INSERTION OF ‘GREEN WEBS’ – A HOLISTIC APPROACH TO URBAN TREE PLANTING IN DALLAS COUNTY, TEXAS

Niveditha Dasa Gangadhar

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By

NIVEDITHA DASA GANGADHAR

Presented to the Faculty of the Graduate School of

The University of Texas at Arlington in Partial Fulfillment

of the Requirements for the Degree of

MASTER OF LANDSCAPE ARCHITECTURE

THE UNIVERSITY OF TEXAS AT ARLINGTON

MAY 2020

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my committee chair Dr. Diane Jones Allen, and my committee members Prof. David Hopman and Dr. Amy Archambeau for all your guidance and encouragement throughout this journey.

Also, I would like to thank my family for their unwavering support and patience throughout this journey.

May 2020

ABSTRACT

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Niveditha Dasa Gangadhar, MLA

The University of Texas at Arlington, 2020

Supervising Professor(s): Diane Jones Allen

The urban space poses many challenges for the growth and survival of trees. The urban fabric is often knitted with concrete, stone, copper, and iron, in the form of sidewalks, parking lots, buildings, wires, and pipes, which displace elements of the natural environment. This has given rise to urban heat islands, polluted air, ineffective water management, and other social problems (Nowak et al., 2010). Currently, efforts are being made worldwide to bring back the natural environment through green infrastructure strategies.

Ecological inserts in the urban fabric called ‘Green Webs’ can provide environmental, economic, and social and ecological benefits. ‘Green Webs’ are networks of mature trees with interconnected root systems made possible via mycorrhizal fungal activity. The fungal networks facilitate transfer of nutrients among related trees (Grant, 2018), improve urban soil conditions, empower nature to self-heal, reduce local temperatures and storm water run-off, and consequently increase their carbon retention capacity. This study assessed the potential of connecting tree roots below ground by mycorrhizal networks for better functioning of the urban trees to enhance tree longevity, to gain environmental and ecological benefits, create a sense of place, and connect humans back to nature. By evaluating the current urban tree planting strategies in Dallas county, Texas, and exploring the science of tree connectedness by mycorrhizal networks through literature review, precedent studies and interviews, policy recommendations and Preliminary steps to facilitate 'Green Webs' in urban areas is provided.

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CHAPTER 1. INTRODUCTION

1.1 Overview

A revolution has been taking place in the scientific understanding of trees. Peter Wohlleben, a German forester, and the author was the first to convey the research about these natural wonders to the general public through his book "*The Hidden Life of Trees*". According to Wohlleben, all the trees within a forest are connected through underground fungal networks. The trees share water and nutrients through these networks. They also communicate by sending distress signals about drought and disease, and other trees receiving these messages alter their behavior accordingly. These underground networks, known to scientists as mycorrhizal networks, are comprised of fine, hair-like root tips of trees joined with microscopic fungal filaments. These basic links of the network facilitate a symbiotic relationship between trees and fungi.

For communicating through mycorrhizal networks, trees send chemical, hormonal, and electrical signals, which scientists are just starting to decipher. Edward Farmer at the University of Lausanne in Switzerland has been studying electrical pulses, and he has identified a voltage-based signaling system. Monica Gagliano at the University of Western Australia has gathered evidence of some plants emitting and detecting sounds like crackling noise in the roots at a frequency of 220 hertz, inaudible to humans. Also, at the University of British Columbia in Vancouver, a professor of forest ecology, Suzanne Simard and her graduate students are making astonishing discoveries about the sensitivity and interconnectedness of trees in the Pacific temperate rainforests of western North America. She is best known for her extensive research into mycorrhizal networks, and her identification of hyperlinked "hub trees" or "Mother trees" (Grant, 2018).

According to Simard, Mother trees are the oldest and biggest trees in the forest with the most fungal connections. With their deep roots, they draw up water and make it available to shallow-rooted seedlings. They help neighboring trees by sending them nutrients, and when the neighbors are struggling, mother trees detect their distress signals and increase the flow of nutrients accordingly (Grant, 2018).

1.2 Urban Trees

Urban areas lack in using trees as powerful tools to heal the environment. By the impacts of climate change, the urban forestry movement has been invigorated by massive city tree-planting campaigns. A million Trees initiatives have been launched in Los Angeles, Denver, Philadelphia, New York City, and many more cities. These initiatives are justified by models that estimate and monetize the environmental and socioeconomic benefits of trees (Seamans, 2013; Young, 2013). Realizing the ecosystem services through tree planting depends on tree survival. Despite the tree planting over the last few decades, it is found that the overall canopy cover levels in the U.S cities have been declining (Nowak & Greenfield, 2012). Tree planting and natural regeneration are insufficient to offset the current losses.

Achieving tree canopy goals solely by a mass planting of trees will not effectively help mitigate the impacts of climate change. Belowground and above-ground conditions, environmental and ecological factors and mortality rates need to be addressed while planting. Therefore, an approach that holistically addresses these factors is required to effectively improve the success rates of urban tree planting.

1.3 Research Objective

The purpose of this study is to assess the potential of using ‘Green Webs’ as a tool in the urban space of Dallas county for restoring natural ecosystems and building resilience against environmental degradation by:

1. **Assessing** the potential of connecting tree roots below ground for better functioning of the urban trees, by understanding the current urban tree planting strategies in Dallas county, Texas.

2. **Determining** how the science behind tree connectedness will contribute towards environmental, social, and economic benefits.

3. **Developing** policy and tree planting recommendations for Dallas county, Texas, for insertion of ‘Green Webs’.

4. **Providing Insights** to landscape architects to incorporate ‘Green Webs’ through Education and training, for better urban tree planting practices.

1.4 Research questions

- What are the urban planting and maintenance strategies that can be adopted to enhance and facilitate ‘Green Webs’ in Dallas County, Texas to restore natural ecosystems?

1.5 Definition of Terms

Mycorrhizal networks – According to Southworth et al., (2015), " Mycorrhizal network can be defined as a belowground system of interconnected hyphae and roots".

Urban Forestry – According to Nowak et al., (2010, p.4), **"**Management of urban trees and associated resources to sustain urban forest cover, health, and numerous socio economic, and ecosystem services is known as urban forestry".

Wood Wide Web - The interconnected web of organisms like fungi and bacteria which swap nutrients between soil and roots throughout the woods (Popkin, 2019).

For the purpose of this research,

Green Webs are networks of mature trees and plant communities in the urban environment with interconnected root systems made possible via mycorrhizal fungal activity.

CHAPTER 2. LITERATURE REVIEW

2.1 Urban Forests

Over the years, urbanization has resulted in the displacement of the natural environment. We have reached a point in time where there is a need to integrate the natural environment back into the built environment in order to restore natural ecosystems. In many countries around the world the importance of the natural ecology of urban forests is being realized. There are various projects aimed at preservation and restoration of natural ecosystems, ranging from elimination of invasive plants to reintroduction of original species and riparian ecosystems (Nowak et al., 2010; Elmqvist et al., 2015). About eighty percent of the population of the United States live in or near urban areas. The people in these urban spaces benefit from the urban forests around them. The urban trees influence urban quality of life by providing innumerable annual ecosystem services that affect both the local physical environment such as air and water quality, and social environment such as individual and community wellbeing. Some of the benefits are improvement of real estate and business, and wellbeing & public health. Tree canopy cover serves as measuring factor of critical services provided by urban trees to residents.
The amount of urban forest canopy cover varies across the cities in the United States, depending on the location and size of the city, population density, development intensity, and surrounding natural vegetative cover. Tree cover and density are typically greatest in parks, forests, and residential lands in urban areas (Nowak et al., 1996).

In the United States, the current urban tree cover pattern is a result of various physical and social forces that both limit and enhance canopy cover. In areas with low tree canopy cover, there are several opportunities to enhance the tree canopy cover. In most cases, maximum tree cover might not be optimal tree cover because optimal tree cover is based on mix of ecological, social and economic costs, community desires, and ecological, social and economic services provided by trees. Urban forests are exposed to wide range of natural and human caused challenges, all of which can be compounded by climate change. The proximity of the urban forests to relatively larger population of people and associated development can increase the complexity of the management challenges. Some of the challenges posed are by insects and diseases, invasive plants, additional development, wildfire, catastrophic events, air pollution, climate change, and many more. Knowledge of urban forest ecology and its conservation will be critical to developing appropriate management strategies to enhance optimal urban forest cover and to sustain urban forest health and benefits into the future (Nowak et al., 2010).

According to Hopman, (p. 224), “Trees are highly desirable for urbanizing areas of North Texas, a state that is warming faster than most in the United States. The average statewide 2.8 degree increase in summer temperatures from 1984–2014 is exacerbated by the growing urban heat islands that come with rapid growth. The many benefits of using trees to mitigate heat and a host of other environmental, aesthetic, and even sociological problems are well documented and continue to be extensively studied. Therefore, at the macro scale, a forest biome, with exceptions for sunny places, makes sense as an overall model for the cities of North Texas—despite their location in a former prairie. In North Texas, this means studying the mesic (moist) forests in the riparian corridors. This biome will have both canopy trees and shade tolerant understory plants that will be compatible with building shade, tree shade, and the frequently compromised subsurface drainage that is found in the small patches of soil in urbanizing areas”.

2.1.1 Building the Urban Forests

The definition of urban forest can vary between individuals based on their training, experience, and perception of opportunities for acting within the landscape. For some, urban forests are a collection of isolated trees within the urban fabric. Others may view it as an ecosystem including their dynamic relationships and interactions with biotic and abiotic factors. Forests have served as an inspiration, as a model, and as a tool for designers. Landscape architects have started to focus on trees to explore forest elements and ecological structure for their cultural value and productive function (Carlisle, Pevzner, & Piana, 2014). The wild plant communities serve as an inspiration to the designers. They are well adapted to the site, contain rich layers, and have a strong sense of harmony and place, and these qualities are highly desirable for designers (Rainer & West, 2015, p. 20).

According to Carlisle, et al. (2014), "Many design projects that engage the vocabulary of the urban forest, however, remain firmly rooted in the territory of metaphor, borrowing either the spatial qualities, the performative attributes, or the terminology of forests without attempting to actually create a functioning forest ecosystem."

In contemporary urbanism, the presence and performance of urban forests is one of the most pressing topics. A great many new ideas and techniques are emerging by increasing the number of projects focusing on shaping, managing, and advocating for a new generation of urban forests (Carlisle et al., 2014).

2.1.2 Restoration of Urban Forests

Urban forests are often managed as individual trees instead of whole forest ecosystems. Cities manage these tree species to meet many important needs such as energy conservation, beauty, and recreation in the city. But there are many opportunities for urban forest restoration to provide additional ecological benefits such as storm-water management, wildlife management, and biodiversity. Restoring the urban forest ecosystem is re-establishing the ecological health of the urban forest ecosystem. To return the urban forest to a form which is more ecologically sustainable for the community should be the goal of the restoration plan.

Urban parks are typically composed of trees and grass requiring intensive maintenance inputs such as fertilizing, irrigating, mowing, and raking. Restoring these parks by taking advantage of natural processes such as nutrient and water cycling will help in saving money, energy and resources for the community. There are several opportunities in the urban areas for restoration of ecosystems, including yards, vacant lots, shopping centers, schoolyards, parks, industrial parks, and waterways. The acts can include eliminating leaf-raking in a park to reestablish the natural forest floor and the natural cycling of nutrients, establishment of understory plant species in a schoolyard to promote wildlife, eradication of an invasive plant species which is eliminating much of the understory biodiversity in a park, re-design of a parking lot to decrease stormwater runoff and provide a small ecological wetland. The two key ingredients that make these projects so successful are the involvement of people from the community and the formulation of a restoration plan (Duryea, 2000).

The urban forest ecosystem is an open system with energy and materials constantly entering and exiting the system. Producers which are mainly green plants and consumers which are organisms dependent on living and dead plant and animal matter make up the living portion of all ecosystems which are linked together in complex networks called food webs. The urban forest ecosystem can provide many opportunities for ameliorating the drain and stress on our natural resources. For example, we are less dependent on outside natural resources for air conditioning by cooling the city with a forest canopy. When leaves, branches, and grass-clippings are left on-site instead of being removed, these natural materials sustain the natural nutrient cycle and provide the same benefits that we ascribe to mulches in gardens and landscapes. Urban forests can also help reduce atmospheric CO_2 build-up in two ways by reducing fossil fuel (energy) use and by increasing carbon storage (Duryea, Binelli, & Gholz, 2000).

2.1.2 Urban Tree Root Requirement

The limited root space available in planting pits in paved areas will ultimately limit the size and longevity of the tree (Fluckiger and Braun 1999). Average tree life expectancy in a side-walk tree pit can be as little as ten years (Kopinga 1991; Nowak et al. 2004). Crown spread and trunk diameter of trees growing in parking lots is reduced as surface area of non-paved surfaces is reduced (Grabosky & Gilman 2004). Ninety-six percent of parking lot trees with at least 28 m^3 of soil were in good condition, compared to only sixty percent in less than 14 m^3 of soil. However, over eighty percent of the trees had been planted in the last twelve years (Kent et al. 2006), and condition of trees is likely to deteriorate as the trees grow and reach the limits of even the most generous root space.

2.1.4 Roadblocks and Opportunities to improving urban forests

The ecosystem services provided by trees can be recognized as cultural (e.g., recreational, spiritual), provisioning (e.g., food, water, fiber), supporting (e.g., pollination), and regulating (e.g., climate and flood control). There are tree disservices that act as barriers to advance urban forests, and the disservices vary with culture, environment, and income. There are financial costs due to urban trees planting and management, injury to humans and infrastructure due to accidents, trapping of air pollutants under the canopy. There are also some social disservices caused by urban trees like generating allergens, obstructing views and passage, engendering crime or injury. There are environmental disservices caused by misuse of chemicals in tree maintenance, displacement of native species with exotic plantings. By associating urban forestry and ecological engineering, opportunities are provided to focus on building with nature to achieve self-designs that satisfy human needs and advance in ecosystem conservation. A field involving the entire community, urban forestry is a transdisciplinary field, with its members and their interactions contributing to the many unknowns in formulating holistic policy, science, and management for sustainable cities (Endreny, 2018).

2.2 The Miyawaki Method of building Forests

Akira Miyawaki is a world-renowned specialist in the restoration of natural vegetation on degraded soils. The goal of this Japanese botanist is to restore forests as they were at the origin of the world before human intervention. Due to depleted resources in highly urbanized areas, it is important to investigate natural methods of restoring natural vegetation on degraded soils. His method of planting is based on four main principles.

- **Selection of native species of the region** or finding the Potential Native Vegetation (PNV) of the region.
- **Random disposition of seeds**, which creates the complexity of a natural environment by competition between species, which accelerates vegetation cycles.
- **Soil fertilization** using organic materials like wood chips, humus, decomposed plants before planting young shoots.
- **Autonomy of obtained forests** where human intervention is not required for management of forests after two to three years (Lise, 2017).

With the current environmental problems, reforestation should take place at a faster rate because we live in a world where urbanization is developing rapidly. Ecological reforestation involves recovering topsoil and growing seedling in pots to get fully developed root systems from terminal vegetation in succession. Based on the system of ecological reforestation, he has proved through his research that multi-stratal quasi- natural forests can be built in the span of fifteen to twenty years in Japan, and forty to fifty years in Southeast Asia. He succeeded in the restoration of native forests from cold temperate to tropical zones (Miyawaki, 1999).

2.2.1 Ecotechnology and its vegetation - Ecological approach

According to (Miyawaki, 1998, p. 158), " Ecotechnology is a large field. It is vegetation-ecological approach is to build multi-layered greenery to meet the potential power of the area. The goal of the vegetation ecological approach is to create real green environments as the basis of human existence. Field surveys are fundamental to create Eco technologically sound environments. By recognizing the remaining native trees in the field, considering topography and comparing soil profiles, potential natural vegetation is identified. The main goal of ecotechnology is to use the concept of potential natural vegetation in building native forests with the functions of environmental protection and disaster prevention.

Many experiments were conducted in Japan and many other countries to test ecological reforestation based on potential natural vegetation. Since the 1980s, with the help of government agencies, environmental protection forests were built in 600 locations in Japan along highways, rivers, around harbors, dams, airports, new towns, shopping areas, schools, and houses. Seedlings were cultivated in pots until they grew up to thirty to fifty centimeter, and roots adequately developed. After three years of dense , mixed ecological planting and maintenance, human based management was not required, as nature began to manage itself. The forest reached 20 meters in height in 23 years of planting multistratal environmental protection forests in experimental areas of Japan. Also, a highlight was when an earthquake hit western Japan, elevated highways, railways and building of iron and cement were instantly destroyed. But none of the tree of the potential natural vegetation fell. It also helped in fire prevention and protected many roofs from collapsing. This tragic event proved the importance of native environmental protection forests which was also functioned as disaster-prevention forests by saving lives and property (Miyawaki, 1998).

