Chapter 2

Urban Agriculture Case Studies in Central Texas: From the Ground to the Rooftop

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Additional information is available at the end of the chapter

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Abstract

Urban agriculture is practiced in various forms and scales. Practices range from the production of edibles in small to large lots or plazas to vertical production on walls and rooftops. Produce is grown in rural locations and sold at farmers markets in urban locations or grown onsite. Efforts to produce, maintain and sell products of urban agriculture involve many participants and leaders from multiple disciplines. This chapter highlights an introduction to several urban agriculture concepts and case study examples representing activities in Central Texas, home of the Texas A&M University. These case studies highlight a modular pavilion type farmers market and urban garden in downtown Bryan, Texas, designed and built by students and faculty collaborations. The farmers market is designed to be a flexible structure to accommodate current and future needs. A rooftop crop pilot study at Texas A&M on walls and roof deck highlights the varieties grown on top of a four-storey building. The diversity of activities taking place in Central Texas exhibits concepts transferable to many locations across the world. The challenges for these projects include adaptability of crops to the Central Texas climate, structural and community support and the presence of a viable market for locally grown produce.

Keywords: Architecture, Landscape Architecture, Design/Build, Interdisciplinary Learning, Rooftop Farming

1. Introduction

Urban agriculture exists in a variety of forms worldwide. There are various ways how the food is grown and sold. Production, for example, varies from large-scale plots on private or corporate property to small-scaled applications for private or public consumption. Crops are grown in urban areas for sales in local farmers markets, for private use, for restaurants or grown through community- or municipal-supported efforts. Distribution varies from private sales from the back of a truck roadside to public selling of food, crops and marketable goods in farmers markets or local stores. Urban agriculture exists on private and public land as well as on rooftops exposed to the elements or concealed in greenhouses. Urban agriculture exists as permanent ventures as well as temporary or seasonal events by small groups, organizations or private individuals. Urban agriculture has historically had strong ties to small-scale grassroots movements and ties to agrarian beginnings, but recently in North America and abroad, there is greater need for people living in cities to reconnect with nature, taste fresh seasonal produce, socialize and learn [1].

One unique example of a municipal level (top down) production of crops outside North America is the Edible City Project at the village of Andernach, Germany [2]. There, the public right-of-way is used in the town Center to grow fruits, vegetables, cut flowers and some produce such as fresh chicken eggs. Permaculture concepts are implemented to maximize healthy yields and reduce environmental risks. The yields are free to the public via self-picking, but programmed harvests are organized by local unemployed workers under the direction of a city program. There, the workers earn a minimum wage and learn marketable skills such as growing food, harvesting, selling and managing operations. The food is produced organically at a small scale in the city proper, but a larger permaculture farm exists outside the village to sustain greater quantities of produce for the local outlet. Proceeds go to reinvesting in the program. Seasonal crops and cut flowers are sold in the downtown market (**Figure 1**).

Figure 1. Local goods grown in the public right-of-way in Andernach, Germany, for sale in a downtown market (photo by B. Dvorak).

Across the United States, there are many examples of a variety of forms of urban agriculture including farmers markets, selling of local produce in commercial stores, co-ops and along roadsides in small-scale structures or the back of a truck. Urban agriculture in Texas exists in similar forms and is experiencing a rebirth. Texas' agricultural roots extend back to their formative years and are well known for its cattle and cotton. Urban centers were traditionally the life of this cultural exchange in the Public Square or market. Today, food in the United States is not centrally distributed in a city Center but is sold widely across supermarkets dispersed widespread across metro areas. The popularity and revival of famers markets suggest that citizens enjoy getting outside, visiting with local producers and learning about the current farming practices and supporting local producers.

The agricultural roots of Central Texas are found in the heart of the Brazos Valley. Brazos County, Texas, includes a population of over 200,000 and is named for the Brazos River, which forms its western border and forms the Brazos Valley. The significance of the river to Spanish explorers can be seen in its name *el Rio de los Brazos de Dios,* which translates to "the River of the Arms of God," which influenced the naming of the county to Brazos County. The river contains a very rich soil that it came just second place to soil from the Nile river in Egypt in an international competition about soil fertility [3]. The Brazos County was formed in 1841 and organized in 1843. Originally one of the state's poorer counties, in 1870 it donated 2416 acres of land to create Texas A&M University, which has since enabled the county to be among the state's most financially stable [4].

