June 2024

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Tree Protection for Street Corridor Development in Massachusetts

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MassDOT Office of Transportation Planning

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16. Abstract
Massachusetts is home to millions of trees located not only in forests but also along streets and roadways in urban, suburban, and rural environments. The people living in these communities rely on street trees to provide necessary ecosystem services, such as shading and cooling, or stormwater mitigation. MassDOT has developed a comprehensive capital improvement project to facilitate the necessary improvements of pedestrian and cycling pathways statewide that will impact the existing urban forest ecosystem. MassDOT is seeking a cohesive collection of best-practice standards to ensure that urban forest health and preservation remains a priority in these upcoming transportation improvement projects. The information gathered from the survey and discussion with the expert panel will be used to create a comprehensive guide that will be an overview of current best practices to inform planting and tree protection management techniques during construction. This review will inform strategies applied across the state that will prioritize street trees during development and foster thriving urban forests for all. This work will provide a framework for the reimagining of the Commonwealth's transportation corridors as functional urban greenspaces that will grow alongside their communities.

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Tree Protection for Street Corridor Development

Final Report

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Disclaimer

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Executive Summary

This study of Tree Protection for Street Corridor Development was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

Massachusetts is home to millions of trees located not only in forests, but along streets and roadways across urban, suburban, and rural environments. The people living in these communities rely on street trees to provide necessary ecosystem services, such as shading and cooling, or stormwater mitigation. When street trees are damaged during construction projects or other infrastructure development work, communities lose out on these services. Street trees and urban forests are often an afterthought in the construction process and may be severely damaged during construction without proper protection and preservation measures.

As Massachusetts develops comprehensive capital improvement projects as part of the Complete Streets initiative, the necessary redevelopment of pedestrian and cycling pathways statewide will impact the existing urban forest ecosystem. The Massachusetts Department of Transportation (MassDOT) oversees many of the projects involving roadways and transportation corridors in the Commonwealth. This organization strives to lead by example by evaluating and updating their existing guidelines to reflect current industry best practices. MassDOT is seeking a cohesive collection and assessment of industry approaches to ensure that urban forest health and preservation remain a priority in upcoming improvement projects.

This report contains an assessment of current project development guidelines used by MassDOT and evaluates the existing standards in accordance with insight from contemporary sources. We assessed major themes including soil compaction and root zone preservation, awareness on the construction site, and methods for successful reforestation following construction. Our first task was to review the relevant literature to determine the current state of best practices. The literature review focused on street tree preservation techniques during construction and development, as well as design alternatives and remediation strategies. The content surveyed included peer-reviewed research publications, technical documentation, and reference guides from other jurisdictions. The next step was the creation and distribution of a survey for professionals nationwide to assess the current status of street tree preservation practices. Finally, the information gathered from both the literature review and the survey was synthesized, and the existing MassDOT guidelines were evaluated in accordance with the research findings. At the time of writing, the existing resource for tree preservation and landscape design for MassDOT projects was an online compendium known as the Project Development and Design Guide (PDDG). Recommendations were made to update and improve the existing MassDOT PDDG to reflect current practices and new insight.

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List of Acronyms

Acronym	Expansion
ACEC	American Council of Engineering Companies
ANSI	American National Standards Institute
ASCA	American Society of Consulting Arborists
BSLA	Boston Society of Landscape Architects
CRZ	Critical Root Zone
ISA	International Society of Arboriculture
ISANE	International Society of Arboriculture – New England Chapter
ISSR	Institute for Social Science Research
MAA	Massachusetts Arborists Association
MassDOT	Massachusetts Department of Transportation
MGL	Massachusetts General Laws
MATWFA	Massachusetts Tree Wardens and Foresters Association
NYCP	New York City Parks
PDDG	Project Development and Design Guide
ROW	Right of Way
TPZ	Tree Protection Zone
UMTC	University of Massachusetts Transportation Center

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1.0 Introduction

This study of Tree Protection for Street Corridor Development was undertaken as part of the Massachusetts Department of Transportation (MassDOT) Research Program. This program is funded with Federal Highway Administration (FHWA) State Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

1.1 Urban Forestry in Massachusetts

The Commonwealth of Massachusetts spans a variety of environments, from downtown metropolitan communities in the east to rural farm and forest regions in the west. Throughout all these localities, green spaces provide numerous benefits and values to community members. Massachusetts therefore uses a novel approach to the governance of these greenspaces, particularly urban forests, through the implementation of town tree wardens. As outlined in the Massachusetts General Laws (MGL) Chapter 87, the tree wardens program helps with the governance of municipal trees [1]. The laws laid out in this chapter include restrictions on the removal of public shade trees, the process for planting street trees, and regulations for trees on state highways. The inclusion of street trees in the laws of the Commonwealth are indicative of widespread community values that support urban forests and sustainable development.

The Massachusetts Department of Transportation (MassDOT) is participating in a nationwide initiative known as Complete Streets, which is an effort by Smart Growth America and the National Complete Streets Coalition to reimagine roadways across the country to improve safety and accessibility for all users [2]. The main priorities of Complete Streets address the planning, design, construction, and use of roadways. They include improving (1) safety of vulnerable users such as cyclists and pedestrians, and (2) connections across metropolitan areas to serve all communities. The initiative tackles systemic problems of safety and equity and will result in improved safety, mobility, and connection for individuals nationwide. Two common themes in building a complete street are (1) the redevelopment of the roadway corridor to accommodate changing traffic patterns and (2) the addition of pedestrian facilities and bike lanes. In the process of effecting these changes, roadway corridors may be widened, resurfaced, or otherwise altered in ways that have significant impacts on existing vegetation in the corridor.

1.1.1 Community Benefits of Trees and Urban Forests

Trees and urban forests are an integral part of communities around the world and provide residents with a wide variety of benefits. Ecosystem services include filtering and sequestering air pollutants, mitigating stormwater run-off, and shading and cooling neighborhoods [3,4]. These services are quantifiable, and metrics can be provided for residents and community members regarding energy savings, carbon sequestration, and oxygen production [5]. There are a variety of online tools that provide property owners with estimates of the value of the benefits provided by their trees. This information can be compared across municipalities to investigate relationships between neighborhood demographics and the status of the urban forest.

While harder to quantify, the mental and physical well-being of a community is also impacted by the presence of street trees and urban greening. Trees provide identity in communities, and many people forge strong connections with the trees they encounter on a daily basis [6]. The presence of trees in neighborhoods is also associated with stress reduction, improved mental health, and safer streets for all users. Urban forests are an essential part of all communities and must be managed so that they may continue to grow and develop alongside their respective municipalities.

1.2 Trees and Construction

Construction projects have the potential to severely damage trees unless the proper precautions are in place to preserve and protect trees on site. Damage to the aboveground portions of the tree (trunk and branches) is usually most obvious and must be avoided, but unseen damage to the root system is typically the most serious and has the greatest adverse impact on long-term tree health [7]. Construction that involves digging, trenching, resurfacing, and grade changes has the greatest potential to harm trees. Roots typically grow shallow and wide, usually within the top eighteen inches of soil, and extending well beyond the dripline of the tree [8]. The Critical Root Zone (CRZ) is the area in which any damage to the roots is critical to the overall health of the tree; precautions must be taken to protect both the roots and soil within this zone. The Tree Protection Zone (TPZ) is the area in which activity is restricted to prevent construction activities from impacting site trees [9]. The TPZs of individual trees may be combined into a single broader zone to provide more effective coverage. Figures 1.1 through Figure 1.3 display further configurations for CRZ's and TPZ's, including a standard configuration (Figure 1.1), a combined arrangement (Figure 1.2), and alternatives for when the standard circular CRZ cannot be completed due to obstructions near the tree (Figure 1.3).

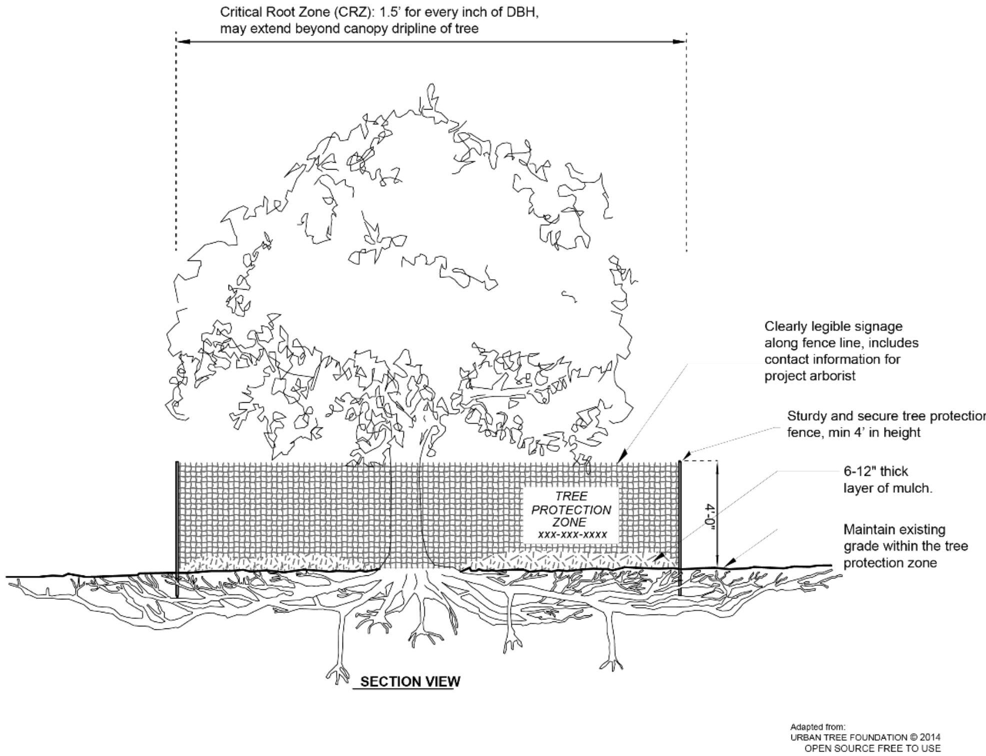

Figure 1.1. Standard setup for a CRZ around a single tree

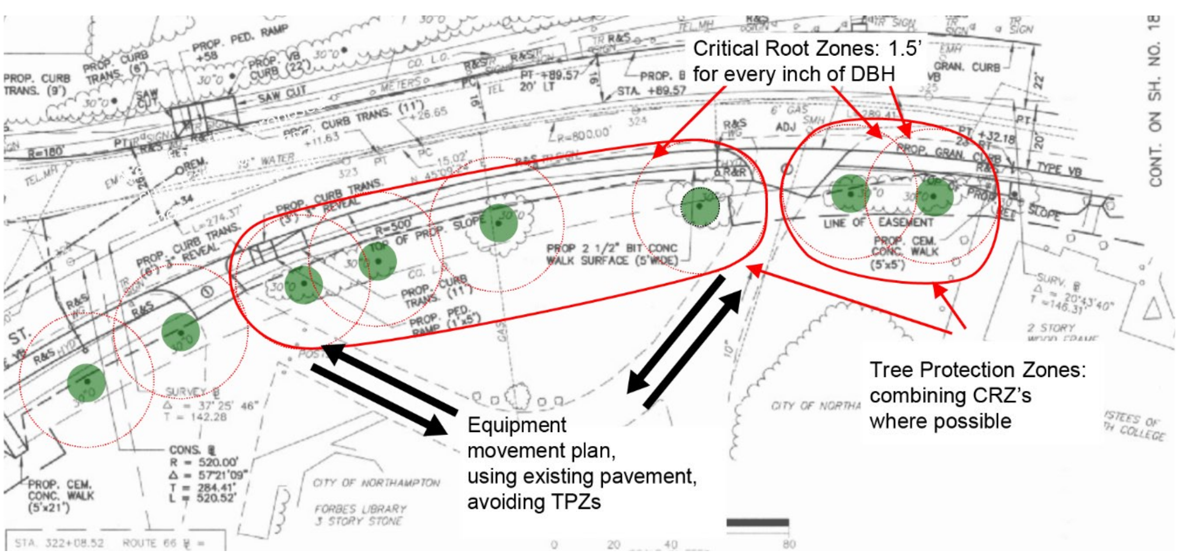

Figure 1.2 Combination of multiple CRZs into a TPZ

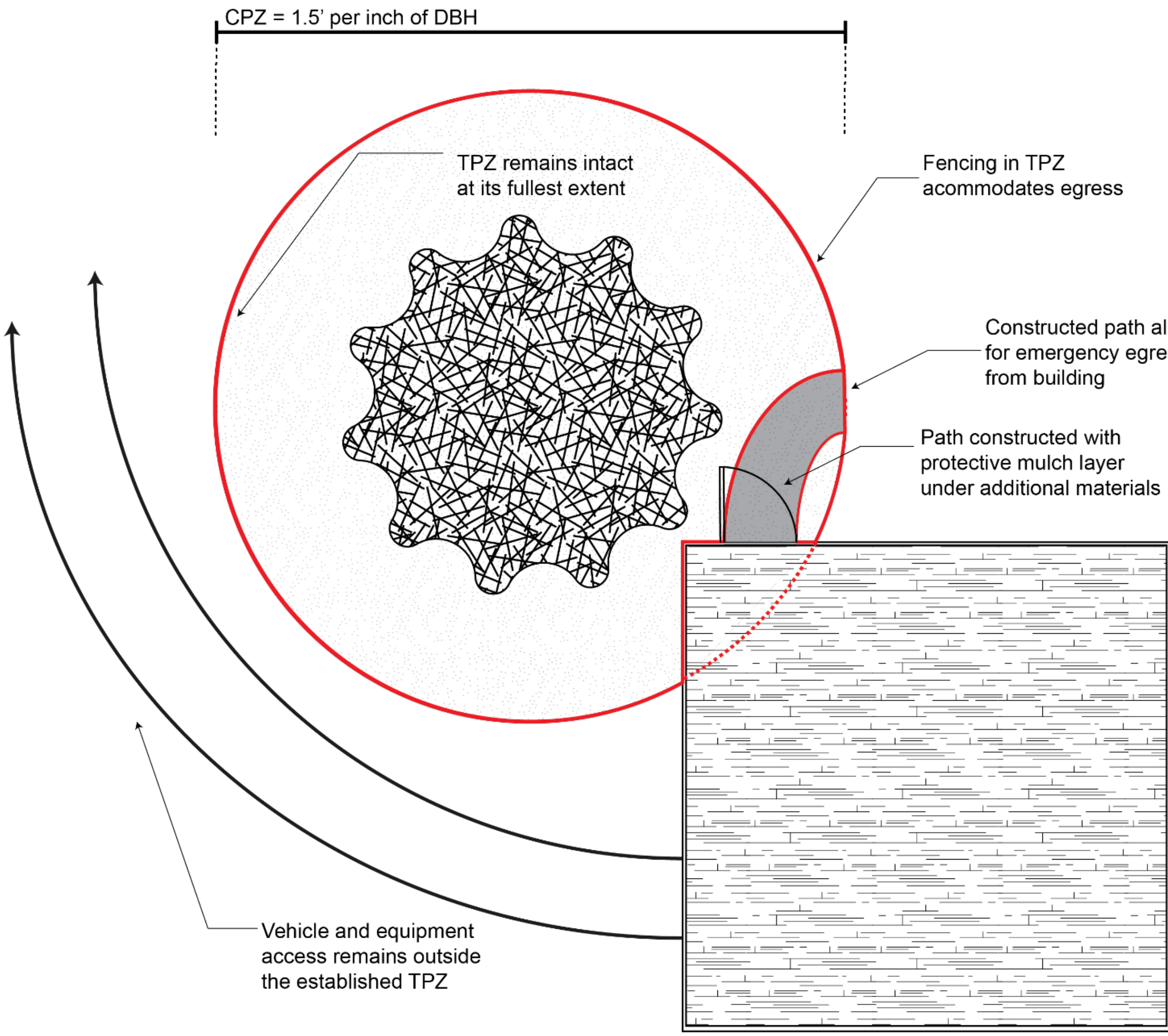

Figure 1.3 Alternatives when the standard circular CRZ cannot be completed

The most common injuries to trees during construction processes are damage to the root system and wounds to the trunk and branches. Overall tree health decline often follows—sometimes years after the conclusion of the project—due to the number of stressors the tree encounters during the construction process. Root system damage and trunk injuries are frequently the result of equipment movement or operations, particularly in digging or trenching operations. Root systems can further be damaged from soil compaction during the project. Soil compaction can be caused by vehicular or pedestrian traffic, or the storage of equipment and materials around the base of the tree [5].

Root health is critical to overall tree health. Roots are essential for tree growth and stability, providing water and nutrient uptake and storage, as well as anchoring the tree in the ground. For roots to grow and function effectively, the surrounding soil must be of sufficient quality so that the roots may perform the necessary tasks for tree survival.

The ideal soil for most tree species will be well drained and have a high organic matter content. The solid particulates in an ideal soil will consist of approximately 90% inorganic particles (sand, silt, and clay) and 10% organic material. For optimal growing conditions, solids will make up 50% of total soil volume, and pore space makes up the other 50% [10]. Proper drainage ensures the roots receive an adequate water supply but are not so saturated that they are starved of oxygen or begin to rot. Organic matter, often in the form of composted material, improves the nutrient density and water-holding capacity of the soil, improving the overall health of the tree. These factors in conjunction with soil texture and bulk density help to provide an ideal growing environment for tree roots. When soils are packed too tightly, potentially from pedestrian or vehicular traffic, they become compacted, which hinders the ability of roots to grow and survive.

In compacted soil, the amount of space the roots have to grow and take in water and oxygen is then reduced and the health of the tree suffers. Problems in trees that result from soil compaction include limited and shallow rooting (resulting in instability and failure), reduced crown appearance, and overall poor health leaving trees more susceptible to threats from pests and diseases. The goal of this project is to advise and adapt current tree protection guidelines in Massachusetts to ensure tree and urban forest health across all communities.

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2.0 Research Methodology

2.1 Project Overview

The objective of this research was to review and revise the existing tree preservation guidelines for MassDOT projects in anticipation of increased construction impacts to trees following street corridor development. With a rise in projects impacting roads, sidewalks, and bike lanes, it was necessary to reevaluate the existing tree preservation practices to ensure better access for communities without impacting urban trees and forests. Project partners worked to develop the following tasks to meet the outlined objectives: (1) A literature review of current professional journals and publications, relevant to the subject of tree preservation across a variety of topics including arboriculture, engineering, planning, and landscape; (2) Assembling a panel of cross disciplinary experts to advise on topics and project progress, engaging individuals with expertise in arboriculture, planning, landscape design, and project management; (3) An online survey of industry professionals across disciplines, seeking input on planning, design, and preservation practices across practices and municipalities; (4) A synthesis of information gathered from Tasks 1–3, developed in conjunction with recommendations for amendments to the existing MassDOT PDDG.

2.2 Task 1: Literature Review

We reviewed the literature to assess the current state of tree preservation practices during construction projects. The review covered a variety of sources from both print editions and online resources, as well as technical documents from professional and expert members of an advisory panel (described in Task 2). Print materials, including peer-reviewed research papers, industry best management practices, and university extension publications, were sourced through the UMass Library system and interlibrary loans from academic libraries around the country. Additional resources, including technical memoranda, construction documents, and company guidelines were collected by email from various professionals and experts involved in the panel.

All these materials were reviewed for their relevance and insight into the core research areas. The four core areas of focus in the literature review were (1) preserving trees during construction (including preliminary assessment of trees that may be impacted); (2) restoring or enhancing trees following construction; and (3) design alternatives and site enhancements to improve survival and growth rate of trees planted following construction. These topics were assessed with consideration to all stages of a construction project, and the information organized by the construction process time line, beginning with best practices in the planning and design stages, then moving through the construction process to completion and finally replanting and landscaping procedures. Figure 2.1 references the project development process as seen in Chapter 2 of the PDDG (2006 ed.). For the purposes of this report, these project development stages were simplified into several broad categories, (1) planning, (2) design, (3) active construction, and (4) post-construction maintenance.