Afforest is a service provider based in India, who have adopted the Miyawaki method of planting native forests. By adopting Miyawaki’s method, they have a six-step process in creating a native forest as seen in Figure 1.

Figure 1

Six step process adopted by Afforest

(source:https://www.dropbox.com/s/pgofw7noxmpfwxg/Miyawaki%20Methodology%20Explained.pdf?dl=0)

- **Step 1 – Soil survey**

This step includes soil analysis of the site to assess soil parameters like physical texture, organic carbon, nitrogen, soil pH, visible evidence of micro or macro fauna in the soil. This process helps in determining and quantifying material for soil nourishment. Examples include perforation material such as agricultural crop husk, water retention materials like coco peat, mulching material such as straw, and liquid and soil microbiology enhancers to increase beneficial bacteria and fungi.

- **Step 2 – Native species and Biomass survey**

They visit native forests to find potential natural vegetation and collate primary and secondary data to validate it. The quantitative and qualitative data of the species is collected to create species combination according to Miyawaki method. Each of the species is allocated to a different layer in the forest like Tree, Sub tree, Shrub, and Groundcover. This is followed by finding suppliers of healthy seedlings and ensuring genetic authenticity of the seedlings. Final quantity and order list is created to balance layers and combinations of major, supporting, and minor species.

For Biomass survey, appropriate suppliers are found to purchase soil nourishment materials. It is important to make sure that materials match the quality standards defined and ensure no adulteration of any form has been done.

- **Step 3 – Sapling procurement**

This step also involves finding suppliers and assessing quality at source to match the quality standards of the saplings. The root zones are assessed to ensure fully developed root zones along with healthy shoots.

- **Step 4 – Soil preparation**

This step includes enriching biomass mixture by using soil microbiology enhancers, and uniform mixing into soil up to depth of 1 meter and securing and finishing of the mound.

- **Step 5 – Plantation**

The species are planted based on the layers as per instructions by experts. Each of the sapling is staked by using appropriate materials and the forest floor is mulched as per standards.

- **Step 6 – Maintenance and Monitoring**

Site specific maintenance is accounted for and materials are added or replaced as per project needs. (*Afforestt*, Miyawaki method of forest creation).

2.3 Mycorrhizal Networks

Formation of mycorrhizal networks are influenced by factors such as soil fertility, resource availability, host or myco-symbiont genotype, disturbance, and seasonal variation (Simard et al., 2012).

2.3.1 Existence of Mycorrhizal Networks

Evidence that mycorrhizal fungal mycelia can link plants together in a network, and how the mycorrhizal network (MN) can facilitate fungal colonization or interplant transfer of compounds has intrigued scientists for decades (Leake, Johnson, Donnelly, Muckle, Boddy, & Read, 2004; Selosse, Richard, He, & Simard, 2006; van der Heijden & Horton, 2009). Mycorrhizal Networks have been shown to facilitate the establishment, growth, and survival rates of individual plants in a wide range of ecosystems (Horton, Bruns, & Parker, 1999; Dickie, Guza, Krazewski, & Reich, 2004; Teste, Simard, Durall, Guy, Jones, & Schoonmaker, 2009; Song, Zeng, Xu, Li, Shen, & Yihdego, 2010). With an ecological perspective, it is increasingly realized that MNs are important in carbon (C), nutrient and water cycling (Eason, Newman, & Chuba, 1991; Treseder, 2004; Allen, 2007).

Perhaps the single most compelling attribute of MNs is their potential to act as belowground avenues for the transfer of carbon (C) and nutrients among plants within a community. A hyphal path for transfer of resources among plants and trees protects important resources from competition with soil microbes, fauna, chemical adsorption of nutrients to soil particles or physical disturbances of the soil structure (Newman, 1988; Philip, Simard, & Jones, 2010).

The degree to which Mycorrhizal networks are formed between fungi and plants is context dependent. According to Simard et al., (2012),"The colonization patterns of networking mycorrhizal fungi are influenced by the availability of an alternate host, host plant stress and Carbon (C) allocation patterns, plant and fungal genotype, interactions with other mycorrhizal species and soil microbes , and environmental factors."

2.3.2 Mechanism of Mycorrhizal Networks

Mycorrhizal fungi are necessary for ecosystem functioning and the survival of plants. About 80 - 90% of all plant life is believed to engage with at least one of the seven types of mycorrhizae. The most important forms of mycorrhizae in the urban setting are the arbuscular mycorrhizae (AM) and ectomycorrhizae (EM) because of their prominence on many economically important garden and landscape plants and known benefits to their related plant hosts.

The mycorrhizal fungi colonize the roots of an appropriate host plant and develops threads of fungal material or hyphae into the surrounding soil. This increases the absorption rate of the root systems, access to water and limiting nutrients such as phosphorous and nitrogen. The nutrients and the water are transported through the hyphal networks into the roots, where they are exchanged with sugars produced by the plants through photosynthesis. The plant derived sugars are essential for the survival of the mycorrhizal fungi. This beneficial interaction helps plants establish in resource poor areas and helps to improve the ability of the host plant to compete with various soil microbes. Plants associated with mycorrhizal fungi typically have increased growth, productivity, nutrient status, and high survival rates when compared to non-mycorrhizal plants (Kleczewski, Lewandowski, & Bonello, 2016).

An ecologist, Thomas Crowther, mapped global distribution of trees in 2015 and reported that Earth has about three trillion trees. He gathered inventory data of the trees starting in 2012, from government agencies and individual scientists who had identified trees and measured their sizes around the world. Being inspired by the mapping of trees, a biologist from Stanford university, Kabir Pay, suggested mapping the web of underground organisms that connects forest trees. The researchers wrote a computer algorithm to identify the correlations between the ectomycorrhizae and arbuscular mycorrhizae associated trees in Crowther's database and local environmental factors such as temperature, precipitation, soil chemistry, and topography. The correlations found by the algorithm were used to predict what kinds of fungi would live in places where no data had been collected, including much of Africa and Asia (Popkin, 2019).

2.3.3 Benefits of Mycorrhizal networks

It is important to include mycorrhizae in growing practices as these symbiotic organisms play a crucial role in building a healthy ecosystem for the plant community within the growing media, the rhizosphere. According to research, diversity of mycorrhizae in plant's root system is important, as different species provide different benefits under variable circumstances. Some are better at assisting nutrient uptake, while others assist the plants with water efficiency, mitigating toxins from reaching the plant's vascular system.

In the symbiotic relationship of mycorrhizae, most of the absorbing area is fungal hyphae. Hyphae are finer and thinner than root hairs and able to penetrate the tiniest pores and fissures in the soil. The numbers of hyphae on a root system can be prodigious. A teaspoon of healthy soil can carry up to several miles of fungal hyphae. In agricultural land, the soil often contains a broad range of nutrients, but their availability may be limited to the crops. According to research, mycorrhizae play an important role in mobilizing phosphorus, nitrogen, zinc, iron, calcium, magnesium, manganese, sulfur and other tightly bound soil nutrients by enzymatic release and transport them back to the plant. Mycorrhizal fungi also play a major role in a plant's natural defense against root diseases such as phytophthora, fusarium, phythium, and rhizoctonia. Research studies on mycorrhizal fungi have documented that they defend root systems by forming a physical barrier prevent invasion by soil pathogens (*Australian Farm Journal*, 2011).

2.3.4 Types of Mycorrhizal networks

Ectomycorrhizae is the most well known as the fungal mycelia and easily visible on the roots. Characteristic fruiting bodies develop in the growing medium or above the ground. There are two types of ectomycorrhizal injections. One is vegetative injection which contain strands of mycelia and it is usually incorporated in the growing medium prior to sowing seeds. Second is spore inoculum (injection), which has an extended shelf life as it can remain dormant for an extended period. They can be introduced to the growing medium through water after the plant is established. Arbuscular mycorrhizae are often unrecognized because of internal root structures and therefore not visible to the naked eye and fruiting bodies are not produced. (Amaranthus, Simpson, & Landis, 2009). The spores are relatively large, and both soilborne and waterborne. This slows down the re-colonization processes in areas with soil erosion, disturbance, and loss of vegetation (Perry & Amaranthus, 1997; Reeves, Wagner, Moorman, & Kiel, 1979).

2.4 Plant populations with varied size and age structures

For greater resilience and broader ecological function, ecological landscapes should aim to develop populations with varied size and age structures. Genetic diversity helps in facing environmental pressures and provides basis for beneficial evolution of that population. Variation in age and structure promote resilience of that plant population in the face of insect pests and disturbance. Urban forests are one place in the built environment where size structure can be discerned (Beck, 2013).

In 2001, city of Syracuse, New York, an urban forest masterplan was published based on a comprehensive assessment of the city's existing urban forest. It was found that more than half of the city's trees had a DBH (Diameter at Breast Height) of six inches or less. The data represented a young population of trees with poorly developed size distribution. It also reported that trees with DBHs of thirty-three inches or more remove about fifty times more airborne pollutants and seventy times more carbon per year compared to trees with DBHs less than three inches. Trees with different sizes react differently to pests, droughts, storms, reducing the potential for catastrophic losses (Beck, 2013).

2.5 Mimic the structure of natural communities while substituting

Moving away from natural models will result in conflicts with environmental suitability, processes of plant establishment, and competitive relationships, which will require external maintenance rather than being able to function by themselves. In the philosophy of 'Forest gardening', the demonstrated functionality is preserved, while allowing more design freedom by keeping structural component of the native community but substituting individual species. These gardens are a collection of useful shrubs, trees, vines and herbaceous plants which provide food, fiber, and medicine for their caretakers (Jackie & Toensmeier, 2005).

2.6 Creation of Ecosystems

The built landscapes comprise of physical and biological components known as hardscape and softscape. The hardscape is designed to respond to the programmatic needs, and plants are placed in the remaining spaces, making planting an afterthought. When the physical environment does suit the ecological components, it should be taken care, for example by irrigation, fertilizations, etc. (Beck, 2013)

According to Stankey, Clark, & Bormann, (2005), " A promising approach to managing complex systems, about which we may have only an incomplete understanding, is adaptive management." Adaptive management is a four-step process. First steps involves integrating experience and existing information to propose approaches that are possible to solve a management problem. Second, one or more of the approaches are tested in a rigorous manner. The outcomes are evaluated, and the next round of actions are planned based on evaluations (Beck, 2013).

2.7 Impact of trees on Health and Social well-being

Trees and green spaces are known for reducing negative thoughts, reduced symptoms of depression, increased life satisfaction, and better reported moods (Berman et al., 2012; Bratman, Hamilton, Hahn, Daily, & Gross, 2015; Li, Deal, Zhou, Slavenas, & Sullivan, 2018; Lohr & Pearson-Mims, 2006; Mayer, Frantz, Bruehlman-Senecal, & Dolliver, 2009; Taylor, Wheeler, White, Economou, & Osborne, 2015; White, Alcock, Wheeler, & Depledge, 2013). A view of trees and greenery out of a hospital window can help patients recover (Ulrich, 1984), and there are lesser cardio-metabolic conditions in communities lined with trees (Kardan et al., 2015). Studies have shown that view of trees from school classroom windows can improve concentration levels (Li & Sullivan, 2016). The presence of trees encourages physical activity which the very act of planting and caring for tree promotes mental and physical health. Trees bring communities together and make them more livable. Well maintained trees and plant communities can improve the ecology of the communities, reduce violence, aggression in households, and limit criminal activity.(Turner-Skoff & Cavender, 2019). A study showed, by the loss of ash trees which was due to emerald ash borer in Cincinnati there was increase in crime (Kondo, Han, Donovan, MacDonald, 2017). Regardless of the perception that trees increase crime in some areas, evidence indicates that trees make communities feel safer (Kuo, Bacaicoa, & Sullivan, 1998). Also, research shows when green spaces do not comprise of trees or dense vegetation, it has negative impacts on people (Kuo, Browning, Sachdeva, et al., 2018; Kweon et al., 2017; Matsuoka, 2010; Reid, Clougherty, Shmool, & Kubzansky, 2017).

2.8 Trees bring meaning to space

Urban trees are valuable elements in creating exterior spaces in urban areas. Trees can act physical tools to transfer meaning and can be placed to evoke emotions through psychological channels. Trees can be arranged to evoke feelings through psychological channels. A well-cared group of trees refer to a clean and nurtured urban environment, and then the arrangement, sizes or sounds of trees may evoke deeper emotions. Although trees make unique contributions to urban areas, they are perceived with a narrow frame in urban planning and design (Cihanger, 2013). The trees can help create meaningful urban places apart from their practical benefits. Recent studies emphasize the psychological benefits of trees in cities (Nadel, & Oberlander, 1977). According to some scholars, psychological ties and special bonds between people and trees are essential in people's lives (Sommer, 2003; Arnold, 1993).

According to Arnold (1993, p. 7), "There is little or no evidence that tree planting was a deliberate design consideration in planning the geometry of any districts of our cities. Rather it is apparent that trees were used to fill in the left-over spaces that resulted from building and circulation demand which shows spaces are usually not planned for trees." Similarly, a statement by Nadel et al., (1977, p. 32) states that "Trees planted in leftover spaces or at corners of buildings, their presence is afterthought. The planting of trees should always be integrated with design, from the original drawing to the final construction." Trees in cities not only provide environmental and ecological benefits, but also suggest feelings of freedom, sense of belonging, comfort, peace and serenity (Nadel et al, 1977; Ulrich, 1991).

Table 1

Trees bring meaning to space

Components of Experience of Place	Connecting Places and Trees	Characteristics of Trees
MEANING	Religious, cultural, historical meanings Positive Psychological Impacts	Symbolic Values Psychological Effects
ACTIVITY	Aesthetics, Climatic Comfort	Physical Characteristics: Height, Changing Colors, Providing Shade and Coolness etc.
FORM	Urban Design Interventions	Location of The Tree within the Urban Fabric

(source: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.632.9931&rep=rep1&type=pdf)

2.9 The state of Urban Forests of Dallas

The Texas Tree Foundation (TTF), has launched several major tree initiatives in Dallas over the years to preserve, beautify and expand parks and other public natural green spaces, to beautify the public streets, boulevards and rights-of-way by planting trees and encouraging others to do the same through educational programs. Over the past six years, Texas Trees Foundation, in partnership with the City of Dallas, has compiled data from four studies with a goal of understanding Dallas' urban forest structure, function and value.

According to State of the Dallas Urban Forest by Texas Tree Foundation, there are nearly 1.8 million potential tree planting sites throughout Dallas and over 35% of the surface area in Dallas is covered with impervious surface such as buildings, cement, roads, and parking lots. In Dallas, over 25% of the surface area is covered in irrigated turf. The city's average tree canopy is 29% and the area south of I-30 represents 37% of the total tree canopy. The Great Trinity Forest accounts for nearly 20% of all tree benefits and covers one-sixth of the total area. (Texas Tree Foundation, 2015).

The urban tree canopy (UTC) is the layer of leaves, branches, and stems of trees that cover the ground when viewed from above. Researchers estimate that tree canopy cover in urban and metropolitan areas across the U.S. averages 27% and 33%, respectively. Additionally, trees are subject to a wide variety of stressors, which significantly shortens their lifespan. The i-Tree Eco Study revealed that Dallas' urban forest has 14.7 million trees with a UTC of 29%. This equates to 62.4 trees per acre. However, like many urban cities, Dallas' trees are not evenly distributed throughout the city. Nearly half of all trees are in the Great Trinity Forest: 46% of the entire canopy. The remaining 54% of the canopy is heavily concentrated in areas zoned for residential and park land. Some commercially zoned parcels in Dallas have a UTC of less than

5%. With such a large portion of the city's tree canopy focused in specifically zoned areas, it is important for Dallas to take steps to protect and enhance the urban forests by setting canopy goals. There is a strong correlation between land use and canopy cover.

The diversity of a forest is measured by the number of different species found in an area. High species diversity is characteristic of a healthy functional forest. An increase in tree diversity can contribute in minimizing destruction by a species-specific insect or disease. Native plants can be at risk if the exotic species out-compete and displace native plants. The Foundation's study identified 80 different tree species, 60% of which are native to the North Central Texas region, while 27% of the population would be considered exotic. The study revealed that of the 14.7 million trees in Dallas, 61% have a diameter of less than 6 inches, while less than 15% have a diameter more than 12–inches. The relative size of trees provides important information about region's forest. Out of 61% of the tree population that are less than 6-inches DBH, only 20% are species that will grow into quality, large trees at maturity.