The authors, also faculty members at Texas A&M University's College of Architecture, have lead and directed numerous interdisciplinary learning initiatives that focused on urban agriculture. These initiatives investigated the role of both architecture and landscape architecture disciplines in activating real-life experimental projects that involved graduate and undergraduate students and collaborated with community members and local farmers. In this chapter, case studies are presented and discussed: a farmers market pavilion structure in the City of Bryan, Texas, and a rooftop and wall garden pilot project on campus.

The Central Texas case studies are designed and build — or currently under development — by students and faculty from Texas A&M University and in partnerships with real clients and government officials. Our inquiry stems from an interdisciplinary approach to collaborate, educate and disseminate knowledge to both college level students and our community citizens at large about urban agriculture and farming. The systematic approach of research and applications is correlated with the current industry trend of Integrated Project Delivery method (IPD) where group decision-making from both industry experts and design educators takes place in the early phases of the design process. Our research is experimental in its nature and requires testing of ideas through the physical realization of the proposed community projects.

2. Farmers markets

The U.S. Department of Agriculture estimates there are over 8100 farmers markets nationwide, a jump of almost 5000 from the previous decade [5]. The recent success in creating new businesses, increasing vendors and public partnerships was achieved in two recently built farmers markets in North America, one in Covington, Virginia, and the other in Bertie County, North Carolina. Both of these projects were surprisingly designed and built by students and architecture faculty members with community participation, and established the role of service learning initiatives that involve students to contribute to the public good and community development. These two case studies inspired us to lead the efforts for a third one in Central Texas by framing the opportunity for our students and integrating a unique learning experience to their design curriculum.

In this section, three case studies of pavilion type farmers markets are presented and discussed: Covington Farmers Market in Southwest Virginia, Bertie County Farmers Market in North Carolina and Bryan Urban Farmers Market in the Brazos Valley in Texas. All case studies are designed and build — or currently under development — by students and faculty and in partnerships with real clients and government officials.

The idea for this project was to design and build a pavilion type structure that can serve users beyond the selling and buying activities of a typical farmers market and that the building itself becomes a landmark of its community, demonstrating the power of architectural design, sustainability thinking and community partnership. The land and the structure would be paired together to propose a solution for multi-use development of the dedicated properties. At farmers markets, most produce vendors use simple, generic white canopies that need to be light-weight and portable, which also means that vendors have to get creative when they anchor them to the ground (no stakes allowed). Most vendors cannot afford a custom tent, so they are all white, with flimsy signage [6]. Often as is the situation in Bryan, Texas, a parking lot serves as a host site for farmers markets. Contemporary solutions such as the Lafayette Gardens in Detroit, Michigan, and others demonstrate that the integration of structures and site can make for dynamic relationships and activate the underutilized spaces. Our goal was to design and build a permanent pavilion structure as part of the ongoing community service design/build program offering high-impact design/build initiatives. We worked with the city of Bryan to secure a site in downtown to extend the development of the urban farming model. We have established connections with key players and closely worked with them and the city of Bryan to realize the project. The inquiry for students was to design and build a farmers market for the Bryan/College Station community. Students visited the current markets found on typical Google search and revisited the question of material sourcing and harvesting and tie that to their design proposal. Two major issues with farmers markets in the BCS area included parking for visitors and timing of operation. Some of the questions that students were challenged with were as follows:

- All goods sold at this market required to be produced within a 100-mile radius; could this distance become also a goal for the procurement of construction materials?

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- How does the building meet the sky and the ground? How does it meet the street and the landscape around it? Far and near?
- What role the building will play in the community when there is no buying and selling? What kind of night lighting conditions could make the building a lantern in the dark for example?

2.1. A unique community project collaboration

Since 1960, there has been no significant structure on site for a farmers market in the Brazos County, which constitutes Bryan and College Station area (**Figure 2**) [7]. In the spring of 2015, a group of second-year architecture students designed a farmers market for the BCS community. The students started by researching, learning and then evaluating the existing situation of the farmers and local markets to understand how and when vendors sell their produce. Making use of local material sourcing and harvesting was the approach integrated into their design proposal. The interdisciplinary approach of thinking was achieved by collaborating with landscape architecture, structural engineering and construction science students. The design proposal was developed, engineered, priced and prepared for construction by the end of fall 2016 and a full construction document set will be ready to build the market. Students will utilize the Architecture Fabrication Facility at their university to prefabricate the building's components, then transport and assemble them onsite. The site design and development took place during the 2015–2016 academic year.

