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Tree-Structure Relationship in Landscape Design and Management

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Abstract

The study aims to examine the tree-structure relationship based on the literature, determine the damages tree roots can cause to the structures, and suggest potential solutions. As a result of the literature review, we examined the following topics in this study: The structure of tree roots, the effects of tree roots on the soil, the risks that trees might create in structures, the methods for minimizing these risks, and finally the criteria to be taken into account when selecting the plant species nearby buildings. As a result of the literature review, we conclude that if the plant species selected are incompatible with the area, the structures might be damaged. Accordingly, we suggest potential solutions to prevent this damage. Furthermore, we examine factors to be considered when selecting plant species and the species we recommend not to prefer. Lastly, we explain the GPR technology used to observe tree root growth and prevent damage.

Keywords: *Tree and structure relationship, root structure, root barriers, ground penetrating radar.*

Peyzaj Tasarımında ve Yönetiminde Ağaç-Yapı İlişkisi

Öz

Çalışmanın amacı ağaç-yapı ilişkisini literatüre dayalı irdeleyerek ağaç köklerinin yapılara verebileceği zararları saptamak ve potansiyel çözümler önermektir. Literatür incelemesi sonucunda, bu çalışmada; ağaç kök yapısı, ağaç köklerinin toprağa etkileri, ağaçların yapılarda yaratabilecekleri riskler, anılan risklerin en aza indirgenmesi için kullanılabilecek yöntemler ve son olarak da bitki tür seçiminde dikkate alınması gereken kıstaslar irdelenmiştir. Literatür incelemesi sonucunda seçilen bitki türlerinin alan ile uyumlu olmaması durumunda yapılarda hasar meydana gelebileceği sonucuna ulaşılmıştır. Ardından, çalışmanın sonuç ve öneriler kısmında bu hasarın meydana gelmemesi için potansiyel çözüm önerileri getirilmiştir. Anılan çözüm önerilerine ek olarak, bitki türü seçiminde dikkate alınması gereken faktörlere değinilmiş ve yapılarda hasar oluşturabileceğinden seçilmemesini önerdiğimiz bitki türlerine (her türe özgü açıklamalarla) yer verilmiştir. Sonuç ve öneriler kısmının son başlığında ise ağaç kök gelişiminin gözlemlenmesi ile hasarı önlemede kullanılan bir teknoloji olan yeraltı radarı (GPR) teknolojine değinilmiştir.

Anahtar Kelimeler: *Ağaç ve yapı ilişkisi, kök yapısı, kök bariyerleri, yeraltı radarı.*

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1. Introduction

Tree roots are essential organs for trees to attach to soil and thus absorb and transmit water and nutrients. The spread of the root system differs according to the size and type of the plant, yet it also grows and evolves depending on the soil conditions. Under some conditions, the uncontrolled growth of tree roots might be harmful enough to damage the existing city infrastructure. Uncontrolled growth of tree roots can cause problems such as clogging water and wastewater lines and weakening foundation walls. For this reason, it is essential to pay attention to the relationship between trees and structures, performing periodic maintenance, and use root barriers under the necessary conditions.

1.1. The Structure of Tree Roots

The root is an organ that grows at depths of the soil through positive geotropism, generally in grown plants adapted to terrestrial conditions. The primary functions of the roots are to anchor the plant to the soil and absorb water and inorganic nutrients, which are then transmitted to the stem. Also, roots can store nutrients, even if only temporarily (Yakar Tan & Bilge, 1979; Şahin, 1989). The surface area of the root system, composed of the main root (primary root) and its associated lateral roots (secondary roots), is usually equal to or greater than the total surface area of the stem or branches above the ground. Roots spread radially from the stem and can extend more than 1m into the soil. A single long root (taproot) may penetrate even deeper in some plants. This root functions more as an anchor, similar to the thick roots beside the stem (Design Council, 1976).

As depicted in Figure 1, thick roots close to the stem serve the primary function of anchoring the plant to the soil, while numerous lateral roots, which emerge from these thick roots and possess absorptive root hairs, are primarily responsible for nutrient uptake. In nature, these nutrient-absorbing roots are abundantly found along the projection line of the tree canopy (Figure 1) (Zion, 1968).

