



European Tree Technician



STUDY GUIDE

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1.6.2. Tree Revitalisation

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GENERAL OBJECTIVE

To have a general knowledge of how to improve the health, growth, and life expectancy of urban trees by reducing problems with soil and poor root vitality.

SPECIFIC OBJECTIVE

A European Tree Technician is expected to:

- be able to identify and describe normal growth and architecture, as well as diagnostic features indicating poor vitality;
- be able to identify the horizontal and vertical extensions of the root zone;
- be able to analyse the soil condition and the vertical distribution of roots across the soil profile;
- have knowledge about the requirements for good root growth;
- have knowledge about techniques to improve the growth media for trees;
- improve tree sites in accordance with technical regulations; and
- carry out operations such as soil decompaction, soil aeration, and soil replacement.

SEE TOGETHER WITH:

Tree Development and Growth Stages, Soil Science, Site Selection, Diagnostic Features (abiotic agents & biotic agents), Tree Assessment, Trees on Construction Sites, Tree Site Improvement and Remedial Measures

ESSENCE OF THE TOPIC

Tree revitalisation is the process of restoring the health and vitality of trees that have been damaged or weakened due to various factors, such as disease, pests, environmental stress, or improper care. One of the main causes of urban tree deterioration, however, is related to the soil, often the compression of the soil. Basically, tree revitalisation aims at improving the tree's water and carbohydrate balance, which stimulates the tree's regenerative and protective processes, thereby stimulating the increment and defence mechanisms of the tree. This essentially comes down to the improvement of the growth media. Therefore, the ETT should be able to assess the possibilities and limitations for improvement of the tree's growth media. As most tree condition problems are soil-related, it's essential to improve the soil.

KEY TERMS

Carbohydrate-balance: carbohydrate budget, fine root turnover, root decay, sugar

Diagnosing: diagnostic features, life expectancy, root friendly, soil compaction, soil horizon, soil vitality, symptom controlling

By improving, we mean getting as many of the natural processes of the soil back up and running as possible. It is rarely possible to get all three components of soil health (chemical, physical, and biological) back to optimal levels, but the root environment will at least be improved by revitalisation work. So, our goals are to improve soil processes that improve soil health and encourage high longevity for roots, which will, in turn, sustain tree vitality.

It is essential to know that revitalisation is a process. In Chapter 2.4 Tree Site Improvement and Remedial Measures, we explain in more detail the process of tree revitalisation in practice with a detailed flow chart; however, for this chapter, the following steps are a good starting point:

- Diagnosing a tree's decline
- Choosing the right solution
- Monitoring

The Carbohydrate Balance

Revitalisation work basically aims at improving the carbohydrate balance and thus the increment and defence mechanisms of the tree. An improved carbohydrate balance will improve increment in general, enhance twig and leaf mass, improve leaf colour, enhance root regeneration, and, above all, improve the maintenance of barriers for decay within the living woody body. Ancient trees always have more-or-less hidden wounds in their roots,

Solution: air pressure, chemical imbalance, loosening the soil, natural process, radial trenching, vertical mulching

Monitoring: baseline data, monitoring goals

stem, and crown, where the woody body degenerates and dies back. But even without decay, ancient trees will have problems supplying the whole crown with enough water. As the stem becomes bigger, the tree is no longer able to provide sufficient growth for its complete structure. A central purpose of revitalisation work is to slow down the spread of decay and degeneration. Or, to put it in the terms of urban forest managers, to enhance the remaining life span of the tree by several decades. Alternatively, we can draw an analogy with human medicine: It is not about fixing a broken leg; it is about improving the patient's immune system and general fitness so that he or she will recover from the broken leg faster.

The carbohydrate balance is an accounting of the input and output of carbohydrates ("sugar"). The input of sugar from photosynthesis, and the output of sugar from growth and maintenance respiration. The balance is improved either by enhancing photosynthetic productivity or by reducing inefficient sugar consumption. The production (input) of sugar in elder or stressed trees is commonly limited by a poor water supply to the crown (causing prolonged closure of stomata), although the shaded leaves lower in the crown can continue to carry out photosynthesis. This, again, is most commonly caused by poor root conditions. Therefore, an improvement in the growth media is often very effective in enhancing root distribution, root longevity, photosynthesis, and sugar reserves.

Poor root conditions also tend to speed up the 'fine root turnover'. Fine roots have a life span of 6-12 months on average (some live many years, others live only a few weeks or days), meaning that the fine root population tends to be replaced at least once a year in a healthy tree with a good soil environment. It is anticipated that the turnover of fine roots is many times enhanced in urban trees with poor growth conditions.

In normal, healthy deciduous forest trees with a “normal” viable carbohydrate balance, the sugar produced is consumed by the following sinks (a sink is a carbohydrate-consumer within the tree):

- +/- 30% is used for the development of new leaves (in spring and summer)
- +/- 30% is used for the current renewal of fine roots (fine root turnover all year around)
- +/- 30% is used in branches, stem, and woody roots for increment, wound protection, and repair of rot barriers.
- +/- 10% is used for mycorrhizal fungi and other soil organisms.

This carbohydrate budget is a rough average covering one year – a dynamic equilibrium (with inputs and outputs) of carbohydrates stored and used in various places at various times of the year. In urban trees with poor growth media, fine root turnover is likely to consume more than 60% of the total carbohydrate budget, which reduces the resources for growth and maintenance.

B. Step 1 – Diagnosing a Tree’s Decline

B.1. Finding the Cause(s)

Tree revitalisation specifically aims to improve the tree’s fundamental life processes, with a focus on a longer-term increase in the remaining life expectancy of the tree. The focus lies in finding the cause or multiple causes of the tree’s deteriorating health and not on controlling the symptom (diagnostic features). Of course, in practice, both are dealt with at the same time. The purpose of the investigation is to identify the most critical factors and mechanisms that limit the carbohydrate budget. These may either be flaws in carbohydrate production (photosynthesis) or mechanisms that heavily consume carbohydrates.

When searching for the cause(s) of deterioration (Chapters 1.5.1. Diagnostic Features and 1.5.2. Tree Assessment) we must carefully look at how the tree is reacting to the stress it is suffering from.

By reading or assessing the state of the diagnostic features, an ETT is able to deduce the overall or partial condition of the tree. However, the diagnostic features, which are, in essence, symptoms of natural processes that occur above and below ground, are not the cause. An ETT should go deeper to find the source(s) of the problem, which mostly lie in these natural processes. As we saw in Chapters 1.2.1. Soil Science and 1.1.2. Tree Development and Growth Stages, it all comes down to being able to assess the natural processes of the tree (above and below the ground).

Tree revitalisation is a biologically complicated matter and may be at the edge of the competencies of many ETTs. A correct diagnosis is a particularly complex matter that demands extensive knowledge and experience. Some ETTs may develop specialised skills within the subject, but all ETTs should be aware of the possibilities this provides, as well as the techniques used within it. Support from specialists in urban soil management and tree biology will often be needed.

B.2. The Most Common Cause: Soil Problems

In essence, we want to make non-root-friendly soil into root-friendly soil. The diagnosis clarifies whether this is possible and how to achieve a root-friendly soil environment by assessing the different soil horizons. In urban soils, these horizons can be lacking or reduced to just one. Ideally, we want good conditions within all three components of soil vitality (physical, chemical, and biological) in the root-friendly horizons. In real life, however, we are often restricted by the site at hand. In particular, the biological component may be difficult to restore as the necessary ecosystem interactions (decomposition of leaves, interactions with low flora, migration of soil fauna, etc.) are absent. It is not always easy to introduce these interactions in a built-up environment. But wherever we can remove paved surfaces and restore a more natural system, we should. Success in the application of mycorrhiza inoculum varies

a lot, partly because of the many unknown interactions of fungi with climate and soil components. Therefore, it is essential to add mycorrhizal fungi that are appropriate for the tree species and are of local origin. Commercially available inocula might

not contain the right fungi, and their origin may be unknown. So, the fungal species in the inoculum may not be appropriate for the tree species or environment.

URBAN SOIL

Very many urban trees do not grow; they seem to remain static in size and shape and then gradually degenerate. The reasons very often relate to problems below ground. Although it is often due to limited root space (Urban 2008), it is very often a consequence of poor soil conditions and poor root health as well. Although suburban areas might still have some authentic, natural, and undisturbed soils, most soil in European cities is not natural but instead consists mainly of fill materials. Old historic cities may have several metres of old building materials, debris, waste, and random soil materials placed above the original historical soil surface. Quite often, various qualities of “mull” soils (topsoil from forests or agricultural land with organic material) have been used as fill material with the intention of improving growth conditions, often with poor results due to poor layering or compaction. Organic material needs a good gas exchange in the soil to have a positive effect on growth conditions. Urban soils are very often compressed with poor gas exchange (oxygen down, carbon dioxide up). Thus, ‘good mull’ in deep

horizons often does not do any good; in fact, quite often the opposite is the case. A high content of organic matter below 30 cm often induces fermentation or anaerobic respiration, through which phytotoxic substances are produced. Many urban soils contain old building materials like iron, broken glass, brick, concrete, and mortar. Although brick material and coarse sand might be beneficial in improving stable structures, aeration, and drainage, bricks are commonly associated with mortar and cement, which provide the soil with an unfavourably high pH value (pH > 8), which induces a deficiency of manganese, iron, and phosphorous. Urban soils commonly lack or have poor biological activity in the form of natural soil flora and fauna. Thus, normal soil food webs and carbon cycling should not be expected in urban soils (though they might be stimulated). Relevant mycorrhizal fungi are not to be expected either. However, in our experience, the most frequent problem in urban soils is the compression of the soil, leading to poor gas exchange and waterlogging. Other problems related to water include a lack of available water and inadequate natural drainage, which can cause anoxia (an anaerobic condition). Compression often induces secondary problems with water, such as surface runoff and poor drainage).