Students had an in-depth hands-on rich learning experience, which is based on an active participation from students and peer-learning principals of funding, designing, engineering, management, fabrication, production planning and construction. The following case studies proved that the integrated experience is outstanding and students graduate with a rich understanding of interdisciplinary collaboration. Students will be able to understand the “value” that other disciplines bring to the teamwork and learn to think as collaborators. The project is an active and dynamic learning experience in planning, budgeting, scheduling, design, construction management and community engagement. A group of farmers were an integral part of that renewed discussions exploring possibilities for design and construction of a covered, multi-function pavilion in the vacant area north of downtown Bryan to be used for farmers' market, as well as other group activities. Students worked toward identifying design features that would be critical or desirable for vendors. Farmers' members participated with their input to the preliminary design process and attended design reviews with students. Community members believed that a covered and attractive pavilion for a farmers market could be a major asset in the continuing redevelopment of downtown Bryan, as well as encouraging a more robust farmers market culture in the community. The community surrounding Texas A&M campus could sustain the growth of the locally grown fresh-food movement that is second to none in Texas.

Figure 2. City of Bryan Original Farmers Market Circa 1931 (photo from Downtown Bryan Association).

2.2. Case studies: small farmers markets reshaping community development

2.2.1. Covington Farmers Market, Virginia

Covington is a small town in Southwest Virginia that shares similarities with other towns across the United States, especially with Bryan, Texas. The working-class heritage town was built on railroads and resource extraction activities surrounded by beautiful mountains as its backdrop. The farmers market was formed with no resources by a group of local farmers. They had been operating on an open parking lot for some time but lacked a shelter and the means to realize one. The small town was all of the sudden on the map of design magazines and national news when a student-led team built a small farmers market in downtown. The market has brought new life to downtown Covington, and has been featured by Architect Magazine and received awards from the Virginia Society of the American Institute of Architects and others [8].

Former students of Auburn University's Rural Studio, Keith and Marie Zawistowski, took their passion to Virginia Tech School of Architecture and Design. In their first design/build project, students were asked to design and build a farmers market in Covington, Virginia. After studying and researching existing markets through literature and site visits, each student developed an iterative for the project. After several rounds of extracting principals and converging ideas, students arrived at one scheme to build and it was through that collaborative design process that all students owned the design idea rather than the chosen scheme. The

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integrated nature of the design process insured a healthy development throughout the duration of the project and minimized conflicts between students [8].

The market, which opened in late May 2011, was conceived as three parts: Ground Plane, Occupied Space and Pavilion Roof (**Figure 3**). Offsite prefabrication was a key factor in dissecting the market into 10′ wide sections, which were put together at the fabrication facility of the university, then transported and assembled on site. The clarity of the project components gave much appreciation to the articulation of its architectural elements. The roof stands as the highlighted figure of the project with its sculptural form, the floor as a floating performance stage and the slender steel posts are carefully inserted in between the two planes and autonomously rising. The project was a yearlong process that focused on the research, development and implementation of innovative construction methods and architectural designs.

Figure 3. Covington Farmers Market, Virginia (used with permission).

2.2.2. Bertie County Farmers Market, North Carolina

Bertie County is a place dominated by rural poverty. It has a median household income of $31,194. Its school system is suffering from major issues: lack of interest from students, very low passing rates and young generation of low-wage workers and farmers who lost hope in education. Studio H worked with the school board members to introduce a new curriculum that empowered students by design education [9].

Figure 4. Bertie County Farmers Market, North Carolina (used with permission).

The Windsor Super Market is the only farmers market pavilion in the country designed and built entirely by high school students. The first Studio H project, by 13 high school juniors from Bertie County, North Carolina, constructed the 2000-square-foot structure. Our students spent two semesters and the following summer researching, prototyping, engineering and building the structure, as well as spearheading the launch of the local farmers market association in their hometown of 2000 people. The story of the Windsor Market is told in a documentary film, “If You Build It” [9].