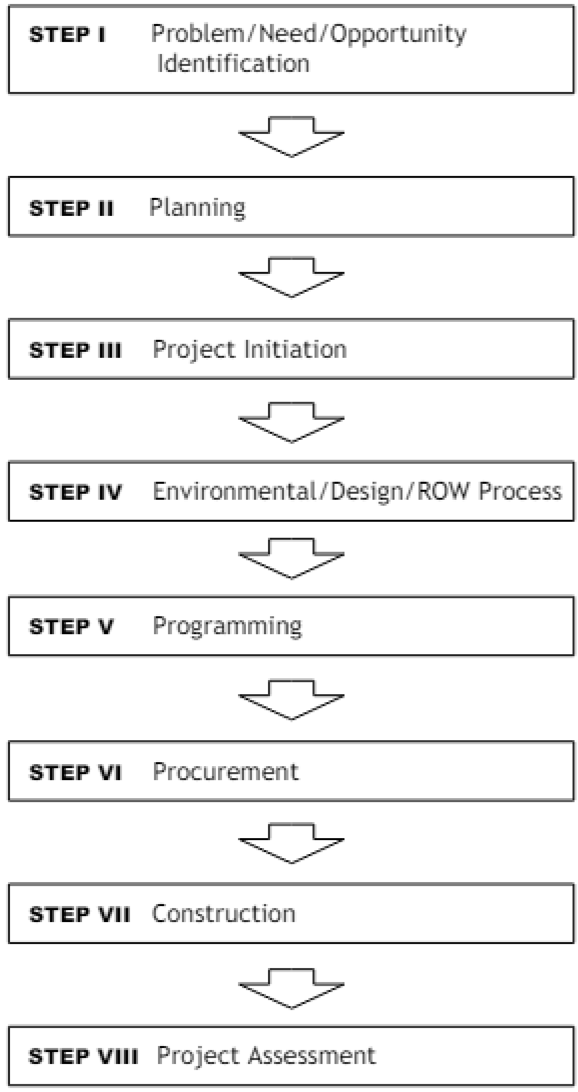

Figure 2.1 MassDOT project workflow

Source: Chapter 2 MassDOT PDDG 2006 ed.

The literature review provided the foundational information to (1) assess the current state of tree preservation practices, (2) highlight common themes and techniques, and (3) identify new and novel approaches. The literature review was further discussed with the panel of experts to workshop content and flow, as well as begin to develop the survey tool. The literature review is presented in full in Appendix A.

2.3 Task 2: Stakeholder Engagement

The second stage of the project consisted of the formation of a panel of local and regional experts representing a variety of disciplines relevant to the project scope. The panel was designed to advise on current best practices and methods for tree preservation, provide insight into the construction and engineering perspectives, and shape appropriate objectives for subsequent project tasks. Individuals were invited by email to join the expert panel, and all prospective members were enthusiastic to join the project (Table 2.1). Meetings were conducted using the Zoom video conferencing platform to accommodate members' schedules and geographic distances. Panel members were introduced to the project in a kick-off meeting in June 2022 and presented with a working draft of the literature review for comment. Feedback included suggestions for topics for consideration in the literature review, relevant articles to add to the list of citations, and comments describing members' experience with or expertise on a particular topic. Panel members' additional insights were incorporated into a second draft of the literature review during the summer of 2022. An additional panel meeting was held in September 2022 to complete the literature review. A full list of panel meetings and objectives is available in Table 2.2.

During the meeting in September 2022, panel members were also asked to comment on the creation and distribution of the survey (described in Task 3). Members were advised on the content to be covered, the format and length of the survey, and proposed organizations that would be candidates for receiving and distributing the survey. Panel members' input was essential during the iterative process of survey creation, and with the support of the UMass Institute for Social Science Research (ISSR), the survey was ready for distribution in March 2023. At the conclusion of the survey, members were briefed on the results, as well as the next tasks in the project. Members were continually engaged to provide support in the drafting and creation of technical memoranda advising proposed changes to the current MassDOT tree protection practices as reflected in the PDDG.

Table 2.1 Panel members and affiliations

Panel Member	Role	Affiliation
George Ackerson	Consulting Arborist	Horticultural Technologies
George Batchelor	Supervisor of Landscape Design	MassDOT
Julie Coop	Urban Forester	MA DCR
Madeline DeClerck	Project Manager	MassDOT
David Hawkins	Consulting Arborist	Urban Forestry Solutions
Jamie Magaldi	Tree Warden and Engineer	Wilmington MA
Matt Mann	Manager of Research	UMTC/Baystate Roads
Andrew Schlenker	Senior Landscape Architect	MassDOT
Violet Wilkins	Transit Coordinator	MassDOT

Table 2.2 Schedule of panel meetings

Meeting	Date	Topics Discussed
1	November 22, 2021	Introduction of project co-champions
2	January 5, 2022	Scope of research project
3	April 20, 2022	Review of literature review outline
4	June 27, 2022	Additional topics for literature review
5	July 22, 2022	Updates to literature review topics and format
6	Sept 12, 2022	Closing out literature review, beginning survey process
7	October 25, 2022	Survey topics and distribution process
8	November 21, 2022	Refinement of survey topics, overview of distribution
9	January 4, 2023	Review of survey questions
10	January 31, 2023	Review of survey questions
11	February 23, 2023	Final review of survey questions
12	May 22, 2023	Survey results and next steps
13	October 18, 2023	Review of the updated PDDG
14	March 13, 2024	Recommendations to the PDDG, best practices summary
15	June 20, 2024	Project close-out meeting

Note: All meetings were conducted virtually via Zoom.

2.4 Task 3: Survey Methodology

2.4.1 Survey Development Process

A formal survey was conducted to gauge professional opinions on matters of street tree preservation across the United States. The survey was carefully workshopped by project investigators with feedback from the expert panel to ensure topics encompassing the project scope were all appropriately addressed and that question language and format were easily understood. The UMass ISSR also provided feedback in the formulation of survey content, as well as assistance with the Qualtrics XM platform (Qualtrics 2005).

The first step in the survey process was a meeting with the panel to review the contents of the literature review and identify areas that would benefit from further investigation. These topics included preservation operations, municipal and contractor procedures, and further specification of methods and details. The overall objective of the survey was to reach a broader audience across the United States and receive feedback from individuals representing a variety of occupations and their respective opinions on tree preservation.

After receiving input from the panel and developing a list of desired topics to cover, I began to structure questions into categories, chronologically following the project development process.

2.4.2 Survey Creation

The survey included 40 questions of several formats, including multiple choice, ranking and rating, and open-ended responses. The questions started with five demographic questions to establish answerers' geographic location and role in the construction process. Respondents were then guided through questions asking about their experience with and opinions on techniques and strategies for tree preservation during construction projects throughout all stages of the process. Respondents were also able to present specific opinions and free response questions or provide further resources at their discretion. A complete copy of the survey as presented to recipients can be viewed in Appendix B.

First, we gathered demographic information about respondents. This was done so that we would be able to interpret the lens through which respondents viewed tree preservation, including information such as their occupation category, the type of environment in which they work, and the US state in which they worked.

The next section of the survey contained questions relevant to the planning stage of the process. These questions included topics regarding operational use of tree protection guidelines, the timing of tree protection discussions, and potential obligations in construction projects. Also in this section, respondents were asked to rank the effectiveness of a variety of methods for successful tree establishment and stormwater management, as well as tree protection strategies. The next set of survey questions included subjects regarding the design process of a project. The questions included more rankings for design strategy effectiveness and an opportunity to provide in-depth specifications for design parameters. Parameters could be specified through a structured text response or through the opportunity to upload documentation or web pages. At the end of this section, respondents were asked about the tree inventory process and their level of involvement in that process. Respondents who reported themselves to be involved in the tree inventory process were directed to an additional set of questions about tree inventory and assessment. Respondents who reported not to be involved were directed to the next section regarding topics of active construction.

Respondents who selected involvement in the tree inventory and assessment process were asked about the level of detail at which the assessment was conducted and additional factors of consideration. Respondents were also able to provide open-ended feedback in this section regarding the inventory and assessment process.

All respondents were then directed to the section covering measures of active construction protection. This included inquiries regarding protection reference documentation, measures of awareness and enforcement, and another opportunity for open ended feedback. The final section of the survey covered topics of site and planting maintenance after construction. The questions in this part dealt with contractor maintenance obligations, warranty periods, priorities and responsibility in maintenance plans, and a final call for open-ended feedback throughout the process. A flowchart detailing survey progression is shown in Figure 2.2. All survey respondents were presented with the first three sections covering demographics, planning, and design questions. At the end of the design questions, a question asked respondents about their personal involvement with tree assessment in regard to development projects. Participants declining involvement were directed to Section 4 (construction) and through the remainder of the survey. Participants answering with involvement were directed to separate block of questions on tree assessment. After respondents in the tree assessment subgroup completed Section 3.1, they were directed to Section 4 (construction) and through the remainder of the survey.

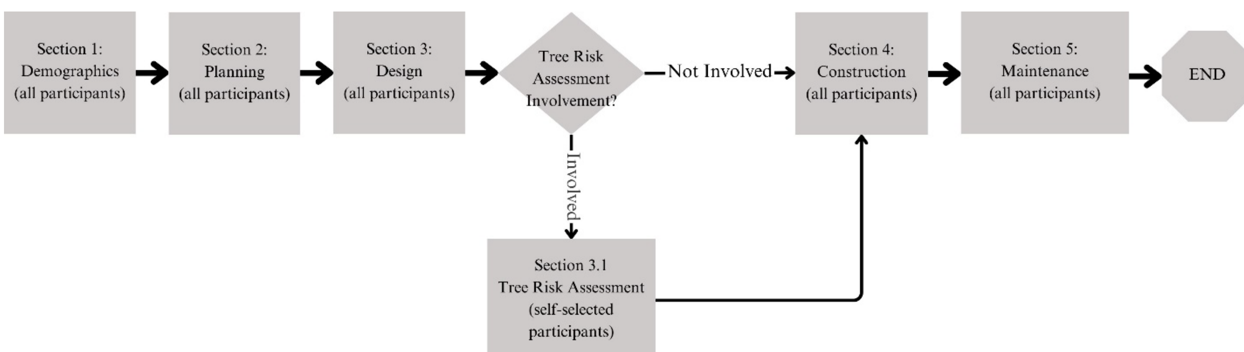

Figure 2.2 Survey flowchart

2.4.3 Distribution Process

Concurrently with the development process, I met several times with individuals from the UMass ISSR department for assistance with the format and distribution process. ISSR first advised on survey processes, including notification letters, appropriate timing intervals, and potential methods of distribution. After deciding that an online survey would be most appropriate for this project, ISSR staff provided both licensing information and instruction on using the Qualtrics XM platform. They provided guidance on structuring and formatting questions, organizing survey layout, and feedback on questions, working to optimize readability and respondent interpretation. Once the survey was made available online, ISSR staff also provided direction on understanding, reviewing, and exporting response data.

A selection of professional organizations in disciplines relevant to the project scope were selected to be the recipients of the survey. The organizations contacted are listed in Table 2.3. Administrative representatives for each organization were collaborated with to ensure seamless distribution to their organizations via newsletters and email listservs.

Table 2.3 Organizations contacted for survey distribution

Organization	Distribution Method
American Council of Engineering Companies—MA chapter (ACEC/MA)	Email list
American Society of Landscape Architects—Boston chapter (BSLA)	Email list
American Society of Consulting Arborists (ASCA)	Email list
International Society of Arboriculture—New England Chapter (ISANE)	Email list, newsletter
Massachusetts Tree Wardens and Foresters Association (MATWFA)	Email list
Massachusetts Arborists Association (MAA)	N/A, no response
New York City Parks (NYCP)	Email list
University of Massachusetts Transportation Center (UMTC)	Email list

Respondents were first notified of the incoming survey in early March 2023 via a cover letter, and then a follow up notice on March 13, 2023, when the survey was opened to recipients. A copy of one of these notices can be found in Appendix C. The survey remained open for eight weeks, and all recipient organizations were sent a reminder notice one week prior to closing. This time line and communication process was in conjunction with recommended practices by UMass ISSR staff and with methods recommended by Dillman et al. (2014) [11].

2.4.4 Survey Analysis

Following the 8-week response period, the survey was officially closed to responses. A total of 58 unique respondents opened the survey link before the closing date, and 45 fully completed the survey. Of the 13 incomplete responses, 6 responses were entirely discarded. These 6 responses were discarded because respondents did not complete the first section of the survey, the demographic information. The other 7 of the 13 incomplete responses were included in the demographic analysis to better understand the survey's reach. However, in the subsequent sections of the survey, these 7 responses were discarded because respondents did not complete the survey in full.

Survey results were mostly collected in the form of multiple-choice questions, where respondents were able to select one or multiple options that best described their answer. These questions were processed using Microsoft Excel (Microsoft Corporation 2021) to organize the data and develop tables and charts reflecting responses. If respondents were given the option to select multiple answers, percentages were calculated to determine the fraction of the total audience who represented that choice. Some questions asked recipients to classify techniques based on their perceived effectiveness. For these questions, the total count of each effectiveness level per technique was tabulated to determine the percentage of respondents who responded as such. For questions using a ranked choice format, the average rank for each option was calculated and used to process results.

Throughout the survey, there were opportunities for respondents to provide additional comments on open-ended questions regarding design strategies, tree assessment and protection, and long-term maintenance. These comments were compiled and screened for common themes and new insights that were incorporated into the best practice recommendations (Section 3.3).

3.0 Results

3.1 Survey Results

3.1.1 Survey §1: Demographics

In the demographic information, eighteen US states were represented, with most respondents from California, Massachusetts, New York, and Florida (Figure 3.1). A recipient from the United Kingdom provided information and guidance used in his tree care company, but his response was excluded in the survey analyses. Respondents represented many professions, most from arboriculture-related professions (e.g., arborists, urban foresters, and tree wardens) (Figure 3.2). The remainder of individuals represented landscape architects, civil engineers, managers, and those reporting as “other,” which included DPW directors and landscape economists. Respondents represented a variety of work environments, with most reporting they worked in urban or suburban residential and commercial communities (Figure 3.3). Some individuals included additional environments such as groves and plant nurseries. The amount of a respondent’s daily work that was related to transit corridor construction is shown in Figure 3.4. Many respondents indicated that at least some of their work involved pedestrian facilities; many fewer respondents indicated that “all” or “none” of their work was related to transit corridor construction. Opportunities for continuing education were available to the vast majority of respondents but only mandatory for half of respondents (Figure 3.5).