Often, we must be satisfied with an improvement in the physical components of soil ecology (porosity, drainage, gas exchange), as improvements in the chemical components of soils are often somewhat more complicated. A very low pH is the easiest chemical problem to deal with. Laboratory analysis may reveal nutrient imbalances, which may also be counteracted by targeted fertilisation. However, as soil compaction and poor gas exchange in deeper soil layers are the most common problems in urban soils, large improvements will often only be possible by improving gas exchange in these deep soil layers (O_2 down, CO_2 , and poisonous gases up). Furthermore, a high availability of oxygen is also likely to have a beneficial spinoff on the chemical and biological components of soils.

The main task of soil diagnosis is to clarify whether a soil horizon is “root friendly” or “root hostile” by using soil profile assessments. It should also reveal the reasons for the condition of the soil as well as analyse the effectiveness of any measures taken. To do this, it is important to carry out the soil profile analysis at a proper distance from a larger tree on the site (3–8 metres from the trunk), so that the vertical distribution of roots can guide you in the interpretation of the “root friendliness” of the different horizons.

Step 2 - Choosing the Right Solution

Once the cause of the tree’s decline has been identified, steps can be taken to provide the tree with the proper care it needs to recover. As already stated, this is mostly a soil problem, and in Chapter 1.2.1. Soil Science, we explain the natural soil processes that are the foundations of soil health. As previously discussed, a system consisting of physical, chemical, and biological components is required to maintain soil health for trees. Below, we describe what happens if these natural processes fail by showing the common problems in urban soil. The focus here is to recognise these problems and know what type of natural process(es) they influ-

ence. Practical technical solutions are explained in Chapter 2.4.

- The anthropogenic influence on urban soils: Very often, the soil is made up of artificial “fill materials” of a more-or-less beneficial kind. However, the layering of the fill materials is often not suitable.
- Poor gas exchange in the soil: low or abundant levels of O_2 and accumulation of CO_2 in the subsoil. Gas exchange and drainage can be evaluated by several parameters: A) odour/smell; B) colour (a blue-grey colour is a sign of reduced iron, whereas a red or yellow colour is a sign of oxidised iron); C) the condition of roots (absence of roots where roots should otherwise be present); D) the state of compression or cementation of the soil; and E) the presence of earthworms (their number should be evaluated conservatively as they may eat their way through compressed soil, but they create good macropores). If poor gas exchange is the only problem in the soil, then it is commonly easy to solve.
- Compression of the soil (commonly leading to poor gas exchange, anoxia, poor natural drainage, and a lack of deep roots or roots characterised by a clustered presence of finer roots): Soil compaction can be measured in several ways, as discussed in Chapter 1.2.1. “Loosening” the soil with air pressure has become increasingly popular, although, despite frequent positive effects in the short term, we do not really know very much about the intensity and vertical distribution of new macropores after the loosening. Certainly, the soil is not loosened bulk-wise; only scattered macropores and/or cracks are created. Moreover, in soils with a high clay content, simultaneous injection of a stable substrate into the macropores is crucial, as, otherwise, the pores risk being clogged by mud after rainfall. Alternatives for loosening soils are radial trenching, vertical mulching, and soil replacement.

- Lack or excess of humus: Soil fill often consists of pure mineral materials without organic material. This can be remedied by adding compost or sphagnum IF (AND ONLY IF) the enriched soil layer has access to oxygen. Excess humus in soil fill is a common problem in deeper soil layers because gas exchange is limited. This issue of excess humus may, therefore, be lessened by improving the gas exchange in the soil.
- The removal of organic matter over many years: Very often, this is solved by adding a mulch layer under the trees; however, adding mulch after years of having removed all the leaves can seriously disturb the fungal ecosystem, such as mycorrhiza. The point is that mycorrhizal fungi protect tree roots against parasitic fungi. Mycorrhizal fungi can benefit from nitrogen-poor circumstances, but not from a thick layer of mulch.
- Unfortunate layering: If humus-rich layers are buried under layers of gravel or sand, these layers may be remixed with the use of a digger. Compression may also be reduced efficiently through “soil profile rebuilding”.
- Lack or excess of water: The soil column may be completely dry due to a slope in the terrain and/or compressed topsoil. Alternatively, the soil might be waterlogged due to poor drainage in the subsoil. Both problems may be solved by proper remedial action.
- Chemical imbalances or pollution: It is common to have a pH above 8 in urban soils. Lowering the pH with sulphur is possible, but it demands a thorough analysis in the soil lab to determine the amount of sulphur needed. Reducing the pH too fast can alter or destroy the soil food web. Also, it may take time for the soil to reach a new balance in the acid/Ca balance. For safety reasons, amendment with sulphur should only be carried out spot- or trench-wise so that roots can find soil spaces with different pH values. Adding organic material (sphagnum) to the topsoil will also mitigate a high pH.

An example is shown in Figure 1.



Figure 1 (C.C.Nielsen). Soil analysis: As a minimum, a soil profile must be analysed before initiating any soil improvements. This profile shows three layers of soil fill. Large roots are only present in the upper 15 cm layer. Horizons 2 and 3 are lightly compressed. Spread clusters of fine roots are found in all three horizons. The deepest and 3rd horizon has a high content of organic matter but also has a blue-grey colour. This colour indicates Fe^{2+} – the reduced (and phytotoxic) form of iron. This indicates a lack of oxygen. Initiatives to improve the gas exchange in deep layers might improve the “root friendliness” of this layer.

SCREWDRIVER TEST

The “screwdriver test” is the simplest and quickest method for assessing soil compaction. Test the soil by inserting a screwdriver into the soil (this works best if done 2 days after rainfall during the growing season). If the screwdriver goes into the soil easily, the soil has minimal or no compaction. If the screwdriver can be pushed into the soil but requires some pressure, the soil is moderately compacted. If the screwdriver cannot be driven into the soil by hand, the soil is severely compacted (Cappiella et al 2006). Please be aware of the strong bias inherent in this method if the soil is dry. When assessing the soil profile, it is recommended to use the “screwdriver test” horizontally in every important soil horizon in order to reveal barriers to gas exchange and drainage.

Step 3 - Monitoring

Tree revitalisation is an ongoing process, and it is important to monitor the tree’s progress over time to ensure that it is responding to the care it is receiving. Monitoring involves regularly checking the progress of the tree’s health and growth after implementing the revitalisation plan. Here are the steps involved in the monitoring process of tree revitalisation:

1. Establish baseline data: Before initiating any revitalisation work, it is important to establish baseline data on the tree’s health and condition. This includes information such as tree species, size, age, location, and any existing issues with pests, diseases, or environmental stressors. This baseline data serves as a reference point for tracking progress during the monitoring process.

2. Set monitoring goals: The goals of the monitoring process should be clearly defined and specific to the tree’s needs. These goals should be based on the tree’s baseline data and should be measurable, achievable, and relevant to the revitalisation plan. Goals could include increased foliage density, improved root growth, or reduced pest infestation.
3. Regular inspections: Regular inspections are necessary to evaluate the tree’s progress towards meeting the monitoring goals. These inspections should occur on a predetermined schedule and should involve a thorough examination of the tree’s foliage, bark, roots, and soil.
4. Record-keeping: All monitoring data should be recorded and maintained in a database or other record-keeping system. This data should include the tree’s baseline information, monitoring goals, inspection results, and any maintenance activities or treatments performed.
5. Adjustments to the revitalisation plan: Based on the results of the inspections and monitoring data, adjustments may need to be made to the revitalisation plan. For example, if the tree is not responding well to a particular treatment, alternative treatments may need to be considered. These adjustments should be made in consultation with a qualified tree care professional.
6. Continuous monitoring: Tree revitalisation is an ongoing process, and monitoring should continue for the life of the tree. Regular inspections and record-keeping should continue to ensure that the tree remains healthy and thriving.

Chapter 2.4 explains in more detail how this works in practice.



SELF-CHECK QUESTIONS

1. What is tree revitalisation?
2. What is the carbohydrate balance/budget?
3. How do urban soils differ from old-growth forest soils?
4. Describe common problems with urban soils.
5. Explain fine root turnover.
6. Which soil factors commonly limit root vitality in urban soils?
7. At what distance from a tree do you analyse the soil profile in order to gain an understanding of its vertical root distribution?
8. Beside soil compression, what other factors may cause tree roots to be absent in the upper 50 cm soil layer?

PRACTICAL EXERCISES

1. Go in the field to an urban tree, make a soil profile, and then assess the soil profile for root friendliness.
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ESSENTIAL READING

The text in this chapter summarises many years of scientific work and practical experience within different fields of science (whole tree physiology, biomass research, forest ecosystem research, root morphology and soil science). The present text is essentially new and similar is not found otherwise. We cannot recommend any additional reading list.