The Windsor Market pavilion was featured in Architectural Record and on NPR’s The Story with Dick Gordon, and has created 2 new businesses and 15 new jobs since its opening in October 2011 (**Figure 4**). Students learned a wide range of design, drafting and building skills, applying them to a series of projects for their community. The Mayor gave the Project H students the key to the city — the second key to the city ever given out. The sense of pride that grew among the students spread to their families and out to the wider community. The school system in Bertie County is suffering from major issues; lack of interest from students, very low passing rates and young generation of low wage workers and farmers who lost hope in education. Studio H worked with the school board members to introduce a new curriculum that empower students by design education.

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2.2.3. Bryan Urban Farmers Market, Texas

Downtown Bryan is passionate about supporting and advancing commerce, culture and community. They actively work toward these goals through economic development, support of local art and culture and community engagement. This environment has created the perfect conditions for the proposed farmers market building by the College of Architecture at Texas A&M students, which will be the highlight of the initiative and will demonstrate the power of design to the larger public. The project will be the seed for future community engagements and interventions by the COA interdisciplinary design/build group. As the case with the previous case studies, jobs are expected to be generated as well as new businesses and cultural activities. The design of a covered, multi-function pavilion to be used for farmers' market, as well as other group activities, will provide permanent pavilion that is attractive for both vendors and shoppers.

Our students' design for the market was derived from the knowledge gained from the previous projects. Sourcing and tectonic details were at the forefront of conceptual design. A farmers market is a very humble entity that leaves much room for tectonic expression of simple construction methods. Essentially, the design derives from a tent and a system of modularity that simplifies the construction. The complete design of the farmer's market encompasses the entire site. The modular unit is designed for the farmer and the community. With a 15′.6″ × 16′.6″ base, the module allows for easy flow underneath and ample space to set up a booth in which to sell produce (**Figure 5**). Entirely constructed of true 2 × 6 cedar boards and custom steel plates, the module lends itself to ease of construction and deconstruction. The connections throughout the design echo the idea of creating connections within the community. Every wood member is connected to one another by a steel plate, emphasizing the actual structural connection itself well. Stretched over the top of this wood and steel frame is translucent polycarbonate layer. With a life span of over 50 years, the layer would be diffusing all direct sunlight and providing the maximum shade. With a clearance height of 10′, farmers are also able to drive their trucks within the structure to allow ease of accessibility in unloading and loading the produce.

The market is a community development project with a focus on green spaces. Incorporated into this site is our modular structure that offers a dynamic range of implementation whether it be a farmers market, concert, wedding or birthday party. Just being north of downtown Bryan, Texas, the area lends itself to both daytime and nighttime foot traffic. This will allow the market to be used almost the entire year, creating a constant income for the city. Located near shopping centers, the site will become a landmark and a central location for the public to reside in. The structure itself only covers 48% of the total square footage, allowing the other space to be used for green design such as planters or water recycling (**Figures 5** and **6**). We hope as well that the city of Bryan, Texas, is not the only community to utilize this module. Offering the kit of parts to other communities would allow a universal market structure to be built in a number of different orientations around the state.

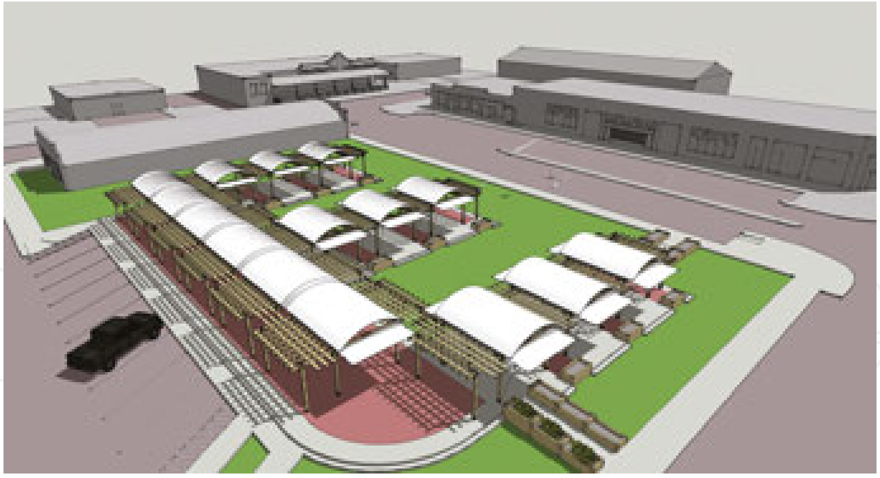

Figure 5. Bird's eye view of the proposed modular market.