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon a tree can sequester, and store is increased with the size and health of the tree. Young, healthy trees sequester carbon at a much higher rate than older more mature trees, but large trees store significantly more carbon. For example, Live Oak represents 2% of the total tree population but accounts for 8% of the total carbon stored.

With a canopy cover of 29%, Dallas' urban forest seems adequate compared to other urban centers. However, there is a large discrepancy within various regions of the City where canopy cover ranges from 7% to 60%. The greatest threat to the existing canopy continues to be the land development process. To ensure Dallas' urban forest will benefit future generations, long-range policies and programs for maintaining and expanding tree cover must be developed.

Increase in tree canopy can be achieved by large-scale tree planting initiatives, improved landscape requirements and maintenance standards. Expanded species selection, updated landscape requirements, maintenance requirements, and cost should be included in long term strategic planning (Texas Tree Foundation, 2015).

2.10 Urban Transportation infrastructure

The transportation infrastructure in Texas becomes a major part of urban spaces spanning great distances. The intersections can sometimes be sparsely planted, or they can be formally landscaped with turf grass, tree and shrub beds, which can be irrigated or non-irrigated (Texas Department of Transportation, 2018). Even after addressing policy of maintaining 30 feet of mowed area for the shoulders and considering right of way and sight lines, the spaces adjacent to the freeways and interchanges are spotted unutilized. Interchanges occupy deceptively large land areas. The bridges, along with their approach embankments, dominate the visual field. When aesthetic design is given some attention, the appearance of interchanges can be enhanced.

Because of the sinuous architectural qualities of interchanges, they tend to be the primary focus of landscape and aesthetics design concerns. There are several good reasons for this:

- Because of the structures and landforms involved, interchanges have a high level of visual interest.
- Interchanges mark entrances to adjacent communities and business properties and therefore strongly influence first impressions of that community.

- Because traffic is slower in the entrance and exit ramps of the interchange, architectural detail is more visible and more aesthetically important.
- TxDOT has full control over the design of the interchange.
- Interchanges are usually associated with freeways in heavily urbanized areas. Because of their size they dominate the visual landscape even in areas with large buildings.
- Planting is most effective in areas of low slope. Planting on the slopes is difficult to maintain and will shade out grass cover, which leads to erosion.
- Planting is most effective when placed in the driver's line of sight and where the background is either sky or light-colored structures.

(Texas Department of Transportation, 2017).

2.11 Summary of Literature Review

In summary, with many major planting campaigns, it becomes important to understand survival rates of the trees, number of trees reaching mature size at which their environmental and socioeconomic benefits are maximum, implications of future tree death for managing the urban forests, in terms of tree removal and replacement. In order to reap the benefits of urban tree planting programs, the trees have to survive, thrive, and grow, within the context of an existing urban forest population of varying ages. Planting a few hundred trees, or even a million, does not automatically translate into an increase in the overall tree population over the long-term. To increase population levels, the survival and planting rates have to out-weigh losses from tree death and removal, including both old and young individuals. The survival and planting rates have to out-weigh losses from tree death and removal to increase population levels of trees.

Managing towards a canopy cover goal necessitates consideration of urban tree population cycles: planting, growth, removal, and replacement (Roman, 2014).

According to Roman, (2014, p.6). "Collaboration between researchers, arborists, urban forest managers, planners, and designers will be essential to produce longitudinal urban tree data, analyze that data with appropriate tools, and connect research results to practice".

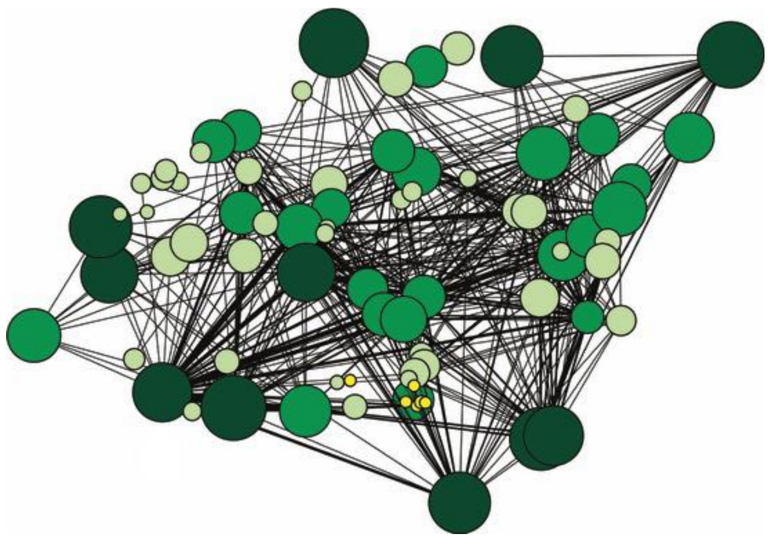
2.12 Precedent studies

2.12.1 Mycorrhizal networks of Douglas-fir Forests, North America

The distribution of Douglas-fir trees in Western North America is being impacted by climate change and disappearing from the grassland interface in the southern interior of British Columbia. This shift has been caused due to the practice of clear-cutting. This harvesting practice aims at reducing competitive effects of residual mature trees on new regeneration, but in doing so, it ignores its facilitative effects. The study demonstrated that access to a mycorrhizal network (MN) and proximity to trees have important influences on seedling performance. On six sites, they established trenched plots around 24 mature Pseudotsuga menziesii var. glauca (Douglas-fir) trees, then planted Douglas-fir seedlings into four mesh treatments that served to restrict MN access or into impermeable bags (grown in isolation) at four distances (0.5, 1.0, 2.5, or 5.0 m). Seedling survival tended to be greater and water stress lower where seedlings had full access to the MN. Seedling height, shoot biomass, needle biomass, and nutrient uptake peaked at 2.5-5.0 m from mature trees. Seedlings 0.5 m from mature trees had lower CO2 assimilation rates and compared to seedlings 5.0 m away. Competition for soil resources was highest near mature trees but facilitation was relatively greater at further distances, resulting in a zone of net benefit for seedlings. These results show that intraspecific tree-seedling interactions are both competitive and facilitative in dry Douglas-fir forests, and that they are spatially dependent (Teste, & Simard, 2008).

Figure 2

Image result of hub tree mapping. Dark green nodes are hub trees with a maximum number of mycorrhizal networks.



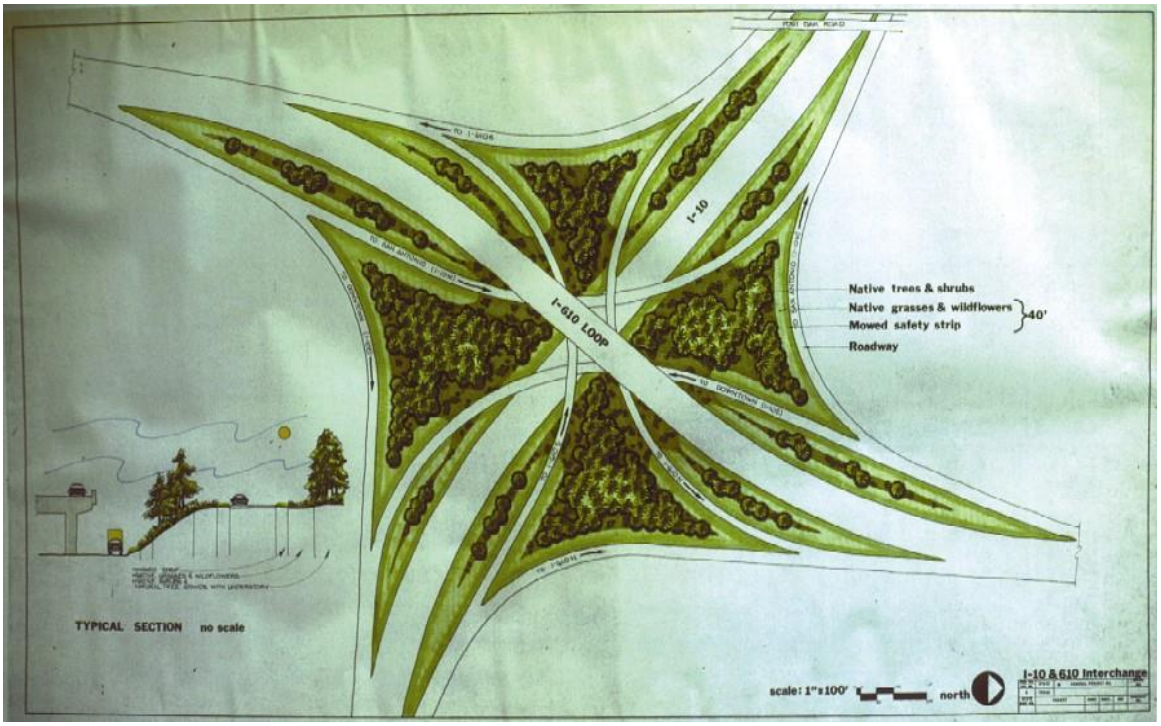
(source: https://e360.yale.edu/features/exploring_how_and_why_trees_talk_to_each_other)

2.12.2 Green Ribbon project, Houston

The Texas Department of Transportation (TxDOT) has launched a district-wide effort to meld modern-day mobility and aesthetic principles and restore some of the area's natural beauty along Houston's roadways, including US 290. TxDOT implemented a program designed to transform some of these concrete-dominated landscapes into ribbons of green. This program, a corridor aesthetics and landscape master plan, was created with input from a special committee, consultant team and the general public. The master plan is now known as the Green Ribbon Project (Texas Department of Transportation).

Figure 3

Urban intersection, Houston District.



(source: http://onlinemanuals.txdot.gov/txdotmanuals/veg/special_mowing_situations.htm)

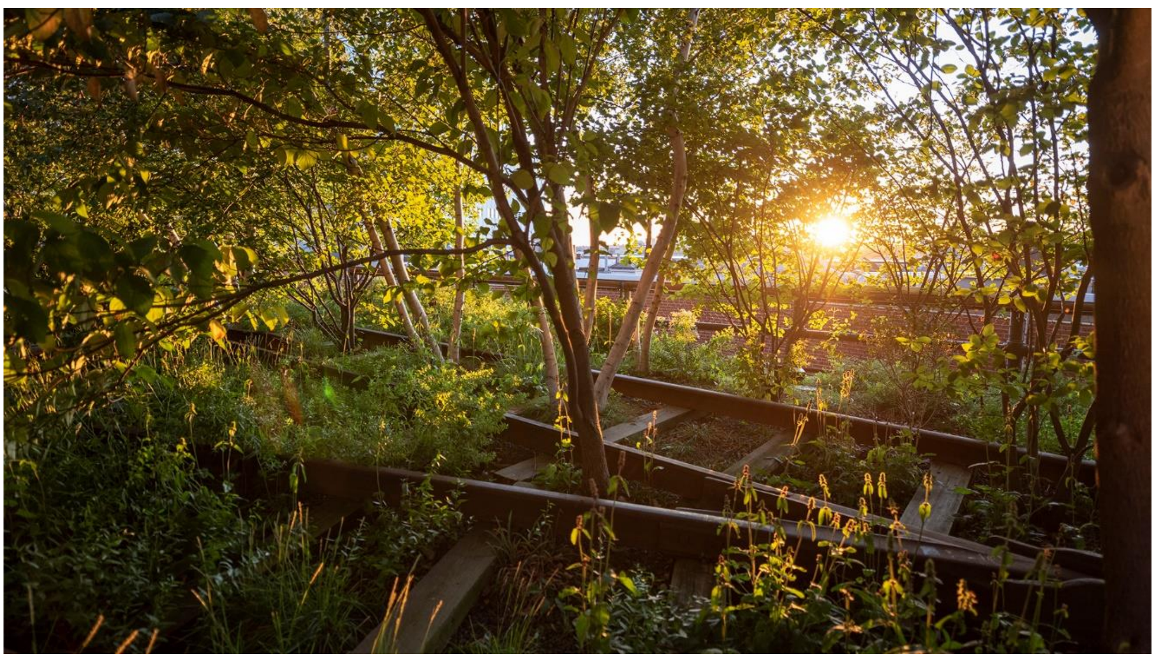
2.12.3 New York Highline project

The Highline was the former West Side industrial railway, and an open competition was held in 2003 to convert the existing 1.45 mile long elevated, steel structure into a public park. The park gives an opportunity to experience an elevated space amidst the chaotic urban area with uninterrupted views of Hudson River. The landscape was inspired by the wild seeded landscape left after the line was abandoned. The 1.45 mile is digitized into discrete units of paving and planting into variety of gradients from 100% paving to 100% softscapes with richly vegetated biotopes (Cilento, 2009).

The horticulturists believe that letting the gardens in rest will allow native songbirds to congregate, monarch butterflies to flutter, and pollination by bees. The gardens are purposefully allowed to rest to restore fertility which helps in repopulating with beneficial insects, and other organisms to thrive in the urban landscape. The Highline gardens were designed to mimic the natural ecosystems as mentioned by the Director of Horticulture for Highline. The sustainable approach to designing skylines used native plant species which were drought tolerant and needed low maintenance. All the garden waste from the site is converted to compost, reducing the amount of material into the waste stream (*High line*).

Figure 4

Highline, New York



(source:https://www.thehighline.org/blog/2020/04/01/high-line-wallpapers-for-video-calls/)

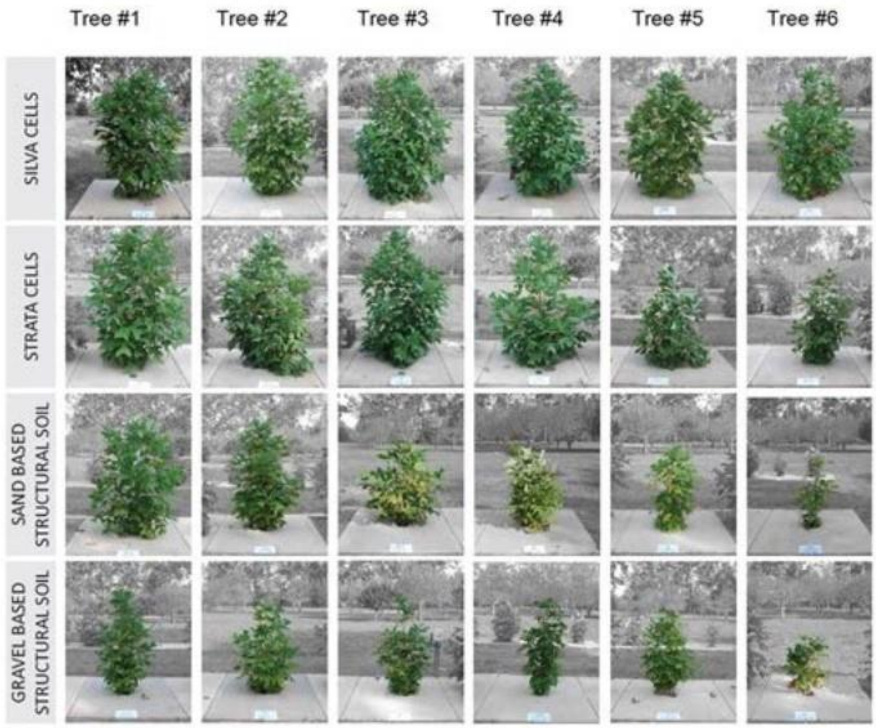
2.12.4 Bartlett Lab Field Trials

In 2005, Dr. Tom Smiley with Bartlett Tree Laboratories began examining different design approaches for creating rooting spaces under paving. The purpose of the study was to test the effectiveness of different load bearing soil options for better tree growth. Six different treatments were installed. They were Soil mix compacted to 80% Proctor, soil mix compacted to 95% Proctor, Silva cells with soil mix compacted to 80% Proctor, Strata cells with soil density not tested, Sand Based Structural Soil (SBSS) compacted to 96% Proctor, and Structural soil compacted to 95% Proctor.

Tulip poplar trees (*Liriodendron tulipifera*) were planted in 90-foot plot which simulated a sidewalk and trench was lined with fabric to contain roots within the specific growing conditions. All the trees were given the same treatments. The preliminary study results showed significant performance by Silva cells showing the most consistent response and confirmed that trees grow best in loamy soils with intact structure and rooting areas which open vertically and horizontally. Each of the growing conditions were replicated six times to assess the response.