UK Up by Roots (International Society of Arboriculture) by James Urban.

Reference work on working in urban soils. Some chapters explain methods of remediation, and remedification of urban soils for trees.



2.4. TREE SITE IMPROVEMENT AND REMEDIAL MEASURES

Christian Nielsen

GENERAL OBJECTIVE

This chapter guides the planning and practical implementation of a revitalisation project that will help to improve the health, growth, and life expectancy of ancient urban trees by reducing problems with the soil and poor root vitality.

SPECIFIC OBJECTIVE

A European Tree Technician is expected to:

- through dialogue with the client, help with a preliminary definition of the problem and influence the content of the initial assignment. Please refer to the chapter introduction for legal and economic aspects to be aware of;
- carry out a professional diagnosis of the health problems that the tree is suffering from. Often, a specialist must be consulted for complicated soil/root interactions;
- formulate alternative solutions to improve the health of the tree, taking work safety, biosecurity, and habitat protection into account.
- organise and implement the task; and
- try to arrange a monitoring of tree increment to evaluate the effects of revitalisation.

SEE TOGETHER WITH:

Tree Development and Growth Stages, Soil Science, Diagnostic Features, Tree Assessment, Tree Revitalisation, Tree Care and Remedial Measures.

KEY TERMS

General framework

Explanation framework: fine-root turnover, flaws in the carbohydrate-balance

Hints: soil gas exchange

Technical aspects: anaerobic soil respiration, "root-friendly" soil horizon, water-logging

ESSENCE OF THE TOPIC

This chapter provides guidance on how to organise a tree revitalisation project from the first contact with the client through implementation and final control of the desired results. The flow of the process is described and sketched in the flowchart below.

As we saw in Chapter 1.6.2. Tree Revitalisation, tree revitalisation aims at improving the tree's water and carbohydrate balance, which stimulates the tree's regenerative and protective processes. This essentially comes down to the improvement of the growth media. The essence of tree care and remedial measures for tree site improvement is that the actions or decisions must be well supported through a holistic methodology, as described in Chapter 2.3. Tree Care and Remedial Measures. This decision-making process helps in making effective and sustainable tree revitalisation decisions. Be aware that such a decision-making process is not a one-time event but must be repeated every time the question of tree care arises as the situation can change over time. In other words: this process is looped in time.

A. General Framework of Tree Care and Remedial Measures

In Figure 1 you will find a flowchart on how to approach a tree revitalisation project. Note that this flowchart is a guide and not a standard and the flowchart presented in Chapter 2.3 is also applicable to tree revitalisation. We will keep them both as neither of them is a standard and both illustrate beautifully the general concept and essence explained in chapter 2.0.0.

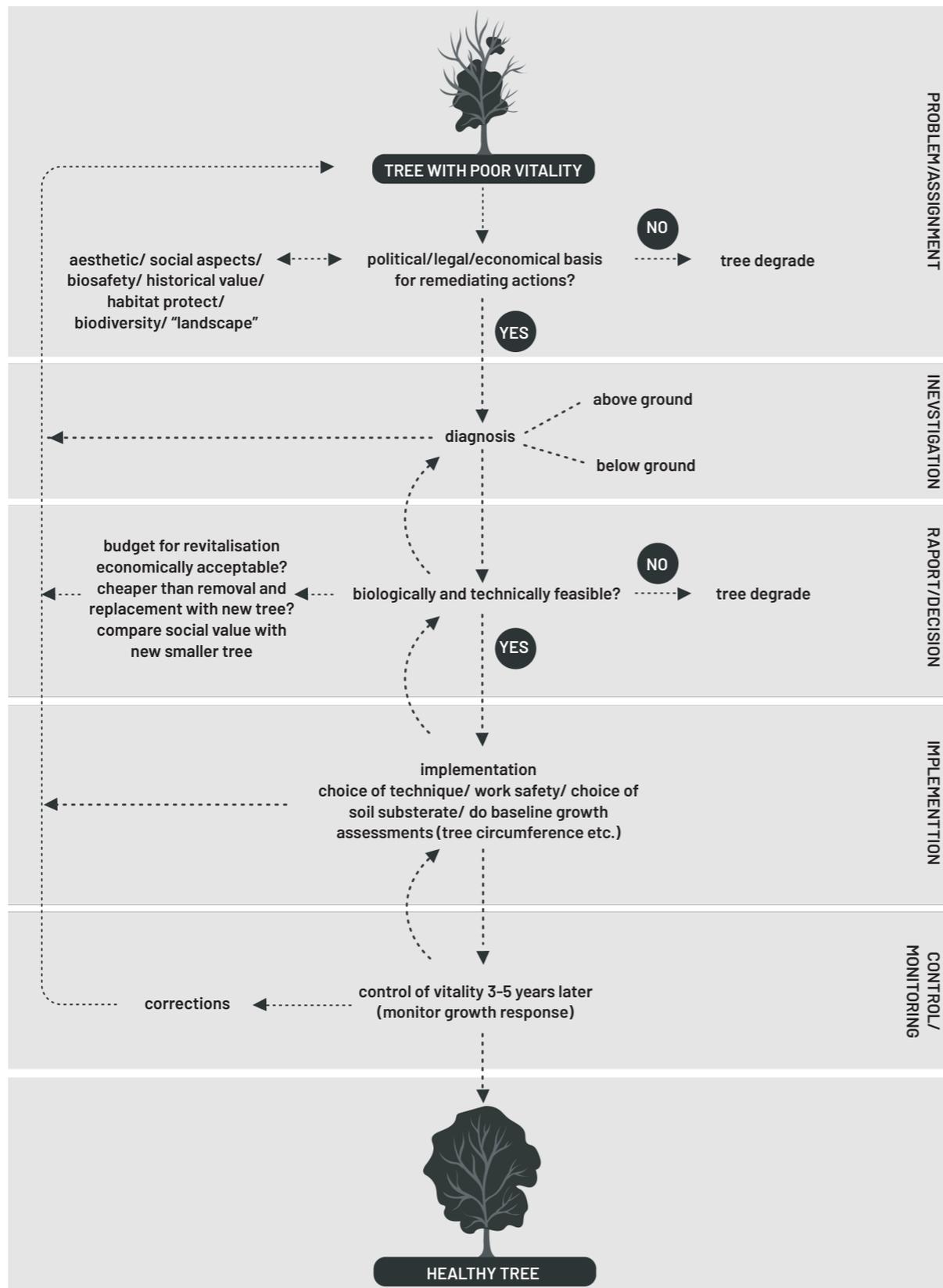
B. Explanation of the Framework

Let us explain in more detail what the flowchart is all about. We will do this by elaborating on significant points in the framework. It is not our ambition to explain all the different types of tree

revitalisation techniques and methods; however, since there is no European Tree Revitalisation Standard, we will try to describe the most common kinds of remediation work. The main purpose of this framework is to develop a thinking pattern or a handhold that can be used to help us ask the right questions in any given situation and to come up with a sustainable solution. This flowchart helps remind us of all the important questions and prompts us to find good answers to them. Notice the possibility of looping every step back to the previous step, which is an essential aspect of Part 2 of this study guide. This 'going back to the previous step' is, in reality, a common situation, as the result of one step has an impact on the previous step. For example, the diagnosis can reveal that bats are living in the tree. As bats are protected by European law, that can change the assignment, as now the tree must be kept at all costs. Notice also the 'big loop' which can 'shortcut' some steps, since some steps in the flowchart do not apply to all trees with poor vitality.

B.1. Problem Definition and Assignment

The problem with poor tree vitality is commonly identified by the client (but may also be identified by an ETT during a larger survey). Most clients may recognise a problem but may not have sufficient knowledge to properly diagnose it. Thus, during the initial contact, an ETT should stress the necessity of a thorough investigation and also help the client to perceive the potential full extent of various remedial actions. If the client has a sufficient legal and financial basis for remedial work, then an assignment should be formulated in writing. Note that the preconditions (habitat value, aesthetics, social value, etc.) should also be clearly formulated in order to start the next steps.



REVITALISATION

is both relevant for amenity trees and for veteran trees because no matter whether the purpose is to improve the tree's aesthetics or protect biodiversity, a prolongation of the remaining life span of the tree is desirable. It is important to realise that the nature conservation value of veteran trees can be dramatically enhanced by improving the carbon balance of the living parts of trees.

B.2. Investigation/Diagnosis

The tree may have many different kinds of damage or health problems, which means that the problem should be investigated both above and below ground. There may be unstable bifurcations in the stem; large dead, broken, or pruned branches; stem hollowness; severed roots; fungi attack; crown decline symptoms, and so on. Many of these kinds of problems can be handled directly by employing specific measures (pruning, cabling, fertilisation, etc.) to deal with the specific symptoms – see the relevant sections in Part 1 and 2. The best way to diagnose the problem is to follow the questions in the flowchart in Chapter 2.3 Tree Care and Remedial Measures until you arrive at a basic assessment (interpretation and evaluation).