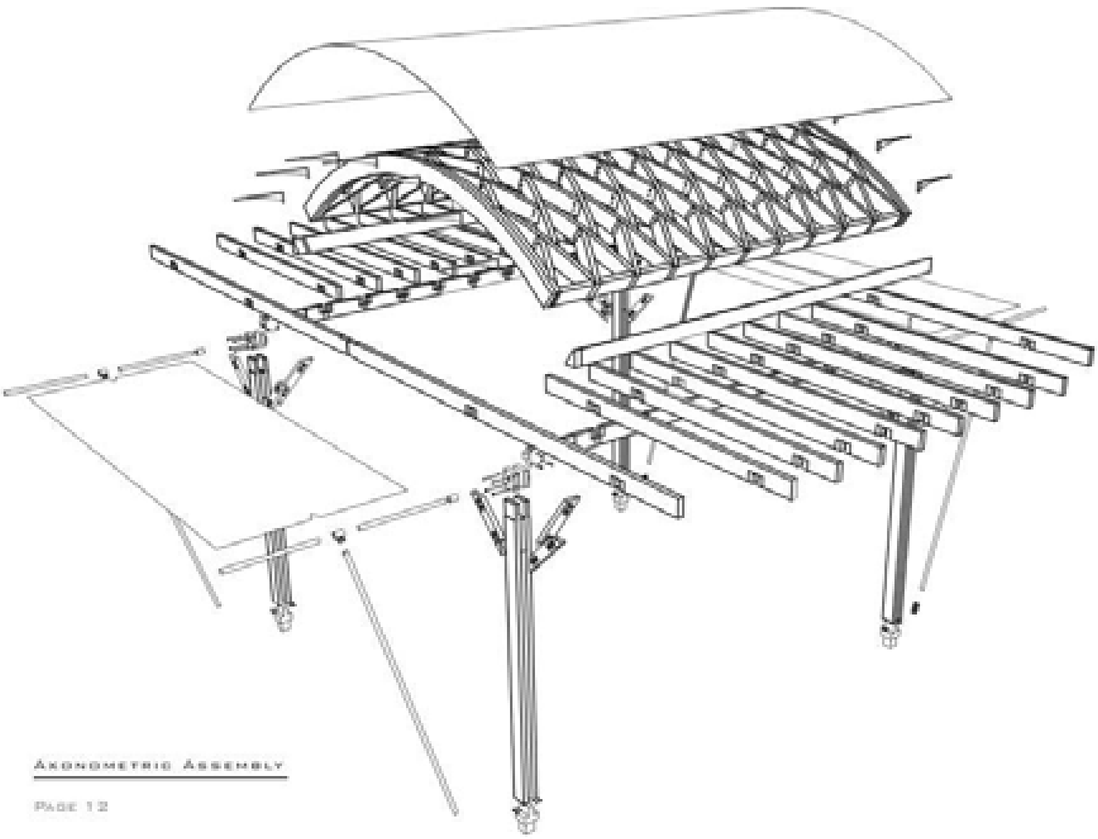

Figure 6. Assembly of the modular unit.

2.3. Conclusion

Urban farming or urban agriculture is quickly becoming an integral part of today's modern living, but what is the contribution of architecture and landscape design disciplines in that

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growth? Does “good design” play a role in activating a sense of “place-making” and enhancing the public perception? What schools of design and architecture in the higher education system can offer to enhance its learning environments that prepare future citizens as architects and designers?