Figure 5

Six trees replicated in different growing conditions

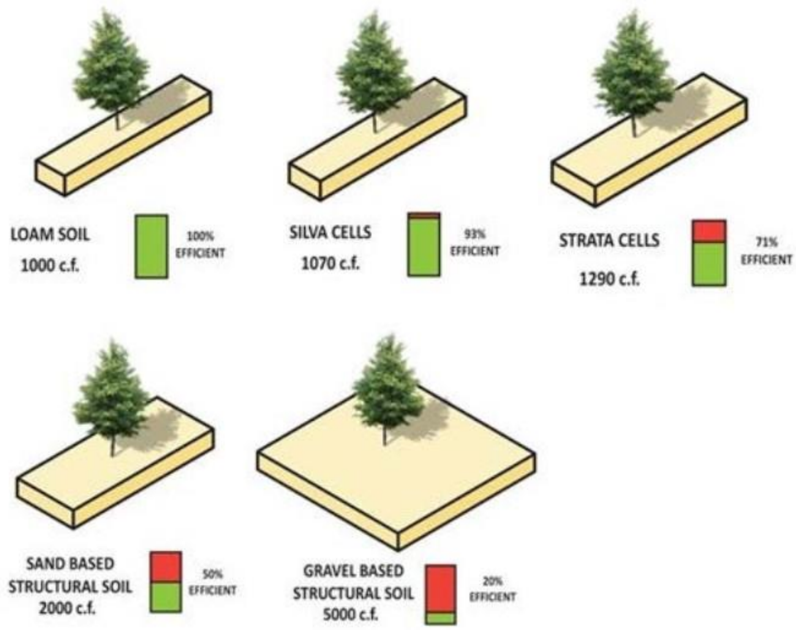


(source: https://www.deeproot.com/blog/blog-entries/which-planting-solution-is-best-bartlett-lab-field-trials)

The net soil delivered by each of the treatments were substantially varying. The condition in which the tree was growing best suggested that soil volume calculations should always be based on efficiency of the soil rather than area, volume or amount of the product as shown below (Deep Root infrastructure, *News Feed*).

Figure 6

Tree Growth efficiency based on soil



(source: https://www.deeproot.com/blog/blog-entries/which-planting-solution-is-best-bartlett-lab-field-trials)

2.13 Summary of Precedent studies

The precedent studies provided insights of getting inspired by wild landscapes to achieve sustainable designs and use transportation infrastructure which occupy large portions of urban areas to accommodate urban trees. The on ground scientific studies helped in understanding the role of soil health and influence of Mycorrhizal networks for better tree functioning, which should be helpful in the emergence of new planting strategies in urban areas.

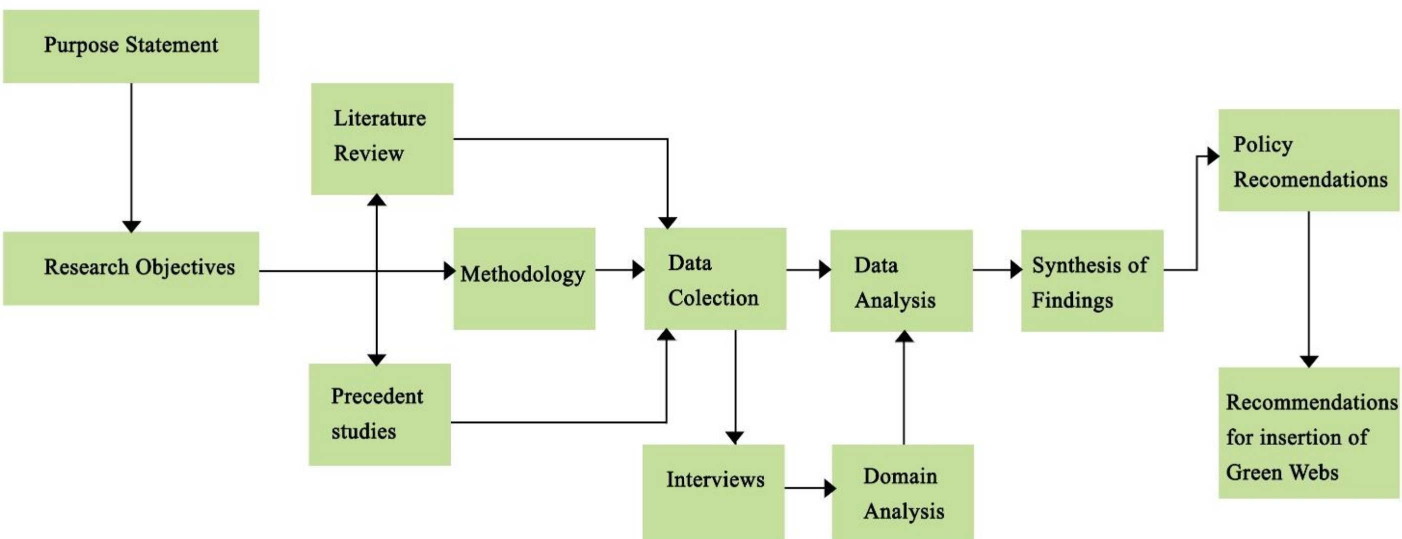
CHAPTER 3. METHODOLOGY

3.1 Introduction

This study will be carried out in a five-step process. The five-steps include: (1) Literature review; (2) Precedent studies; (3) Interviews; (4) Domain Analysis and Findings, and (5) Policy Recommendations.

Figure 7

Research Methodology Diagram.



3.2 Literature Review

This thesis reviews literature on topics that recognizes urban tree planting problems and contributes in building the concept of 'Green Webs'. They include the urban forests, its restoration, opportunities, and benefits. It reviews the science of tree connectedness and studies about the mycorrhizal networks, its existence, mechanism, and benefits. It identifies the methods which use soil microbes to quickly grow urban forests called Miyawaki method, and it emphasizes on how inspiration can be drawn from the naturally occurring plant communities.

3.3 Precedent studies

Precedent studies help in understanding the science behind tree connectedness through on ground experiments. Projects which aimed at utilization of urban infrastructure for tree planting were recognized in terms of promoting understanding the impact of wild plant communities in an urban scale. Planting design related studies are also explored to understand best practices for improving tree growth and survival in urban areas.

3.4 Interviews

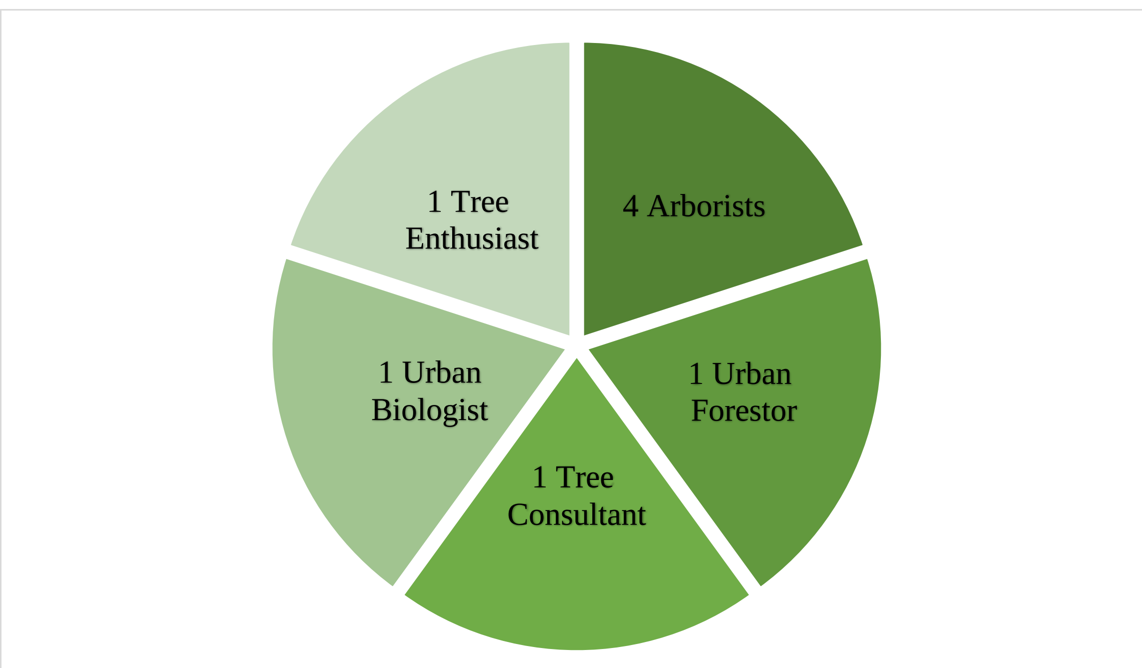
The primary goal of this study is to implement ‘Green Webs’ in the urban areas of Dallas county. Therefore, interviews were conducted to understand current planting strategies, urban planting problems, local ecology, soil suitability and professional’s opinion on tree connectedness and mycorrhizal networks. The list of interview questions was approved by the Institutional Review Board (IRB). Potential interview participants were selected based on their professional expertise in urban tree planting practices of Dallas County. The list of interview questions was sent to each potential informant with a request to schedule a telephone interview or respond to the interview questions electronically and return them by email.

3.5 Interview participants

Ten participants were chosen for their professional experience in science, design, and management of urban trees in Dallas county. Initially members of Texas Tree Foundation were approached, as literature review mentions most of Tree planting activities and research that was conducted by them. Their initial responses expressed their concerns about busy schedules, and with time they were not able to respond even after several follow ups. The researcher approached a mycologist to get his views on application of mycorrhizal fungi in urban tree planting, and the request was denied. So, as a result the focus for identifying potential informants changed to contacting professionals who work in fields which involve urban trees of Dallas county. Researcher approached four arborists, one urban forester, one urban biologist, one tree consultant, and a tree enthusiast who also had professional history in landscape architecture and worked for Dallas County. All of them responded. The interview sample was consisted of eight interview informants consisting of four certified arborists, one urban forester, one tree consultant, one tree enthusiast, and one urban biologist. All participants in the study will remain anonymous.

Figure 8

Sample of interview informants by profession



3.6 Data collection

The interview questions were formulated for each of the professionals with the majority of questions remaining the same across all informants, except for two or three additions or deletions based on their profession ,i.e., Arborist, Urban Forester, Tree consultant, and Tree enthusiast. The idea of interviews was to:

1) Understand the **health of urban trees of Dallas county**
2) Identify **urban tree planting problems**
3) Learn about **practices that facilitate tree connectedness**
4) Gauge expert's **awareness on Mycorrhizal Networks.**

   The interview questions were sent out to each of the participant with consent documentation attached through university email. Participants were given an option to schedule a phone interview or submit answers to the interview questions electronically. All participants opted to answer electronically, except for one which was through a phone call. Data captured was digitally saved and the unedited interview transcripts were compiled for analysis. The questions are included in the Appendix A.

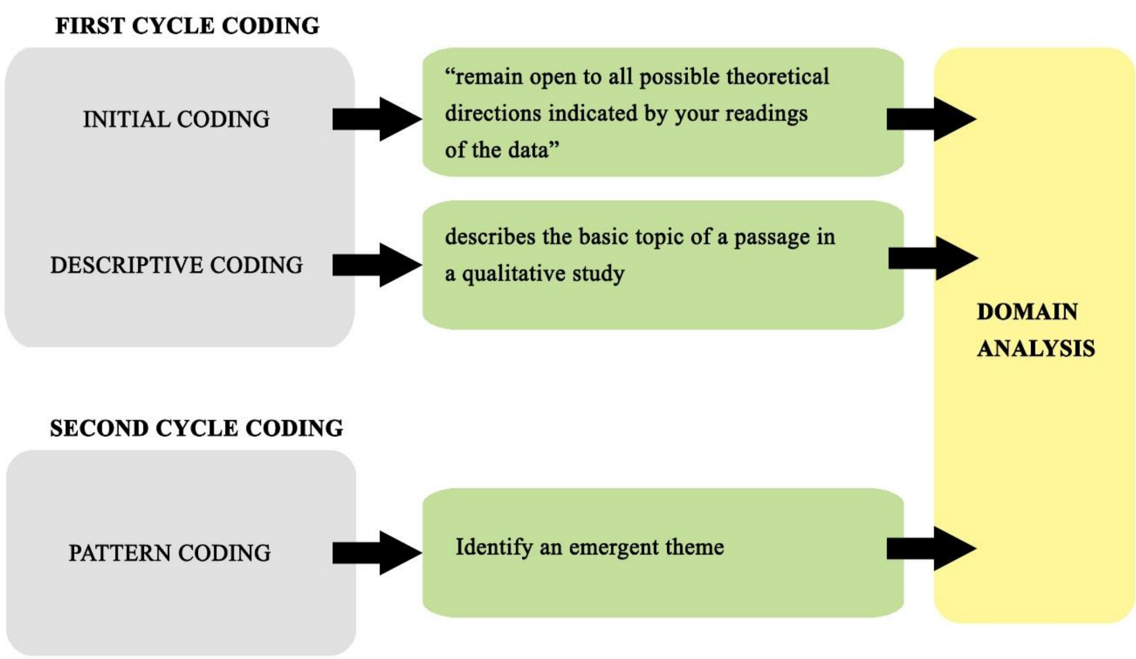
3.7 Domain Analysis and Findings

Prior to Domain Analysis, interview data was coded. It was coded using first cycle and second cycle coding methods using Saldana's Coding manual. The first cycle included initial coding and descriptive coding. The goal of initial coding is to "remain open to all possible theoretical directions indicated by your readings of the data" (Charmaz, 2006, p.46). The similarities and differences in the data are compared in this method by breaking down the qualitative data into discrete parts and closely examining them (Strauss & Corbin, 1998, p.102).

The second round of descriptive coding was conducted which describes the basic topic of a passage in a qualitative study (Saldana,2009). In second cycle coding, pattern coding was used to identify the emergent themes. Pattern codes are “explanatory or inferential codes, ones that identify an emergent theme, configuration, or explanation. They pull together a great deal of material into a more meaningful and parsimonious unit of analysis. They are a sort of meta-code. … Pattern Coding is a way of grouping those summaries into a smaller number of sets, themes, or constructs” (Miles & Huberman, 1994, p. 69).The outputs of coding were organized using the online subscription software from https:/www.dedoose.com.This software is used for “analyzing qualitative and mixed methods research data, including text, photos, audio, videos, and spreadsheet data” (Home, Dedoose). The coded data was analyzed by the Domain Analysis method described by Atkinson & Haj (1996).

Figure 9

First cycle and Second cycle coding process.



3.8 Policy Recommendations

The findings from the literature review, precedent studies, and interview data helped in formulating recommendations for policy and urban tree planting practices for insertion of ‘Green Webs’ in an urban area.

3.9 Research Limitations

The main limitation of the research is that the concept of ‘Green Webs’ has not been tested by a modelling software, which requires other experts to achieve validated results. Additionally, there was a specific lack of response from experts who participate in research of mycorrhizal fungi. Also, this research does not address equity as an issue in implementing ‘Green Webs’ in the urban fabric of Dallas.

CHAPTER 4. ANALYSIS AND FINDINGS

4.1 Introduction

This chapter describes the analysis of eight interviews. The findings from the interviews were organized into the four main intentions of the interview which are to:

1) Understand the **health of urban trees of Dallas county**
2) Identify **urban tree planting problems**
3) Learn about **practices that facilitate tree connectedness**
4) Gauge experts' **Awareness on Mycorrhizal Networks.**

Domain analysis was performed using the four-step process outlined by Atkinson & Haj (1996):

1) Identify the domains
2) Construct a taxonomy of sub-categories
3) Specify the components
4) Relate the domains

4.2 Domain Analysis of Interview data

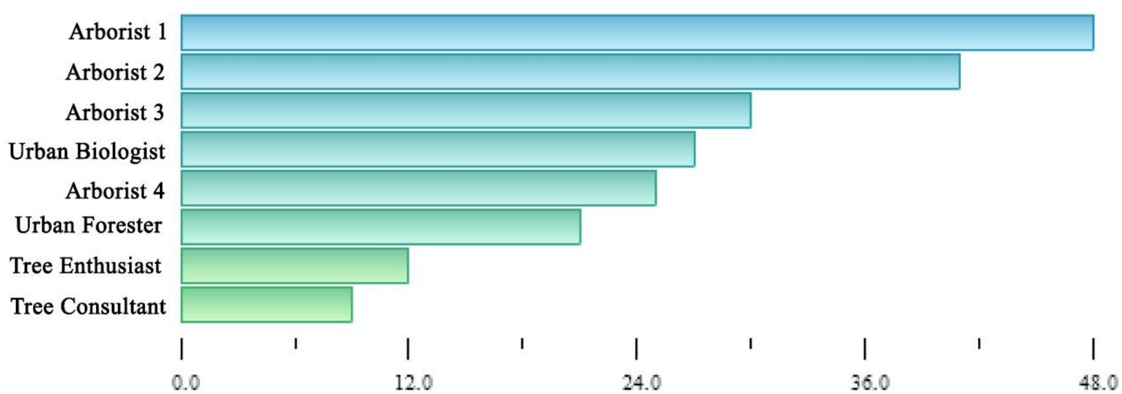
4.2.1 Initial analysis of interview data

During the initial phase of identifying interview informants, a mycologist denied the request for interviewing, expressing concerns about conflict of interests. It was clear that the mycologist was disinterested in application of mycorrhizal fungi in urban areas. Only three arborists and the urban biologist were aware of the existence and benefits of mycorrhizal fungi in soil. The others expressed lack of knowledge but were curious to learn about it. All professionals discussed problems related to planting strategies in urban conditions and gave suggestions based on their experience in the field. The arborists and urban biologist had the best knowledge to provide insights about urban planting in Dallas county. Only one of the arborists had a disagreement on the idea of connecting tree pits, and the reason given was not clear and instead suggested to provide better spacing for trees to reach their maturity. All professionals followed the standards mentioned in code for tree planting, and some expressed dissatisfaction with the standards.