The revitalisation process aims at improving the carbohydrate balance of the tree. Poor carbohydrate balance commonly causes symptoms of poor vitality, as described in Chapter 1.1.2. Tree Development and Growth Stages, Chapter 1.2.1 Soil Science, Chapter 1.5.1. Diagnostic Features, and Chapter 1.5.2. Tree Assessment. An improved carbohydrate balance will improve increment in general, enhance twig and leaf mass, improve leaf colour, enhance root regeneration and, above all, improve the maintenance of barriers for decay within the living woody body. Older trees always have more-or-less hidden wounds in roots, stem, and crown, where the woody body degenerates

and dies back. A central purpose of revitalisation work is to slow down the speed of decay and degeneration. Or put it in the terms of urban forest managers: to enhance the remaining life span of the tree by several decades.

The purpose of the investigation is to identify the most critical factors and mechanisms that limit the carbohydrate balance. These may either be flaws in carbohydrate production (input=photosynthesis) or mechanisms that heavily consume carbohydrates (output). Sugar production in old trees is very often limited by poor water balance, which very often comes back to poor water uptake, which again commonly relates to poor root architecture (poor horizontal AND vertical extension of the root system). Excessive carbohydrate consumption is often found in the fine-root turnover complex (see Chapter 1.6.2. Tree Revitalisation).

A correct diagnosis is very important in evaluating the feasibility of a revitalisation project and suggesting the proper measures to be taken. It will often be necessary to involve a soil/root specialist in the project in order to ensure a correct diagnosis. Tools:

- Mallet
- Binocular/drone for the study of the crown structure and foliation (example:



- Iron rod for analysis of stem hollowness and for detection of soil compression (test horizontally or obliquely in every major soil horizon)
- Spade and hand shovel
- Camera and measuring tape, pen, paper etc. for documentation
- Field tools for pH assessment of major soil horizons
- Brush to clean root samples
- Botany magnifying glass (10x) for the study of the root surface

B.3. Reporting/Decisions

Improvement of a tree's biology is always possible. However, is it possible within certain economic restraints? As we saw in Chapter 2.3 Tree Care and Remedial Measures, the question that needs answering is, 'What are the results of a cost-benefit analysis?'

The answer relies on several steps of analysis:

- Describe the biological/technical measures. Can you formulate alternative measures?
- Can you provide rough cost levels for each alternative and the long-term monitoring of effects?

Here is an example of the cost-benefit analysis applied to tree revitalisation: the costs for improving a tree during its life span should be compared with the monetary and social values of the tree. This evaluation may also include the costs for the replacement of the old tree with a new one including costs for site improvement.

The report should also be formulated in a way (or at least contain a summary) that is suitable for dialogue between your client and other stakeholders (politicians, community etc). Two courses of action that are always options are 'do nothing' or 'remove the tree'.

B.4. Implementation

Signs and symptoms that support, contradict, or extend the original diagnosis are likely to show up during the implementation of the revitalisation operations. Please register such observations. After the operation has ended, it is a good practice to carry out a baseline assessment of stem circumference for later, simple control of the remedial measures carried out.

B.5. Control

It is good practice to monitor and control the process so that the anticipated positive effects on

tree vitality are achieved. The first signs of improved vitality are often an improved density and colour of the foliage; however, it may take 3 to 5 years before there is any visible evidence of improvement. If the tree does not respond to the revitalisation as expected, explanations for this should be searched for. A revised diagnosis and supplementary work might be necessary.

C. Hints Regarding Diagnosis / Investigation

Before attempting any improvements, carry out a diagnostic analysis, including

- above-ground factors involved in tree degeneration (see Chapters 1.5.1 Diagnostic Features and 1.5.2 Tree Assessment);
- below-ground problems.

Below-ground problems are commonly related to one or both of the following factors:

- Limited root space
- Poor soil quality

Determination of a tree's root space – horizontally and vertically – is very difficult in an urban environment. Not least because tree roots tend to exploit every found macropore and therefore "run wild" in many unexpected directions. Such a job is for specialists. Having said that, obvious limitations to root expansion close to the tree should be acknowledged. Root spread in park soils *may* be less complicated.

An attempt should be made to evaluate the soil quality, even though this also constitutes a challenge, because practically all available theories and textbooks on soil assessment relate to more-or-less natural soils in forestry or agriculture. Good instructions for urban soil assessment are missing. Urban soils are affected and often deteriorated by humans and are exposed to different problems compared to "natural soils". The texts of Urban (2008, chapter 7) and EPA (2011) provide some inspiration, but they are not sufficiently "hands-on". Great care should be taken not to use

"copy-paste" guidelines: Table 14 in Cappiella et al (2006) is an example of guidelines that should only be followed after a thorough analysis. Therefore, in order to help you undertake an urban soil evaluation, we have compiled some key questions that can help you build up an idea of its condition.

Former land use should be noted if possible – particularly with respect to contamination of the soil with pollutants and heavy metals. If the soil is polluted, soil exchange could be a relevant option.

Is the soil a recipient for de-icing salt from nearby streets or pedestrian paths? Does the soil have a sufficiently coarse texture and structure to "wash out" salt from the soil column?

The hydrology of the site should be considered. Does the site seem to have natural vertical drainage through the soil, or is surface runoff the primary mechanism of rainwater disposal? Will the site be suitable for stormwater management? Can the site receive roof water for improved growth conditions?

The soil assessment is always a must. This job is not easy because the soil as growth media for tree roots is a complicated ecosystem (refer to Chapter 1.6.2. Tree Revitalisation).

D. Technical Aspects

Soil biodiversity and old root channels – particularly valuable in deep clay horizons

Deep clayey soil layers may contain old root channels (macropores), which are extremely important for drainage, gas exchange, and new root expansion. Such soil horizons are created over thousands of years and are crucial for soil biodiversity and soil health. Please take care not to ruin such deeper soil layers.

Rough or gentle techniques for soil work

1. Pneumatic tools (air pressure and vacuum): When the old soil is loosened with an air spade and removed by vacuum, it is possible to work close up to the trees with comparatively little damage to the root system. Roots smaller than 1-2 mm will be lost, but they regenerate quickly. However, please be careful not to damage the root bark with close-up air pressure.
2. Backhoe/ripper drainage plough, etc: When using tools that sever roots, the "critical root zone" (CRZ) should be respected (see Chapter 1.6.3). Although it means that it is harder to work closer to the tree, it may still have a significant effect.
3. Combination of backhoe and manual shovelling: Combining the backhoe work with careful manual soil removal around roots makes it possible to remove soil closer to the tree.

Before using techniques 2 and 3, gather data about root distribution to formulate the CRZ.

General root protective measures:

By root work, please note the following:

- always keep exposed roots moist and protected against sun and light, e.g., with wet burlap;
- try not to damage roots thicker than 30-40 mm;
- whenever such larger roots are severed, they should be treated with a clear cut to stimulate regrowth and prevent decay;
- fine roots will commonly get lost during root exposure, which is a minor problem as fine roots regenerate vigorously given the right growth conditions.

Critical Root Zone (CRZ)

When using one of the rough methods to sever roots, the CRZ must be considered (refer to Chapter 1.6.3. for references to CRZ). Either by doing a prior analysis of root spread or by starting the work at a greater distance from the tree and then gradually approaching the tree. When digging or ripping no (or very few) roots being thicker than 3-4 cm should be cut in the CRZ. Please note that the CRZ varies a lot among tree species and strongly depends on how deeply rooted the soil is.

Correction of soil chemistry

During soil work, low or high pH may be corrected – although this is not an easy job. Ideally, soil samples should be titrated in a soil lab to provide us with an idea of the pH buffer in the soil, but in the real world, it is very difficult to hit the right dose and get the dose correctly mixed with soil particles. Furthermore, it may take time for the soil to achieve a new pH balance after the addition of either lime or sulphur. One way of minimizing the risk from chemical amelioration is to add our corrective material to spatially limited spots, lines, or sections. Another method for reducing the risk of “chemistry running wild” is to use coarse material, for example, coarse lime instead of common agricultural fine-textured lime. An unbalanced nutrient situation may be corrected by using proper fertilizers. Please also consider the risk of killing roots with overdoses of fertilizers.

E. Technical Solutions

Whereas Chapter 1.2.1. explains soil processes and soil assessment and Chapter 1.6.1. reveals the problems, the following is about finding the appropriate solutions.

Deep Ripping

Soil compression in the topsoil is easier to deal with: Mechanical tilling, frost and thaw, and root

activity will commonly counteract compression of the topsoil. But vehicles with an axle load of more than 5 tonnes will compress the soil to a depth of 60-70 cm. Loosening of the subsoil is a much larger challenge. Loosening with a backhoe is generally very effective. Ripping with 70-100 cm-deep “ripper tines” or a chisel may also be effective. The soil should be dry during the treatment. The macropores created in soils with a high clay content may close again when clay particles are leaked downward during water infiltration. Sandy soils are more likely to gain from deep ripping in the long term. On clay soils, deep-rooting crops may be considered (canola, alfalfa, and lupin) to enhance the creation of deep macropores.

Soil Drainage

Water input in large parts of northern Europe is between 600 and 1000 mm of precipitation per year. Between 300 and 450 mm of water is commonly lost from forest ecosystems via evapotranspiration. Thus, between 300 and 600 mm of rain must drain off urban landscapes. This may happen in three ways:

- surface runoff (e.g., to sewer systems),
- horizontal drainage within the soil to low-positioned recipients, or
- vertical drainage through the subsoil.