On a larger scale, by framing the opportunity for design students to make a difference in their communities, they will learn the positive impact they can affect in the communities where they go to work. As a result, these projects will engage this community that plants the seeds for community engagement and improvement through design, in students who will work across the state, nationally and internationally. On a micro-scale, the projects will economically benefit the Brazos Valley by creating another reason to visit the downtown area to shop for fresh produce and learn more about sustainable and healthy living. It will benefit local farmers by creating a space for display, and promotion of their efforts to the public, that will serve to strengthen the value of healthy living in the community. It will benefit the local schools by providing a place where children can take field trips and be immersed in the urban agriculture through the display of wall gardens and through good design. There are doubtless many other specific beneficiaries that will be identified in the planning and programming that will occur.

Sustainable design is critically essential to sustainable living, as more people join the current movement who search for healthy and balanced living: urban agriculture can certainly benefit from good design and planning. We believe as design educators that we can make a difference in people’s life through good design. Just as one might enjoy a fresh ripe and organic sweet tomato after years of tasteless produce, the effects of good design on the place-making to serve the community is priceless.

3. Rooftop agriculture

3.1. Background

Green roofs are used in urban areas to mitigate detrimental effects of urbanization. Green roofs slow down and retain precipitation, mitigate rooftop temperatures, provide habitat for regional vegetation and wildlife, and extend the life cycle of roofing materials [10–14]. Rooftops can occupy up to 35% of built land in urban environments, therefore, judicious use of flat rooftops is warranted [15]. Rooftops then are valuable space in urban areas, especially where land costs are high and structural loads allow some rooftop greening. Green roofs offer unique opportunities for entrepreneurs to produce food crops in urban areas that often lack affordable space or open ground for production [16,17]. Interest in food crop production on rooftops is growing in various climates in the United States. Some argue that production of rooftop produce is essential for food security in metro areas to meet growing global populations [1,18]. There are several outstanding examples of food production on rooftops in the United States. In New York City for example, Leslie Adatto identified 10 exemplary and popular rooftop farms in the city. At the kitchen garden scale, the Crosby Street Hotel maintains a rooftop garden that produces food for a number of items on its restaurant menu. The garden grows blueberry bushes (producing up to 15 gallons of berries in July), heirloom tomatoes, rosemary, basil, arugula and edible flowers [19]. This garden exemplifies how a rooftop garden can complement a restaurant menu. Chicago, Boston and a number of cities in the United States have restaurants with rooftop produce served on the menu.

Large-scaled rooftop farms can and do make a much more visible and widespread impact. In Brooklyn, New York, for example, the Brooklyn Grange, a one-acre rooftop, hosts one of the largest and most active open sky rooftop agriculture production sites in the United States (**Figure 7**). A project brief here outlines some of the important components and functions of rooftop agriculture. The crops on the Brooklyn Grange include vegetables, herbs and cut flowers. Crops grow in raised mounds from 20 to 25 cm high. The soil is a manufactured growing medium supplied by Rooflite®. Irrigation is provided by drip lines watered daily for 30–40 min depending upon watering needs of plants and weather conditions. There are also a few chickens raised on the roof. Environmental concerns over growing plants and food production on rooftops are valid and can only be determined through individual research. The Brooklyn Grange site has been subject to a few studies and was determined to leach slightly high levels of pH, runoff that is more turbid than a comparison sedum green roof [1]. This

Figure 7. Brooklyn Grange rooftop crops and drip tube irrigation are shown in the foreground, with the New York City skyline in the background (photo by B. Dvorak).

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means that when it rains enough to generate runoff, the Brooklyn Grange roof may sometimes carry more effluent compared to the sedum roof. However, the sheer volume of stormwater retained likely outweighs the effect of occasional effluent. The roof absorbs more than a million gallons of storm water annually [19]. No urban heat island benefits or social benefits have been determined yet and would be needed to help gain a comprehensive view of environmental impacts of rooftop agriculture.

Rooftop agriculture will only maintain a presence well into the future if it is environmentally and economically sustainable. The Brooklyn Grange rooftop farm also engages the public and sustains social and cultural benefits and thus exemplifies the "Triple Bottom Line" [19,20]. The farm welcomes trainees to work on the farm and is open to visitors for self-guided tours. The roof is open to celebratory dinners for events and organizations. For example, the 2015 *Cities Alive* green roof annual conference hosted a guided tour and dinner serving a menu made from seasonal produce from the roof.