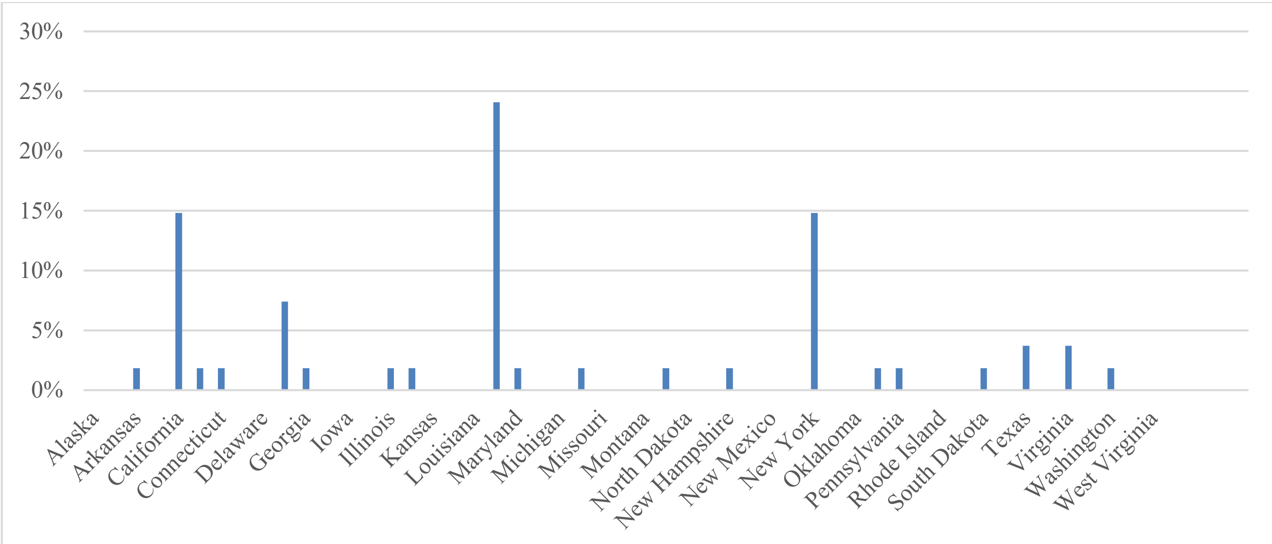

Figure 3.1 Respondent location

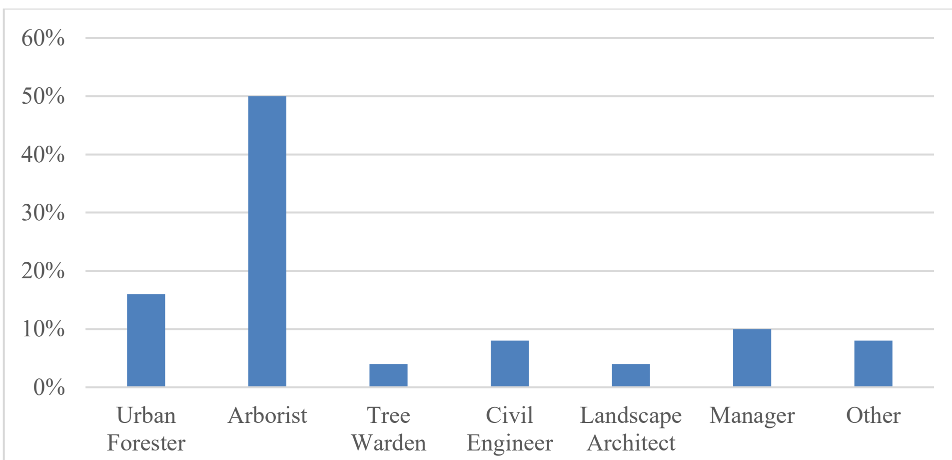

Figure 3.2 Respondent profession

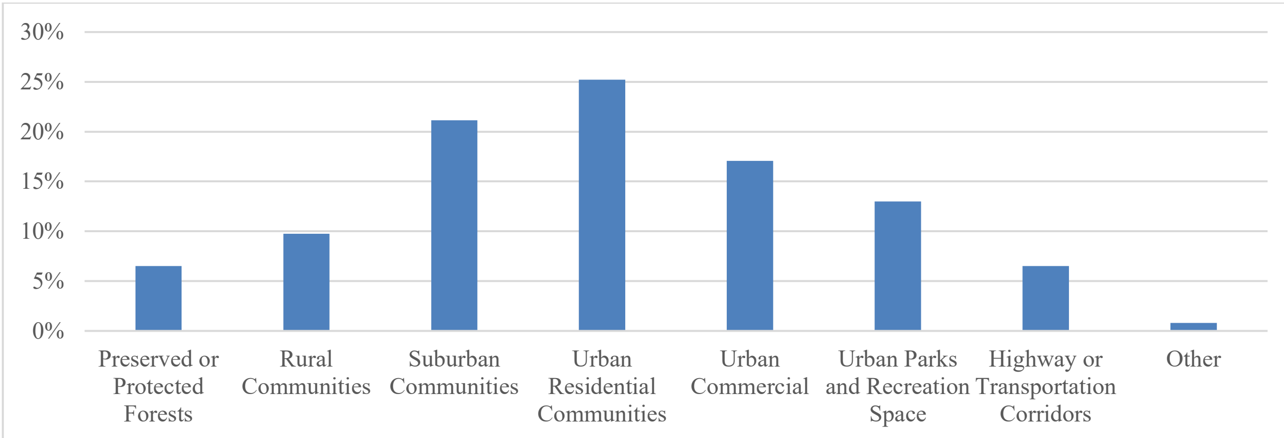

Figure 3.3 Respondent work environment

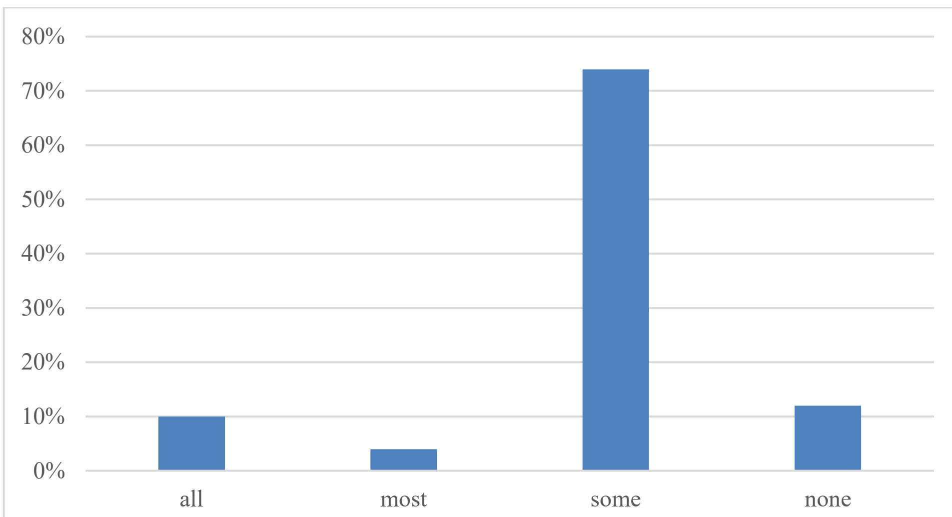

Figure 3.4 Daily work with transportation corridor construction

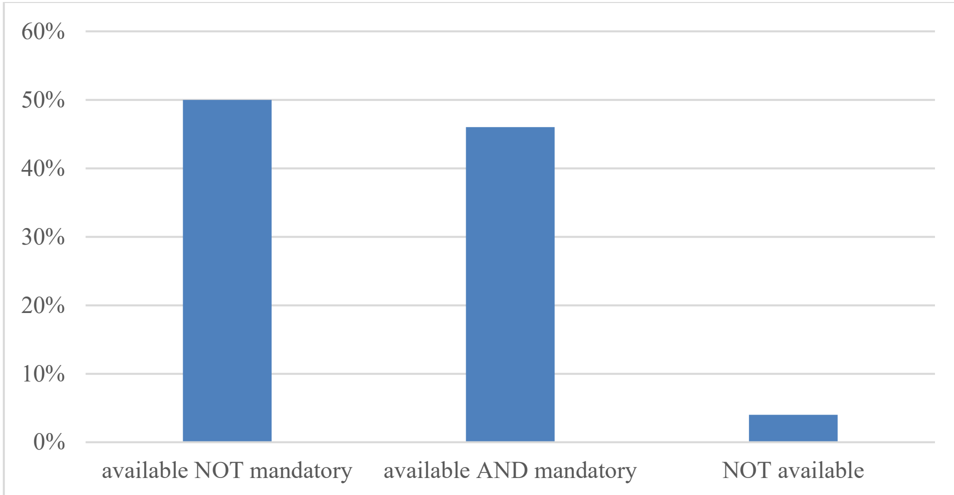

Figure 3.5 Availability of continuing education opportunities

3.1.2 Survey §2: Planning

The next block of questions asked about the planning and preparation process in construction project development. Most reported the company or municipality they represented had policies for the construction of sidewalks and transit infrastructure along road edges (Figure 3.6). The majority of respondents stated that they operated with tree protection guidance, and most guidance was sourced from ISA BMPs, the ANSI A300, or municipal and local guidelines. A full breakdown of guidance types can be seen in Figure 3.7. Many recipients said they or their team began to consider tree health on the construction site starting in the planning stage, with smaller counts saying later in the process or that tree health was not a primary consideration (Figure 3.8). Some respondents said that new tree planting requirements were project dependent, whereas others reported that the number, area, installation, and maintenance were mandated (Figure 3.9). Participants indicated a variety of elements that may be included in their planting and reforestation guidelines, including soil remediation practices and long-term maintenance (Figure 3.10).

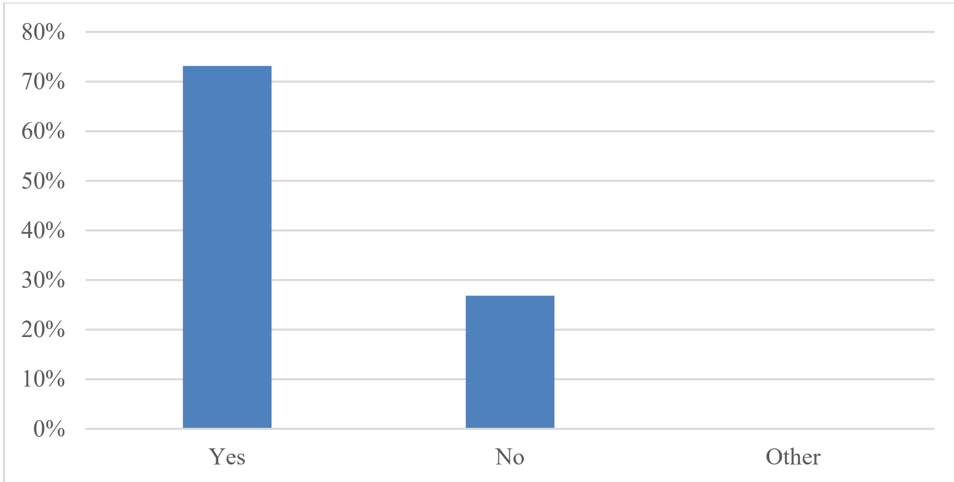

Figure 3.6 Incorporation of tree protection guidance

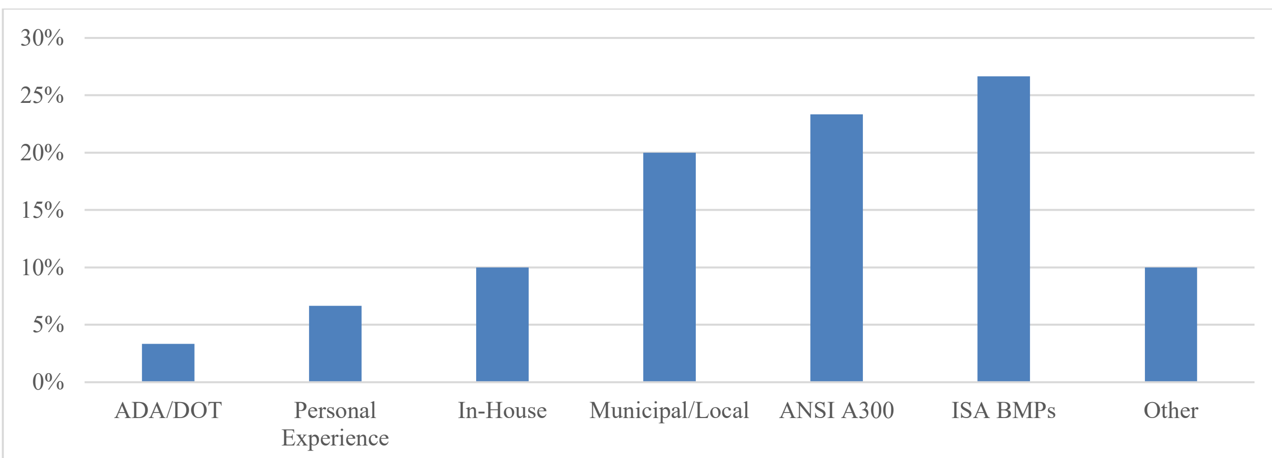

Figure 3.7 Tree protection guidance source

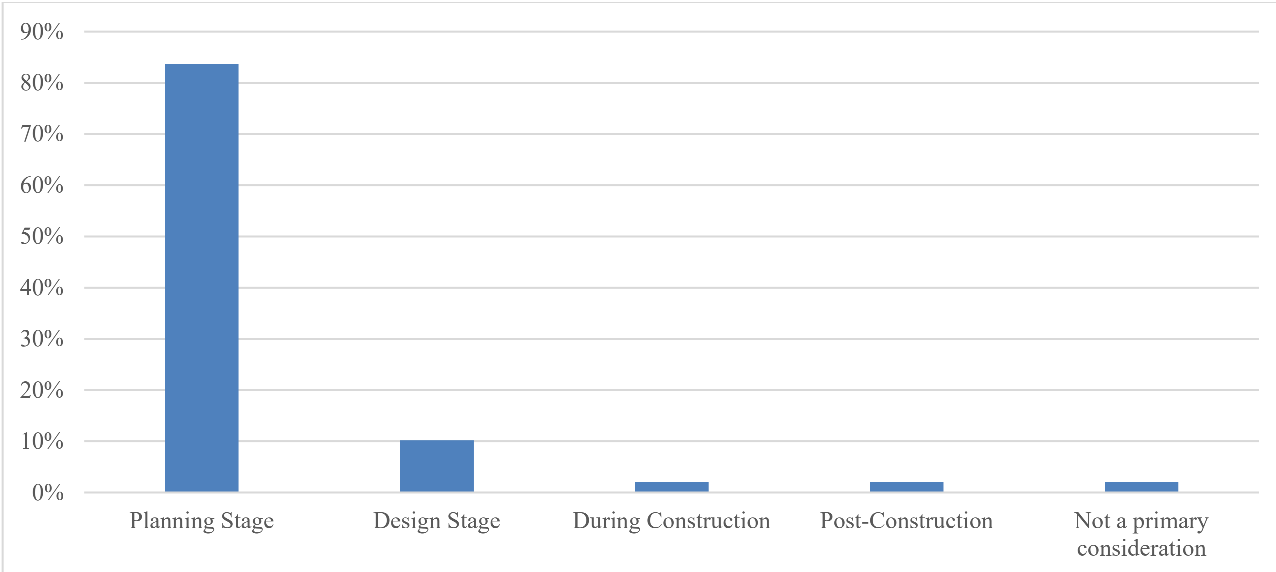

Figure 3.8 Tree protection consideration by stage

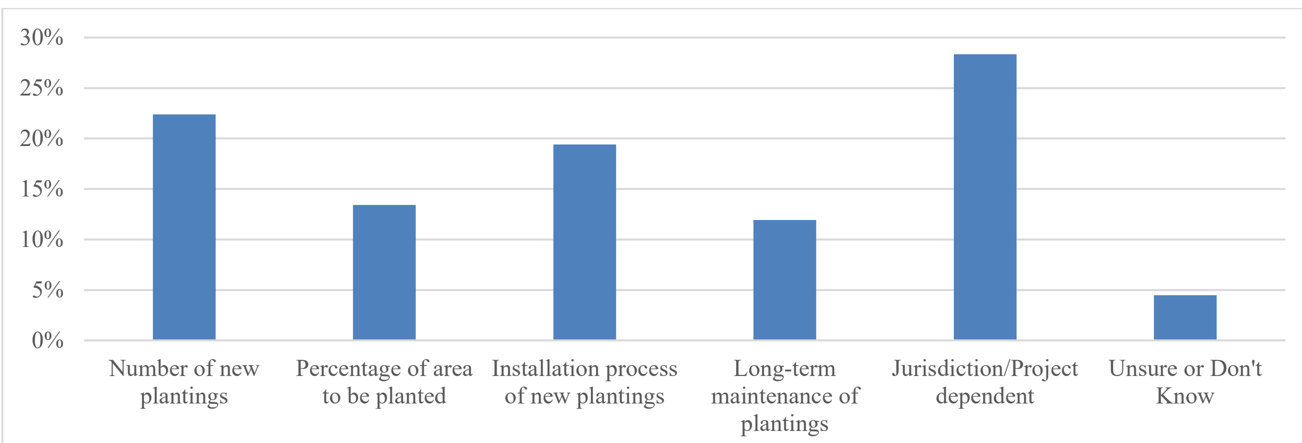

Figure 3.9 New tree planting requirements

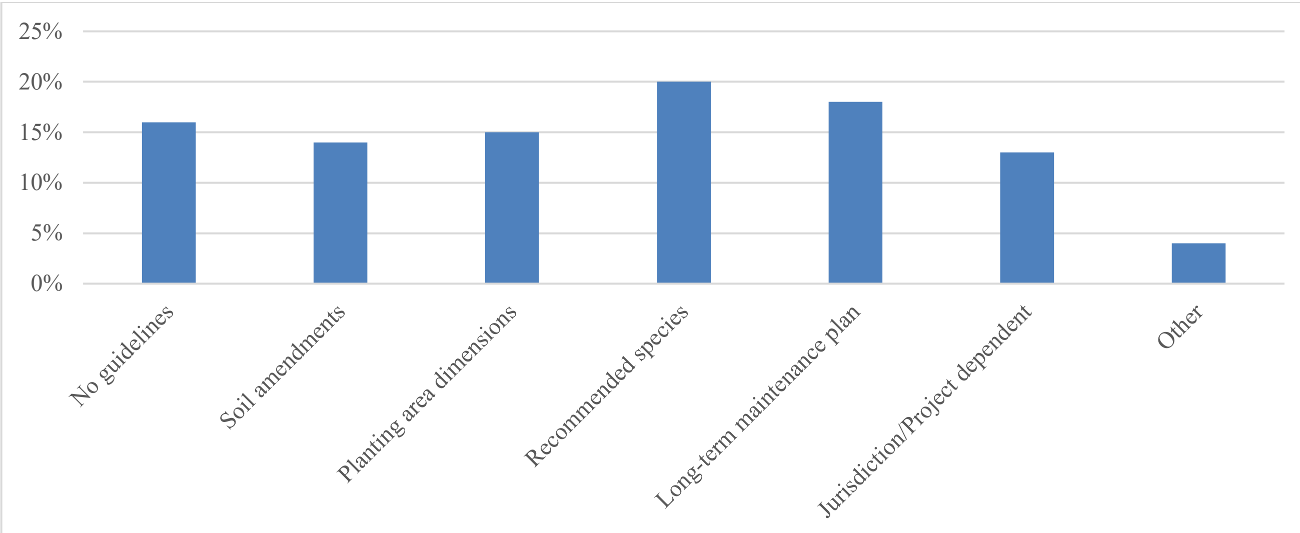

Figure 3.10 Planting and reforestation guidelines

Respondents considered most suggested methods of improving tree success in construction to be at least "somewhat effective." Some methods considered to be very effective included soil remediation and aeration. Several reported that they considered preemptive root pruning to be detrimental to the success of trees following construction projects (Figure 3.11).

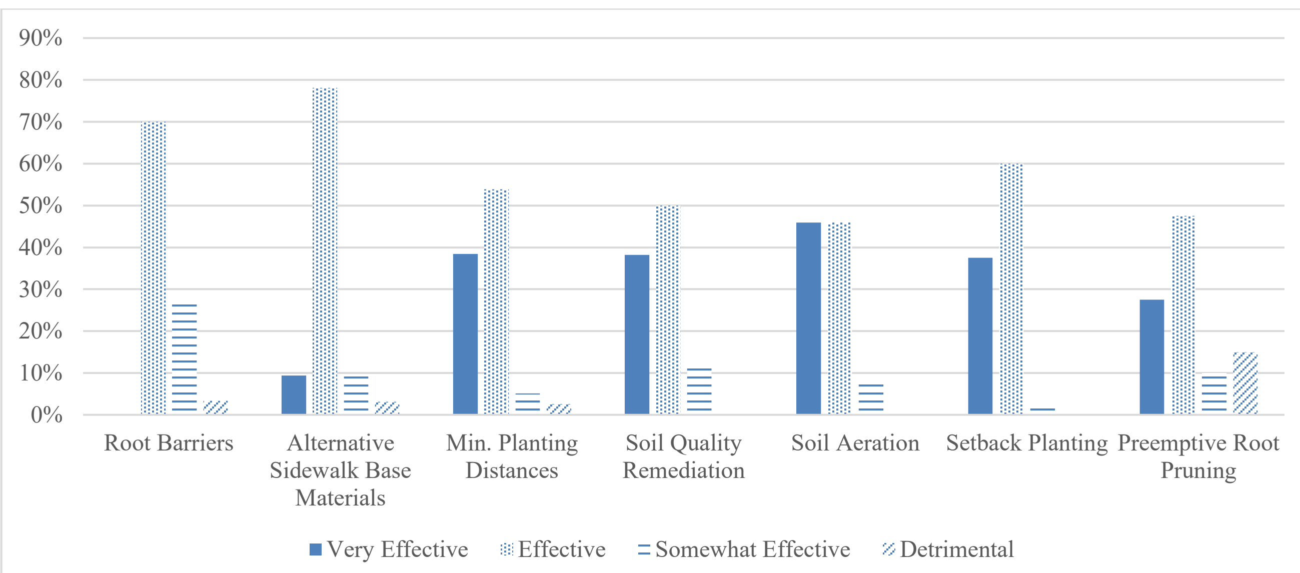

Figure 3.11 Effectiveness of tree success methods

A majority of recipients said their work did not include planning for street trees in conjunction with stormwater management improvements (Figure 3.12). Most indicated that the provided methods of stormwater control were "effective" or "very effective." However, measures such as stormwater tree pits and permeable pavements were considered to be only "somewhat effective" by some respondents (Figure 3.13). Many reported that a tree assessment, root protection zones, and designated storage areas were very effective tree protection strategies. No strategies listed were considered to be detrimental by respondents (Figure 3.14). Approximately half of the participants reported that their definition of a CRZ was site dependent, a smaller amount reported using the ISA standard definition of 1.5 feet of root zone per inch of DBH, as seen in Figure 3.15.