At any site where trees are growing, it is useful to spend a little time considering these basic hydrological issues – not least to consider how much water will be available for the trees at various soil depths.

Where water stagnates and accumulates in the subsoil, the soil becomes waterlogged. Rainwater contains oxygen, but the content of oxygen in soil water is gradually reduced to a critically low level within a few days (within a maximum of a week). Thus, stagnating soil water quickly becomes anaerobic and toxic to fine roots. After being waterlogged for months, woody roots also tend to die,

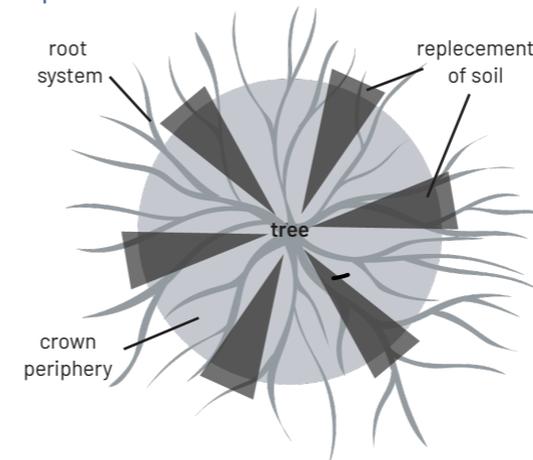
but resistance to waterlogging varies tremendously between tree species.

Accumulated free water in the root zone is commonly detrimental to tree health. Where a risk of waterlogging in the subsoil is present, drainage of the subsoil is necessary for good tree growth. Moreover, where the outlet of drain tubes is not under water, drain tubes also enhance gas exchange to the subsoil, and we do see that root growth is particularly intensive close to drain tubes in such situations. Trenches with coarse gravel covered with geotextiles may be used instead of drain tubes. Finding a recipient for the drain water often constitutes a challenge for the drainage of urban soils.

Soil Profile Rebuilding (Backhoe Treatment)

Where urban soils contain different layers of varying root friendliness, remixing the soil may be useful. This is efficiently carried out with a backhoe. This operation may, at least, break up compressed soil layers. Please refer to Day (2016). Before carrying out such a profile rebuilding, it should be carefully considered whether the soil texture and structure will be suitable after remixing. Sometimes the supplementary supply of soil materials may be beneficial (e.g., coarse sand if too clayey, clay if too coarse material, the addition of compost or mull in the upper 25 cm, aeration tubes, etc.).

Replacement of Soil



Poor urban soils are commonly replaced by a specific urban tree soil substrate before the establishment of new trees. But soil replacement may also be an option around an older standing tree. When done close to the tree where the intensity of coarse roots (>3 cm) is high, removal of the old soil must be carried out using pneumatic tools (Fite 2016). Where replacement is carried out at larger distances from the trees, normal digging equipment may be used for removal. Please consider the CRZ. Besides the common root protection guidelines above, please note the following:

- The anchorage/stability of the tree must be maintained during the operation. Therefore, only replace the soil in sections of the root zone (see Figure 1). The best time for this kind of operation is late winter/early spring, in order to provide the roots with a growing season for root regrowth in the new soil.
- Use refill material that is suitable for the site, minding the traffic load, etc.
- Actions should be taken to ensure proper soil moisture, at least during the first growing season after soil exchange.

Air Tilling

This method can be used to loosen compressed topsoil. It may also be used to mix compost down into the upper soil. Please refer to Fite (2016).

Pneumatic Creation of and Filling of Macropores with Compost (or other material)

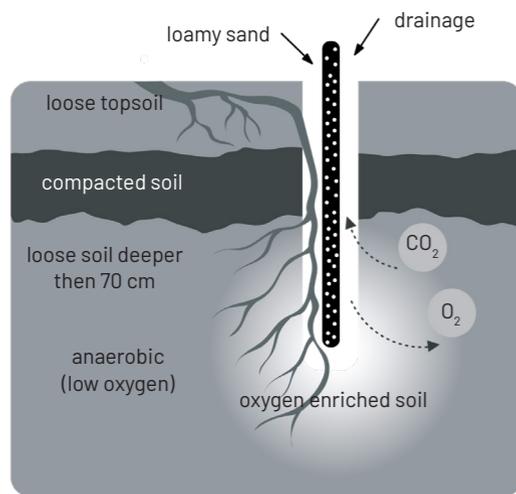
A method now widely used in the Netherlands and Belgium is an attempt to loosen up compressed soil by means of soil picks (a tool similar to an air spade) and high air pressure. This operation must be accompanied by the insertion of a material that prevents the created macropores from closing after mud filling, particularly in soils with high clay content. Air pressure creates only a few widespread macropores. This method does not resolve and loosen compressed soil, but it improves the drainage and gas exchange in the soil to an

unknown depth. Depending on the character of the inserted material (crushed lava, biochar, compost) the macropores may be more or less permanent.

Radial Trenching

This is either an air tilling or a soil replacement procedure involving radial trenches going radially outward from the tree. Depending on the depth and width of the trenches, this concept is an intermediate technique between the real "soil exchange" and "air tilling" and "vertical mulching". Please refer to Fite (2016).

Vertical Mulching (with or without aeration tubes)



Vertical mulching is the creation of vertical holes in the soil, which, after refill, serve both as channels for vertical root growth and as ventilation channels for O₂ (down) and CO₂ (up). Vertical mulching may be appropriate where root growth is restricted to a shallow band of topsoil; however, it is not helpful in all cases.

In anthropogenically compressed soils, the major limitation of the vertical expansion of the root system is a lack of oxygen in the subsoil. In such situations, compression may be restricted to the upper 60-80 cm of the soil. If the subsoil below this compressed layer is "root friendly" (or is enhanced

in root friendliness by e.g., liming or fertilisation), roots may expand below the compressed layer and thus improve the water balance and health of the tree.

However, vertical mulching is not always a proper solution. If the subsoil is waterlogged or otherwise not root friendly, the benefits of vertical mulching may be limited. Some effect may arise from the improved soil gas exchange in the proximity of the vertical borings.

Root Collar Excavation / Studies of Root Health

One common problem in arboriculture is "planting too deep". This commonly leads to poor root expansion and, not infrequently, fungal infections. The health of the root flare may be improved by a "root collar excavation". Please refer to Fite (2016). The health of supporting horizontal roots after attack by *Meripilus giganteus* or *Armillaria mellea* may also be clarified by air spade removal of the topsoil around the stem base.



SELF-CHECK QUESTIONS

1. Mention typical signs of poor water- and carbohydrate balance (carbohydrate=sugar, starch, etc.).
2. At what distance from the tree will you investigate the soil profile in order to evaluate vertical root distribution?
3. Are you capable of carrying out a diagnosis of the "root friendliness" of soil horizons down to ~1 metre depth?
4. List the technical methods for replacing urban soils close to trees and present the pros and cons of each method.
5. List the methods that can be used to loosen or drain urban soil and discuss their pros and cons.
6. Consider the availability and costs of various tools in your region for root work (air spade, vacuum, backhoe, etc.).
7. How can exposed roots be protected after soil removal?
8. Define the criteria for CRZ.
9. Describe artificial urban tree soil substrates that are suitable for soil replacement around trees.
10. Discuss the pros and cons of using vertical mulching versus radial trenching.