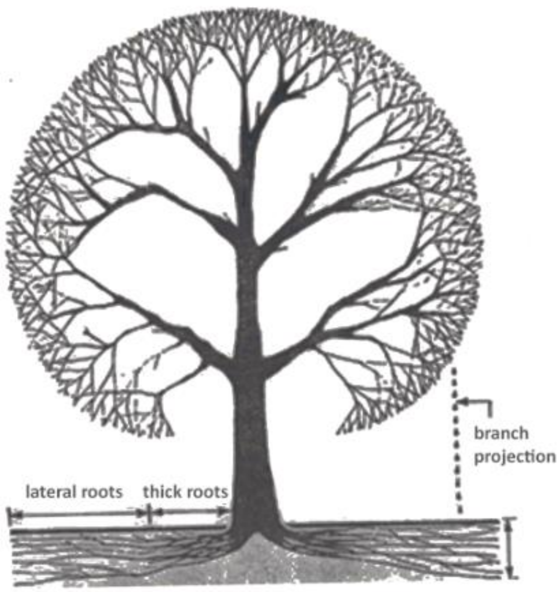

Figure 1. Root system (Zion, 1968; Şahin, 1989)

As shown in Figure 2, there is a tip at the end of each root. This tip ensures the elongation of the root by forming young cells continuously. If the tip of the root is cut, the root elongation stops.

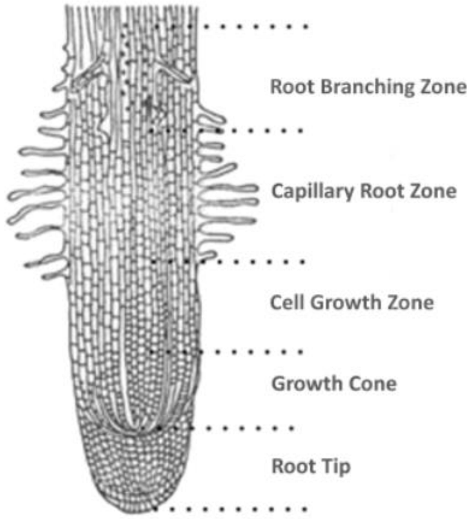

Figure 2. Root tip of tree (Bernatzky, 1984; Şahin, 1989)

There are root-sucking hairs near the root tip. These hairs, formed by the extension of the cells of the layer surrounding the outside of the root, absorb water and dissolved nutrients from the soil. As the plant matures and the roots continue to grow, the absorptive root hairs higher up on the root fall off, and new ones grow towards the tip. This continuous renewal of absorptive structures ensures that the roots' nutrient acquisition capabilities remain effective. In older roots, the absorptive capacity diminishes, mainly transporting inorganic nutrients to the stem (Sueur, 1949).

The tendency and form of the root system, whether horizontal or vertical, vary among plant species. Some trees, such as oaks, have deep-rooted structures, while certain plants exhibit surface spreading of their roots. The characteristics of the soil depth and surface conditions also play a significant role in this regard. Species like beech, black poplar, and poplar trees, known as fast-growing plants, may extend their roots to considerable depths to access nutrient sources (Sueur, 1949). Consequently, tree roots can exert significant force and potentially cause damage to building foundations or underground infrastructure, especially in urban areas.

1.2. How Do Tree Roots Affect the Soil?

Trees might indirectly damage structures nearby while drawing water from the soil (McLean, 2009). Tree roots, even the growing or small ones, are remarkably powerful. The tree root zone continually expands as the tree seeks to find more water and nutrient sources. The environmental effects of this expansion vary on the type of soil in which the tree is planted. There are two main types of soils that can be significantly affected by tree growth (Watson, Hewitt, Custic & Lo, 2014). These two main types of soils present quite different outcomes in the case of tree growth. In clayey soils, tree roots passing through the clayey soil tighten the soil. During summer, water decreases, and the clayey soil shrinks. In late autumn, winter, and early spring, the soil expands again with the return of water along with the rains (Mercer, Reeves & O'Callaghan, 2011). On the other hand, loose and rocky soils lead roots to move more easily since the loose and rocky soils tend to shift and move around. Yet, the climate conditions also should be well-evaluated within this frame. Accordingly, during drought periods, the roots can shrink as the clayey soils dry. During heavy rainfall, the roots can expand as they absorb water. These shrinkage and expansion processes can affect the structural integrity of the soil (McLean, 2009). In this context, determining the soil type in the landscape architecture project area is highly beneficial.