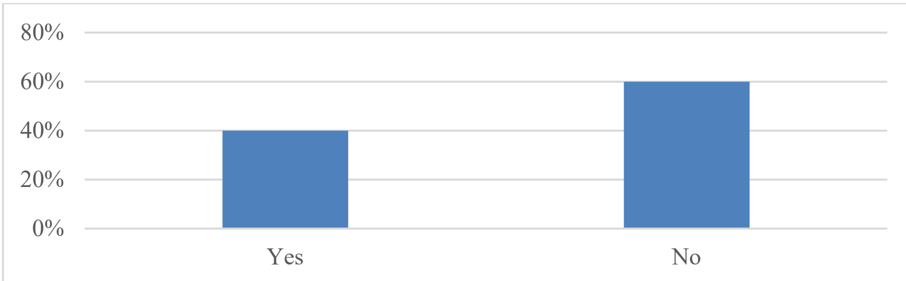

Figure 3.12 Respondent work with stormwater management

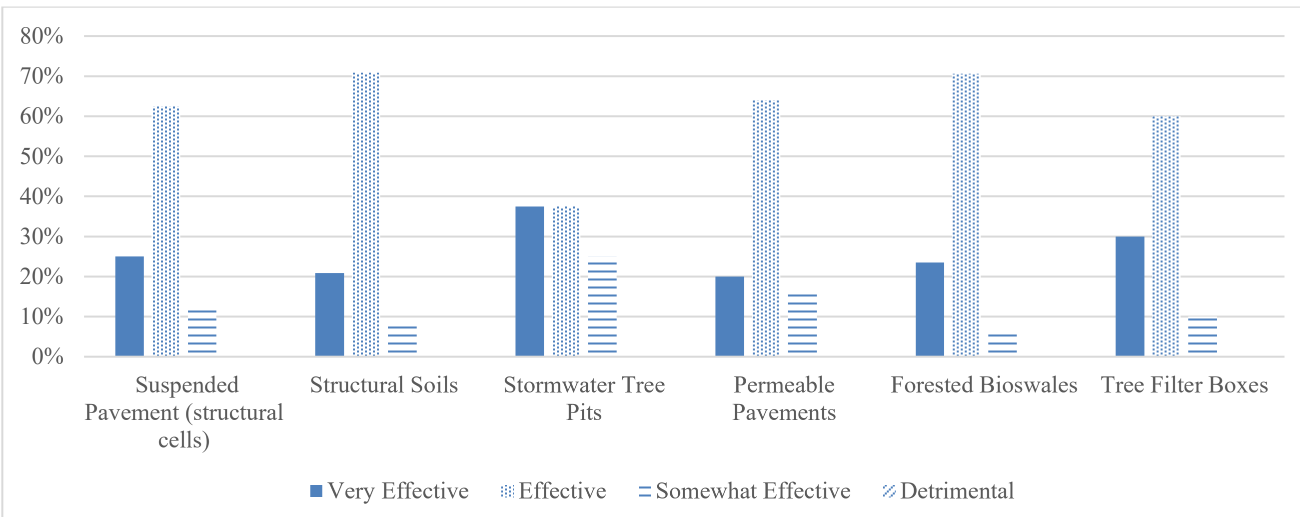

Figure 3.13 Effectiveness of stormwater control methods

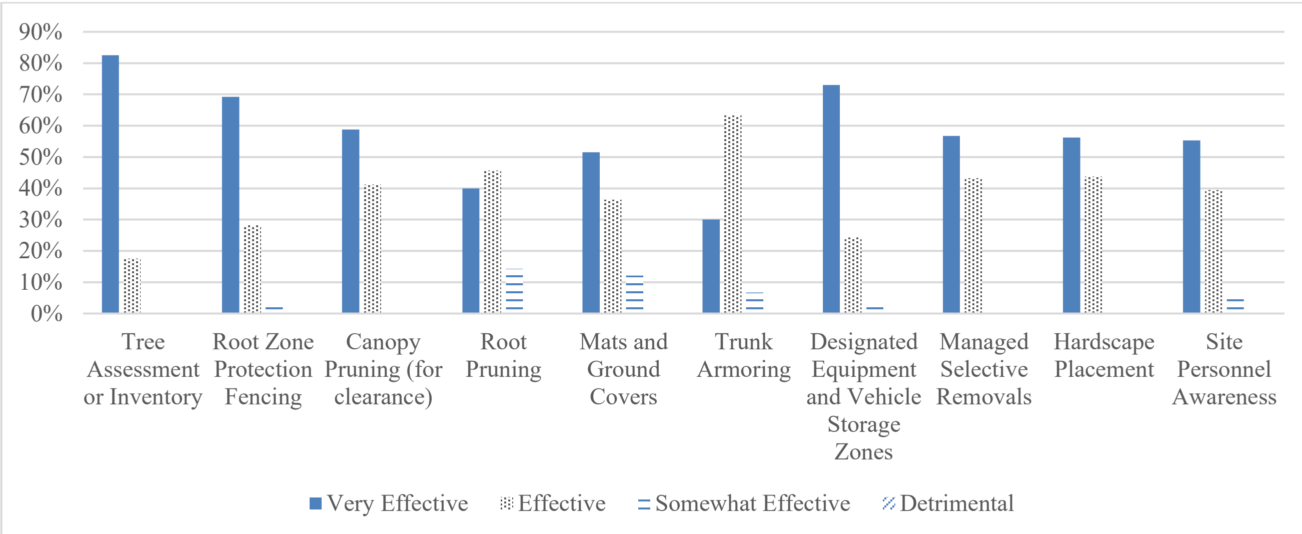

Figure 3.14 Effectiveness of tree protection strategies

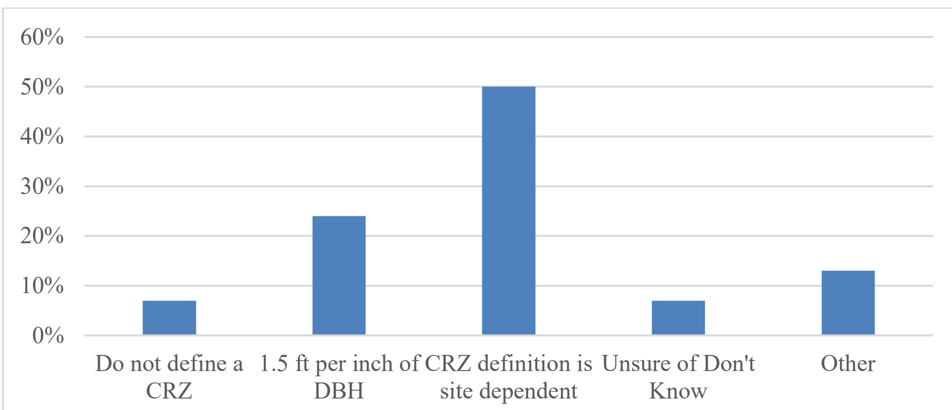

Figure 3.15 Operating definition of CRZ

3.1.3 Survey §3: Design

The next set of questions covered topics in the design stage of the construction process. Most strategies offered for minimizing tree and infrastructure conflicts were considered to be at least somewhat effective, including grouped tree trenches and porous pavements. Some respondents reported methods such as raised tree planters and root barriers to be detrimental (Figure 3.16). The following questions asked recipients about their specifications for parameters of the previously mentioned design strategies, which resulted in a variety of metrics. Respondents were also given the option to upload or attach additional documentation, but none elected to do so.

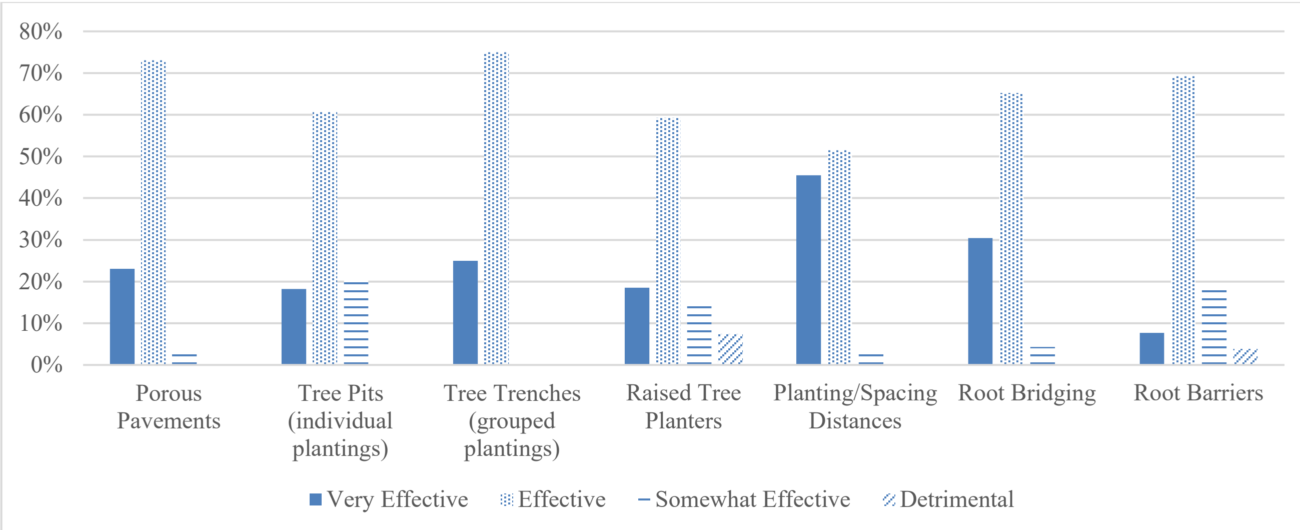

Figure 3.16 Effectiveness of strategies for minimizing infrastructure conflicts

Most respondents reported that for the projects they work on, a tree inventory is conducted and required, and some stated that an inventory was conducted but not required (Figure 3.17.) The majority of recipients responded that they were personally involved in the tree inventory and assessment project (Figure 3.18.). Those responding that they were involved were directed to the following subset of questions, those declining involvement skipped to the next question block.

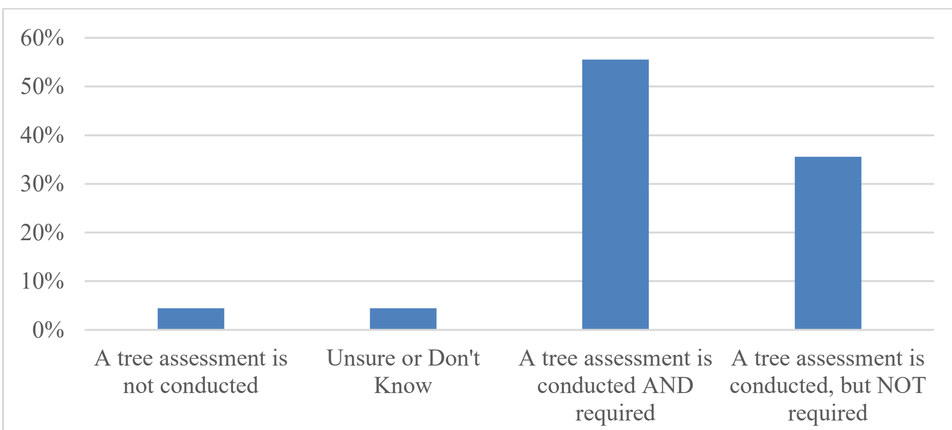

Figure 3.17 Tree assessment requirements

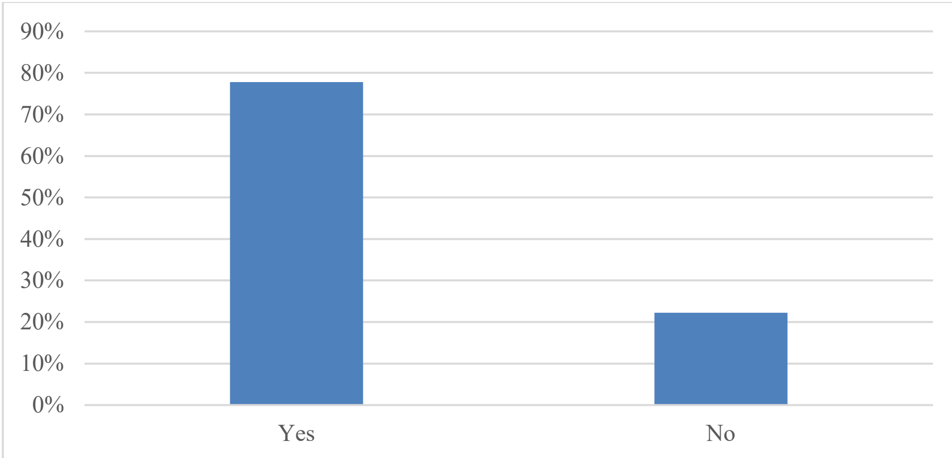

Figure 3.18 Respondent involvement in tree assessment

3.1.4 Survey §3.1: Tree Assessment

Most participants said that they personally conducted the assessment, with fewer saying the assessment was conducted by someone in their department or by an external consultant (Figure 3.19). The majority of respondents said the assessment followed ISA procedures, while some said they followed adapted or partial guidelines (Figure 3.20). Most responded that the tree assessment was conducted at a level 2 (according to ISA procedures) a basic assessment with simple tools (Figure 3.21). Some said that the level of inspection varied with project circumstances. Additional factors considered in the inventory process included utility relocation, pavement and hardscape expansion, and construction equipment mobility; a full breakdown is shown in Figure 3.22.

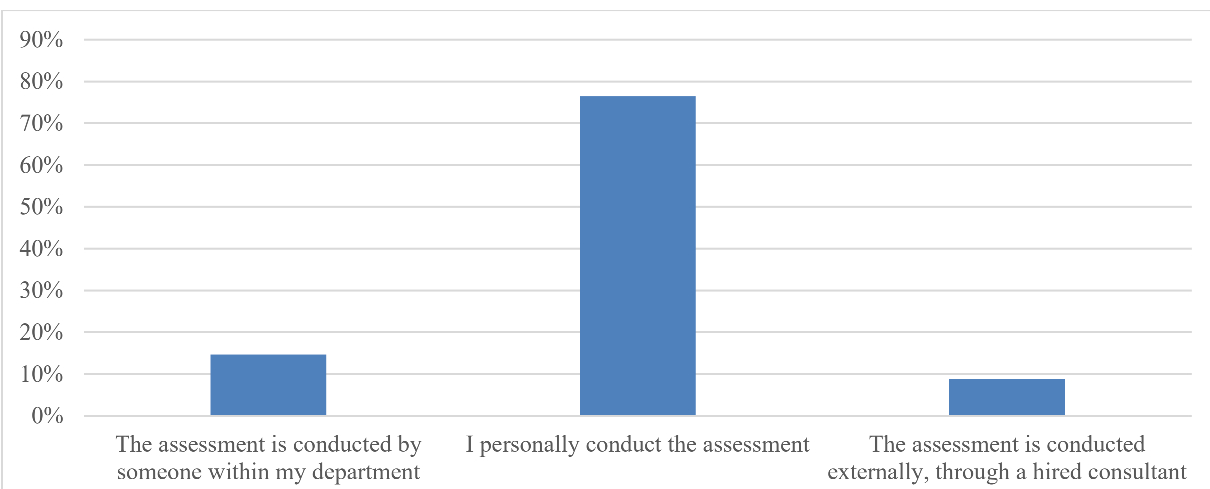

Figure 3.19 Personnel conducting tree assessment

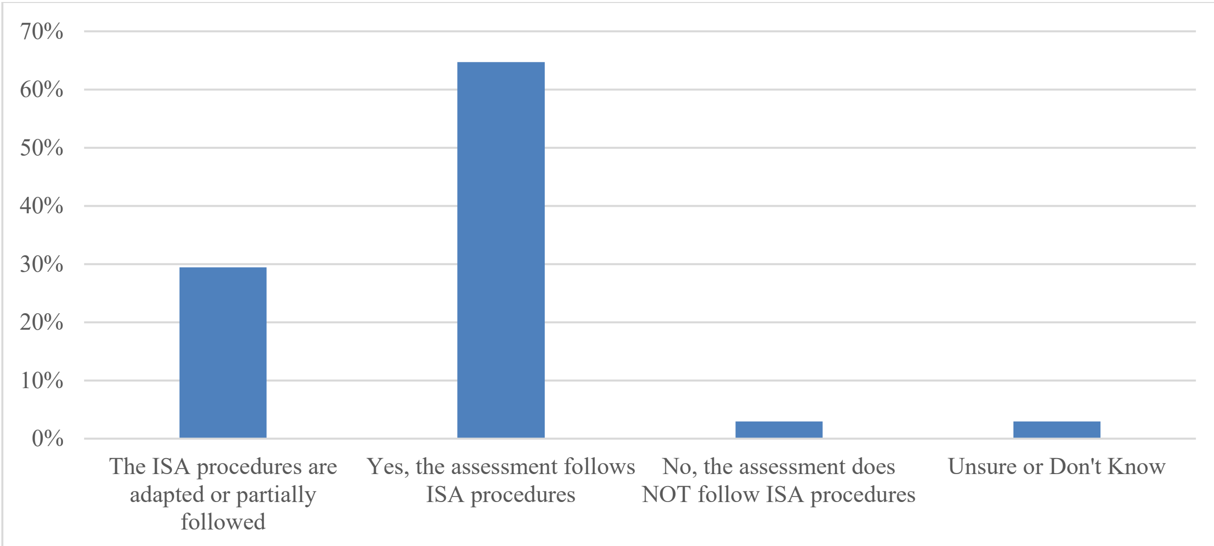

Figure 3.20 Tree assessment guidelines

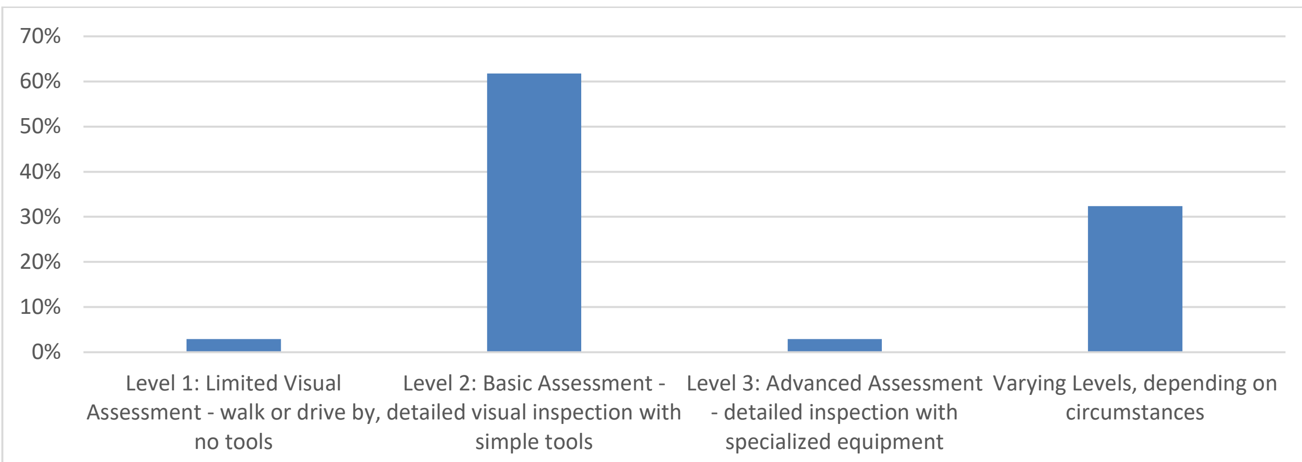

Figure 3.21 Tree assessment level

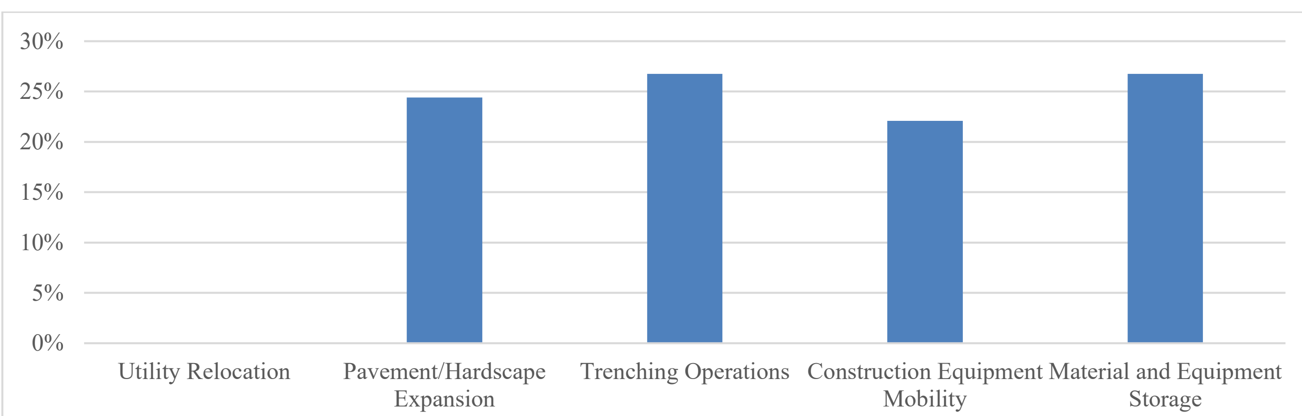

Figure 3.22 Additional factors in tree assessment

3.1.5 Survey §4: Active Construction

All respondents were directed to this block of questions, regardless of their previous responses. The majority of respondents said they had a reference document for tree protection and management during construction projects (Figure 3.23). A variety of methods were reported to ensure awareness on site about tree preservation. These methods included signage, meetings, and memos. Responses can be seen in Figure 3.24. The majority of respondents stated that they did conduct site visits to ensure tree protection measures were being adhered to (Figure 3.25). The last question in this block invited respondents to share additional comments and strategies regarding tree protection for active construction projects. Many respondents underscored the importance of site monitoring and inspection to ensure the tree protection is not removed or disregarded. Communication was also an important theme in these responses as individuals remarked on the importance of understanding the reasoning behind the measures on site.