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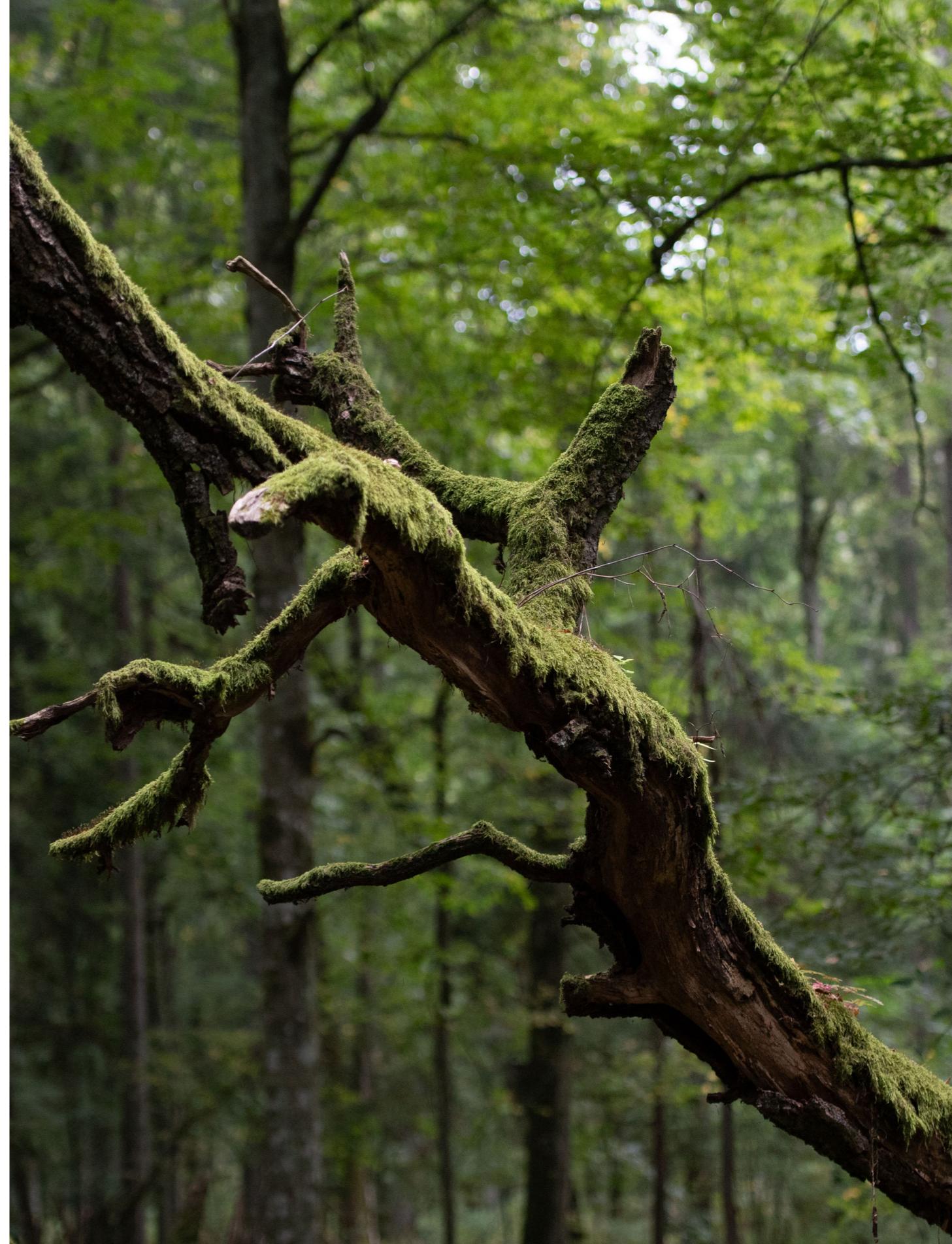
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ESSENTIAL READING

- UK** AirSpade, Technical Applications Bulletin, Use of Compressed Air-powered Excavation for Arboricultural Site Works, by Fite, K. et al. (2016)
Comprehensive and very thorough on the use of airspade.
- UK** Soil Profile Rebuilding: An Alternative to Soil Replacement by Day, S.D. (2016)
A short text on how to rebuild a soil profile.
- UK** Up by Roots by Urban, J.
A standard work for everybody who is working with soils of urban trees.
- GE** PFLANZGRUBEN IN DER STADT STOCKHOLM. EIN HANDBUCH by Trafikkontoret Stockholm (2009). Chapter PFLANZGRUBENRENOVIERUNG. Retrieved from: https://www.skovbykon.dk/images/stories/PDF_skovbykon/TK_Pflanzgruben_in_der_Stadt_Stockholm_Ein_Handbuch.pdf
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All the information you need on the Stockholm system for tree roots.

ADDITIONAL READING

- USA** Evaluation of urban soils. Suitability for green infrastructure or urban agriculture. By EPA (2011)
Easy to understand document on how to evaluate the soil in
- DK** Træernes indbyggede forældelse by Nielsen, C.C.N.
The limitations of built-in trees.



1.6.3. Trees on Construction Sites

Christian Nielsen & Bregt Roobroeck

GENERAL OBJECTIVE

To know how to protect trees on construction sites before, during, and after construction; and to know how to implement these strategies in practice. This involves being able to plan, instruct, supervise, and control tree protection work on construction sites.

SPECIFIC OBJECTIVE

A European Tree Technician is expected to:

- describe methods used to prevent damage to trees on construction sites during remedial operations;
- make a site survey of the future building site or location of an event and give the preconditions for the preservation and/or protection of trees;
- make an arboricultural impact analysis based on the design of the future site or location for an event;
- describe the protection measures in the arboricultural impact analysis (erecting fences, trackways, root pruning, trunk protection, etc.);
- contribute to a roadmap for tree protection during events; and
- supervise the implementation of and compliance with the protective measures imposed in the tree impact analysis and/or roadmap.

SEE TOGETHER WITH:

Amenity and Monetary Value of Trees, Social Value of Trees, Soil Science, Diagnostic Features, Tree Assessment, Tree Revitalisation

ESSENCE OF THE TOPIC

As we saw in Chapter 1.3.1. Amenity and Monetary Value of Trees and 1.3.2. Social Value of Trees, ecosystem services increase with size. To maximise tree benefits, preserving trees should be the priority strategy on construction sites for an ETT. When dealing with trees at event sites and construction or demolition sites, it is vitally important to protect valuable trees.

KEY TERMS

Involvement and communication: site control, site meetings

Prior construction work: arboriculture impact analysis (AIA), compliance with regulations and policies, construction methods, tree protection plan (TPP), potential impacts, technical and management mitigation measures, site organisation

This process is divided into 3 phases:

- Phase 1: Prior to design and construction work
- Phase 2: During the construction work
- Phase 3: After the construction work

As part of the first phase, it is essential that an “Arboricultural Impact Assessment” (AIA) of the construction work be carried out. The AIA assesses the impact on the tree of the proposed works and forms the basis of communication with the stakeholders as it makes the proposed work and scenarios specific. The AIA will lead to a tree projection plan which tries to minimise the impact on the tree or trees in question. Therefore, when construction works impact trees, the AIA must be properly carried out. During the construction work, the essence is to supervise, inform, and/or guide critical actions. After the construction work, the trees need to be monitored for a sufficiently long period of time, as the impact of the construction work can stay hidden for several years.

Throughout the whole process, communication between the arboricultural specialist and the client is essential. Keep in mind that tree protection starts already in the (re)design process and should, ideally, be an integral part of the definition of the project.

During construction work: clean cut of severed roots, control and violation of TPP

After construction work: monitoring

Concepts: crown protection, critical root zone (CRZ), tree protection zone (TPZ), stem projection

A. ETT Involvement and Communication

A typical process for establishing or maintaining green infrastructure has a (re)design, construction, and management part. In an ideal world, an ETT can have a great impact on preserving trees during the (re)designing process. However, in reality, the ETT is not always consulted during the (re) design stage, but when construction has already started with all its consequences. Note that architects and planners commonly lack knowledge about soil, roots, and trees and, therefore, fail to respect the needs and demands of the trees. Hence, it is important that ETTs are involved in the design and planning process as early as possible by defining optimal growth conditions for trees, identifying valuable trees and their root zones on the site, analysing the impact of the (re)design on the trees, and defining any protective actions necessary to prevent or mitigate negative impacts.

However, tree specialists are very often consulted to deal with damages to trees and soil that have occurred during a construction or demolition process by entrepreneurs. Construction personnel have, in general, very little knowledge about tree and soil biology and, in particular, no understanding of the negative effects of root severance, soil compression, and other tree demands within the rooting zone.

In conclusion, an ETT is therefore needed to guide planners, architects, and entrepreneurs in their work around trees and is the first contact point for the tree stakeholders. Basically, an ETT coordinates actions around trees.

The following communication scenarios commonly involve ETTs on construction sites:

- Design process meetings
- Site control on the field: informing and monitoring the contractors in the field
- Site meetings: giving status updates and analysing problems
- Reporting to the client

When communicating, it's important to write it down in a report or email as legal documentation.

B. Prior to Construction Work

Throughout the entire design process, from the idea and concept to the final design, architects, designers, and planners must have an overview of the preservation status of standing trees and any potential impacts that the designs might have on the soil, the root environment, and the trees on the site.

B.1. Arboricultural Impact Assessment (AIA)

Whenever construction or demolition work is to be carried out in the vicinity of trees, a plan for tree protection as well as monitoring during the work process must be arranged before any work is initiated. The core idea of an AIA is to describe the expected effects of the activities on the trees. By activity, we mean the changes in use or design of the space below and above ground in the vicinity of the trees, either temporal or permanent. This is done by collecting data, making an objective analysis, and describing the impact to the stakeholders. In essence, the AIA answers the following questions:

1. Can the tree be sustainably preserved in its current location while maintaining at least the same technical quality (condition, vitality, residual lifespan, etc.) and amenity (value, function, etc.)?
2. If not, what are the mitigating actions needed to have a positive answer to Question 1.

3. In many cases, the trees' actual growth conditions are not optimal and, in such cases, options for revitalisation should be described.

To answer these questions, the AIA consists of the following steps:

- Desk research
- Field survey
- Analysis
- Advice and conclusion

B. 1.1. Desk Research

To start with, identifying the scope of the assignment is crucial and should be stated very clearly to the client. This can be done by postulating the above questions and defining what will be evaluated and what will not. To best understand the current situation, the ETT should then gather all the information on the plans, project specifications, relevant policies and regulations, past studies, as well as on how the work will be done practically (e.g., machines, storage location, etc.). Also list the bottlenecks, conflicts, and crucial activities with regard to the planned construction work.