Understanding the soil type is crucial in landscape architecture to anticipate how tree roots may interact with the soil and surrounding structures. Proper assessment of soil characteristics can aid in selecting suitable tree species and implementing measures to mitigate potential damages caused by tree root growth. By considering the soil's behavior and the dynamic interactions between trees and their environment, landscape architects can develop sustainable and resilient designs that accommodate both the aesthetic appeal of trees and the preservation of surrounding structures.

2. Material and Method

During the research, it was observed that the literature on the scope of the study was quite limited. In this context, the limited literature on building and root relationship is reviewed, and the impact of tree root system on building structure is revealed. Standards and application examples related to this subject have been investigated. In line with the research, tree root system characteristics and requirements for building protection were examined, and suggestions were made about the plants that could be used. The proposed trees, as well as protection requirements, may change with the geographical conditions.

As a result of the literature review, the main topics examined within this study are as follows:

- Tree root structure,
- Effects of tree roots on the soil,
- The interaction between trees and buildings (i.e., Potential damages and damage prevention),
- The factors that should be taken into for tree selection,
- The plants that are not recommended for use in landscape architecture projects near structures,
- Monitoring tree root development with remote sensing technologies.

3. Findings and Discussion

3.1. What Damages Can Trees Cause To Buildings?

In arid climate regions, it is possible for the tree roots to expand in order to find water. If tree roots reach buildings, they can potentially encircle and damage wastewater pipelines (Figure 3). This damage can be seen especially in old systems, as these were built with materials that could deteriorate with time, such as bricks or concrete (Randrup, et al., 2001). If cracks or openings exist, fine roots may penetrate and develop inside the pipelines, thus leading to blockages. Furthermore, the roots' proximity to natural gas lines and underground electrical cables should also be considered (Figure 4). Trees planted too near the buildings typically do not exert enough pressure to damage the foundations of the buildings. However, fine roots may still infiltrate cracks or small openings in search of water, causing potential damage (Gasson & Cutler, 1998).

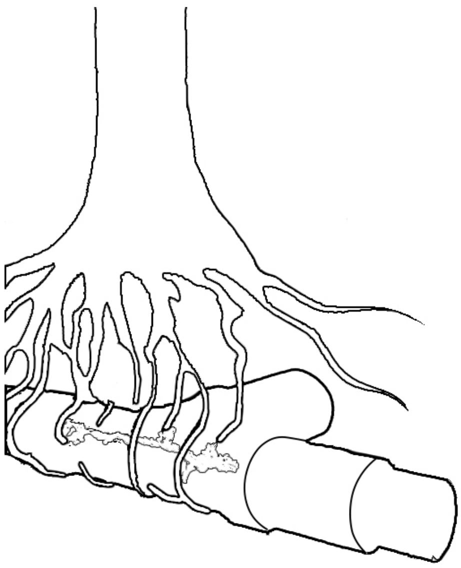

Figure 3. Infiltration of roots into cracks (developed by Author C. Korkmaz, 2023)

Figure 4. Effects of tree roots on sewer line (911HVAC, 2019)

When water is drawn from the soil beneath buildings' foundations for any reason, soil shrinkage can cause the foundation to move downwards, resulting in subsidence (Mercer, Reeves & O'Callaghan, 2011). To prevent this situation, the use of materials (plastic, iron, or reinforced concrete) used in the construction of modern water sewers will minimize the damage. Potential leaks, such as those caused by a fractured joint (Schrock, 1994) or poor construction (Sullivan et al., 1977; Brennan et al., 1997), may cause roots to enter the pipe and eventually obstruct it.

The most detrimental effect known of tree roots occurs in structures where there is soil filled between foundation walls. If the tree is nearby the building's kitchen, toilet, or bathroom drains and there is any wastewater leakage, the roots can penetrate the foundation walls from the bottom and grow upwards. Consequently, the tree roots can cause disturbances even in the building's flooring (Mattheck, Tesari & Bethge, 2003).