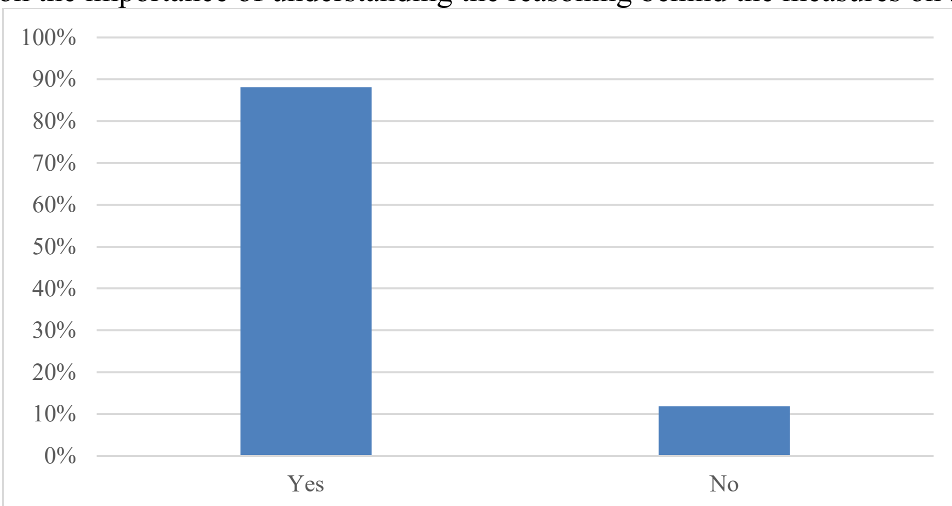

Figure 3.23 Reference documentation for tree protection

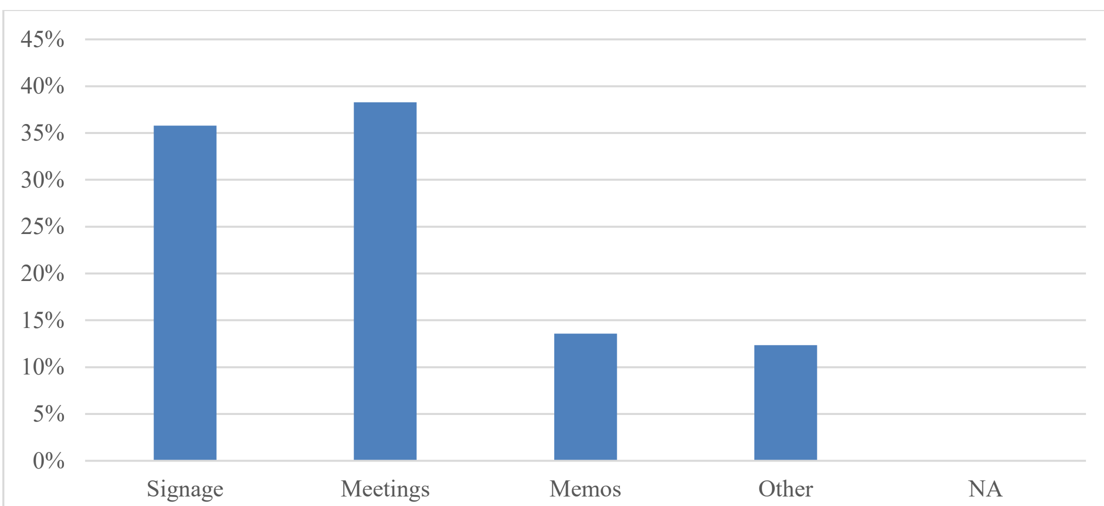

Figure 3.24 Methods of tree protection awareness

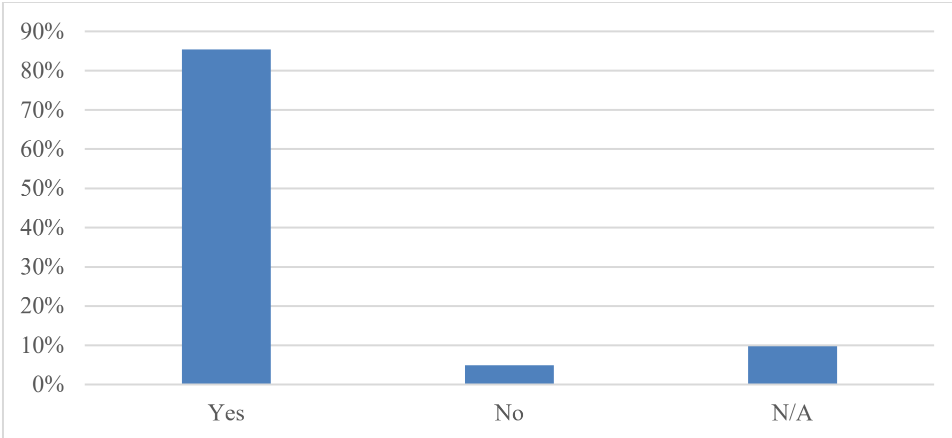

Figure 3.25 Tree protection enforcement

3.1.6 Survey §5: Post-Construction and Maintenance

The final block of questions polled respondents on the long-term maintenance plans included in the contracts they work on. Most respondents reported that a long-term maintenance plan was in place, followed closely by those who reported that a long-term maintenance plan was not included in their contracts (Figure 3.26). The majority of respondents did include a warranty period, with most reporting a one- or two-year period (Figure 3.27). Some respondents stated that the warranty was jurisdiction dependent, and some reported that a warranty period was not included in contracts. Respondents indicated that risk assessment, mulching, and watering were among the highest priorities, with fall clean-up and trash collection being the lowest (Figure 3.28). Most recipients considered the listed irrigation methods to at least be effective, with some respondents reporting auto irrigation systems and watering bags to be detrimental (Figure 3.29). The majority of respondents reported that external contractors were responsible for tree and planting maintenance following the completion of the contract, followed by in-house staff. The responses are shown in full in Figure 3.30.

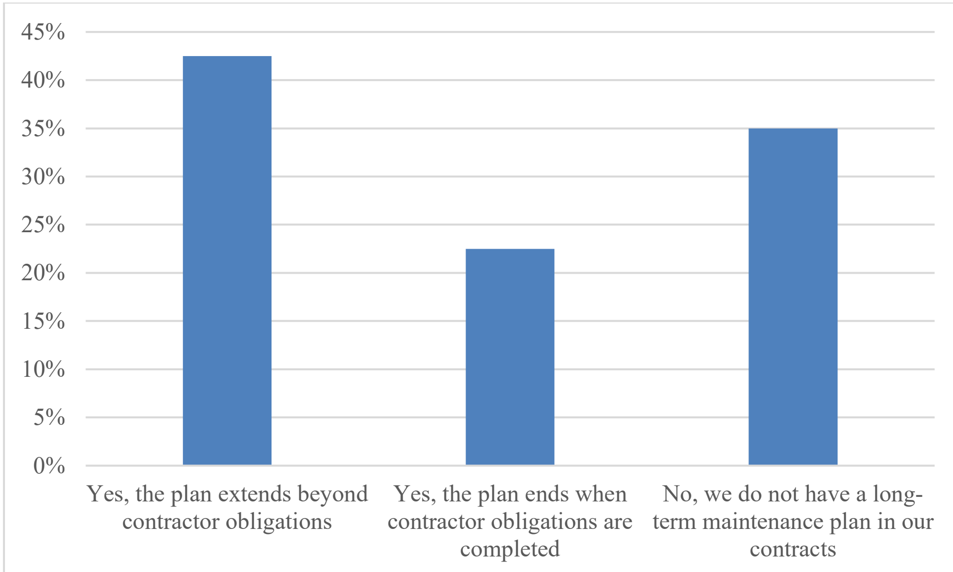

Figure 3.26 Long term maintenance plan inclusion

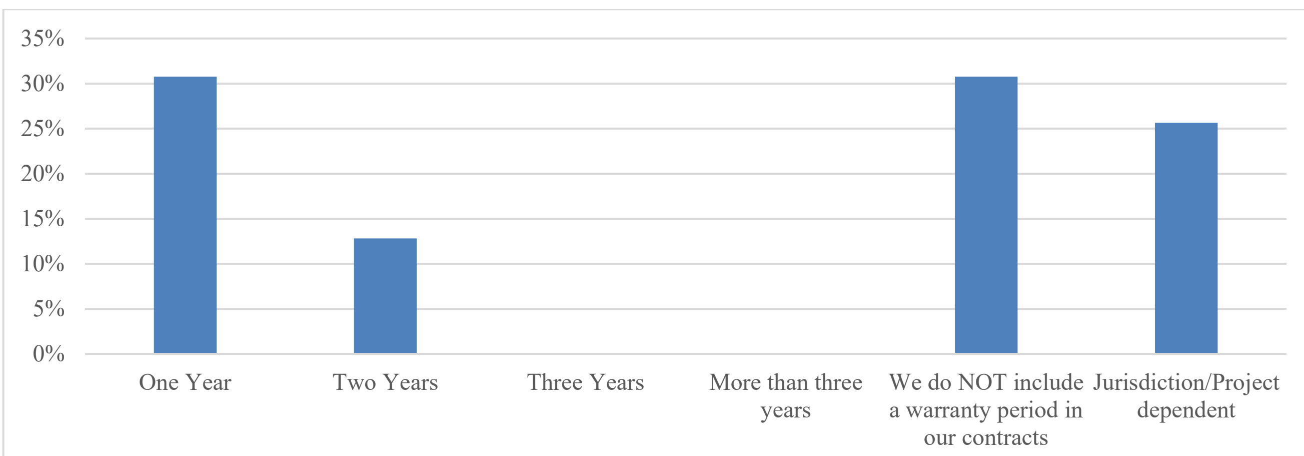

Figure 3.27 Maintenance warranty period

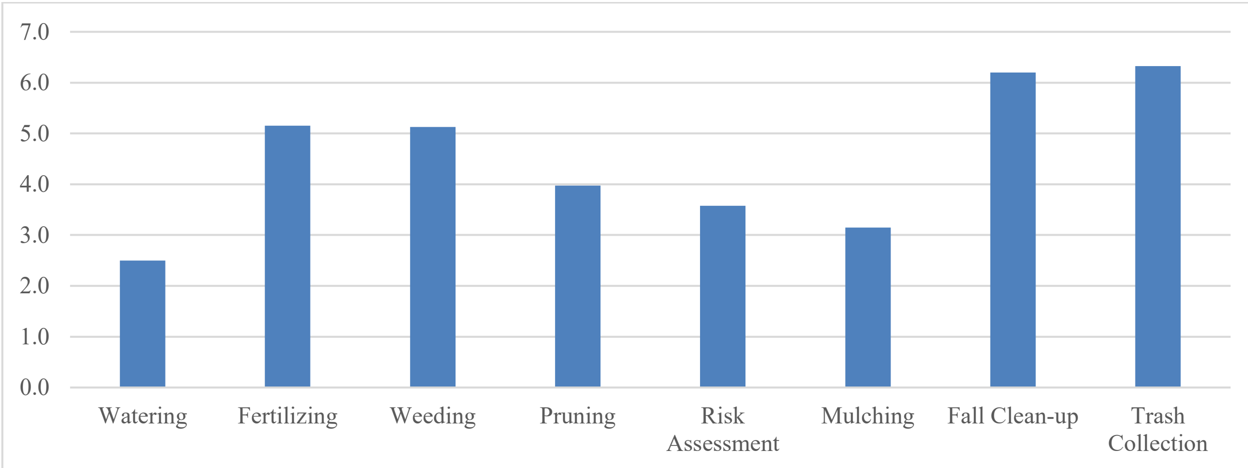

Figure 3.28 Maintenance priorities (*average priority value, 1 high)

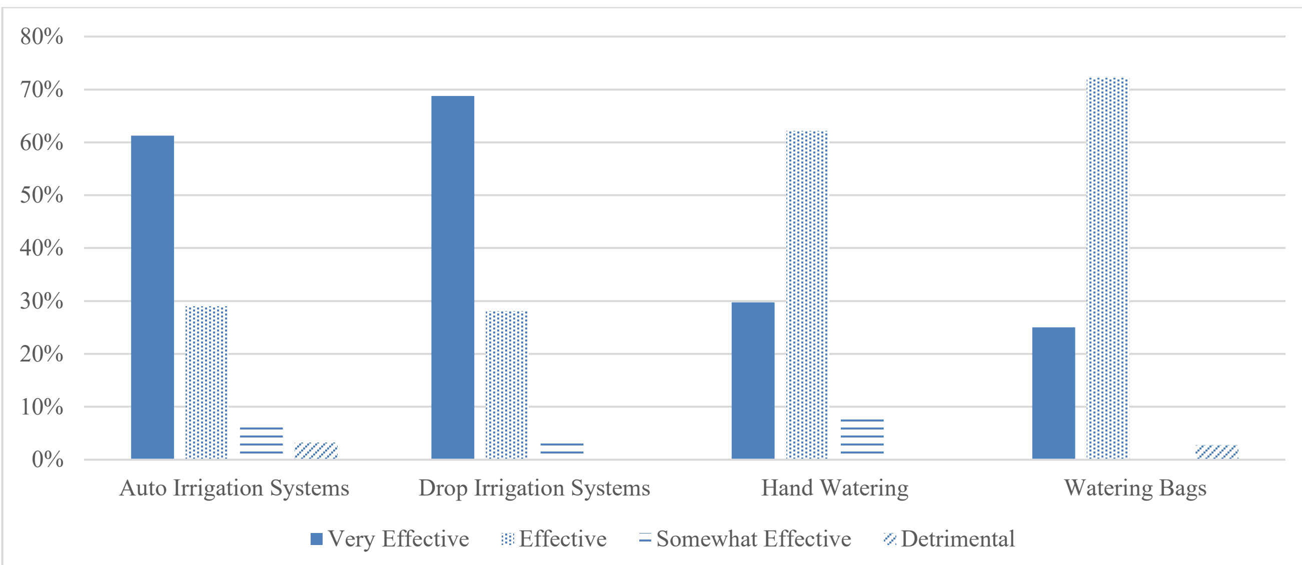

Figure 3.29 Effectiveness of irrigation methods

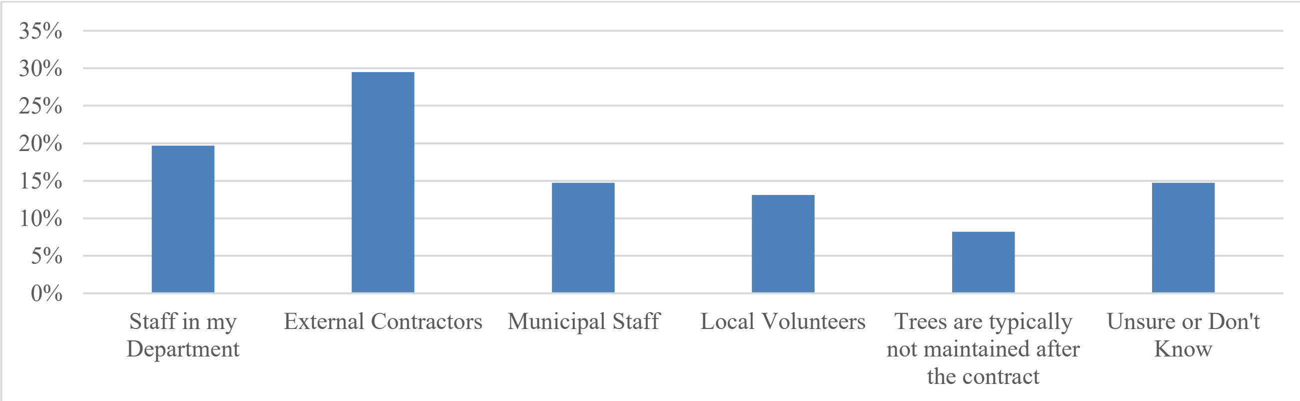

Figure 3.30 Personnel responsible for maintenance

The final question of the survey asked respondents for any final comments or strategies regarding street tree preservation and protection during construction projects. These comments pointed to many key themes regarding issues of education, communication, and access. Many respondents mentioned how successful and consistent communication is the most valuable tool in increasing awareness about tree preservation measures. Standardization of these measures leads to the creation of effective policies; however, these policies must be adaptable to suit the varying needs of projects and municipalities. Respondents suggested that the best practices for preservation in every stage be laid out and regular monitoring implemented to ensure the adherence to these measures. In reference to their role in supervising the implementation of preservation measures, one respondent said, "When the parties understand I am maintaining or increasing value and reducing their risk, it's a win for all." These individuals recognize their own responsibility in educating on-site parties about tree preservation and acknowledge the necessity in following up on-site for optimal results.

3.2 Survey Discussion

In survey responses, there were several overarching themes that were also reflected in the literature review and in panel discussions. On the subject of design strategies and modifications, respondents from the survey, as well as panel members, brought up the concept of adapting design plans to mitigate impacts to existing plantings. The option to remove specimens that conflict with plans and replant with new plantings may seem like an easy solution. However, the removal of a mature tree, assumed to be in good condition and not deemed hazardous, results in the loss of ecosystem services for the community. New plantings will take decades to match the shading extent, carbon sequestration capabilities, and aesthetic value of a mature planting. The accommodation of healthy existing plantings should be a high priority in the project planning phase.

Additionally, in the design of the post-construction plan, many respondents emphasized the importance of thoughtful plant selection and placement given the site conditions. New tree and shrub plantings should be sited with longevity in mind. An understanding of how the plant will grow and develop is critical, as is the consideration of anticipated site changes that may impact the plantings. Communication is vital for reconciling these difficulties, with all responsible parties understanding the long-term vision for the site, coupled with the immediate needs of development and revision.

On the subject of tree assessment and inventory, recipients underscored the varying nature of this process and how different governing bodies may approach assessment techniques. Also common in many responses was the significance of communication and understanding. Despite the varying procedures in place for each project, it is critical that a credentialed individual conduct the inventory, and then assemble the information to be distributed among the entire project team. This ensures that all involved parties have access to the same information regarding the tree inventory, and accompanying preservation recommendations and procedures.

When asked for further comment on the subject of tree preservation during active construction, respondents repeatedly emphasized the necessity of regular site monitoring and communication. Many stated that consistent supervision was often necessary to ensure preservation measures were being followed on site. They also noted that it is important to begin to consider preservation early in the design process and reinforce the reasons behind these measures through education and communication with project staff. Here recipients noted that a lack of resources often impedes their ability to conduct site visits to the degree and frequency desired for maximum effectiveness. Throughout the feedback sections, respondents reiterated how essential communication is to the preservation process, but how lack of resources frequently impedes the desired level of contact. Increased education and understanding for all will help alleviate the burden and assist all parties in working toward common goals of community enhancement and urban forest health.

3.3 Synthesis of Best Practices

This summary is of best practices for each stage of the construction process, following the review of all data collected during the project. The summary is structured chronologically through the project phases, starting with planning and design, through the end of planting and into maintenance.

3.3.1 Prior to Construction

The following actions are an overview of the recommended process to prepare the trees, site, and team members for construction activities. A recurring concept among all resources and expert feedback was the importance of communication, and the early establishment of a tree preservation plan. It is essential that the planning process begins with clear communication between all site personnel regarding the trees on site and the accompanying preservation plan.

1. Tree Inventory and Inspection

As early in the design and planning processes as possible, a tree inventory and assessment should be conducted by an arborist possessing appropriate qualifications from the ISA or MAA. These qualifications must include the agency's arborist certification and tree risk assessment qualifications but may also include municipal, utility, or other specialized certificates [12]. The inventory should include information on the location, size, condition, health, growing environment, and valuation of all trees and shrubs on site. The results of the inventory are shared with the design team and the arborists, designers, engineers, and architects who will work collaboratively to determine a preservation plan.

To ensure that trees are minimally impacted by the project, the location of the critical root zone for each tree should also be incorporated into the plans and drawings. From the plans, locations of sidewalks, utility lines, grade changes, trenching, or any other potentially damaging operations may be reassessed with this additional information [7]. If relocation of the infrastructure is not deemed to be feasible, the tree and root system should be carefully prepared in accordance with guidelines outlined by the ISA [13]. Please refer to the sections below that review best management practices for tree preparation and preservation. Additionally, the planning stage provides an opportunity to consider alternative materials that may be implemented on site to help improve the health of the trees. Porous hardscape options, structural soils, and suspended pavement are just some of a variety of material alternatives that should be considered and implemented as feasible.