B. 1.2. Field Survey

The next step is to conduct a site inspection by evaluating the existing trees and vegetation. Data such as the health, size, age, species, and condition of each tree is often absent from desk research and should be gathered by carrying out a tree inventory. Information on significant features such as root systems and wildlife habitat, as well as information on trees with cultural or historical significance, should also be collected when performing this task. In practice, a lot of time will be consumed by searching for roots on which an impact assessment can be carried out. This is done by mapping the root zones of the tree and performing a soil quality assessment, as seen in Chapter 1.1.3. Soil Science. For example, if the trees are affected by a temporary lowering of the groundwater table, the AIA must deal with the consequences

for the trees and provide guidance on how to mitigate damage to the trees (such as irrigation in the event of a lowering of the groundwater level).

B. 1.3. Analysis

When the information from the desk research and the field data is gathered, the analysis can start. Based on the site plans and project specifications, the analysis should have an objective response to the postulated questions. The analysis should have more or less the following structure:

- **Evaluate potential impacts:** Use the combination of field observations, site plans, and modelling to assess the potential impacts of the proposed development on trees and vegetation, both above and below ground. This may include predicting tree mortality rates, changes in tree growth and health, as well as impacts on wildlife and other ecological processes. Think, also, about the option of moving the trees to a new location.
- **Identify technical mitigation measures:** Determine what measures can be taken to minimise impacts on trees and vegetation, such as pruning, root zone protection, and retaining or relocating trees. Consider the feasibility, effectiveness, and cost of each measure. This can also be included in the tender specifications.
- **Identify management mitigation measures:** Determine what structural communication and monitoring are needed between all the stakeholders during the process. This can also include tender specifications.
- **Determine compliance with regulations and policies:** Evaluate the project's compliance with the relevant regulations and policies, such as local tree ordinances, environmental laws, and so on.

B. 1.4. Advice and Conclusion

The conclusion must clearly answer the questions postulated in the project definition of the AIA, and the advice should also be straightforward and easy to understand for non-tree specialists. This can be achieved, for example, by sketching the life span before and after the activities. This can be visualised by a colour code on a digital map, as shown in the figure below. Further, list all the preconditions and requirements that the activities around the tree must meet as a minimum. The preconditions must be practically feasible. Last but not least, in order to preserve a tree that would otherwise be cut down during the planned construction work, alternatives must be explored. For this, the ETT will often have to look outside his/her own field. This requires consultation and coordination with experts in other fields. There may be technical, alternative proposals in which the implementation has no or less impact on the tree. Keeping the existing trees should be the first goal of an ETT.

B.2. Tree Protection Plan

The Tree Protection Plan (TPP) is a document that outlines measures to protect trees and other vegetation during construction or development activities. It specifies the actions needed to prevent the loss of the tree or mitigate the negative impact. It should be negotiated and finally accepted by all the other stakeholders. This process of coordination should, at a minimum, involve tree officers, engineering advisors, and the entrepreneurs. It is strongly advised that the head entrepreneur establish a construction site work plan that is coordinated with the tree protection plan. In some countries, it is part of the arboricultural impact analysis for trees on building sites (or the AIA is part of the TPP), although these documents might also be separate documents.

A TPP typically includes the following information (though not limited to it):

- **Tree protection zones (TPZ) and Critical root zones (CRZ):** The establishment of tree protection zones around each tree based on the field survey of the IAI, which delineate areas where construction activity is prohibited or restricted to prevent damage to roots, trunks, and branches. The TPP should also include the type of protection (fences, signalisation, etc). Ideally, the establishment of fences and protection measures are implemented by the owner, developer, or municipality before the constructor is allowed on the site so that the contractors do not own the fences. However, it is fairly common that the establishment of fences and protection is part of the construction tender. Further, where digging is necessary within a TPZ, the definition of the Critical Root Zone is necessary, and any activity within the TPZ should be supervised by an arboricultural officer.
- **Tree preservation measures:** Specific measures that will be taken to ensure the long-term health and viability of the trees, such as pruning, soil improvement, mulching, and watering.
- **Construction methods:** Details of construction methods that will minimise the impact on the trees, including the use of specialised equipment and techniques to protect the root systems and other sensitive areas around the trees. Techniques and costs for revitalising compressed soil should be presented and estimated; however, prevention should always be the first option.
- **Site organisation:** A plan with the location of the TPZ and where materials, machinery, etc. can be stocked, and where transportation is possible. Making a map helps the contractor organise the working sites within which restrictions need to be respected, such as the location of any temporary ground protection that needs to be installed.
- **Monitoring and maintenance:** Plans for regular monitoring of the trees during construction

as well as ongoing maintenance to prevent any form of damage. This includes the frequency of the monitoring of the construction site.

- **Communication:** A procedure for reporting tree protection plan violations: a) type of report; b) responsible supervisor; and c) phone number/email addresses of entrepreneurs and supervisors. Explain the role of the ETT and what authority he/she has.
- **Contractor informing/training:** Requirements for contractors to be trained on the tree protection plan and to follow best practices for protecting trees during construction.
- **Permits and approvals:** Any necessary permits and approvals from local or state authorities to implement the tree protection plan. Also, suggest defining financial compensation and/or fines for violation of the tree protection plan and setting up large labels on fences that explain the fines that will be given if the tree is damaged. This is highly recommended. Use national rules for communicating tree value. Put the value of the tree on a large sign on the fence.

C. During Construction Work

During the construction, the process must be controlled, monitored, and reported on with photo documentation. Site visits can be carried out at random and/or when crucial activities around the trees occur. Violations of the tree protection plan must be communicated to stakeholders and the authorities. If damage to soil, roots, stem, or crown is noticed, remedial measures may be organised – at once when roots are severed or after project closure when soils are compressed. The tree protection plan may be continuously communicated to all constructors working on the site, particularly subcontractors, who may not be sufficiently informed about the tree protection plan. Explain the consequences of not following the TPP and what the role and authority of the ETT are in site inspection.

TREE PROTECTION PLAN (TPP) AS A LEGAL CONTRACT

The manager of the tree protection plan may be the owner, the builder, or the local authorities. No matter who manages the TPP, it should be part of the legal basis of any construction work. As mentioned previously, the TPP should also contain

Whenever damage to stems or roots is identified, the following actions should be taken:

1. Severed roots thicker than 30-50 mm must be treated with a clean cut and covered in order to avoid desiccation of the soil and root cambium. The soil volume around cut roots should be filled with a proper urban soil substrate, which allows good gas exchange and good water retention.
2. Stem bark wounds must be covered with black plastic within a few days (after 14 days the plastic cover will have no effect) in order to stimulate “surface callus” (woundwood on the exposed woody surface) – see references of Stobbe et al.

D. After Construction Work

When the construction/demolition work has ended, a follow-up meeting should be carried out in order to discuss any violations of the tree protection plan that have occurred. Final remedial measures must be taken, and the costs of these measures should, if legal, be covered by the stakeholder who violated the tree protection plan. During this meeting, where constructors are “handing back” areas and trees, it is important to emphasise that the actual symptoms of the tree are less relevant, as the consequences of severed roots or a destroyed root zone often do not show until years later (typically after drought events). It is therefore wise to monitor the trees for several years (approximately 5 years). Also, make sure that at the end of the

clear figures for fines or compensation in case of violation of this plan, implying that the TPP should be included in the tender as one of the criteria. This implies that tree protection plans are most commonly defined on construction sites. However, the concept of tree protection plans is not limited to construction but also stretches to demolition projects or events held in public parks.

construction work, a final report is made and the condition of the trees is documented.

E. Concepts of the Tree Protection Plan

As already mentioned, the protection of the tree root system is the No.1 priority when dealing with trees on a construction site. In order to communicate clearly with all stakeholders, it is necessary to clearly

E.1. Tree Protection Zone (TPZ)

Tree protection zone (TPZ in the US, reference Clark) = Root Protection Area (RPA used in the UK, reference BSI) = “Trädskyddområdet” (SE, reference Östberg). This is the area that is considered to be occupied by a significant number of tree roots responsible for tree health and stability. Please note that the TPZ also involves protection of the crown space – so TPZ ensures protection both above and below ground and reaches as high as the tree.

There are numerous standards for TPZ. BSI takes a radius around the tree equivalent to stem diameter*12. The Polish standard has varying definitions (Dworniczak). Several other estimates are used in various literature, but it should be noted that root spread varies a lot between tree species and depends also on the ability of the soil to provide a deep-rootable rhizosphere. Trees compensate for shallow rooting by extending the horizontal

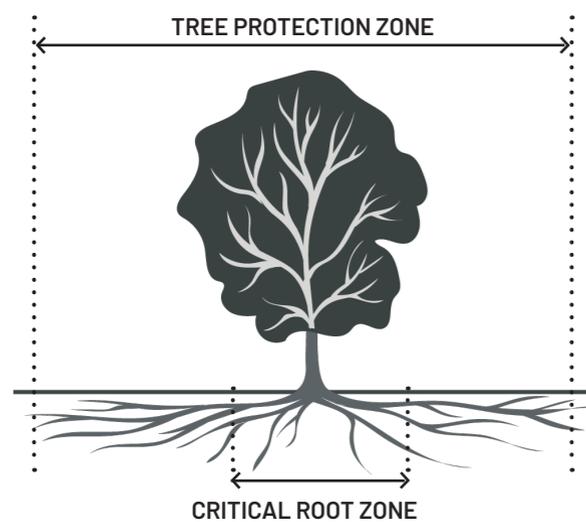


Figure 2. Definition of TPZ and CRZ. Modified from C.C.N.Nielsen.

roots further. TPZ around ancient and veteran trees is 15 x stem diameter (measured at 1.50 m above ground level) or 5.0 m beyond the edge of the canopy, whichever is greater. However, it is strongly recommended that a root specialist carry out local mapping of root spread, especially with valuable trees. Östberg suggests investigating root spread through vacuum digging. See also Chapter 1.6.2 for more information on the methods used to carry out this task. Care should be taken to avoid soil compression and severed roots. TPZ should be protected by stable fences that are difficult to move. If traffic cannot be avoided inside the TPZ, the soil should be protected with temporary ground protection that both prevents soil compaction and provides oxygen and water for tree roots. It is suggested that a maximum of 20% of the TPZ should be covered with temporary ground protection.