Certain tree species' roots can cause more issues than others. For instance, the roots of a fig tree are excessively dense, strong, and extensively spreading. Being highly attracted to water, the roots of this plant tend to penetrate and pass through obstacles instead of encircling them like other plant roots (Figure 5). When tree roots carry water toward the outer soil-covered surface of a basement's concrete or masonry wall, the wall's resistance decreases, leading to cracks in the wall and, ultimately, water leakage into the lower sections of the building (Mattheck, Tesari & Bethge, 2003).

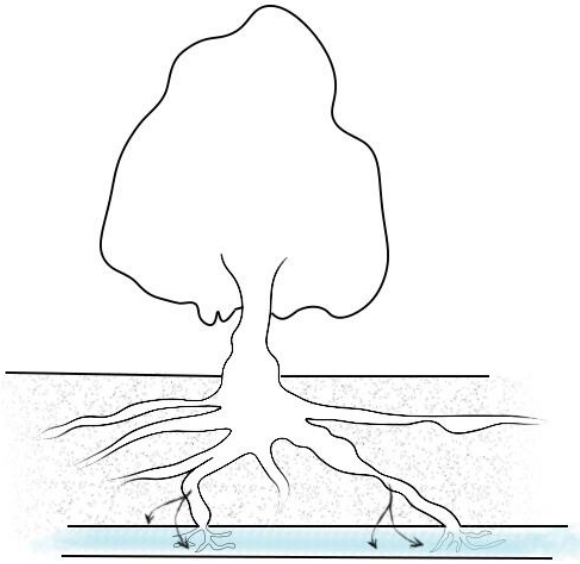

Figure 5. Roots directed towards the pipe (developed by Author C. Korkmaz, 2023)

It is commonly argued that ivy or other climbing plants can damage the mortar or joints between bricks and stones on the external walls of buildings, particularly in older structures. When the mortar or joint material between bricks or stones is in poor condition, ivy can indeed weaken the wall structure once it becomes abundant. Ivy roots absorb moisture as they grow; therefore, considering a wire mesh system on the external walls can be beneficial both aesthetically and for the health of the building (Gasson & Cutler, 1998).

According to some scientific evidence, when a tree growing in clayey soil is cut down or removed, the absence of roots that previously absorbed the water in the clayey soil can lead to the soil becoming saturated with water and subsequently swelling. In this case, the foundation of the building could rise, which the opposite result of the foundation is moving downwards to the soil. In other words, removing a mature tree near a building can also cause damage to the structure. These situations may not generally be visually apparent in the building's structure, yet among other signs, the cracked and elevated window frames can be seen (NHBC-Standards, 2023).

Considering these potential risks, it is important to implement proper measures during landscaping and building maintenance. If plant selection and care are handled prudently, especially for climbing plants, it can help preserve buildings' structural integrity and aesthetic appeal in the long run. Architects, landscape designers, and homeowners must be aware of these potential effects and take proactive steps to protect and maintain the health of buildings and their surroundings.

3.2. Can Tree Roots Cause Damage to Building Foundations?

Although tree roots are often considered the cause of damage to buildings' foundations, they rarely constitute the primary source of the problem. While small roots can penetrate existing cracks in foundations, their growth does not typically lead to mechanical damage. However, soil subsidence can indeed cause harm to buildings (Mercer, Reeves & O'Callaghan, 2011). While the roots themselves may not directly harm buildings and foundations, increasing soil movement can endanger the integrity of the soil on which the building rests and its supporting structure. Consequently, if the soil moves, everything resting on it will also move (Figure 6) (Satriani, Loperte, Proto & Bavusi, 2010).

Figure 6. Tree roots growing under foundations (CNT Foundations, 2020)

The damage frequently occurs in "concrete settlement". When concrete settles, the possibility of shifting and cracking increases. Depending on the magnitude of the movement, the overall structure of the building can be affected. Support beams may shift, walls may collapse or crack, and ceilings may become unsteady (Satriani, Loperte, Proto & Bavusi, 2010).