2. Accommodating Planned Grade Changes and Retaining Walls

In the event that the surface grade must change within a TPZ, there are certain measures to take to ensure tree survival. If the grade is to be lowered, structural root pruning may be necessary, but should be avoided if at all possible. Tree islands and retaining walls are a solution to accommodate existing tree roots and a lower grade. For increases in grade, keep soil fill away from the trunk and root flare of the tree, and construct retaining walls for grade changes of more than 2 to 3 ft [7]. Root pruning may be necessary to cleanly and correctly sever roots that will interfere with retaining wall construction.

3. Meeting with Team Members

Any and all personnel who will be involved in the project, either on or off site, should be made aware of the tree protection plan. Members should meet to discuss the importance of a healthy urban forest, the common sources of damage to trees on a construction site, and the resulting consequences of any damage that occurs. The contract manager of the project should also discuss with contractors to establish and make clear any legal or financial consequences of damage to trees on both public and private lands.

At the meeting, a document should be distributed among all parties that contains the information for the tree protection plan and consequences for violation. This document should be easily accessible to all parties, with visual aids, plain language, and in a format for quick reference both on and off site.

4. Establish Site Movement and Storage Plan

In the early planning stage, accommodations should be made that delineate places for equipment and material storage well outside the TPZ. The storage of materials, equipment, vehicles, or machinery can severely compact the soil, which in turn can inhibit root growth, production, and overall tree health. A designated storage area outside of the TPZ allows for an organized site while simultaneously avoiding soil compaction and root damage.

In addition, traffic routes on site should be designated on the plan and all personnel made aware of the flow of equipment and machinery on site. The traffic plan should allow for safe and efficient workflow for the construction team but restrict driving in designated TPZs.
Protocol must also be established for the controlled removal and disposal of waste products. Washout and contamination from concrete, paint, gasoline, or any other materials can severely affect tree and soil health, as well as have greater consequences on the broader urban ecosystem.

3.3.2 Tree Preparation

Once the tree protection plan is developed and finalized, the physical measures must be implemented before any site work begins. The municipality, contractors, and any other personnel will delegate responsibility for sourcing and installing all protection measures in a timely fashion, and all members will ensure measures are applied in accordance with the tree protection plan.

1. CRZ Fencing

At a minimum, the critical root zone of each tree should be established and securely fenced off. The CRZ is conventionally assumed to be a circle with diameter of 1.5 ft for every inch of trunk diameter measured at breast height (DBH). For example, the CRZ for a tree with a DBH of 30 in. is a circle with a diameter of 45 ft centered on the trunk of the tree. If possible, combine the CRZ for multiple trees and expand into a broader TPZ to allow for improved tree resilience and reduced likelihood of damage (see Figures 1.1 through 1.3). The TPZ should be fenced off with sturdy materials and secured for the duration of the project. Fencing should be a minimum of 4 ft in height and ideally up to 8 ft in height. Plywood or 2×4s may be used to erect an anchor frame to support a secondary material such as chain-link. Snow fencing or similar temporary fencing is not recommended due to its instability and ease of removal or displacement. Access within the TPZ should be extremely limited, and any exception shall be approved in writing prior to construction. Any activity within the TPZ shall be done under the supervision of the project arborist.

If there are obstructions present within the TPZ, such as buildings, sidewalks, or roadways, the TPZ should still be fenced off to the fullest extent possible. Means of emergency egress from the building or on impervious pathways should be maintained for pedestrian safety, but the placement of mulch and mats may help to guide pedestrian traffic safely through the work zone (see next section, “Ground Mats and Mulch”). Fencing may be implemented along the edges of the access corridors for further reinforcement. Construction activity within an altered TPZ must still be limited, and any access to the TPZ must be overseen by the project arborist.

2. Ground Mats and Mulch

Boardwalks, mats (plastic, plywood, or steel), and mulch all reduce soil compaction on highly trafficked areas by distributing the weight of heavy machinery over a larger area. Doing this reduces the load per square foot on the soil and roots. If installed, these measures should be promptly removed following the activity that requires their placement. If mulch is placed, geotextile fabric may be placed under, and a 12 in. layer of mulch spread on top [7]. Following completion, the fabric and layer of mulch should be removed to prevent adverse consequences of long-term placement such as reduced water infiltration, vegetation dieback, and altered planting depth. Multiple methods may also be used in conjunction with each other, such as fabric with mulch and mats placed on top.

3. Trunk Armoring

Armoring can be an effective measure for preventing damage to the trunk of the trees when applied correctly. However, in most cases, if operations are close enough to be a threat to the trunk, the activity and equipment is within the CRZ and should not be there in the first place. Certain trees may be potential candidates for trunk armoring due to their proximity to the roadway or to access routes where large equipment may be entering and exiting the site. Trunk armoring should be implemented under the supervision of the project arborist, and no material should be mounted directly to the tree. Wooden 2×4s placed vertically around the trunk may be lightly fastened around with rope or plastic binding. Armoring should be removed promptly following the activity and the trunk regularly inspected for damage and wounding.

4. Root and Clearance Pruning

If roots must be severed, the work should be done carefully and by the project arborist. Avoid root pruning during the active growing season or in times of heavy stress such as drought or pest presence. Cuts to the roots should be made with clean sharp tools, either hand or mechanically operated. Air excavation may be necessary to access the root system so cuts can be made precisely. Roots should never be ripped or torn with excavating equipment. If roots are torn by accident, the tear should be cut cleanly to prevent further damage. Following pruning, the cut roots should be protected from drying out and covered with soil, mulch, or compost and regularly irrigated.

3.3.3 Active Construction

The following actions are recommended to adequately protect the trees on site during the construction process.

1. Regular Monitoring and Communication

The project arborist and other local authorities should plan frequent site visits and inspections during the work process to ensure adherence to the tree protection plan. All those involved should be in regular communication, and any issues must be addressed and remedied promptly. All personnel should be made continuously aware of the tree protection measures and the reasoning behind these actions. This may take the form of regular meetings, signage throughout the site, and the distribution of documents for reading and reference.

Incidents may occur in which the tree protection plan and designated zones are violated, and consequences may need to be levied. The project arborist should inspect the tree or trees and assess any incidental or potential damage. The construction or development company may be responsible for the costs of repair work, replanting to repair canopy cover, and any fines previously established for violation of the TPZ and protection plan.

2. As-Needed Adjustments

All members involved in the project will understand the fluid nature of the construction process and that there will be instances where the original plan must be adapted. Any changes made will be discussed with the project arborist and any other members on the tree preservation committee to ensure that the needs of the project are met without sacrificing the protection of the trees on site.

3.3.4 Post-Construction

The following actions are recommended following the conclusion of active construction activity on-site to ensure long-term tree success.

1. Inspection and Assessment

Upon the conclusion of active construction, the project arborist should conduct a follow-up assessment of the trees on site. Any damage will be noted at the time and the appropriate steps taken to repair and remediate. This inspection may also reevaluate any changes to risk assessment based on the new conditions (pedestrian pathways, consequences of damage, etc.). The trees on site should be monitored for a minimum of two years following the conclusion of the project, because it may take several seasons for dieback or decline to become apparent. Contractors must be prepared to take responsibility and corrective measures until this period is elapsed. The trees will also be more susceptible to pest and disease infection having already been through the stress of the construction work, therefore, the trees should be monitored for signs of infection over the following seasons.

2. Treating Tree Injuries

Any branches that are damaged, diseased, or dead should be removed by the project arborist in accordance with proper pruning techniques. If there is damage to the bark or trunk, any loose bark may be gently and cleanly removed, and jagged edges cut back in a procedure known as bark tracing. Wound dressings should only be applied if necessary to combat local pest or disease infections. The canopy of the tree should not be reduced to accommodate root loss as was once common practice.

3. Soil Remediation

The soils at the site should be tested following project completion for compaction, moisture, nutrient content, and corrective action taken as needed. Air spading or excavation is one common method for remediating heavily compacted soils while minimizing root disturbance. Compost or other organic materials can be worked into the soil at this time, as well as additional soil to restore any material lost in the construction process. Mulch should also be applied following the construction process; a 3-in. layer should be spread over the root system of the trees as far as practical but avoiding direct contact with the trunk. Maintaining adequate irrigation is also crucial in allowing trees to recover from construction stresses. Monitoring for moisture content is recommended, as well as periodic deep watering, especially in the summer months. Fertilization is not recommended immediately following construction so that the local ecosystem may reestablish equilibrium and to avoid further chemical stress on area plantings [14]. In the following growing seasons, fertilization may be necessary to correct for loss of soil nutrients. A soil sample can be sent to a soil testing lab for nutrient analysis, which includes identification of specific deficiencies and options for corrective treatment.

3.3.5 Tree Planting Best Practices

The first step in any new tree planting is the careful selection of a tree species well suited to the proposed planting site. Environmental conditions of the site should be carefully assessed, as well as any infrastructure concerns that may be affected by tree size or form. Once a planting plan has been established, a long-term maintenance plan should be developed to ensure that new plantings are set up for success. At this point, a reputable local nursery can be contacted to supply the desired stock. The project arborist should inspect the nursery stock prior to delivery to ensure plantings are of good structure and condition, and free from pests or disease. There are many types of nursery stock available for purchase; the appropriate selection will depend on the needs of the project and plan.

When planting a tree, first inspect the nursery stock to evaluate for health and vigor, particularly a well-developed root system. Major roots that show circling or girdling tendencies may be judiciously pruned out at this time, but the pruning of the aboveground portion of the tree is not recommended at this time.

Site soils should be tested upon project completion but prior to planting preparation. Test the soil for drainage capabilities, as well as soil nutrients, pH, and presence of organic matter. Evaluate test results and correct any deficiencies with these conditions. The hole should be dug just deep enough so that the root flare of the plant is positioned just above the soil line after planting. Shape the soil at the base as necessary to provide adequate support for the root ball. Because the majority of initial root growth occurs laterally within the soil, the width of the planting hole should be at least twice as wide as the root ball diameter and up to three times as wide. Remove all burlap, wire cages, or other fasteners from the root ball before placing in the planting hole.

After situating the planting, backfill the soil into the hole, watering and lightly tamping soil as layers are added. Once soil has been leveled with the existing grade, mulch may be added to help with water retention and suppress weed growth. Spread mulch in a circle around the planting to a width of up to 3 ft per caliper inch. The mulch layer should be no more than 2–3 in. thick and should not be piled directly against the base of the tree trunk.

Following planting, prune minimally to remove broken or dead branches but avoid pruning for structural or compensatory reasons. Supervise plantings carefully supervised in their initial years to ensure proper establishment. Irrigate, fertilize, and prune according to ISA recommendations.

Install support systems such as stakes or guy lines as needed under the supervision of a certified arborist. Most new plantings are stable following correct planting procedures; however, support systems are beneficial in some cases. New plantings in areas of strong winds, nursery stock with undersized root balls, or evergreen species are all potential candidates for support systems. Guying and staking are commonly used to support newly planted trees. Regardless of the chosen support method, the system should allow some movement so that the tree may respond to natural forces and develop trunk and root stability.

Guying is a method in which lines (cable or rope) are attached from an external anchor to the trunk. Guying material at the point of attachment to the tree should be wide, smooth, and flexible to avoid damaging the bark and trunk. Guying systems typically consist of three lines, each running from approximately two-thirds the height of the tree to the ground anchor at a 45-degree angle [16].

Similar to guying, staking is an alternative method of early planting support. Metal or wooden stakes are driven in to the ground and then each tied to the trunk with wide flexible material. Again, the point of attachment should be left loose enough to not damage the trunk of the tree. The tension in the support system should allow natural movement of the tree without total restriction. Inspect support systems regularly to ensure appropriate tension. They can typically be removed 1 year after planting.

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4.0 Implementation and Technology Transfer

4.1 Synthesis of Recommendations

The MassDOT Project Development and Design Guide (PDDG) was last issued in 2006 and currently serves as the standard reference document in planning and preparing projects. In October 2023, an updated version of the PDDG was published online, including updates to many chapters and providing a baseline for further expansion into these topics. The MassDOT website offers some additional resources covering broader topics in landscape design and maintenance.

Chapter 1 of the PDDG serves as an introduction to the guide, covering the purpose, guiding principles, and context. Chapter 2 outlines the process of project development, beginning with the identification of a problem or need, and moving through the design, planning, initiation, and construction stages. This workflow has been reflected throughout the scope of this project, including the arrangement of the literature review and survey. Chapter 13 of the PDDG, "Landscape Design," provides an overview of landscape design in project development for transportation corridors. Chapter 13 outlines three further objectives of the landscape design process, including protection of natural and cultural resources, restoration of landscapes, and enhancement of the corridor.

The PDDG provides the building blocks for a corridor development project and should be amended accordingly to reflect the most up-to-date information on tree preservation practices for construction projects. The following section contains a summary of these recommendations, targeting the aforementioned chapters of the PDDG, as well as overall memos for the improvement of communication and understanding of preservation best practices.

4.2 Summary of Recommendations: By Project Action and Stage

4.2.1 Overall Recommendations to the PDDG

Most information in the updated PDDG was consistent with the external sources referenced in this project. However, there were several areas that would benefit from additional refinements to further and more accurately communicate the best practice guidelines. Consideration should be given to the format and distribution methods of the PDDG. Both the literature review and comments from the panel and survey underscored the importance of communication and understanding to ensure comprehensive urban forest health throughout construction projects. The PDDG, as it is currently published, remains an excellent online resource but may prove difficult to access and interpret for all individuals engaged in construction and tree preservation projects. MassDOT may wish to explore additional distribution formats for the PDDG and its accompanying guidelines, including hard copy publications for quick reference, as well as translation and distribution in more languages beyond English to improve overall accessibility.

In continuing to improve accessibility and ease of distribution, MassDOT could reach a broader audience that will be able to commit to collective goals of improving urban forest health throughout street development projects. It is of the utmost importance that these goals are understood by all parties involved. More individuals on a jobsite who are familiar with the guidelines for tree protection and preservation will lead to more effectively implemented and reinforced strategies across the duration of the project.

MassDOT may wish to explore the addition of a quick guide for tree preservation best practices that includes a succinct version of the aforementioned and subsequent recommendations as well as accompanying illustrations for easy referral onsite. All participants in this research project have indicated the importance of collective understanding of tree protection, and the more actions that can be taken to reinforce this importance, the greater are the odds of success. Such action will include measures to increase interpretations (e.g., illustrations and diagrams) and translation into a variety of languages to encompass the dynamic backgrounds of all those employed under the project scope.

Additional language could be included throughout the PDDG and accompanying guides to emphasize the integrity of these tree protection measures and the consequences for non-adherence. Clear and definitive language minimizes misinterpretation and ensures that all parties strive to meet the collective goals of urban forest health. Terms such as *TPZ* should be clearly defined, with the definition repeated as necessary to reinforce learning. Similarly, in the definition of terms like *TPZ*, accompanying measurements or methods should be consistent throughout the publication so that the same standards are met across the Commonwealth.

In addition, MassDOT may seek to further explore the enforcement of tree preservation measures, particularly tree protection zones and the restricted actions within these zones. Regular site visits by the project arborist may result in fines or other stoppage penalties if the jobsite is not adhering to the agreed upon protection plan. Periodic enforcement and accompanying penalties will hold all parties responsible for comprehensive street tree health as well as further reinforcing the Commonwealth's goals for urban forest revitalization and success.

4.2.2 Summary of Recommendations by Chapter

The following sections reflect an in-depth analysis of the relevant chapters of the PDDG, and their consistency with the themes reflected in the survey results and panel discussions.

Chapter 1 introduces the guiding principles and applications of the PDDG, as well as the development process for MassDOT transportation corridor projects in the Commonwealth. In addition to the existing objectives outlined in the PDDG, priorities and goals regarding urban forest health and ecosystem longevity should also be included in this section to round out the collective success of Massachusetts communities. These objectives should include targets for minimizing street tree losses, mitigating conditions for pests and disease issues, and improving overall health. More holistic goals for local urban ecosystems should also be covered, including measures for restoring native habitats, encouraging ecotypic planting, and revitalizing community greenspaces.

Chapter 2 details the necessary steps in the project process, from beginning conceptual ideas through active construction. Chapter 2 includes major themes of partnership between organizations, assessing project needs and requirements, and the workflow of a typical MassDOT project. At the time of writing, Chapter 2 of the PDDG was still under development for an updated publication; the recommendations for Chapter 2 refer to the 2006 edition.

A recurring theme in both panel feedback and survey results was consistent communication and involvement of certified arborists throughout the project. A primary recommendation for the PDDG is to underscore this need with the mandated inclusion of a tree inventory and assessment early in the project design process. This inventory will reflect the conditions of the trees on and near the proposed site and will guide the planning and design of the proposed corridors changes, as well as shape workflow on the site. The inventory should be performed by a certified arborist with the appropriate certifications and experience, and the arborist or arborist team should be retained to consult and inspect the project as needed.

The project arborist team should also work closely with the project design team to develop a comprehensive tree protection plan developed from the information in the inventory and the greater needs of the project. The protection plan must detail the necessary protection measures for each tree or stand of trees on site and the site workflow to avoid tree damage. The plan should be discussed and finalized during the early environmental design stages of the project, with interagency coordination with all project partners.

Chapter 13 covers the principles of landscape design that govern transportation corridor development projects. Much of the chapter covers an overview of planning and plant siting practices and introduces preservation and protection practices for existing site plantings. Section 13.1 outlines the current objectives of the landscape design process. Objectives focus on the concept of integration, of incorporating the new and modified landscape with the existing site conditions. The objectives include themes such as preservation, rehabilitation, and enhancement of the natural environment surrounding renovated corridors. The inclusion of these tenets encourages further exploration into quantifying measurable and attainable benchmarks by which to evaluate these goals.

A recurring recommendation to Chapter 13, and to the PDDG as a whole, is the inclusion of explicit benchmarks for achieving the stated objectives. This will help to structure the planning process and ensure outcomes that best benefit their communities. In a similar vein, MassDOT may wish to explore quantifying the economic benefits and ecosystem services of the urban forest as part of the assessment process. These figures will provide the baseline for the implementation of fines and penalties that may be levied for damage to the existing site trees. It may be necessary to enact a system of penalties to developers and contractors who do not adhere to the tree protection plan as outlined. While accidents may happen, it is every person's responsibility to operate carefully and minimize the impact of construction on the urban forest ecosystem. Agreed upon measures for the violation of the tree protection plan (i.e., operating in an established tree protection zone, or broken and damaged limbs) will ensure that individuals are held accountable and that funds are available to restore damage caused to the trees.

In Section 13.4 of the PDDG, tree preservation and protection as it applies to corridor development projects is discussed. The section contains an overview of tree biology and physiology, as well as how common construction actions may impact trees and the urban forest. A common theme in panel discussion and in survey feedback was the importance of education, and the inclusion and communication of this valuable information is important to reach a broader audience. The use of illustrations in this section is also very important to reinforce understanding and expand upon the written ideas. Section 13.4 could reference the modifications and preventive measures able to protect trees from these impacts. Additionally, there is opportunity for even more detailed descriptions of these measures, specifying for instance the appropriate types of fencing for TPZs or quantities of mulch necessary for root zone padding.

Chapter 13 concludes with the specifications and suggestions for replanting and revitalization efforts following construction activities. This chapter contains the necessary information on careful selection of planting locations and appropriate species, as well as further information on the importance of a cohesive forest ecosystem. This includes the planting of understory and groundcovers in addition to trees. The information on plant selection and siting is crucial to the longevity of the newly renovated corridor, as well as the well-being of the greater community.

5.0 Conclusions

5.1 Review

The initiative by MassDOT to evaluate and improve their tree preservation guidelines is well-timed to meet upcoming transportation infrastructure changes and embrace a new era of community development. As the Complete Streets program impacts communities nationwide, planners and developers must be ready to meet the challenge and expand existing corridors to reflect current transportation standards. The impacts to transportation corridors will inevitably affect the existing urban forest but also provide new opportunities to improve and develop current urban greening practices. With a thoughtful approach to tree preservation and planting remediation, these valuable ecosystems will continue to grow with and support their neighborhoods for generations to come.