3.2. Case study of the Texas A&M University rooftop farm pilot study

Climates with long summers and mild winters have much potential to make use of rooftops to grow food; but little is known about which food crops grow on rooftops in these climates. This study investigated food crop varieties on a green roof and a living wall system for one growing season in Central Texas. The objective of this study was to evaluate the suitability of various crop species for agricultural production on extensive green roofs in Texas and to determine which species generated the greatest yield. Thirty-one crop varieties were investigated on eighty-one extensive modular green roofs. Plants were installed on the green roof and living wall during the fall of 2014 and spring of 2015 and harvested in spring and summer.

3.2.1. Green roof pilot study

The investigation site is located in College Station, Texas, on top of the Langford Building, a four-storey building at Texas A&M University (**Figure 8**). Crops tested on the green roof modules include arugula, basil, beets, broccoli, Chinese cabbage, chives, cilantro, garlic, kale, lettuce, mints, parsley, radish, shallots, spinach, strawberry, Swiss chard, thyme and turnips.

Crops were installed in eighty-one 4.5" deep modular irrigated green roof trays. The plastic trays were supplied by TectaAmerica (Corp, Skokie, IL) and each tray contained 3.5 inches of FLL compliant engineered soil used as the growing medium for extensive green roofs (Rooflite®drain, Skyland USA LLC). The trays included a non-woven geotextile used to retain moisture. Shallow retention cups used for drainage were filled with expanded shale and 12 holes located about 1 inch above the bottom of the drainage cups provide for excess water. The water holding capacity of the trays is about a 1 inch depth of rainfall. The irrigation was run about 20 min per day [20].

At the time of planting (October, 2014) the growing media was amended with 0.5 lbs of topsoil, and a half cup of Osmocote14-14-14. An additional quarter cup of Osmocote was added to each module January 30, 2015. Modules containing strawberry, lettuce, kale, spinach, broccoli, arugula and Swiss chard were fertilized using Peter's 20-20-20 fertilizer with micronutrients at a rate of one-third gallon per module and 1 teaspoon of Peter's per gallon water on March 6, 2015 [21].

Regarding the late winter early spring harvests, we found that the most productive survivors (80%+) include chives, cilantro, parsley, thyme and mint among the transplants. Among direct seeded crops, strong survivors include arugula, garlic, kale and shallots (**Table 1**).

Crop	*Variety*	*T/D*	*Percent survival*
Mint	Mojito	T	100
Mint	Peppermint	T	100
Mint	Spearmint	T	100
Thyme		T	100
Arugula		D	94
Shallots		D	93
Chives		T	92
Garlic		D	88
Kale	Beira, Red Russian, Toscano	D	86
Parsley		T	86
Beets		D	84
Strawberry	Various	T	81
Lettuce	Butterhead, Iceberg, Romaine	D	77
Broccoli		D	75
Cilantro	Chinese	T	75
Chinese cabbage		D	67
Swiss chard		D	67
Radish		D	55
Spinach	Emperor	D	53
Basil	Bell pepper	T	50
Turnips		D	9

Table 1. Percent plant survival on January 21, 2015. T = live transplant and D = direct seed.

Turnips had the least amount of production followed by spinach, radishes and basil. Many of the strawberry and mint plants died back shortly after transplanting, only to fully recover by mid-March. Strawberry plants had good survival; however, they did not produce much marketable biomass. Birds also found some of the fruits and thus the berries were not marketable. Among harvested plants, the leafy greens and parsleys were the most productive. Butterhead lettuce, romaine lettuce and Beira kale produced the greatest total amount of

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marketable biomass. Parsley was also a productive crop, and generated the most biomass per capita. Red Russian kale generated proportionally the most non-market biomass, as 72% of its biomass production was lost to aphids. While the lettuce varieties were nearly equal in terms of productivity, marketable biomass output was dominated by a single variety of each kale, parsley and spinach. Leafy greens, including lettuce and parsley and other herbs, were found to be viable [21].

Figure 8. The Texas A&M University green roof modules on the Langford Building with crop varieties shown here with about 3 months' growth (photo by B. Dvorak).