The first cycle of coding, the initial coding of the raw transcript data using software, gave rise to many topics, and the arborists' transcripts had the highest number of coding inputs, and tree consultant had the least number of inputs as shown in Figure 10.

Figure 10

Histogram of number of coding inputs for each interview



After initial coding, a second round of descriptive coding was done to promote understanding of the data. The codes derived from initial coding were subcategorized under codes from descriptive coding.

The descriptive coding also helped in measuring the most repeated and commonly used topics across all the interview scripts. Figure 11 is a graphic representation of the relative frequency of topics mentioned. The frequency of the topics in the interviews is depicted by the scale (font size and weight) of the lettering. The topics with largest fonts represent the most repeated topics in the interview transcripts, and vice versa.

Figure 11

Image representing the frequency of topics mentioned in the transcript.

The first cycle coding resulted in identification of Preliminary list of Topics from the interview data.

Table 2

Preliminary List of Topics Identified from Interview Data

Preliminary List of Topics
Tree Canopy - Current tree percentage, desired tree percentage, canopy estimation
Tree Lifespan - Average life span, stress, soil and climate adaptation, invasives, over/under watering, depth of planting, soil nutrients
Urban soils - Suitability, drainage, soil health, natives soil type, removal of organic layer, adaptation to harsh conditions, history of soils, regulations, plant type, promotion of biological activity
Potential tree planting spaces - Low income neighborhoods, schools, parks, churches, older commercial properties, medians, creeks, perimeter of open spaces, parkways, trinity floodplain, shading concrete, placement of trees, underground utilities, infrastructure damage, floodway restrictions, developer decisions, multi-layer plant community, plant community structure, calculation of tree age and condition inventory
Ecology - Lack of ecological considerations, sick tree issues, maintenance issues, aesthetics over ecology, need for education and training, call for collaboration, multi-layered plant community
Tree Connectedness - Role of mature tree, use of understory trees, storm protection, shading of young trees and sun sensitive plants, approved techniques, avenues for sharing, lack of knowledge, better tree survival rates, post planting maintenance, fast growth of seedlings, mature trees are expensive, distance from pavement, appropriate plant groups, connecting green and river drainage
Mycorrhizal networks - Specific location, soil suitability, benefit, inoculation, cost, lack of knowledge, loss of organic horizons, amended soils, promotion of soil micro-organisms, functioning soil web
Planting methods - Code requirements, infrastructure conflicts, tree pit sizes, soil volume, plant selection, plant placement, mulching, lack of knowledge, Silva ells, maintenance, education and training, deep root fertilization, organic fertilizers, improve nursery standards, involve certified arborists

4.2.2 Identifying the domains

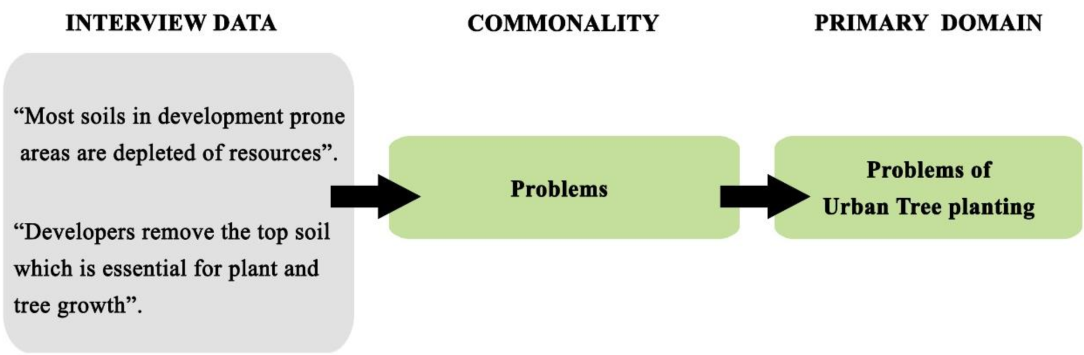
This step requires the researcher to identify the primary domains which recur in the interview discourse. The idea is to identify the concerns of the informants rather than any researcher's pre-defined categories on the part of researcher (Atkinson & Haj, 1996).

A second cycle of coding known as pattern coding was done to identify the primary domains. Pattern coding was utilized to categorize the interview data based on commonalities within the data. Several ideas were brainstormed to categorize the commonalities.

Figure 12 is a graphic representation example of how sample data from the interviews was recognized as a planting problem. In the same way, primary domains are recognized by finding patterns in all interview transcripts.

Figure 12

Second cycle of coding examples: How interview data commonalities led to identification of the primary domain "Problems of Urban Tree Planting."



Primary domains recognized from the second coding cycle were:

1) Urban tree planting practices
2) Problems of urban tree planting
3) Restoration of natural ecosystems in urban spaces
4) Future action

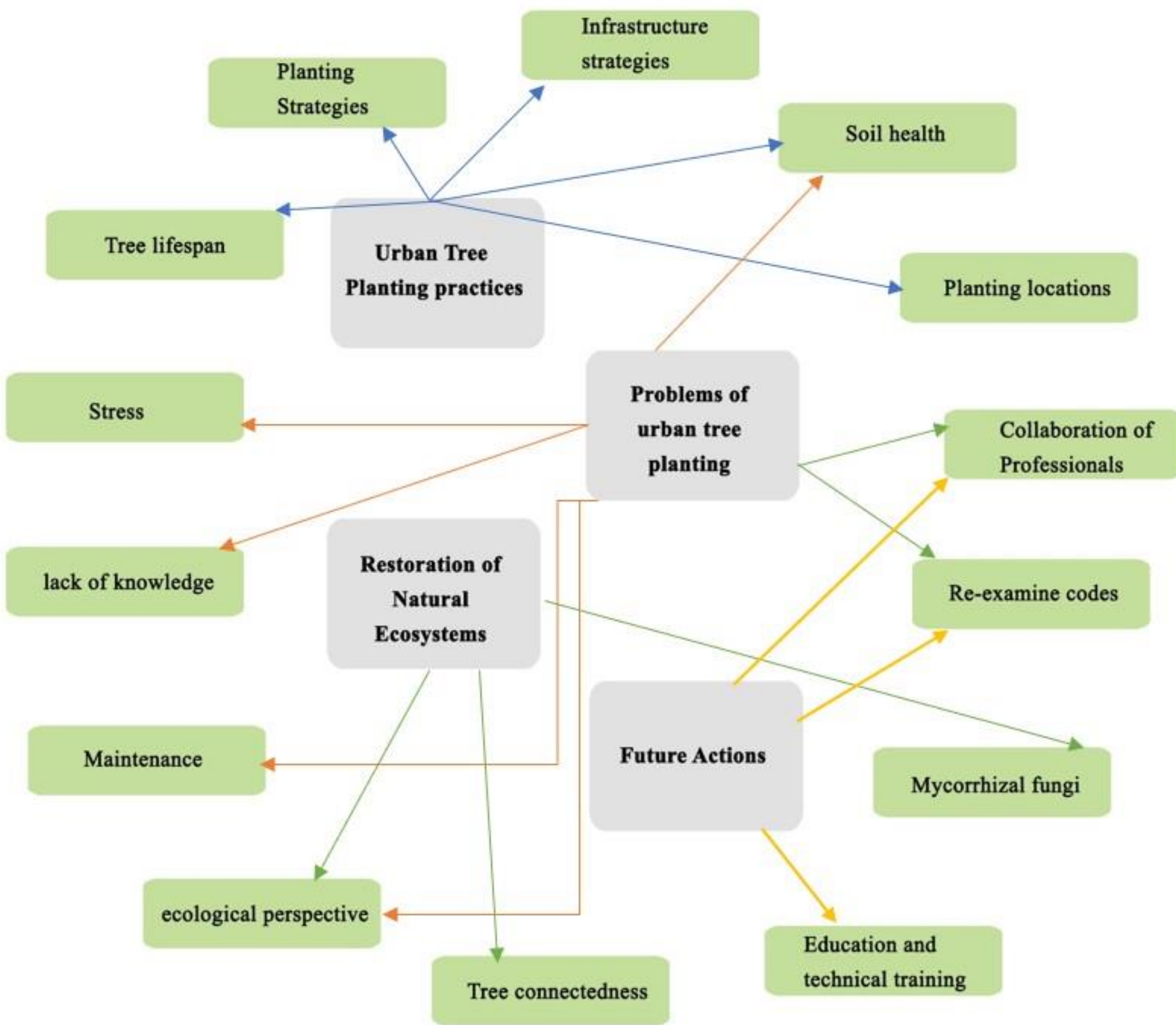
4.2.2 Constructing a taxonomy of sub-categories

The subcategories were recognized by arranging actual text from interviews into the primary domains (Atkinson & Haj, 1996). Most of the subcategories recognized belonged to more than one domain which indicated that domains overlapped or were inter-related.

For example, soil health falls under two domains, Urban tree planting practices and Problems of urban tree planting. Figure 13 is a diagram created to represent the sub-categories and their relationships to primary domains.

Figure 13

Taxonomic Analysis of Primary Domains



4.2.3 Findings - Specifying the components

In this section, the domains were placed into the four data categories that had been identified as the basis for design of the interview questions.

4.2.3.1 Narrative synthesis of obtained interview data based on preliminary categories of interview questions (see 3.6 Data collection)

- **Health of urban forests of Dallas**

Some of the major themes that surfaced concerning the health of the Dallas's urban forest are its tree lifespan, tree canopy percentage, factors for tree decline, soil health, and infrastructure conflicts contributing to negative impacts on urban trees. According to the professionals, the average lifespan of urban trees of Dallas in general is around 25 to 30 years and street trees are around 7 to 10 years, and tree canopy percentage is 29%, which is not distributed equally throughout Dallas. Due to their experience in the field, they claim urban trees experience more stress than trees in nature, and that shortens their lifespan. Urban environmental effects, invasive plant competition, social misunderstanding of how to protect and maintain trees, all are factors that may lead to a decline of the urban trees in Dallas.

The native soil is a nutrient rich clay soil that has poor drainage because of the tight poor spaces. An arborist summarizes the soils of Dallas areas as, " In north Dallas, the soil is black clay that is higher in alkalinity. South Dallas has the same soil with shallow rock in many areas. The far west side of Dallas has sandy soil that is more acidic. Soils in the inner city and urban areas lack the organic material and biological activity to support long lived plants and trees. " Most soils in development prone areas are depleted of resources, and developers remove the top soil which is essential for plant and tree growth. Therefore, the trees in new development struggle to get established or die because of the stress of poor soil. There is a need for new regulations that require developers to return the topsoil after storm water management infrastructure is installed.

- **Urban tree planting problems**

All professionals expressed several urban tree planting problems in terms of planting techniques, code requirements, absence of topsoil, maintenance issues, lack of technical knowledge, and ecological consideration in urban planting. An arborist said, “The problem is with construction practices. They scrape off all the hummus/organic matter and most times fill back with dirt rather than ‘good stuff’. Healthy soils = healthy trees. If you want healthy trees, you’ve got to get the soils back to a minimum what was native before construction transpired. This rarely happens in my experience.” The suitability of urban soils for planting trees in Dallas is low and in some areas of Dallas County one just hits rock.

Main problems include discovery of underground utilities, locating away from overhead and underground utilities, unknown ability of person planting and selecting the location of the tree, and, providing maintenance to the tree after planting is also too often overlooked and underprepared in Dallas.

Most of the professionals expressed their concerns about the health of urban soils. The Urban soils have been disturbed at some point and therefore will have less nutrients than rural soils. The tree survival and growth rates are also affected by using poor nursery stock and/or not properly inspected prior to tree planting. In terms of maintenance, plants are over or under irrigated, especially during summer due to lack of technical knowledge. In the urban environment there is always lack of space to grow with poor soil health and quality.

According to an Urban Biologist, the major planting problem is “outside groups eyeballing “open space” that would be “good” for trees. That often ends up being the neighborhood play space, or prairie/grass remnants.” The planted trees need initial support and are never taken out at a later point which hinders the growth of the plant and leads to girdling of tree roots. Most of the time, they are planted too low in the ground, and wire is not removed from Ball & Burlap trees.

Lack of space impact the growth and survival of trees and plants in the county. Important factors needed to be considered for a healthy tree is proper technique, location, and soil availability. The assurance of establishing a healthy tree to live a long life will maximize the environmental benefits.

The professionals suggest, the best practices for tree enhancement should include promotion of beneficial microorganisms that promote healthy growth. A senior arborist mentions that organic tree fertilizers are readily available to reduce the risk of root injury from salts in synthetic fertilizers and allow slow realize of nutrients. The addition of organic materials and air into the soil to reduce compaction as well as proper pruning, will improve the health and growth of trees.

In terms of design strategies, larger tree pits will cost less to maintain, and the trees will be healthier for a longer period of time and it is also important to make sure that developed properties establish suitable soils on the construction sites.

The professionals suggested potential tree planting areas in the urban environment which include perimeter of open spaces, low income neighborhoods, parking lots, medians, parkways, schools, parks, churches, older commercial properties, creeks, rivers, and perimeter of sports fields are all areas that need more trees. One of the arborists said, “Few neighborhoods I visit in Frisco, the mandate is to put in two shade trees per yard that are maybe 300 sq feet. It makes no practical sense to do that. It’s barely large enough for even one shade tree. The mandate should be based on room allowed and then work down from shade tree to understory to shrub and so on. It would be so much more ecologically beneficial.” . Trees in urban streetscapes with high density development may be allowed a reduction to 125 square feet of soil volume with a minimum amount of soil open to the sky. Engineered measures can be employed to provide more suitable conditions under sidewalks and other restrictive areas. Most of the participants mention that soil volume should be increased in the urban areas for better growth and survival of urban trees. An Arborist says, “ The more soil volume available that is not covered by hardscapes, the longer lived and healthier the trees will be. “

The professionals urge for provision of training seminars to the public and the planting crew at tree planting events and discourage involvement of non-experts to develop guidelines that do not work. For example, it is important to involve a certified arborist on tree planting operations.

Having asked about tree planting programs to the participants, an arborist informant expressed during the interview that, “ There is some debate on this issue. It is important to have sustainable tree planting efforts. This means that trees are monitored after planting and replaced if they die. Some tree planting efforts performed by other groups are “plant it and forget about it”. These efforts are not sustainable and do not significantly contribute to the long-term canopy percentage.”

- **Practices which facilitate Tree connectedness**

The professionals expressed their perspective on promoting tree connectedness. One of the professionals expressed in the interview that "Connected pits or medians allow avenues for trees to share soil conditions and create the soil volume needed for a tree to reach natural maturity as it would be projected. The greater the distance of pavement from the tree, the more suited it is to a healthy growth cycle." Providing adequate spacing helps to provide the best chance for the tree to achieve it genetic potential and it helps to prevent numerous problems before they occur. Research shows that connected pits with more soil that is not covered by hardscapes, offers the best opportunity for trees to grow longer and healthier lives. If trees are connected, survival rates will be better, but rate of growth depends on resource availability.

Mature trees can play a role in connecting tree underground, but it also depends on the ability of the mature tree to compete and recover from root structure damages and possible soil moisture changes. As for the new nursery stock tree, they may fare better near the mature tree. A professional mentions that, "Typically I would recommend planting a new tree near a mature tree only if that mature tree is in a state of decline and will be removed in the near future. The other situation would be planting an understory species of tree, like a red bud or Japanese maple." They may also provide some storm protection and wind protection. Larger, mature trees shade young trees thus, reducing the stress of environmental factors such as, wind and full sunlight.

