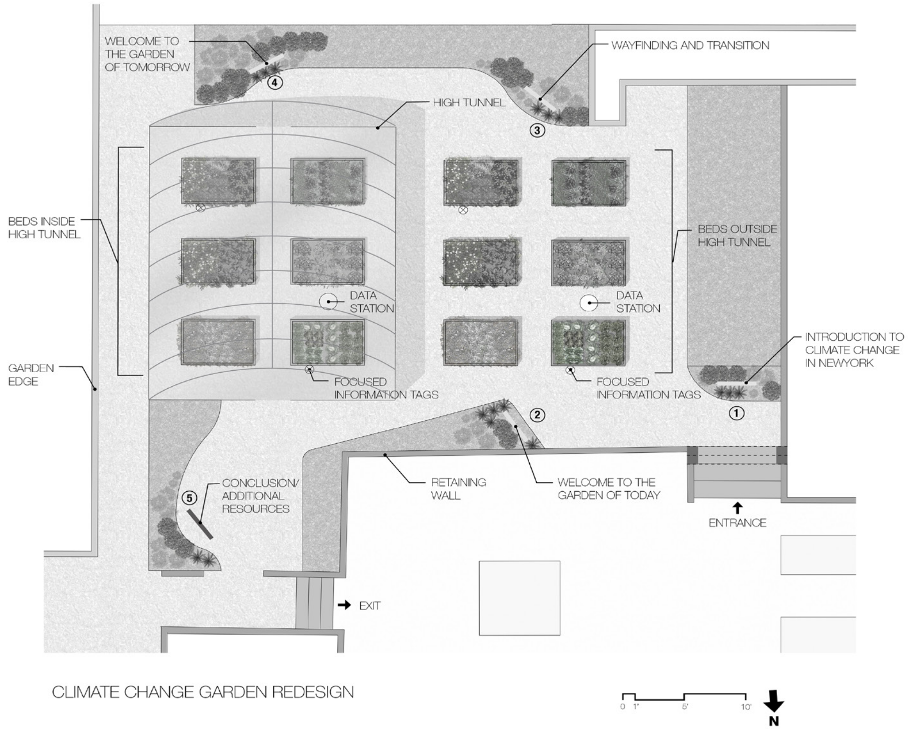

Figure 4. Plan of the proposed climate change garden redesign. (Morouj Akbar, MLA '15)

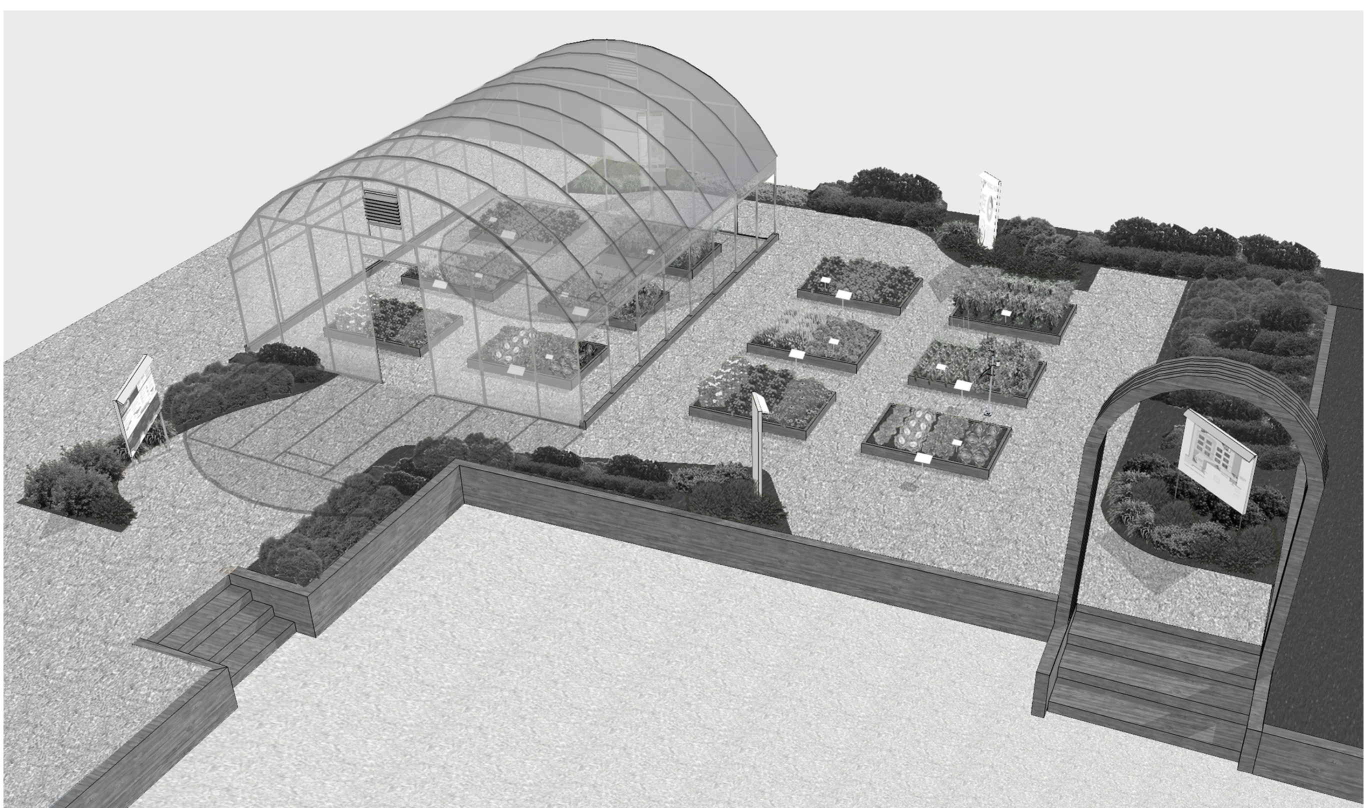

Figure 5. Perspective rendering of the proposed climate change garden redesign. (Morouj Akbar, MLA '15)

Conclusion

It became evident during the course of the project that the Climate Change Garden would become a dynamic and ongoing exercise- a sequenced exploration of research questions, site design and evaluation, followed again by subsequent series of questions, project redesigns, and refined conclusions. Due to the relatively unexplored nature of key linkages between equipment performance, plant phenologic response, and visitor experience, we see our foray into the emerging climate change garden genre as a kind of design research by which the project can be tuned and enhanced over time through a series of iterative redesign exercises. As something of a 'designed experiment' (Felson and Pickett, 2005, and Felson and Pollack, 2010), the design and installation itself are an experimental research exercise, one that will be observed, measured, and evaluated to determine how to better refine it moving forward. This upcoming season we will redesign the project and make key adjustments to climate-associated environmental variables, plant selection and composition, interpretive layout and visitor experience, and visitor survey data collection. In future years, we see the benefit of adding additional equipment to the high tunnel in order to improve precision and automation. As we develop this work, we hope it may inform how other botanical gardens and similar organizations and agencies might develop their own climate change gardens. Ultimately this work could also inform other, more scientific future research investigating resilient planting selection and design (Hunter, 2011).

Climate change is coming to every city, town, and street corner. Behind the work of defining and tuning the climate change garden remains our original intent- that of providing a portal for visitors to experience, understand, and ultimately anticipate climate change and its potential future effects on plants and the region. We seek to open a dialogue with visitors about climate change and its possible impacts, one that may ultimately lead to greater receptivity and understanding of local, regional, and global efforts to mitigate for and adapt to a changing climate.

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