E.2. Critical Root Zone (CRZ)

The Critical Root Zone (CRZ) is the portion of the TPZ that contains the absolute minimum of roots for tree survival. This concept is a fluid one. When the root system (or the soil) is damaged within the



Figure 3 (C.C.N.Nielsen). Protection of the TPZ with a fence.

CRZ, it may be necessary to irrigate and/or artificially anchor/guy the tree for a number of years until the roots have regenerated. Root damage can be an entry point for decay, so an intensive follow-up might be necessary. Please note that the CRZ varies extremely in urban environments depending on the soil type and among species and clones. Thus, local investigations to assess the CRZ are necessary in urban soils, and this task should be carried out by a tree root specialist. None of the European guidelines provides clear definitions for the size of CRZ's, but they mention in various contexts critical root diameters that should not be exceeded when digging inside the TPZ: 25 mm (BSI), 30 mm (Dworiczak, SkovByKon) - 50 mm (Östberg). Ideally, the critical root diameter increases with tree size but decreases with vitality. Very often, the tree protection plan contains values for the TPZ and the CRZ. The CRZ is commonly expected to be restricted to an area within the crown dripline, but this is not always true. Trees developing very shallow root systems due to soil conditions compensate by growing thick "cable roots" at large distances from the trunk. Root spread and root diameter also vary considerably between tree species and varieties. For example, *Populus trichocarpa* clones

only develop very few sinker roots but form very widespread, thick horizontal roots. In large poplar trees, such roots may still have diameters of more than 100 mm at distances far outside the crown dripline. Thus, local investigations to assess the relevant TPZs and CRZs are recommended.

E.3. Crown and Stem Protection

There is always a risk of branches being ripped or broken due to crane work. During the preliminary discussions with the entrepreneurs, the positioning of cranes and their work radii should be noted. Prevention of damage should be the starting point. As the Tree Protection Zone is three-dimensional and is as high as the tree, the ripping of branches should also be part of the penalty clause that is part of tree protection measures. It might be necessary to prune trees to reduce the risk of branch breakage and improve their stability. Prior crown reductions may be preferable to ripped

crowns but are only acceptable when other measures are out of reach. And don't forget that removing and changing parts of the root system has consequences for the crown or might provide access for root decaying fungi.

In the proximity of street trees or other trees surrounded by a permanent hard surface, stem and buttress roots should be protected. The most efficient tool is a wooden box which is stabilised from the inside and strong enough to resist any contact from machinery used during the construction. Commonly, drain tubes are used to maintain a distance between the box and stem, but more firm anchorage (e.g., to the stem) may be necessary.

If soil, roots, stem, or crown have been damaged by the end of the construction project, remedial measures may be necessary – please refer to Chapter 1.6.2. Tree Revitalisation.





Figure 4 (C.C.N.Nielsen). Stem protection of trees surrounded by a permanent hard surface next to a construction site.



Figure 5 (C.C.N.Nielsen). The protection box has been pushed around and lifted in order to place remnant soil inside of it.

PROTECT TREES WITH LICHENS

These two large oaks (*Quercus robur*) in the vicinity of Riga in Latvia were threatened by a large urban development in 2015. Behind the oaks, a road needed to be enlarged, and the project developer wanted to cut them down. During the tree

inventory, the lichen *Pleurosticta acetabulum* was discovered on the tree bark of one of the oaks. This epiphytic lichen growing on deciduous trees in parks and mixed forests is considered to be rare in Latvia, and, as a result, it was considered important to protect the oaks. This example illustrates beautifully how a very small species can protect a very large species.



SELF-CHECK QUESTIONS

1. What is an AIA and how is it structured?
2. How can you carry out an investigation of root spread prior to defining the tree protection plan?
3. Why is it important to include the 3 phases of tree protection in construction/demolition projects?
4. How far out from the stem will there be important roots?
5. What is the difference between TPZ and CRZ?
6. Present methods to detect/define the TPZ.

PRACTICAL EXERCISES

1. Find a case where you can create a small AIA and emphasise the analytical part of the analysis.
2. Find a site with trees where construction is or will be started and evaluate the TPP on site if possible or make a scenario where you need to perform a TPP.
3. Explain in simple terms what the need for a TPP is.

TERMINOLOGY

Critical Root Zone (CRZ) – The area around a tree containing roots essential for the health and stability of the tree / the minimum root growth for tree survival. The CRZ should be defined for every individual tree by a root specialist, but the following diameter limits for roots to be severed may provide some guidance: 25 mm in BSI, 30-50 mm in Östberg and 30 mm in Dworniczak and 30-40 in SkovByKon. This diameter limit should be set individually and much lower for veteran trees.

crown diameter – average distance between crown driplines on opposite positions of the tree

crown dripline – the vertical projection of the crown periphery on the soil

tree protection plan – a plan for greenery and tree protection written by an arborist after soil and tree investigation, also including instructions for continuous control during the work phase

Tree Protection Zone (TPZ) = Root Protection Area (RPA used in the UK) the area around the tree where the soil contains a significant amount of root material important for the maintenance of the current tree health status; TPZ is commonly beyond (outside) the crown dripline

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ESSENTIAL READING

- NL** Bomenstichting and CROW Richtlijn Bomen Effect Analyse (BEA). Retrieved from: <https://www.bomenstichting.nl/winkel/boeken-en-brochures/richtlijn-bomen-effect-analyse.html>
- Small reference book on Arboricultural Impact Analyse for Dutch speaking. Check the video to know what it is all about.*
- USA** Tree Protection on Construction and Development Sites: A Best Management Practices Guidebook for the Pacific Northwest by Oregon State University. Retrieved from: <https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em8994.pdf>
- Helps to understand the TPZ and CRZ.*
- CAN** Compendium of Best Urban Forest Management Practices by Treecanada. Retrieved from: <https://treecanada.ca/resources/canadian-urban-forest-compendium/13-tree-protection-during-construction-trees-and-building-foundations/>
- Starting point to find examples of tree protection plans of Canadian cities.*

ADDITIONAL READING

The text of this chapter provides the necessary knowledge for an ETT. Depending on your home country and language skills, some of the references may be relevant.

- GER** Baumschutz auf Baustellen – Grundlagen und praktische Umsetzung. *Jahrbuch der Baumpflege.* *Reference book on Arboricultural Impact Analyse.*
- USA** Why Definitions Matter: The Tree Protection Zone and the Critical Root Zone by James Clark et al. Retrieved from: https://www.researchgate.net/publication/357128085_Why_Definitions_Matter_The_Tree_Protection_Zone_and_the_Critical_Root_Zone
- Explains very clearly and practically the TPZ and CRZ.*

- NL** Beschermen van bomen, vvog-zakboekje 3, by Openbaar Groen (2021). Retrieved from: <https://docplayer.nl/224416529-Beschermen-van-bomen-voorschriften-ter-bescherming-van-bomen-op-werven-en-evenementen-vvog-zakboekje-3.html>
- Practical and visual reference book, a basic checklist for tree related work on construction sites.*
- NL** Handboek bomen norminstituut bomem 2022. Retrieved from: <https://www.norminstituutbomen.nl/instrumenten/handboek-bomen/>
- The institute has made some very good graphical poster ‘working with trees’ to communicate with all stakeholders. Interesting for all countries.*
- SWE** Skydda träden vid arbeten by Länsstyrelserna. Retrieved from: <https://www.lansstyrelsen.se/download/18.26f506e0167c605d5693d6f6/1612448938162/Broschyr%20-%20Skydda%20tr%C3%A4den%20vid%20arbeten.pdf>
- 4-page brochure on working with trees on constructions site.*
- DK** SkovByKon (2020): Checkliste til god forvaltning af træer. Retrieved from: www.SkovByKon.dk
- A Checklist for good management of trees*
- DK** SkovByKon (2023): Koncept for beskyttelse af træer på byggepladser. Retrieved from: <https://www.skovbykon.dk/byggeri-anlaeg>
- Explaining the Concept for the protection of trees on construction sites.*
- UK** Tree roots in built environment by the Arboricultural Association. Retrieved from: <https://www.trees.org.uk/Book-Shop/Products/Tree-Roots-in-Built-Environment-2>
- Sets out a comprehensive review of tree root biology and covers a broad range of practical issues that need to be considered to grow trees successfully in our towns and cities and to realise the significant benefits they provide in built environments.*
- NL** Een boom hoeft geen obstakel zijn’ by Van Iperen (CROW).
- Slides about utility lines and trees. There is also a handbook about it: Combineren van onder- en bovengrondse infrastructuur met bomen.*