From a landscape design perspective, planting understory trees and ornamental trees next to a mature tree has the benefit of enhancing the beauty of the landscape and property. It is important to be careful not to injure the roots of the mature tree. Wounding the roots of a mature tree can result in infections that are fatal. Small or medium trees next to mature trees helps to provide edge habitat, which is great for wildlife and provides a replacement for a mature tree once it is lost. “If the larger, mature tree dies, you will already have a younger tree there to replace the benefits lost in a shorter amount of time than it would take if you only planted after then mature tree died.” Some professionals also expressed concerns of decline and think planting adjacent to a mature tree needs further research.

The best design strategies are the ones that encourage landscapes with high genetic diversity. That includes trees, shrubs, perennials, annuals, ground covers. One of the arborists explains, “Monoculture of plants has been proven to be poor for plant health and promotes disease and insect pest outbreaks. Examples are Oak Wilt Disease, Rose Rosette, Entomosporium leaf spot on red tip Photinia and Indian Hawthorne, and crape myrtle bark scale. Genetically diverse landscape that include various types of following plants, including native and adapted plants will promote beneficial populations of microorganisms and insects.” Better urban planning to connect natural areas and group planting to establish a healthy ecology increases benefits versus just planting trees that are widely spaced apart.

An urban biologist suggests looking at what was in Dallas historically, and not try to artificially force in another plant community. Grasses may not provide the shading factor, but there are every bit as good at filtering and erosion control functions. This promotes the use of native plant communities. A tree enthusiast who is also a landscape architect suggested “ To have understory trees as a middle layer is important which provides surface area for insects, spiders and other wildlife. An arborist who is also a landscape architect suggests “I think we should be connecting green and river/creek drainage areas into interconnected corridors through all areas.”

- **Awareness on Mycorrhizal fungi**

Most of the professionals lack the knowledge about mycorrhizal fungi and techniques of using them in the urban environment to benefit ecologically. When asked about programs that practice mycorrhizal inoculation, one of the professional replied saying “None here simply because it is not a standard process well known. “

Even though most professionals expressed lack of knowledge by saying “No idea”, arborists were the only professionals aware of the term and few benefits. One of the arborists mentioned that “I am not aware of any specific program that involves this, but it would be beneficial if done properly. Mycorrhizae fungi establish a beneficial, symbiotic relationship with plants, including trees and enhances the uptake of water and nutrients for the plant.” Some exclaim that there is some debate that these fungi are already present in the soil and do not require inoculation. In addition, some professionals debate that the available products do not contain sufficiently viable fungi to justify the expense. There are concerns of cost as mycorrhizal inoculation is expensive and clients deny it for large treatments. One of the professionals’ mentioned about coming across research that indicate inoculation is effective and beneficial and would justify the expense. Arborists, urban foresters and urban biologist are aware about the mycorrhizal fungi but lack the knowledge of implementing it in urban spaces. The fungus already exists in the soil but needs the right conditions to proliferate.

Many urban soils are not healthy and could benefit from treatment programs or amendment to build a healthy soil. The simplest method to building a healthy soil without inoculation is by the use of compost and mulch to increase the percentage of organic matter in the soil, which promote beneficial microorganisms, and establishes a functioning soil food web.

One of the professional expressed curiosity by stating " I would be curious if urban soils would function the same, especially in the heavier clays. We have lost so much of our organic related horizons, and we have amended to soils so heavily to mitigate engineering issues, I am curious how well mycorrhizal networks would get established. "

4.2.3 Summary of Interview Data

The tree canopy is not equally distributed in Dallas county. The soils in the urban area lack organic material and biological activity to support long lived plants and trees. New developments have depleted resources because the developers remove the topsoil during development important for the growth of trees. The codes should mandate the return of good quality soil for better functioning of urban trees. Dallas has soils with low suitability for planting.

The underground utilities, lack of technical knowledge in planting, location selection, species selection, and maintenance practices are some of the major problems in Dallas.

Parks are the open spaces eyeballed most of the time to plant trees, which is often neighborhood play area. Lack of space impacts growth of trees. Organic materials should be used to aerate the soil and reduce compaction. As a result of codes, many neighborhoods have more trees in lesser area. Mandate should be made to plant based on the room available. Engineered measures can be employed to provide more suitable conditions under sidewalks and other restrictive areas. The more soil volume available that is not covered by hardscapes, the longer lived and healthier the trees will be. Experts are not involved enough to make planting decisions which results in poor tree functions. During tree planting initiatives, trees are forgotten after planting.

Connected pits or medians allow avenues for trees to share soil conditions and create the soil volume needed for a tree to reach natural maturity as it would be projected. The greater the distance of pavement from the tree, the more suited it is to a healthy growth cycle. If trees are connected, survival rates will be better, but rate of growth depends on resource availability.

Monoculture of plants has been proven to be poor for plant health and promotes disease and insect pest outbreaks. Most of the professionals lack the knowledge about mycorrhizal fungi and techniques of using them in the urban environment to benefit ecologically. There are concerns of cost as mycorrhizal inoculation is expensive and clients deny it for large treatments.

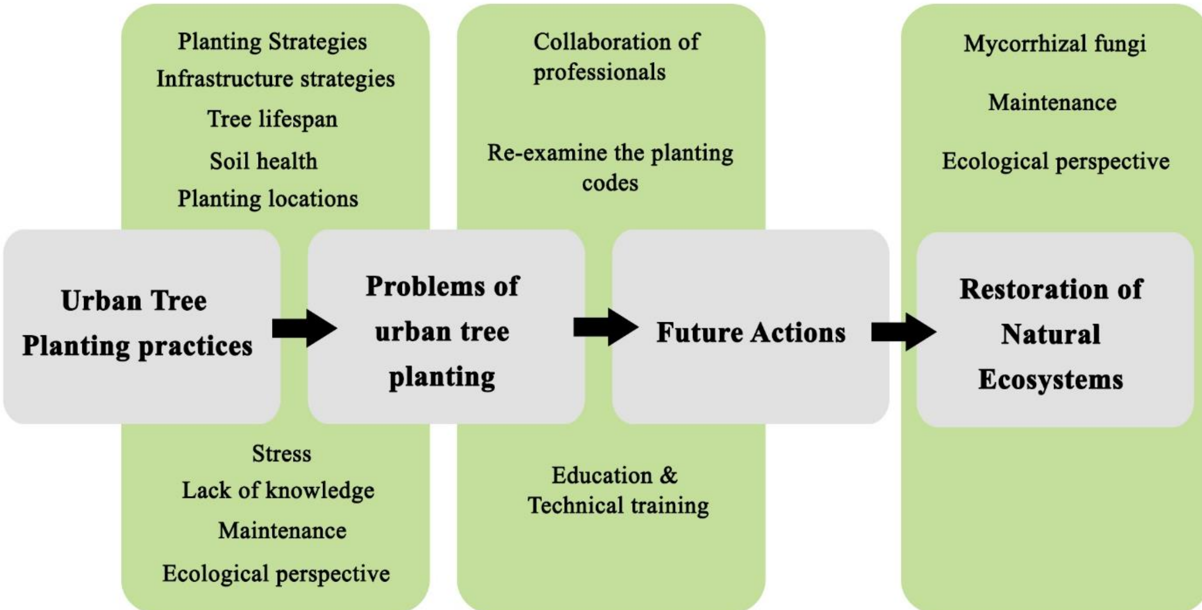
4.2.4 Findings - Relating the domains

The last step of Domain Analysis is to identify the relationship between the primary domains to understand the big picture. In Domain Analysis step two (see Section 4.2.2), taxonomic analysis identified relationships of subcategories to primary domains. The previous step of specifying the components from the interview data helped in understanding the relationship between the primary domains.

The urban tree planting problems are a result of current plant practices which are usually guided by the city codes. The data show there is need for actions to update planting practices, educate professionals, and provide training to restore natural ecosystems.

Figure 14

Relationship between the Primary Domains



4.3 Key Findings from Literature review - Summarized

- Urban Trees are known to influence urban quality of life and provide innumerable ecosystem services and affect physical environment and social well-being (Nowak et al., 1996).
- The Urban tree cover and density is usually greatest at parks, forests, and in some residential communities (Nowak et al., 1996).
- When urban trees are made accessible to larger populations, the complexity of management challenges increases (Nowak et al., 2010).

- Tree cover serves as a measuring factor for critical services provided by Urban Trees to the residents (Nowak et al., 1996).
- The areas with low canopy cover provide numerous opportunities in the urban areas (Nowak et al., 2010).
- Urban forests are viewed as collection of isolated trees, and only some view it as an ecosystem with interactions between biotic and abiotic factors (Carlisle, Pevzner, & Piana, 2014).
- Wild communities have been an inspiration to designers. Forests act as models to explore ecological structure, cultural value and productive function (Carlisle, Pevzner, & Piana, 2014).
- Many projects use the vocabulary of urban forests without attempting to create a functioning forest ecosystem (Carlisle, Pevzner, & Piana, 2014).
- Urban trees are managed to meet important needs like beauty, recreation and energy conservation, but there are opportunities for ecological benefits like storm water management, wildlife management, and biodiversity (Duryea, 2000).
- Restoration of urban forests means re-establishing ecological health of urban forest ecosystem (Duryea, 2000).
- Urban parks are typically designed with trees and grass which requires intensive maintenance inputs (Duryea, 2000).
- Restoration acts are elimination of leaf-raking to re-establish natural forest floor, establishment of understory plant species to promote wildlife, eradication of invasive plants (Duryea, 2000).

- Key ingredients for successful restoration is involvement of community and formulation of restoration plan (Duryea, 2000).
- It is important to provide more soil volume in paved areas to increase tree longevity (Fluckiger and Braun 1999).
- Average tree life expectancy in a side-walk pit can be as little as ten years (Kopinga 1991; Nowak et al. 2004). Crown spread and trunk diameter of trees growing in parking lots is reduced as surface area of non-paved surfaces is reduced (Grabosky and Gilman 2004).
- Opportunities are provided in the urban areas by linking urban forestry and ecological engineering to focus on building with nature to achieve renewably powered self-designs that satisfy human needs and advance ecosystem conservation (Endreny, 2018).
- Restoration of natural vegetation can be done using Miyawaki method of growing forests (Lise, 2017).
- Ecological restoration involves recovering topsoil and growing seedling in pots to get fully developed roots (Lise, 2017).
- According to Miyawaki method, multi-stratal-quasi natural forests can be built in the span of 15 to 20 years (Lise, 2017).
- Ecotechnology – concept of potential vegetation in building native forests with the functions of environmental protection and disaster prevention (Lise, 2017).
- Mycorrhizal fungal mycelia can link plants together in a network, and the mycorrhizal network (MN) can facilitate fungal colonization or interplant transfer of compounds (Leake, Johnson, Donnelly, Muckle, Boddy, & Read, 2004; Selosse, Richard, He, & Simard, 2006; van der Heijden & Horton, 2009).

- MNs have been shown to facilitate the establishment, growth, survival, or defense regulation of individual plants in a wide range of ecosystems (Horton, Bruns, & Parker, 1999; Dickie, Guza, Krazewski, & Reich, 2004; Teste, Simard, Durall, Guy, Jones, & Schoonmaker, 2009; Song, Zeng, Xu, Li, Shen, & Yihdego, 2010).
- The degree to which Mycorrhizal networks are formed between fungi and plants is context dependent (Simard *et al*., 2012).
- Mycorrhizal fungi are necessary for ecosystem functioning and the survival of plants. About 80 - 90% of all plant life is believed to engage with at least one of the seven types of mycorrhizae (Kleczewski, Lewandowski, & Bonello, 2016).
- Mycorrhizae play a crucial role in growing practices as these symbiotic organisms help in building a healthy ecosystem for the plant community within the growing media, the rhizosphere (*Australian Farm Journal*, 2011).
- Developing ecological landscapes with plant communities that include varied age and structure contribute towards resiliency, and broader ecological function (Beck, 2013, p. 42).
- An experiment in Syracuse proved that trees with DBH (Diameter at Breast Height) of 33 inches removed more air pollutants and carbon per year when compared to trees with DBH of 3 inches (Beck, 2013, p.42).
- Mimicking natural models will help in creating a self-functioning ecosystem (Jackie & Toensmeier, 2005).
- The concept of 'Forest gardening' mimics the structure of the native community but substituting individual species (Jackie & Toensmeier, 2005).

- Adaptive management is a four-step process. First intergrate experience and existing information to solve management problems. Second, the approaches are tested in rigorous manner. The outcomes are evaluated to plan the next round of planning (Beck, 2013, p. 101).
- The act of planting and caring for trees promotes mental and physical health and brings communities together (Turner-Skoff & Cavender, 2019).
- Trees can be arranged to evoke feelings and bring meaning to a space (Cihanger, 2013).
- Tree planting is perceived with a narrow frame in urban planning and design (Cihanger, 2013).
- Research says planting of trees should always be integrated with design from the beginning to end of design and construction (Nadel et al., 1977).
- According to a report by Texas Tree foundation of 2015, Dallas has 1.8 million potential tree planting sites, and the average tree cover of Dallas is 29%, and it is not evenly distributed throughout Dallas (Texas Tree Foundation, 2015).
- 46% of the entire tree canopy of Dallas is in the Great Trinity Forest. Remaining 54% is concentrated in parks and residential areas, and some commercially zoned parcels have a canopy less than 5% (Texas Tree Foundation, 2015).
- There is a strong correlation between land use and canopy cover (Texas Tree Foundation, 2015).
- Out of 61% of the tree population that are less than 6-inches DBH, only 20% are species that will grow into quality, large trees at maturity (Texas Tree Foundation, 2015).

- The greatest threat to the existing canopy continues to be the land development process. Under current practices, the decrease in forest density and large native trees, and the increased presence of tree pest and non-native trees.
- In the long-term, strategic tree planting programs must include expanded species selection, updated landscape requirements, maintenance requirements, and cost (Texas Tree Foundation, 2015).
- The urban transportation infrastructure like spaces adjacent to freeways and interchanges are spotted unutilized after addressing policy of maintaining 30 ft of mowed area for the shoulders (Texas Tree Foundation, 2015).
- The survival and planting rates have to out-weigh losses from tree death and removal to increase population levels of trees (Roman, 2014).
- "Collaboration between researchers, arborists, urban forest managers, planners, and designers will be essential to produce longitudinal urban tree data, analyze that data with appropriate tools, and connect research results to practice" (Roman, 2014, p.6).

4.4 Findings from Precedent Studies

- The study demonstrated that access to a mycorrhizal network (MN) and proximity to trees have important influences on seedling performance (Teste, & Simard, 2008).
- Competition for soil resources was highest near mature trees but facilitation was relatively greater at further distances, resulting in a zone of net benefit for seedlings. These results show that intraspecific tree-seedling interactions are both competitive and facilitative in dry Douglas-fir forests, and that they are spatially dependent (Teste, & Simard, 2008).

- TxDOT has encouraged restoration of natural beauty in Houston. According to them, the unique structure of interchanges also creates special opportunities to implement Native Naturalized Zone landscapes at a grander scale than is allowed by the narrower spaces along highway corridors. (Texas Department of Transportation website).
- The gardens in New York High Line mimic the natural ecosystems by using native plant species, natural planting strategies of using compost instead of chemical fertilizers. This has encouraged native songbirds, monarch butterflies, and bees in the landscape (*High line*).
- The skyline gardens have sections of the garden with 100% softscapes, encouraging no infrastructure conflicts or human intrusion (Cilento, 2009).
- Silva cells showed the most consistent response and confirmed that trees grow best in loamy soils with intact structure and rooting areas which open vertically and horizontally (Deep root Green Infrastructure, *News Feed*).