Construction and development work frequently results in undesirable impacts to the urban forest that may result in tree decline, death, or failure. These consequences result in a community-wide loss of the valuable benefits of a thriving urban ecosystem and, if a tree falls, possible property damage or personal injury. With careful planning and consideration of preservation and protection in the construction process, these impacts can be avoided. The objective of this project was to evaluate best practices for tree preservation and use the information gathered to adjust and adapt the existing MassDOT tree protection guidelines to anticipate incoming development project volumes.

The overarching theme among all sources studied was certainly the value of consistent communication. Many individuals and companies may be involved in a single project, with each representing their own vested interest in a specific project component. It is critical that all parties are made aware of the potential impact construction activities may have. Additionally, adequate education procedures are necessary to help everyone understand the long-term community effects of these impacts. Sources analyzed also indicated that a lack of resources frequently contributes to the failure to adequately achieve these communication goals. Without sufficient time, funding, and personnel, the ability of an agency to sufficiently communicate and supervise the preservation process is compromised, often at the detriment of tree health and community vitality.

5.2 Discussion

Upon the conclusion of the initial stages of this project, certain themes emerged and were further reflected in panel discussions and survey responses. The repetition of themes regarding communication, monitoring, and accessibility proves to be central in adapting the existing PDDG to meet modern standards. However, aspects of the research process for this endeavor did not always meet the original expectations, which provides further opportunity for exploration.

The survey process was developed to reach a broader group of professionals with specialties in disciplines extending beyond the scope of the assembled expert panel in Task 2. The organizations contacted for survey distribution (Table 2.3) were selected to represent cross-disciplinary interests for the purpose of developing a holistic approach to tree preservation. However, due to the subject matter of the survey, respondents tended to be individuals with interests in urban forestry, such as foresters and arborists, composing approximately 75% of survey respondents. This distribution reflects the viewpoints of a community with a definitive concern in the subject of tree preservation without an equal counterpoint from those representing alternative interests such as project management and civil engineering. Possible factors that may have contributed to this missing viewpoint may include failure to connect with the desired audience, lack of participant engagement due to survey content or length, or limited accessibility due to the online format. Potential measures to correct these challenges in future exploration could include trialing a broader selection of organizations, an abbreviated version of the survey, and options for a paper or electronic version of distribution. With these modifications, it is possible that a more comprehensive selection of opinions could have been reached, leading to a more robust sampling of professional feedback.

On the subject of access and inclusivity, further challenges arise in the presentation of the PDDG and accompanying guidance. The PDDG in its current format presents several challenges in the access and distribution of the information it contains. With an exclusively online platform, individuals seeking information or guidance may have trouble connecting to the internet or viewing the web page on mobile devices. The PDDG and any accompanying documentation must be presented so that all individuals can conveniently obtain and understand the vital information. The information gathered in my review process can modify the PDDG to most accurately reflect the current nationwide best-practice standards. If the PDDG can reflect these standards and accommodate changing needs of accessibility and reference, then the urban forests of Massachusetts will be well-suited to withstand upcoming construction projects for street corridor development.

6.0 References

1. General Law - Part I, Title XIV, Chapter 87, Section 8. Online. Available from: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleXIV/Chapter87/Section8
2. Complete Streets. Smart Growth America. Online. Available from: https://smartgrowthamerica.org/what-are-complete-streets/
3. Khanal, P. and Straka, T. Benefits of Urban Forests and Determining Their Value. Clemson, SC: Clemson Cooperative Extension, Land-Grant Press by Clemson Extension. 2021.
4. Bartens, J., Day, S.D., Harris, J.R., Dove, J.E., and Wynn, T.M. Can urban tree roots improve infiltration through compacted subsoils for stormwater management? Journal of Environmental Quality. Online. November 2008. Vol. 37, no. 6, p. 2048–2057.
5. Nowak, D.J., Crane, D.E., and Dwyer, J.F. Compensatory value of urban trees in the United States. Journal of Arboriculture. 2002. Vol. 28, no. 4, p. 194–199.
6. Ferrini, F., Konijnendijk, C.C., and Fini, A. (eds.). Routledge handbook of urban forestry. London, UK. Routledge, 2019.
7. Matheny, N.P., and Clark, J.R. Trees and development: a technical guide to preservation of trees during land development. Champaign, IL: International Society of Arboriculture, 1998.
8. Elmendorf, W., Gerhold, H., and Kuhns, L. A guide to preserving trees in development projects. Pennsylvania State University, 2005.
9. Fite, K. and Smiley, E.T. Best management practices: managing trees during construction. Second edition. Atlanta, GA: International Society of Arboriculture, 2016.
10. Lilly, S., Basset, C.G., Komen, J., and Purcell, L., Arborists' Certification Study Guide, Fourth Edition. Atlanta, GA: International Society of Arboriculture, 2022.
11. Dillman, D.A., Smyth, J.D., and Christian, L.M. Internet, phone, mail, and mixed-mode surveys: the tailored design method. 4th edition. Hoboken, N.J: Wiley, 2014.
12. Lilly, S., Gilman, E., and Smiley, E.T. Best Management Practices: pruning. Third Edition. Atlanta, GA: International Society of Arboriculture, 2019.
13. Smiley, E.T., Matheny, N.P., and Lilly, S. Best management practices: tree risk assessment. Second edition. Atlanta, GA: International Society of Arboriculture, 2017.
14. Smiley, E.T., Lilly, S., and Werner, L. Best management practices: tree and shrub fertilization. Atlanta, GA: International Society of Arboriculture, 2013.
15. Watson, G.W. Best management practices: tree planting. Second edition. Atlanta, GA: International Society of Arboriculture, 2014.
16. Smiley, E.T. and Lilly, S. Best management practices: tree support systems: cabling, bracing, guying, and propping. Third edition. Atlanta, GA: International Society of Arboriculture, 2014.
17. Watson, G.W. (ed.). The landscape below ground: proceedings of an international workshop on tree root development in urban soils; presented by the Morton Arboretum held September 30 and October 1, 1993. Savoy, IL: International Society of Arboriculture, 1994.
18. Alberty, C.A., Pellett, H.M., and Taylor, D.H. Characterization of soil compaction at construction sites and woody plant response. Journal of Environmental Horticulture. Online. 1 June 1984. Vol. 2, no. 2, p. 48–53.
19. Fair, B.A., Metzger, J.D., and Vent, J. Response of eight cultivars of *Acer x freemanii* and

Acer rubrum to soil compaction. Acta horticulturae. 2010. Vol. 881, p. 247–250.
20. Neely, D. and Watson, G. (eds.). The landscape below ground II: proceedings from the second international workshop on tree root development in Urban Soils, held in March 1998. Champaign, Ill.: International Society of Arboriculture, 1998.
21. Pike, K., O'Herrin, K., Klimas, C., and Vogt, J. Tree preservation during construction: An evaluation of a comprehensive municipal tree ordinance. Urban Forestry & Urban Greening. Online. January 2021. Vol. 57, p. 126914.
22. Costello, L.R., and Jones, K.S., Reducing infrastructure damage by tree roots. University of California, 2003.
23. McGrath, D., Henry, J., Munroe, R., and Williams, C. Compost improves soil properties and tree establishment along highway roadsides. Urban Forestry & Urban Greening. Online. November 2020. Vol. 55, p. 126851.

Additional Resources

Elmendorf, W. Understanding tree planting in construction-damaged soils. Pennsylvania State University, 2008.

Geiger, J. The large tree argument. Western Arborist. 2004. Vol. 30, no. 1, p. 14–15

Glaeser, C.W. The preservation and protection of urban trees: lessons from the field from the city of New York. Acta Horticulturae. Online. November 2010. No. 881, p. 1063–1068.

Harris, R.W., Clark, J.R., and Matheny, N.P. Arboriculture: integrated management of landscape trees, shrubs, and vines. Fourth edition. Upper Saddle River, NJ: Prentice Hall, 2004.

Hauer, R.J., Koeser, A.K., Parbs, S., Kringer, J., Krouse, R., Ottman, K., Miller, R. W., Sivyer, D., Timilsina, N., and Werner, L. Long-term effects and development of a tree preservation program on tree condition, survival, and growth. Landscape and Urban Planning. Online. January 2020. Vol. 193, 103670.

Landscape Design Guide. 2019. Florida Department of Transportation.

McPherson, G.E. Accounting for benefits and costs of urban greenspace. Landscape and Urban Planning. Online. September 1992. Vol. 22, no. 1, p. 41–51.

MassDOT Project Development and Design Guide. 2023. Available from: https://www.mass.gov/manual/massdot-project-development-and-design-guide.

Miller, R.W., Hauer, R.J., and Werner, L.P. Urban forestry: planning and managing urban greenspaces. Third edition. Long Grove, IL, 2015.

Petit, J., Bassert, D.L., and Kollin, C. Building greener neighborhoods: trees as part of the plan. Washington, DC: American Forests: Home Builder Press, 1995.

Smiley, E.T., Watson, G., Fraedrich, B. and Booth, D. Evaluation of soil aeration equipment. Arboriculture & Urban Forestry. Online. 1 May 1990. Vol. 16, no. 5, p. 118–123.

Smith, K., May, P. and Moore, G. The influence of compaction and soil strength on the establishment of four Australian landscape trees. Arboriculture & Urban Forestry. Online. 1 January 2001. Vol. 27, no. 1, p. 1–7.

Trowbridge, P.J. and Bassuk, N. Trees in the urban landscape: site assessment, design, and installation. Hoboken, N.J.: J. Wiley & Sons, 2004.

Watson, G.W. and Neely, D. (eds.). Trees and building sites: proceedings of an international workshop on trees and buildings: presented at the Morton Arboretum, held May 31 through June 2, 1995. Champaign, IL: International Society of Arboriculture, 1995.

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7.0 Appendices

7.1 Appendix A: Literature Review

1: Introduction
The Massachusetts Department of Transportation, MassDOT, seeks to create a comprehensive reference guide of best practices for tree preservation during development projects. This documentation will inform planners, designers, engineers, arborists, and more as they work through construction projects, such as Complete Streets development, that impact existing tree corridors. The guide will provide information for all stages of the construction process, from planning and design to planting after construction activities are completed.

The first step in the creation of this guide is a broad assessment of the current state of practices in street tree preservation techniques during construction and development. Content surveyed will include peer-reviewed research publications, technical documentation, and reference guides for other jurisdictions. The synthesis of this literature will provide the foundation to build the next steps of the project. This review is organized chronologically and will begin with best practices in the planning and design stages, then move through the construction process to completion and final replanting and landscaping procedures.

2: Overview
Trees in urban environments are subject to a great variety of stressors, and a large proportion of these problems can be traced back to the impacts of soil quality on root health. Urban environments do not allow for the same nutrient cycling processes that occur in forest growing environments, which means they are often lacking the essential nutrients needed to grow and metabolize [17]. Additionally, soils in urban environments often have disrupted structures from over-handling/construction, which result in compaction over time.

Soils that are most susceptible to compaction are clay and loam types, with high moisture content and low levels of organic matter [9]. Compacted soils have decreased aeration, reduced drainage, poor waterholding capabilities, and make for difficult root penetration. [17, 18]. Soil compaction is shown to reduce root growth in trees due to the increased bulk density and decreased porosity [19]. This study analyzed eight species of maple cultivars and found that trees planted in sites with non-compacted soil were larger and had more leaf-biomass than their compacted counterparts [19]. Construction activities are a frequent cause of soil compaction from heavy equipment traffic over tree root zones, or long-term heavy storage on tree root zones [17].

Other construction operations, like digging or trenching, can sever tree roots, which significantly reduces tree health and stability. Roots can be further damaged by debris, fill soils, or changes to the water table and patterns. Chemical damage from runoff or spills can be fatal to roots and foliage, and any injuries to the bark and trunk leaves trees susceptible to pathogens and insect entry. There are some remediation efforts for soil conditions after construction activities have ceased, but any damage to the tree and roots are permanent and can only be compartmentalized rather than healed [9]. The most effective measure for dealing with tree damage is to ensure that the damage does not occur in the first place.

3: The Construction Process

Most construction or development projects follow the same basic sequence. The first phases are planning and design, then pre-construction measures, followed by active construction, and lastly post-construction steps to wrap things up. Tree protection is an essential part of all of these phases and must be understood and considered at every stage. In Britain, a series of documentation was produced that outlined best practices for managing trees and utilities. However, because this documentation was not legally binding, problems would persist due to lack of adherence [20]. This emphasizes the importance of mandated policies, from beginning to end of the project. It is critical that at every phase of the construction process, all individuals involved with the project are made aware of the tree protection measures and procedures, and that appropriate repercussions are in place should these requirements fail to be met. All parties must be committed to tree preservation and informed on the basics of tree growth and development for the plan to be a success.

3.1: Planning Stage

The planning stage is very important for successful tree protection and preservation, a well-constructed plan ensures that tree health will be at the forefront of the project and bring continued success to the environment. The planning stage is the time when architects, engineers, developers, and ideally arborists begin to assess the site and decide on the needs and limitations of the project. At this time, the arboriculture team should conduct a tree inventory, also known as a tree resource evaluation [9]. This assessment helps to site infrastructure so that it will have the least possible impact on existing trees and forest stands.

3.1.1: Tree Inventory

A tree inventory identifies tree and shrub species, size, conditions, locations, and potential risks for each specimen in the project zone [20]. This inventory informs decisions on preservation and applicable protection measures so that existing site vegetation will continue to thrive. It is best to inventory before parcels are outlined and designated in order to work around existing trees and create the accompanying preservation plan at that time. The inventory identifies desirable trees for preservation, including trees on adjacent lots that may be affected by construction activities. Species hardiness is another important aspect for consideration, along with tree age. Younger to middle-aged trees in good condition are likely to tolerate construction stresses more than over-mature or unhealthy trees and are therefore better candidates for preservation. [9]. Soil condition, water table and flow, prevailing winds, and more are also relevant to the inventory and should be noted. The inventory will be part of a larger document that outlines all the actions that will be taken to preserve the trees, from the initial planning stages to aftercare once the project is complete [8, 20].

3.1.2: Tree Risk Assessment

Part of the inventory process includes a risk assessment of all trees on and adjacent to the site. The first step in the risk assessment process is to establish the scope, level of detail, and rating system to be used. Depending on the size of the area and budget of the project, different assessment techniques may be applied. The assessment will identify the likelihood of failure of trees in the area, using whichever techniques are outlined in the scope, the levels of techniques include a limited visual assessment, a basic assessment, and an advanced assessment. The risk assessment report will also detail any mitigation steps necessary to address trees with a high likelihood of failure [13].

3.2: Design Stage

The design phase occurs as the site is mapped out and plans for buildings and infrastructure are situated on the site. At this time, trees are designated for removal versus kept or transplanted. Tree interactions with service infrastructure may not be considered until after the fact when problems present; therefore, it is important for clearances and root growth to be accounted for early in the design process. In the case of buried utility services (electric, gas, communications, etc.), maintenance presents an issue in addition to the installation [20]. The design phase must address any and all interactions between trees and infrastructure planned for the site.

The design plans must also account for any temporary needs of the site during the construction process. Temporary structures, construction zone access and parking, material and equipment storage, and any other processes that will occur in active construction must be recognized and built into the tree protection plan. A site should be designated for long-term storage of heavy vehicles or equipment that does not interfere with the marked root zones [8]. Areas designated for future plantings should also be conserved to ensure healthy growing conditions for new plantings [7]. Tree preservation ordinances are proven to improve soil conditions, and in turn, tree health and survival after construction activities [21]. The protection and preservation plan must be clearly communicated and distributed to all workers on site and appropriately enforced as needed.

The area around a tree that will be protected during the construction process is known as the tree protection zone (TPZ). The TPZ, which is the area around the critical roots, should be fenced off with visible barriers to eliminate traffic and storage on the TPZ. There are many possible strategies for protecting the TPZ, whatever methodology is selected should be outlined in the planning stages.

3.2.1: Tree Protection Zone (TPZ)

The tree protection zone is defined by the International Society of Arboriculture as the "area within which certain activities are prohibited or restricted to prevent or minimize potential injury to designated trees." [7, 9]. This zone extends beyond the critical root zone (CRZ) where essential roots for stability and health are located. A common convention for defining the TPZ is to use the drip line of the tree canopy; however, this is not always adequate for trees of certain forms, in which case the diameter at breast height (DBH) is used. One recommended calculation assigns values to species tolerance and tree age and assigns multipliers based on the aforementioned. For example, a healthy, young hardy species might have a multiplier of 0.5 ft per inch of diameter, but an over mature tree in poor health may have a multiplier of 1.5 ft per inch of diameter [7]. Following a walk-through, TPZs may need to be adjusted to accommodate asymmetries, or existing site infrastructure. If absolutely necessary, the TPZ can be temporarily reduced to allow for a specific activity but expanded immediately following conclusion.

Groups of trees and their respective TPZs are preferred, as the shared root space requires a smaller perimeter to be preserved, and a buffer of smaller, less valuable trees can protect the ones within.

3.2.2: TPZ Protection Strategies

The goal of the TPZ is to restrict movement and impacts within the zone. There are several ways this can be accomplished. Fencing is most commonly used to delineate the TPZ and should be sturdy and highly visible. Chain-link, wire-mesh, or wood are all recommended materials for fencing, and should be at least 4–6 ft high [9]. Any fencing should be clearly marked with signage explaining the circumstances, contact information for the arboriculture team, and the consequences for entering the TPZ. Fencing off around trees helps to protect soil bulk density inside the fences but can still require remediation after the fact [17].

If fencing is not feasible, or movement is necessary within the TPZ, there are alternative methods to disperse weighted loads on the soil within the zone. One such method is using woodchip mulch in the area, applied at 6–12 in. thick, in a radius around the tree, ensuring the mulch itself does not rest on the tree trunk. Another similar alternative is the use of gravel over geotextile fabric, again applied approximately 6 in. in thickness. Plywood, beams, or road mats can also be used over several inches of mulch. To effectively protect the trunk of the tree without fencing, wood beams over foam pads can be strapped around the trunk, not anchored into the tree. All measures of TPZ protection should be continuously monitored during the construction process to ensure they are performing as expected and not inhibiting tree growth in any way. Protection measures should be removed upon the completion of the project [7, 9].

3.2.3: Infrastructure Solutions

During the design phase, solutions for interactions between trees, roots, and infrastructure should be accounted for, and methods explored to understand the best options for the future project. Tree planting should be appropriately selected for the space they will inhabit to maintain clearance with buildings and traffic corridors. Species selection can prevent infrastructure damage due to differing structural characteristics such as root flare and buttress roots [22].

Sidewalks and tree roots are a common interaction that can have severe consequences down the line. Increased planting space is one strategy to reduce root interactions, but it is not always feasible to achieve the recommended minimum measurements. A commonly recognized metric is 6–10 ft in length and width for a planting space [22]. When these dimensions cannot be met, design strategies such as curved sidewalks or pop outs can maximize tree planting space while maintaining sidewalk requirements.

Paved sidewalks actually promote shallow root growth as the pavement traps moisture and regulates temperature which creates favorable root conditions. However, root growth under paved surfaces can create cracks and bumps that present pedestrian or vehicle hazards [16]. Some root control methods, such as herbicides or physical barriers, limit tree root growth and lead to poor tree development. The use of construction debris as a fill under walkways discourages root growth in the rubble, preserving sidewalk integrity. Physical screens and barriers under sidewalk and roadway edges are another effective solution for prohibiting root growth under pavements [17]. Another effective solution is the use of bridges and ramps, to gently elevate the sidewalk over rooting space. However, this solution requires more significant construction costs and must be engineered correctly to prevent the buildup of water and debris.

3.3: Pre-Construction

Prior to construction, the arboriculture team works closely with the development team to set the site up for success. At this time, any trees slated for removal are taken down, TPZs are designated and set up, and access paths and storage areas are laid out. Any fencing, ground covers, and trunk armor should be in place at this stage, well before construction begins. Also prior to construction, necessary pruning can be performed as outlined in the tree inventory.