The crops planted late spring grew into the summer. Some of the highlights of the summer crops include several plants that had great survivability and production. Two mini-watermelons each produced one fruit of about 6 ounces each. The eight tomato plants produced about two to four tomatoes each plant, ranging from 2 to 4 ounces. Four yellow bell pepper plants produced about four small peppers each. Banana pepper plants were productive with plants producing two to five peppers each. The mint plants installed the previous fall continued growing through the summer and produced dense stands all summer. Eleven of twelve rosemary plants survived; however, they remained small.

3.2.1.1. Maintenance

Although plant survival was fair, production of fruits and harvestable material during the summer was not as productive as anticipated. Airborne weed seeds established on the green roof and competed aggressively for space. Several large garbage cans filled with weeds from the vegetable crops were hauled off the roof twice during the summer and once during the fall. Since another green roof on the same location was not regularly watered and had few to no weeds during the same time, it was presumed that the watering to maintain the crops also established and maintained weeds. We did not have weekly student activity during the summer, so maintenance was not consistent. A part-time staff working on the roof would have been very useful in keeping up with maintenance.

Daily watering of the roof was assumed to be a requirement for productivity, especially during July and August when temperatures approach 95°F and above daily, throughout the summer. The watering system was overhead spray irrigation. Since the pilot study had a large variety of plant species and varieties under the same watering treatment, some plants likely received more water than needed. We recommend future set ups to include segregating plants by water needs.

Pests affected some of the crops on the green roof. Snail shells were found on both the green roof crops and the living wall. Crop viability was influenced by position on the green roof (whether this is due to nutrient content, sunlight, irrigation, etc. should be further studied). Other crops and varieties appear indeterminate with the data at hand, and require further experimentation or harvesting to assess viability for green roof production.

3.2.2. Living walls

Seventeen crop varieties were investigated on a FloraFelt (fabric- and soil-based system) living wall (**Figure 9**). Drip irrigation was applied daily from the time of installation until early December, and from late January until the end of spring 2015, except during freezing temperatures. This system is designed to uses plants pregrown from nursery stock in containers (1 gallon size or less). Plant installation typically requires plants to be removed from containers and wrapped with a fabric blanket (FloraFelt® Root Wrap) and stuffed into a pocket of the preassembled panel. For the vegetable living wall project, some plants were purchased as small plants and then installed into a pre-existing media. Some plants were seeded. The prefabricated wall panels include a stiff backing (HDPE plastic) and a thick facade of felt. Felt is made from 100% PET recycled water bottles, is mildew and odor resistant and water absorbent. Drip irrigation tubing was supplied with each panel. Drip emitters flow a half gallon per hour and are spaced approximately three emitters per panel. Total irrigation for the wall was about 103 gallons per week during the growing season. Watering was shut off during times where overnight temperatures fell below freezing, about seven times.

Plant survival for the living wall was favorable; however, most plants were stunted and did not produce much harvestable material. Some of the successful crops include varieties of lettuce, garlic, kale, mint, peppermint, spearmint, spinach, shallots, strawberries and collards during early to middle spring; however, the irrigation system failed late spring and summer and the experiment ended. We learned that different varieties of a given crop may respond differently to the micro-climate conditions of the living wall. The water delivery system was not effective as we found that some portions of the wall remained dry and others were sufficient. Subsequently, after this study we removed the drip emitter watering system, which was out of alignment with the planting pockets, and replaced it with a soaker hose system for even distribution.

Figure 9. The living wall crops shown here after 3 months' growth. Plant survival was favorable; however, plants did not produce much fruit. Strawberry plants had high survival, but few to no berries were produced (photo by B. Dvorak).

3.3. Conclusion

This edible green roof and living wall pilot study demonstrates that some food crops may be adaptable to rooftop production in Central Texas for winter, spring and perhaps summer. Climate during the investigation was typical regarding temperature and precipitation and most plants fared well. The green roof had less competition from weeds during winter and early spring, but summer saw significant competition from weeds. We believe that such an operation demands a dedicated position to manage and maintain plants during production. Since we were not selling or distributing crops, we did not generate revenue to maintain such a position. The restaurant and large-scale case studies in New York and elsewhere had revenue to support full-time staff devoted to maintaining produce. We have plans to participate more actively with a local organic farm on campus called the Howdy Farm. We look to grow the edible rooftop projects with greater resources and participation. We believe these concepts are feasible and directly applicable to local outlets such as the Howdy Farm, farmers markets and or local production of food on campus.

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