CHAPTER 5. CONCLUSION & DISCUSSION

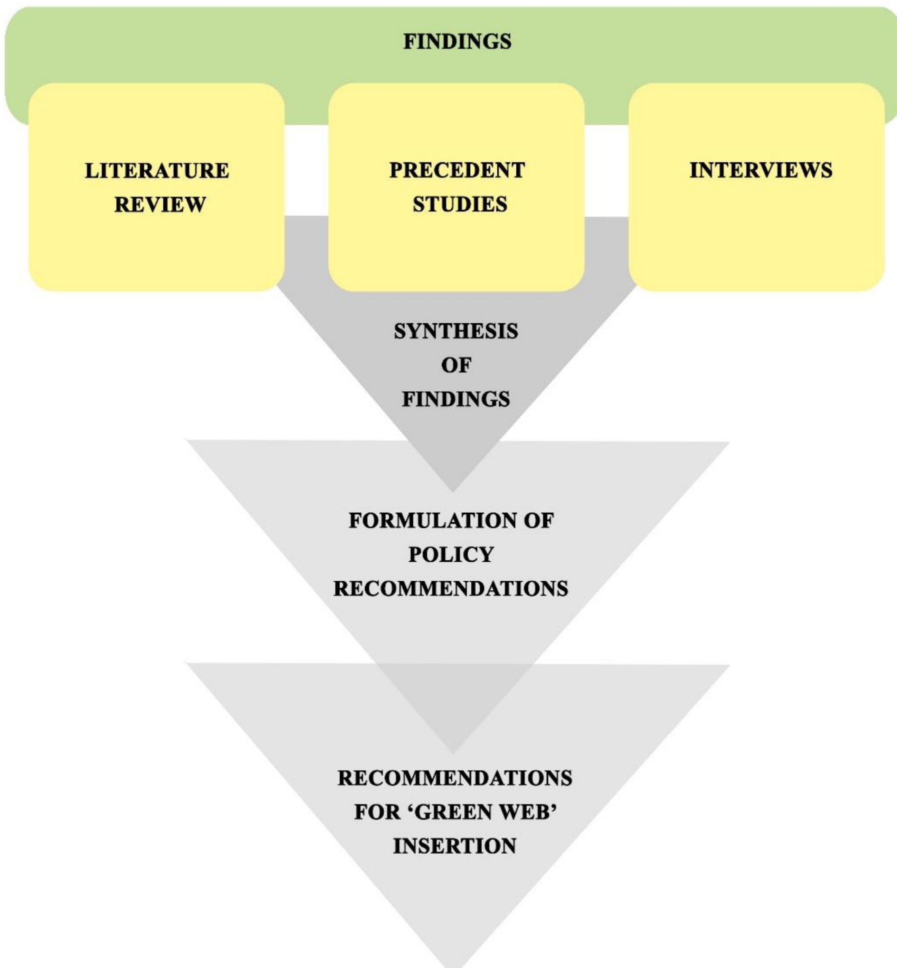
This chapter provides discussion of literature review, precedent studies, and interview participant's contribution towards formulating policies to facilitate 'Green Webs' in an urban environment, specifically Dallas county, Texas. A brief overview of research question is summarized, and relevance to the profession of landscape architecture is discussed and concludes with recommendations for future research.

5.1 Synthesis of Findings

Data from literature review, precedent studies, and interview data is synthesized to formulate County wide in Dallas using a matrix format as seen in Appendix B.

Figure 15

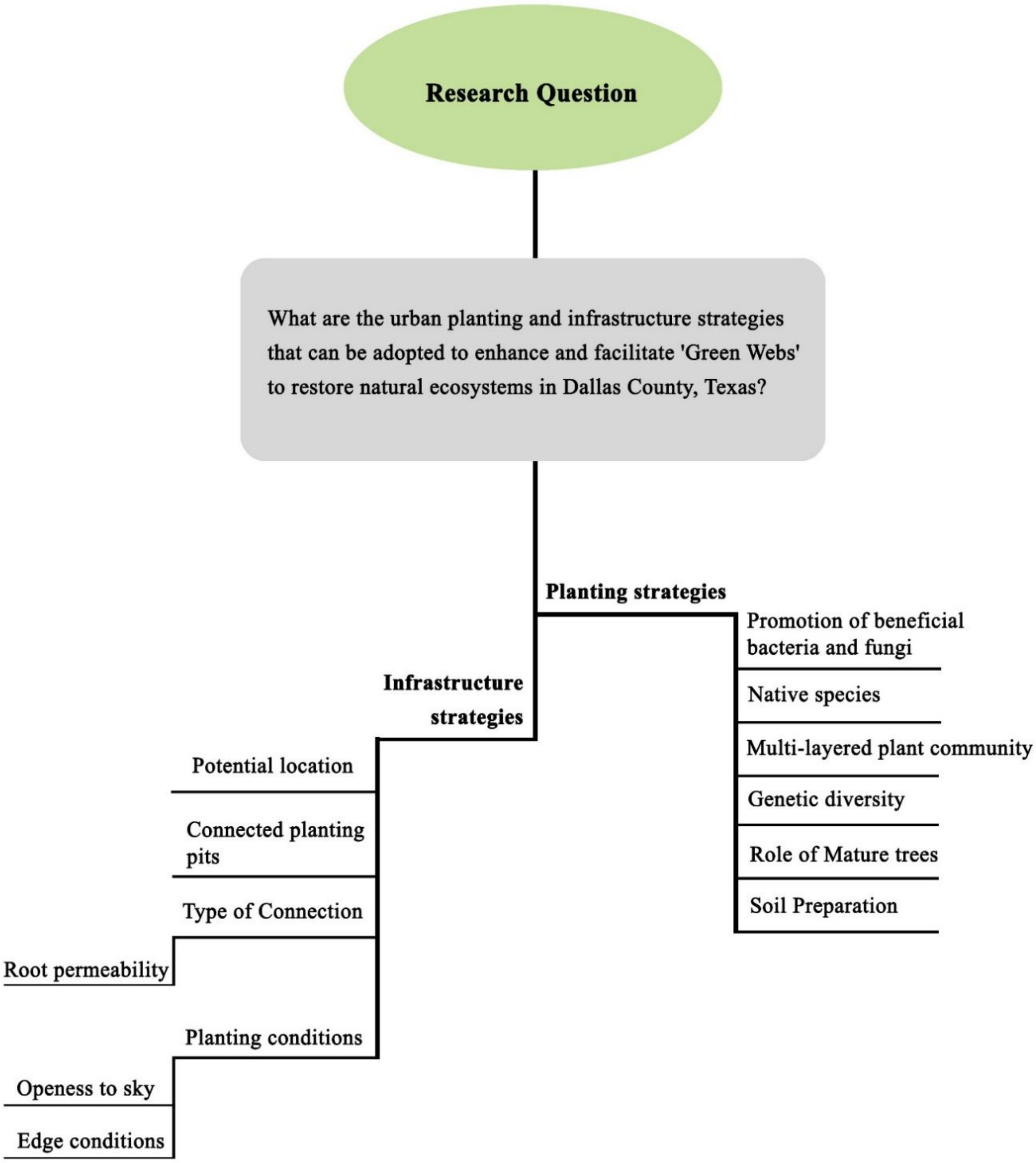
Process diagram of Synthesis of Findings



The research question is answered using the synthesized data.

Figure 16

Research Question Findings diagram



5.3 Policy Recommendations for Dallas County

- Planting urban trees should be a priority in the low canopy areas as it would help in achieving better quality of life by promoting mental and physical health and provide innumerable ecosystem services.
- For the re-establishment of ecosystems, a restoration plan should be formulated, and the restoration acts should involve creating a forest floor condition, use of native trees and plants, planting understory trees, having multi-layered plant community to promote insects and wildlife and promote genetic diversity.
- Codes should mandate return of topsoil after any construction, and design spaces to encourage mycorrhizal networks in soils.
- Natural methods like the Miyawaki method and concept of 'Forest gardening' should guide planting designs in urban areas to promote soil microbes and tree connectedness.
- Tree connectedness should be promoted as a criterion in planting design by connecting plant communities and trees to existing mature trees or well-established species, to build mycorrhizal network.
- Inspiration should be drawn from wild communities to arrange trees in urban spaces that helps people connect back to nature.
- Codes should accommodate urban tree planting from initial planning to post construction.
- In terms of infrastructure design, soil volume should be increased in the urban areas by decreasing paved area and increasing planting areas to promote tree connectedness.
- The edge conditions of planting areas should be treated to decrease soil compaction.

- Natural planting strategies should be adopted for increasing the organic matter in the soil and encouraging biological activity, and fast growth of trees.
- Education and Training is crucial for application of scientific knowledge.
- Group planting of trees should be implemented in areas possible for wind and storm protection.
- For the insertion of 'Green Webs', Adaptive management should be adopted based on literature and it is a four-step process. First integrate experience and existing information to solve management problems. Second, the approaches are tested in rigorous manner. The outcomes are evaluated to plan the next round of planning (Beck, 2013, p. 101).

Based on the Findings from literature review, Precedent studies, and Interview data, General recommendations for insertion of 'Green Webs' in urban areas is suggested.

In this research the first step of Adaptive management is initiated, by integrating urban planting experience by professionals in Dallas County and science behind tree connectedness by mycorrhizal networks.

5.4 General Recommendations for insertion of 'Green Webs' in Urban areas

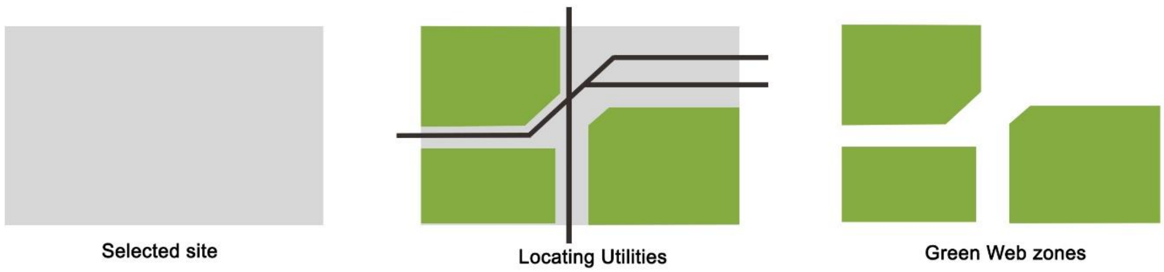
1) **Determining 'Green Web' location**

   Step 1 - Urban areas with least tree canopy percentage in the city or county should be given priority. The Tree Canopy Inventory for the city can help in mapping the low canopy areas. The area chosen can be any urban space including schools, parks, neighborhoods, plazas, school yards, commercial parcels, industrial areas, transportation infrastructure, medians, etc.

Step 2 – The area selected is evaluated to locate underground utilities, determine the land use of the selected area and its adjacent spaces, and programming of the space. Green Web zones are created as a result of the evaluation.

Figure 17

Process diagram for creating 'Green Web' zones



2) 'Green Web' zone analysis

Step 1 – The plant community of the zone is analyzed by collaborating with an arborist to:

a) Locate mature trees

b) Identify native species if any

c) Identify Invasive species

Step 2 – Soil survey should check for the:

a) Type of soil

b) Physical texture

c) Organic carbon

d) Nitrogen

e) Soil pH

f) Visible evidence of micro or macro fauna in the soil.

This step is to determine and quantify material for nourishment of soil like mulching material, perforation material like husk, retention material like peat, enhancers to increase beneficial bacteria and fungi.

g) Compaction percentage

3) Infrastructure design for tree/ plant connectedness

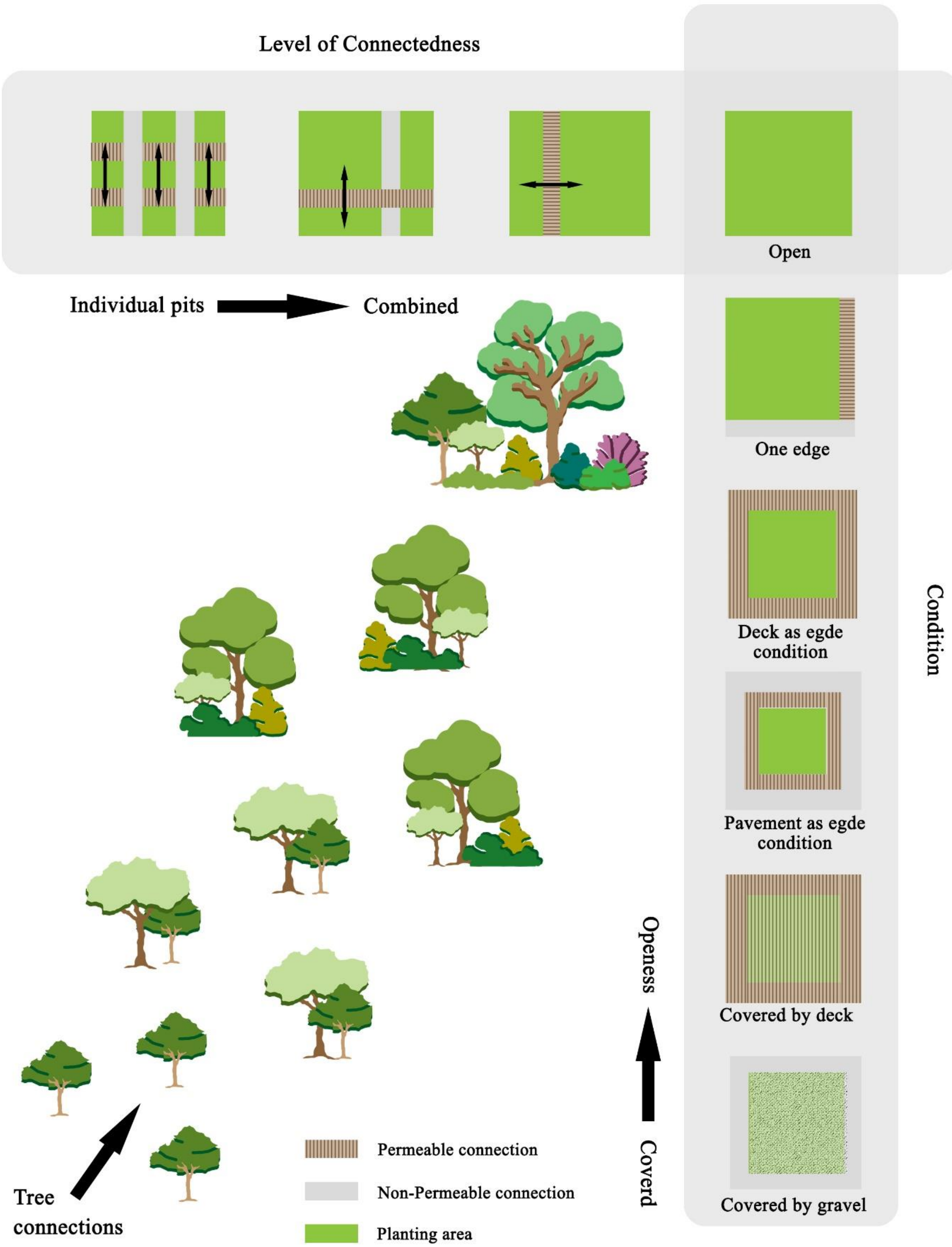
Step 1 - The design of planting areas should promote large pit area instead of multiple small planting pits for connecting trees and plants and facilitate soil sharing.

The level of connectedness should be opted based on programming and planting intentions for the space.

Step 2 – The root penetration between the divided planting areas is facilitated by the use of systems like board-walks, suspended sidewalks, and permeable pavers, Silva cells and other paving systems available in the market. The success of creating a Green Web is dependent on the level of connectedness and the openness of the planting area as shown in the figure below.

Figure 18

Process diagram for creating 'Green Web' zones



4) **Planting strategies for 'Green Web'**

a) **Tree/ Plant selection**

Step 1 - In this step a plant combination list is created by collaboration of an arborist and landscape architect. The plants are allocated to different layers like Tree, Subtree, Shrub, and Groundcover to create a multi-layer community.

Step 2 – Suppliers are contacted for healthy seedlings and genetic authenticity. Final quantity and order list is created to balance layers of major, supporting and minor species.

Step 3 – The root zones of the plants are checked for fully developed root zones along with healthy shoots.

b) **Soil preparation**

As suggested by the Miyawaki method, this step involves enriching the biomass mixture with microbiology enhancers and mixing it into the soil based on the depth of a horizon after consulting with an arborist / urban biologist.

5) **Community engagement**

Based on the project, people from particular communities should be encouraged to participate in planting activities. They should be guided to plant based on layers as per instructions by experts.

6) **Maintenance and monitoring**

The site should be maintained post planting to check on materials to be added or replaced based on project needs.

The images below show spatial application of the recommendation for inserting 'Green Web'. The images show potential 'Green Web' zones as a result of Zone analysis. Designs should be approached in a way to create conditions to maximize rooting space, and sharing of soils for creation of 'Green Webs'.