3.3.1. Pruning

The early inventory and inspection processes will identify any limbs that should be pruned prior to the beginning of construction. However, it is also key to keep pruning to a minimum so the amount of overall stress on the tree is reduced during the construction process. Any limbs that will interfere with construction traffic should be pruned back as needed. A clean cut, just outside of the branch bark collar is easiest and safest for the tree to compartmentalize [12]. The ISA recommends the following pruning clearances from objects to branches: 8 ft for sidewalks, 14–20 ft for roads, 6 ft above residential roofs, and 3 ft from building sides. These recommendations should be adjusted appropriately to reflect the needs of traffic through the construction site [12]. Pruning dressings and paints are not recommended on pruning cuts but may be helpful in the event roots are left exposed to the air.

Root pruning is another task that may need to happen before construction. As with branches, intentional clean cuts are best for the tree as opposed to rough tears that may be made by equipment. If digging or trenching operations must happen where there are tree roots, it is better to cut roots with appropriate pruning tools. Tree stability begins to be affected when root pruning cuts are made within a radius of three times the DBH and increase dramatically as cuts move closer to the trunk [9].

3.4: Active Construction

During active construction, the arboriculture team stays in contact with the development team, with periodic meetings as well as site inspections of the TPZ and protection measures. Penalties for not following the tree protection plan guidelines will also be enacted. The arboriculture team will also treat any incidental damage to trees on the site. This may be making proper cuts in damaged roots or branches, pruning for further clearance, or treating bark damage. Bark wounds should be cut to a smooth oval shape, leaving as much bark as possible. Dressings are not recommended for bark wounds but may be used if there is a known pest in the vicinity [9].

3.4.1: Trenching and Boring

If it is necessary to run utilities within the TPZ of a tree, boring is a preferable alternative to classic trenching operations. Boring allows installation of necessary utilities with minimal root severance. Set up the boring machinery outside of the dripline and bore down 2–3 ft before going across. Avoid boring directly under the trunk in case of tap or heart roots [9].

3.4.2: Grade Changes

In the event that surface grade must change within the TPZ, there are certain measures to take to ensure tree survival. If the grade is to be lowered, structural root pruning may be necessary, but should be avoided if at all possible. Tree islands and retaining walls are a solution to accommodate tree roots and a lower grade. For increases in grade, keep soil fill away from the trunk, and use retaining walls for grade changes of more than 2–3 ft. Aeration can help prevent compaction in filled soils, and new soils should be monitored for composition, moisture content, and structure [7, 9].

3.5: Post-Construction

Once construction has been completed, including all final landscaping measures, it is now safe to remove all TPZ protection measures. TPZ protection measures should remain in place until there is no more development work going on at the site. At this time, a second walk-through should occur to inspect the conditions of the trees and environments. The health and structure of all trees should be evaluated, and any conditions should be treated as needed. The soils at the site should be monitored for moisture and nutrient content and mulch should be applied as needed. Additionally, trees and new plantings should be monitored for any sign of pests or pathogens. A long-term management plan should be in place for the trees and landscape of the completed development.

3.5.1: Soil Remediation

High soil quality is important for improving tree health and providing continued success. Remediation measures for soil compaction and soil composition do result in improved root growth and overall tree health [18]. One such method is "subsoiling," where an excavator turns over soil to loosen it, which results in significant pore volume and air porosity increases. Aeration with a pneumatic Terralift soil aerator has been shown to effectively loosen sandy loam soil types and improve growing conditions but had no effect on clay loam soils [17]. Changes in grade, and the accompanying fill soils often cause decreased oxygen availability, and in turn reduce root respiration. Attempts to aerate the fill soils with a subsurface mechanism resulted in no consistent improvements in oxygen distribution [20].

Different products and treatments applied after construction activities can help remediate damage and improve the likelihood of successful harmony between built and natural aspects. One such product targets issues with urban soil quality. Amsterdam Tree Soil is an artificial soil mix composed of coarse sand and organic matter with clay, such as former topsoils from peat bogs. This mix expands potential rooting space under pavements with light loads (e.g., bike paths and sidewalks) allowing for easier growth [17]. Another effective solution for improving soil quality after construction and compaction is the addition of organic materials to the impacted soils. Adding quality compost, which can be locally sourced such as food or yard waste, can help soil quality and tree establishment, by improving bulk density and soil organic matter concentration. One case study measured the effects of compost addition on newly planted roadside trees. This study found that the compost improved tree establishment, but it is important to remember that tree survival alone is not indicative of overall canopy and forest health [23]. Another additive solution is the addition of lightweight aggregates like fly ash, a by-product from coal production, or expanded slate. These additives have rigid, angular structures, which help support the soil as it breaks down, providing necessary open spaces.

Over the 22 years of the study, it was shown that the aggregates reduced bulk density and increased pore space in the treated soils, creating more favorable growing conditions [17].

3.5.2: Planting
It is also important that trees planted at the site after construction are provided with the right conditions to thrive. Medium shade trees require 300–400 ft^2 of soil volume to ensure success, meaning traditional “tree pits” are not recommended [17]. Most tree roots grow out, not down, in the surface layers of the soil, so sunken or enclosed boxes do not offer adequate growing space. The soil makeup is also a key ingredient for success. Soils made of approximately 3% organic matter and a blend of sandy loam are most productive for planting. Mulch is a good alternative to soil for ground cover, as long as it is applied correctly. Mulch provides water retention best in a thick layer around the tree trunk, however the mulch is not directly piled on the trunk [17]. Soil temperatures are another consideration for crafting ideal growing conditions. Due to the urban “heat-island” effect, increased air temperatures reduce rates of photosynthesis, and sustained heat loads in cities raise soil temperatures. Sustained air temperatures over 90°F were shown to stunt growth, reduce root and leaf area, and decrease rates of transpiration [20]. This presents one more of the many challenges for establishing trees in cities.

3.5.3: Transplanting
Successful transplanting measures are another key component for successful tree establishment. Field-grown root ball methods lose a lot of soil volume and roots in the transplanting process, which has a negative impact on their future growth. Container growing is an alternative to field-grown options. Traditional containers cause circling or roots escape the container and then must be cut during the transplant process. In-ground fabric containers are capable of preserving roots and soil volume during transplanting but can result in root deformation, such as girdling, that can lead to poor mature growing structure. Low profile containers have shallower depth and wider spread, mimicking the natural root growth shape, which results in stronger root system structure in the mature trees. This stronger, widespread root structure reduces the likelihood of tip-over from wind events later down the line [17]. Another new nursery technology is perforated plastic containers known as “Air-Pots.” The perforations allow more oxygen to roots, but also self-prune any escaped roots through desiccation. This allows for a more seamless transplanting process as roots do not need to be cut during uprooting.

For bare root transplanting methodologies, chilling periods can result in increased shoot growth, as it mimics the natural periods of winter dormancy. Paclobutrazol is a chemical agent that can increase small root generation but not on a scale large enough to impact overall growth and survival. The use of hydrogels is not recommended in the transplanting process, due to the possibility of over saturation leading to root rot [17]. For container growing operations, copper treatments can be applied that reduce circling and improve regeneration post-planting. However, if applied in incorrect dosages, these copper treatments can be mildly toxic to the tree [17]. With the application of these solutions, trees are more likely to survive the transplanting process, and begin to establish in the landscape.

3.5.4. Fertilization

Forest grown trees are able to get their required nutrients from minerals in the soil, organic matter decomposition, and deposition from the atmosphere. Urban environments are not privy to these natural processes and are often lacking in essential nutrients, so fertilization is a way to introduce these elements and improve tree health. Before applying fertilizer, an assessment should be done to define health objectives and analyze soil and leaf conditions, so that the correct fertilizer can be applied. The use of organic mulch and leaf litter that decompose over time can reduce fertilizer needs by mimicking the natural conditions of the forest floor [14].

3.5.5. Support Systems

Support systems, such as cabling, guying, and bracing can be used as needed to reduce the risk of breakage or branch failure; however, they do not completely eliminate the risk in place. The hardware used for these systems should be stainless steel or galvanized to prevent rusting and treated to resist ultraviolet degradation [16].

4: Conclusion

The implications of this review will result in prioritizing the health and vitality of street trees during construction disturbance, as well as an emphasis on viable urban greening procedures. This research will decrease the likelihood and severity of tree damage or death as a result of construction and development disruption. With the implementation of these techniques, communities can continue to share in the benefits of safer streets and thriving urban forests. A well-designed landscape takes into account the needs of not just people and vehicles, but the ecosystem as a whole, including trees, understory vegetation, insects, and other wildlife that occupy the space. Some of the current priorities in landscape vegetative design are stormwater management, carbon sequestration, shading, and use of native species throughout. All the elements of successful design, paired with a tree preservation plan and appropriate planting measures, combine to create landscapes that will serve their communities for decades to come.

7.2 Appendix B: Survey

1.0 DEMOGRAPHICS

1. In which US state do you conduct the majority of your work?

[Drop down select]

2. Which of the following roles best describes your professional position?
   - Tree Warden
   - Urban Forester
   - Arborist
   - Construction Professional
   - Civil Engineer
   - Landscape Architect
   - Transportation Engineer
   - Manager
   - Planner
   - Other: _________

3.

3. In which of the following environments do you conduct the majority of your work? Select all that apply.
   - Preserved or Protected Forests
   - Rural Communities
   - Suburban Communities
   - Urban Residential Communities
   - Urban Commercial
   - Urban Parks and Recreation Space
   - Highway or Transportation Corridors
   - Other: __________

4. How much of your work is related to the construction of sidewalks, bicycle lanes, or other pedestrian facilities?
   - All
   - Most
   - Some
   - None

4.

5. Are continuing education opportunities available to you, either through your employer or membership of a professional organization? If so, is participation mandatory?
   - Continuing education opportunities are NOT available to me
   - Continuing education opportunities are available to me, but NOT mandatory
   - Continuing education opportunities are available to me AND mandatory

2.0 PLANNING

6. Does your company or municipality have policies or guidance for the construction of sidewalks and/or infrastructure along the road edge (e.g. Complete Streets policy)?
    - o Yes
    - o No
    - o N/A
    - o Don't Know
    - o Other: please specify __________

7. Do you or your team currently have tree protection guidelines for construction projects? If so, please list the type and source of this guidance.
    - o Yes
    - o No
    - o Unsure or Don't Know

8. At what stage of the design process for construction projects do you or your team begin to consider the health of existing and future trees on site? Select all that apply.
    - o Planning Stage
    - o Design Stage
    - o During Construction
    - o Post-Construction
    - o Not a Primary Consideration

9. Are you or your team obligated to meet any requirements for new tree plantings in road and sidewalk construction projects? If so, which of the following aspects are mandated? Select all that apply.
    - o Number of new plantings
    - o Percentage of area to be planted
    - o Installation process of new plantings
    - o Long-term maintenance of plantings
    - o Jurisdiction/Project dependent
    - o Unsure or Don't Know
    - o N/A

10. Do you or your team have guidelines for planting and reforestation for construction projects? If so, which of the following items are included in the guidelines? Select all that apply.
    - o We do NOT have a set of guidelines for planting and reforestation
    - o Soil amendments
    - o Planting area dimensions
    - o Recommended species
    - o Long-term maintenance plan
    - o Jurisdiction/Project dependent
    - o Other: please specify __________

11. Please rank the effectiveness of the following remediation methods for ensuring tree success. If you have no experience with the method, please select N/A.

	Very Effective	Somewhat Effective	Not Effective	Detrimental	N/A
Root Barriers	○	○	○	○	○
Soil Aeration	○	○	○	○	○
Min. Planting Distances	○	○	○	○	○
Alternative Sidewalk Base Materials	○	○	○	○	○
Soil Quality Remediation	○	○	○	○	○
Setback Planting	○	○	○	○	○
Preemptive Root Pruning	○	○	○	○	○

12. Has your work included planning for street trees in conjunction with stormwater improvements? (e.g. incorporating recommendations from EPA Green Streets.)
   - Yes
   - No
   - Unsure or Don't Know

13. Have you or your team implemented any of the following methods for stormwater control? Please rank the effectiveness for each method used.

	Very Effective	Somewhat Effective	Not Effective	N/A
Suspended Pavement (structural cells)	○	○	○	○
Structural Soils	○	○	○	○
Stormwater Tree Pits	○	○	○	○
Permeable Pavements	○	○	○	○
Forested Bioswales	○	○	○	○
Tree Filter Boxes	○	○	○	○

14. Which of the following actions do you or your team currently recommend or implement to protect existing trees for construction? Please rank the effectiveness for each method recommended.

	Very Effective	Somewhat Effective	Not Effective	N/A
Tree Assessment or Inventory	○	○	○	○
Root Zone Protection Fencing	○	○	○	○
Canopy Pruning (for clearance)	○	○	○	○
Root Pruning	○	○	○	○
Mats and Ground Covers	○	○	○	○
Trunk Armoring	○	○	○	○
Designated Equipment and Vehicle Storage Zones	○	○	○	○
Managed Selective Removals	○	○	○	○
Modified Hardscape Placement	○	○	○	○
Site Personnel Awareness	○	○	○	○

15. The Critical Root Zone (CRZ) is the area around a tree, in which the damage or disturbance of the roots will adversely affect the tree's health and stability. What method do you or your team use to determine the critical root zone?
    - o We do not define a critical root zone (CRZ)
    - o 1.5 ft of root zone per every inch of trunk diameter (DBH) (ISA Standard definition)
    - o CRZ definition is site dependent
    - o Unsure of Don't Know
    - o Other: please specify ___________

3.0 DESIGN

16. Please rank the effectiveness of the following permanent design strategies for minimizing tree and infrastructure conflicts in road and sidewalk construction projects.

	Very Effective	Somewhat Effective	Not Effective	Detrimental	N/A
Root Bridging	○	○	○	○	○
Raised Tree Planters	○	○	○	○	○
Porous Pavements	○	○	○	○	○
Tree Trenches (grouped plantings)	○	○	○	○	○
Planting/Spacing Distances	○	○	○	○	○
Root Barriers	○	○	○	○	○
Tree Pits (individual plantings)	○	○	○	○	○

17. Of the previously selected design strategies, are you able to specify the parameters that you or your team use for effective installation? Select all that apply.
    - Yes, proceed to next question to input parameters
    - Yes, skip to the option to insert a link or upload files
    - Don't Know

18. Use the spaces below to provide the specifications you use for each of the previously selected design strategies. Please specify units (ft/in) and follow the format "length/width/depth" when possible.
    - Tree Pits (individual trees)
    - Tree Trenches (multiple trees)
    - Raised Tree Planters
    - Planting Spacings
    - Root Bridging
    - Root Barriers

Please use the option below to upload any additional documentation you would like to share regarding design strategies.

Please use the space below to link any web pages you would like to share for design strategies specifications.

Do you have any additional comments on design strategies for minimizing tree and infrastructure conflicts after construction projects that you would like to share?

19. As part of the projects you work on, is an inventory or assessment of existing trees in the project area prepared? If so, is this assessment a requirement?
    - o A tree assessment is NOT conducted
    - o A tree assessment is conducted, but NOT required
    - o A tree assessment is conducted AND required
    - o Unsure or Don't Know

20. Are you involved in the process of the Tree Risk Assessment (TRA) or Inventory process prior to construction projects?
    - o Yes
    - o No

3.1 TRA

21. Who is responsible for conducting the Tree Risk Assessment or Inventory prior to construction projects?
    - o An assessment is NOT conducted
    - o I personally conduct the assessment
    - o The assessment is conducted by someone within my department
    - o The assessment is conducted externally, through a hired consultant

22. Does the Tree Risk Assessment or Inventory follow the procedures outlined by the International Society of Arboriculture (ISA)?
    - o Yes, the assessment follows ISA procedures
    - o No, the assessment does NOT follow ISA procedures
    - o The ISA procedures are adapted or partially followed
    - o Unsure or Don't Know

23. To what level of detail is the Tree Risk Assessment or Inventory conducted?
    - o Level 1: Limited Visual Assessment - walk or drive by, no tools
    - o Level 2: Basic Assessment - detailed visual inspection with simple tools
    - o Level 3: Advanced Assessment - detailed inspection with specialized equipment
    - o Varying Levels, depending on circumstances

24. Which of the following additional factors do you consider in the Tree Risk Assessment or Inventory process? Select all that apply.
    - o Utility Relocation
    - o Pavement/Hardscape Expansion
    - o Trenching Operations
    - o Construction Equipment Mobility
    - o Material and Equipment Storage
    - o Other: please specify ___________

Please use this space to provide any additional comments on the Tree Risk Assessment process for construction projects.

4.0 CONSTRUCTION

25. Do you or your team have a plan or reference document for tree protection and management during construction projects?
    - o Yes
    - o No
    - o Unsure or Don't Know
    - o N/A

26. What measures do you or your team currently use to ensure awareness about tree protection on a jobsite? Select all that apply.
    - o Signage
    - o Site Personnel Meeting
    - o Site Personnel Memos
    - o N/A
    - o Other: please specify __________

27. Do you or members of your team conduct site visits to ensure tree protection measures are being adhered to during construction?
    - o Yes
    - o No
    - o N/A

Do you have any additional comments or strategies you would like to share regarding tree protection on active construction projects?

5.0 MAINTENANCE

28. Do the projects you or your team work on include a long-term maintenance plan after construction and installation are complete? If so, does this plan extend beyond the contractor maintenance obligations?
    - o Yes, the plan extends beyond contractor obligations
    - o Yes, the plan ends when contractor obligations are completed
    - o No, we do not have a long-term maintenance plan in our contracts
    - o Unsure or Don't Know

29. For the contracts you or your team work on is a maintenance or warranty period included? If so, for how long is the period?
    - One year
    - Two years
    - Three years
    - More than three years
    - We do NOT include a warranty period in our contracts
    - Jurisdiction/Project dependent
    - Other: please specify __________

30. Please rank the following tree maintenance actions according to priority in the long-term plan. Drag and drop the options below to sort, with 1 being the highest priority and 8 being the lowest.
    - Fall Clean-up
    - Trash Collection
    - Watering
    - Weeding
    - Fertilizing
    - Mulching
    - Pruning
    - Risk Assessment

31. Please rank the effectiveness of the following methods of irrigation for tree and new planting maintenance.

	Very Effective	Somewhat Effective	Not Effective	Detrimental	N/A
Automatic Irrigation Systems	○	○	○	○	○
Drip Irrigation Systems	○	○	○	○	○
Hand Watering	○	○	○	○	○
Watering Bags	○	○	○	○	○

32. Who is responsible for tree and new planting maintenance after completion of the contract? Select all that apply.
    - Staff in my department
    - Municipal staff
    - Local volunteers
    - External contractors
    - Trees are typically not maintained after the contract
    - Unsure or Don't Know

Do you have any additional comments or strategies you would like to share regarding street tree preservation and protection for construction projects?

Use the space below to upload any relevant resources you would like to share.

If you would like to receive follow up publications from the information collected during this project, please enter your email address below. We thank you for your contributions.

7.3 Appendix C: Survey Notice

University *of* Massachusetts Amherst

Department of Environmental Conservation

Arboriculture and Forest Resources

March 10, 2023

Dear Recipient,

I am writing to ask for your help conducting interdisciplinary research on preserving, protecting, and introducing trees in conjunction with road and sidewalk improvement projects.

This survey is part of an initiative by the University of Massachusetts Amherst (UMass Amherst) on behalf of the Massachusetts Department of Transportation (MassDOT) to understand best practices for roadside tree preservation and planting nationwide. The information gathered in this process will help to guide the creation of a manual to inform future actions to preserve and protect our roadside urban forests.

This survey will cover topics of tree protection and preservation, as well as planting space design as part of roadway and sidewalk improvement projects. The survey should take approximately 15 minutes to complete and contains a mix of multiple choice and open-ended questions.

Within the survey, there are opportunities to leave detailed feedback through additional questions. If you have the time and resources to answer these questions, we greatly appreciate your insight, however if you are unable to do so, we are grateful for your responses, and thank you for taking the time to continue to work through the survey.

You may begin the survey by clicking here:
https://umassamherst.co1.qualtrics.com/jfe/form/SV_dj3DvOo8RtzRjEy

If you have any questions, or further comments, please contact Delia Mahoney at umasstreeprotectionsurvey@gmail.com.

Thank you for your participation,
Sincerely,
Delia Mahoney

UMassAmherst massDOT Massachusetts Department of Transportation

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