Figure 19

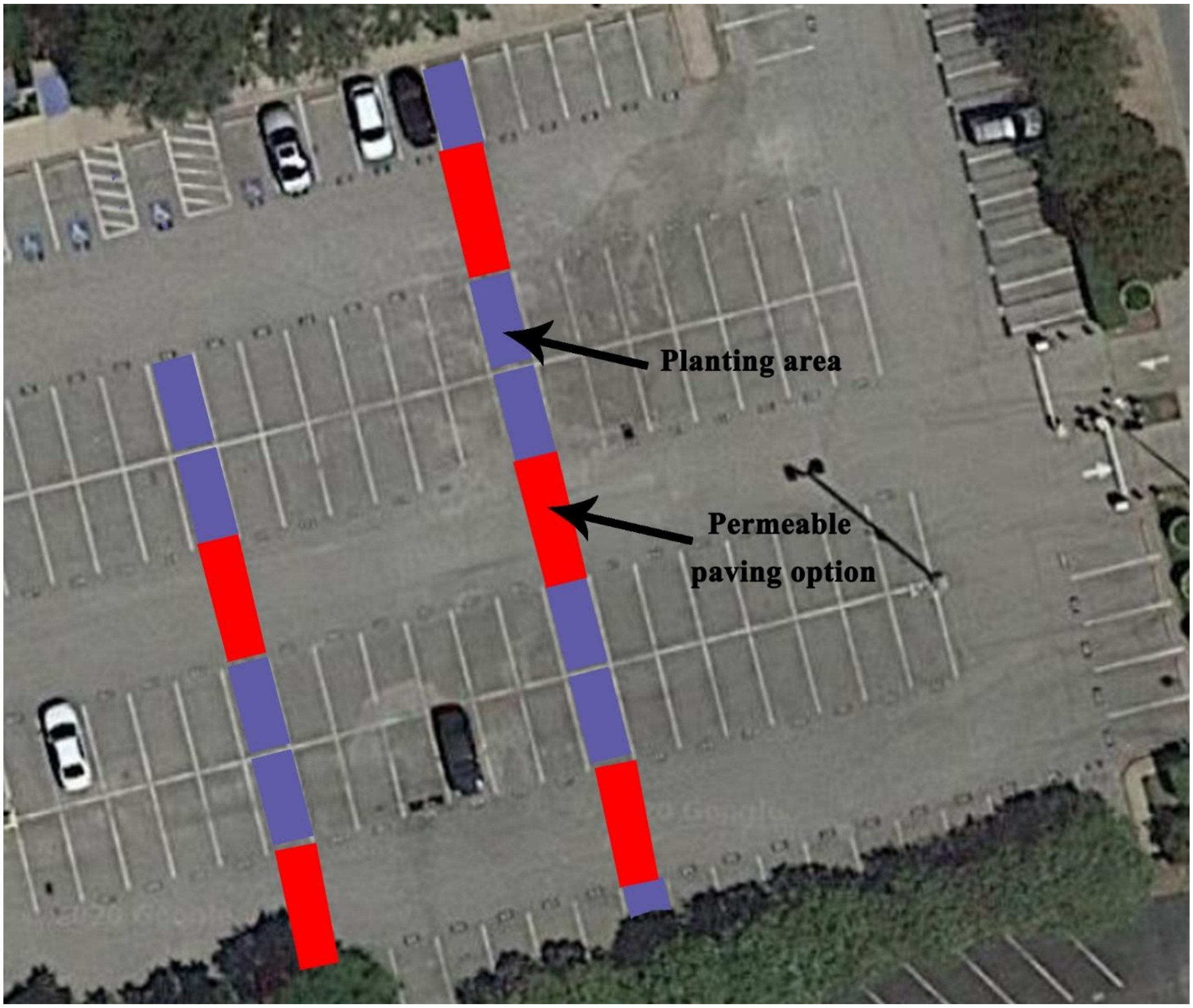
Example of connecting tree pits in Dallas

Figure 20

Example of connecting planting areas using permeable connections in Dallas

Figure 21

Example of connecting planting areas using permeable connections in Dallas



5.6 Relevance to Landscape Architecture

Landscape architects play a role in fostering design ideas to support the concept of ‘Green Webs’ during site planning and design process. Integrating ideas like planting islands, planting young trees next to mature trees, connecting tree pits, spaces to facilitate mycorrhizal fungi, maximizing soil volume and arrangement of trees in the urban landscape to create a sense of place by using trees as landmarks, etc.

5.7 Future Research

This research prompts the need for evidence-based testing of 'Green Webs' using modelling softwares to measure the environmental and ecological benefits. It also provides opportunities for designing innovative connections between planting areas. 'Green Webs' requires research on plant combinations of native species that can be implemented in the urban areas. Research is required for learning about the economic advantages of having urban trees with longer lifespans.

5.8 Conclusion

The idea of implementing small pieces of 'Green Webs' in the urban areas is to help in connecting back to larger ecosystems. In the present times, developing natural methods of restoring ecosystems is a necessity for mitigating climate change. It is important to develop landscapes that are self-functioning to heal the planet.

Appendix A : Interview Questions

Questionnaire for Urban Tree Planting in Dallas county – For Arborists

1) What is the current percentage of tree canopy in Dallas county? What is the desired percentage?

2) Based on your experience, what is the current average lifespan of urban trees in Dallas county? Please explain the reasons behind it.

3) What is the state of urban soils in DFW Metroplex? Explain the level of suitability of urban soils for tree planting?

4) In your opinion, which potential spaces for tree planting in Dallas county are currently underutilized?

5) To what extent are ecological factors (interactions between biotic and abiotic factors) considered in urban forestry of Dallas county?

6) In your experience, is there a difference in tree growth and survival rates when they are planted in single tree pits verses connected tree pits?

7) Does planting new trees around mature trees increase the survival rates of the new trees? Explain.

8) According to codes, what are the recommended sizes for tree pits and soil volume required in Dallas county? What is your opinion about the sizes? Explain.

9) What are the best methods used or available in Dallas county for improving the growth of trees in an urban environment?

10) How well do Silva cells enhance the growth of trees and plants when compared to conventional tree pits? Have Silva cells ever been used in Dallas county?

11) What are the differences in establishing cost and maintenance of group planting in a large pit compared to individual tree pits?

12) What are some of the main problems of tree planting in an urban environment like Dallas county?

13) What changes or new methods would you recommend for tree planting in Dallas?

14) Explain the differences between establishment of a small tree versus a mature tree with respect to initial establishment cost, maintenance cost, mortality rate, and environmental benefits
15) Given the high mortality rate of urban trees, how do tree planting initiatives help in increasing the tree canopy percentage? Will the tree last long enough to contribute to the canopy percentage?

16) In your opinion, do you think there is any benefit of establishing a small/medium tree next to a mature tree? Explain the reason for it.

17) Do any of the tree planting programs involve mycorrhizal fungi inoculation? And why?

18) What are the criteria for facilitating mycorrhizal networks in an urban environment? Do the existing urban soils facilitate the same?

19) What is your suggestion on how to connect plant communities for ecological benefits (interactions between biotic and abiotic factors)? Do you recommend any plant strategies?

20) What sizes of trees are planted during tree planting programs, and how long do they take to create a canopy that would be beneficial?

Questionnaire for Urban Tree Planting in Dallas county – For Urban Foresters

1) In your opinion, does Dallas county's urban forest percentage enough to offset environmental problems like urban heat islands, air quality, etc?

2) In your opinion, which is the most appropriate urban condition for higher survival rates of urban trees?

3) Based on your experience, what is the current average lifespan of urban trees in Dallas county? Please explain the reasons behind it.

4) What is the state of urban soils in DFW Metroplex? Explain the level of suitability of urban soils for tree planting.

5) In your opinion, which potential spaces for tree planting in Dallas county are currently underutilized?

6) To what extent are ecological factors (interactions between biotic and abiotic factors) considered in urban forestry of Texas?

7) In your experience, is there a difference in tree growth and survival rates when they are planted in single tree pits verses connected tree pits?

8) In your experience, does planting new trees around mature trees increase the survival rates of the new trees? Explain.

9) According to codes, what are the recommended sizes for tree pits and soil volume required in Dallas county? What is your opinion about the sizes? Explain.

10) What are the best methods used or available in Dallas county for improving the growth of trees in an urban environment?

11) How well do Silva cells enhance the growth of trees and plants when compared to conventional tree pits? Have Silva cells ever been used in Dallas county?

12) What are the differences in establishing cost and maintenance of group planting in a large pit compared to individual tree pits?

13) What are some of the main problems of tree planting in an urban environment like Dallas county?

14) What changes or new methods would you recommend for tree planting in Dallas county?

15) Explain the differences between establishment of a small tree versus a mature tree with respect to initial establishment cost, maintenance cost, mortality rate, and environmental benefits.

16) Given the high mortality rate of urban trees, how do tree planting initiatives help in increasing the tree canopy percentage? Will the tree last long enough to achieve the canopy percentage?

17) What is the benefit of establishing a small/medium tree next to a mature tree?

18) Do any of the tree planting programs involve mycorrhizal fungi inoculation? And why?

19) What are the criteria for facilitating mycorrhizal networks in an urban environment? Do the existing urban soils facilitate the same?

20) What is your suggestion on how to connect plant communities for ecological benefits (interactions between biotic and abiotic factors)?

21) What sizes of trees are planted during tree planting programs, and how long do they take to create a canopy that would be beneficial?

Questionnaire for Urban Tree Planting in Dallas county – For Tree enthusiasts

1) Based on your experience in urban tree planting, what is the average lifespan of urban trees in Dallas county? Explain.

2) For tree planting programs, what is the criteria to locate potential tree locations? Explain the process.

3) To what extent are ecological factors (interactions between biotic and abiotic factors) considered in urban forestry of Dallas county?

4) In your experience, is there a difference in tree growth and survival rates when they are planted in single tree pits verses connected tree pits?

5) Does planting new trees around mature trees increase the survival rates of the new trees? Explain.
6) According to codes, what are the recommended sizes for tree pits in Dallas? What is your opinion about the sizes? Explain.

7) What is your opinion about planting tree along the highways and interchanges? What are the hurdles of planting along highways?

8) How well do Silva cells enhance the growth of trees and plants when compared to conventional tree pits? Have Silva cells ever been used in Dallas county?

9) What are the differences in cost and maintenance of group planting in a large pit compared to individual tree pits?

10) What are some of the main problems of tree planting in an urban environment like Dallas county?

11) Please share your experience about a tree planting program in Dallas county that brought communities together. How did you approach the communities with the idea of that initiative?

12) Given the low mortality rate of urban trees, how do tree planting initiatives help in increasing the tree canopy percentage? Will the tree last long enough to achieve the canopy percentage?

13) Do any of the tree planting programs involve mycorrhizal fungi inoculation? And why?

14) What is your suggestion on how to connect plant communities for ecological benefits (interactions between biotic and abiotic factors)?

15) What sizes of trees are planted during tree planting programs, and how long do they take to create a canopy that would be beneficial?

16) What changes or new methods would you recommend for tree planting in Dallas county?

Questionnaire for Urban Tree Planting in Dallas county – For Tree consultants

1) Based on your experience, what is the current average lifespan of urban trees in Dallas county? Please explain the reasons behind it.

2) What is the state of urban soils in Dallas county? Explain the level of suitability of urban soils for tree planting.

3) What are the best methods used or available in Dallas for improving the growth of trees in an urban environment?

4) In your experience, what is the difference in tree growth and survival rates when they are planted in single tree pits verses connected tree pits?

5) Does planting new trees around mature trees increase the survival rates of the new trees? Explain.

6) According to codes, what are the recommended sizes for tree pits in Dallas county? What is your opinion about the sizes? Explain.

7) In your opinion, which potential spaces for tree planting in urban areas are currently underutilized?

8) How well do Silva cells enhance the growth of trees and plants when compared to conventional tree pits?

9) What are some of the urban tree problems faced by clients after few years of project completion?

10) What changes or new methods would you recommend for urban tree planting in Dallas county?

11) Explain the differences between establishment of a small tree versus a mature tree with respect to initial establishment cost, maintenance cost, mortality rate, and environmental benefits.

Appendix B : Synthesis of Findings Matrix

RECOMMENDATIONS	LITERATURE REVIEW	PRECEDENT STUDIES	INTERVIEW DATA
Planting urban trees should be a priority in the low canopy areas as it would help in achieving better quality of life by promoting mental and physical health and provide innumerable ecosystem services.	(Nowak et al., 1996). (Nowak et al., 2010), Turner-Skoff & Cavender, 2019).	(Texas Department of Transportation website).	Arborist, Urban Forester, Urban biologist - low tree canopy percentage, eyeballing only parks is a concern
For the re-establishment of ecosystems, a restoration plan should be formulated, and the restoration acts should involve creating a forest floor condition, use of native trees and plants, planting understory trees, having multi-layered plant community to promote insects and wildlife and promote genetic diversity.	(Nowak et al., 2010),(Carlisle, Pevzner, & Piana, 2014), (Carlisle, et al., 2014), (Duryea, 2000), (Beck, 2013, p. 42).	(Cilento, 2009), (High line, website).	Arborist, Tree enthusiast - understorey trees, genetic diversity, use of native trees, gnenetic diversity
Codes should mandate return of topsoil after any construction, and design urban spaces to encourage mycorrhizal networks in soils.	(Lise, 2017), (Simard et al., 2012), (Miyawaki, 1999).	(Teste, & Simard, 2008).	Arborist - Construction practices, new development
Natural methods like Miyawaki method and concept of 'Forest gardening' should guide planting designs in urban areas to promote soil microbes and tree connectedness.	(Lise, 2017), (Leake, Johnson, Donnelly, Muckle, Boddy, & Read, 2004; Selosse, Richard, He, & Simard, 2006; van der Heijden & Horton, 2009),(Horton, Bruns, & Parker, 1999; Dickie, Guza, Krazewski, & Reich, 2004; Teste, Simard, Durall, Guy, Jones, & Schoonmaker, 2009; Song, Zeng, Xu, Li, Shen, & Yihdego, 2010), (Kleczewski, Lewandowski, & Bonello, 2016), (Jackie & Toensmeier, 2005).	(Cilento, 2009), (High line, website).	Arborist, Urban Biologist - promote tree connectedness, soil sharing
Tree connectedness should be promoted as a criterion in planting design by connecting plant communities and trees to existing mature trees or well-established species, to build mycorrhizal network.	(Beck, 2013, p.42), (Cihanger, 2013).	(Teste, & Simard, 2008).	Arborist, Urban Biologist, Tree enthusiast - role of mature trees, lack of planting knowledge
Inspiration should be drawn from wild communities to arrange trees in urban spaces that helps people connect back to nature.	(Jackie & Toensmeier, 2005), (Beck, 2013, p. 101), (Texas Tree Foundation, 2015), (Carlisle, Pevzner, & Piana, 2014), (Rainer & West, 2015, p. 20).	(Cilento, 2009), (High line, website).	Arborist, Urban Forester, Tree consultant - Right tree Right place
Codes should accommodate urban tree planting from initial planning to post construction.	(Nadel et al., 1977).		Arborist, Tree enthusiast - Policy change
In terms of infrastructure design, soil volume should be increased in the urban areas by decreasing paving area and increasing planting areas to promote tree connectedness.	(Kopinga 1991; Nowak et al. 2004), (Grabosky and Gilman 2004).	(Cilento, 2009), (High line, website), (Deep Root infrastructure, News Feed).	Arborist - Maintenance of large pits
The edge conditions of planting areas should be treated to decrease soil compaction.	(Kopinga 1991; Nowak et al. 2004), (Grabosky and Gilman 2004).	(Texas Department of Transportation website), (Deep Root infrastructure, News Feed).	Arborist, Tree enthusiast - code change, soil volume chnages
Natural planting strategies should be adopted for increasing the organic matter in the soil and encourage biological activity, fast growth of trees, and a self-functioning ecosystem.	(Texas Tree Foundation, 2015), (Australian Farm Journal, 2011), (Lise, 2017)	(Cilento, 2009), (High line, website)	Arborist, Urban forestors, Tree enthusiast, Tree consultant - soil health, soil depletion, nutrients, organic matter
For the insertion of 'Green Webs', Adaptive management should be adopted based on literature and it is a four-step process. First integrate experience and existing information to solve management problems. Second, the approaches are tested in rigorous manner. The outcomes are evaluated to plan the next round of planning	(Beck, 2013, p. 101), (Nowak et al., 2010).		
Group planting of trees should be implemented in areas possible for wind and storm protection.	(Miyawaki, 1998).	(Texas Department of Transportation website), (Cilento, 2009), (High line, website)	Arborist , Tree Consultant - Mass planting
Education and Training is crucial for application of scientific knowledge	(Lise, 2017), (Simard et al., 2012), (Miyawaki, 1999).	(Teste, & Simard, 2008), (Deep Root infrastructure, News Feed).	Arborists, Urban Foresters, Tree enthusiast - lack of knowledge

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