3.3. How Can Damage Caused By Tree Roots Be Prevented?

The ways to prevent potential damages that the roots near a building's edge may cause are presented below;

- The first approach to solving this problem is to create a root barrier. Numerous researchers have suggested that root barriers can offer a potential solution to conflicts between green and gray infrastructure (Hamilton, 1984). Root barriers are physical or chemical barriers that aim to restrict root growth away from infrastructure. There are three main categories of root barriers: traps, inhibitors, and deflectors (Coder, 1998).

- Traps do not entirely block root growth. Instead, they allow root tips to enter small holes but then trap and prevent radial growth. Inhibitors are used to control root growth through chemical intervention. Most of these barriers consist of fabric impregnated with a slowly released herbicide. Deflectors, typically made of plastic, act as physical obstacles in front of root growth, redirecting roots away from the infrastructure.
- Root barriers in the form of underground concrete block walls or lightweight plastic membranes, often thinner than 1 mm, would be placed in a trench dug up to two meters below ground level. These barriers should ideally be positioned approximately two meters from the property. The nature of the materials used should provide dual protection, preventing direct root effects and inhibiting the tree from drawing water from beneath the foundations (Figure 7) (McLean, 2009).

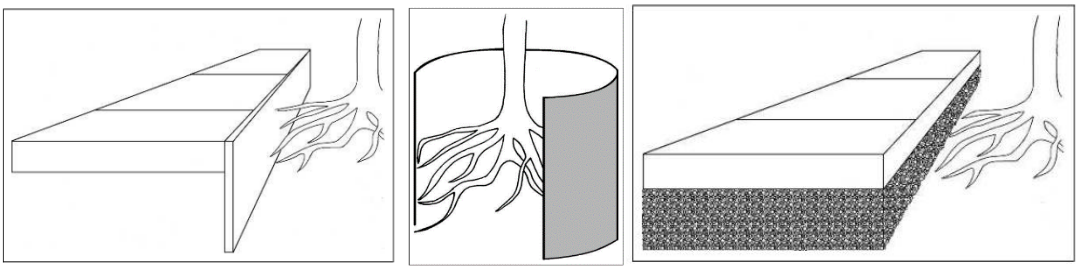

Figure 7. Linear, circular and three-dimensional root barriers (Morgenroth, 2008)

- Another way to eliminate the threat of root damage is to select tree species with less aggressive rooting tendencies and slow growth near buildings. It is essential to avoid trees with deep and aggressive root systems (Mercer, Reeves & O'Callaghan, 2011).
- The most effective method to avoid tree root problems is maintaining a "safe distance" between the tree and the building. Ensuring a "safe distance" between the tree and the structure can minimize the potential for root-related issues (Figure 8).

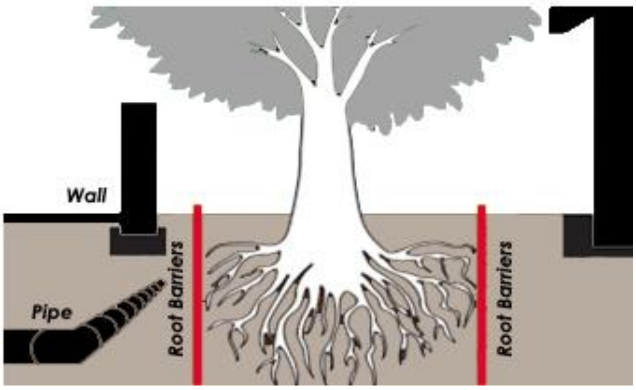

Figure 8. Root barriers for gray infrastructure and building foundation (developed by Author C. Korkmaz from Anonymous, 2023)

4. Conclusion and Suggestion

4.1. What Should Be Considered When Selecting Tree Species?

When selecting tree species that will be used near buildings, the following three factors should be taken into consideration:

- Projection Size
- Tree Shape
- Root Size (Figure 9)

The root structure of trees can grow in suitable soil conditions. Any operation in the tree's root zone or in the zone where the root system is expected to grow under normal growth conditions can cause alterations in the root structure. For example, watering in a garden can lead to hydrotropism (directional growth in response to moisture), where roots tend to grow towards moist soil layers, disrupting their natural symmetry and causing spread. If there are no obstacles, the natural spread of tree roots typically extends to the width of the tree's branch projection (Mercer, Reeves & O'Callaghan, 2011).

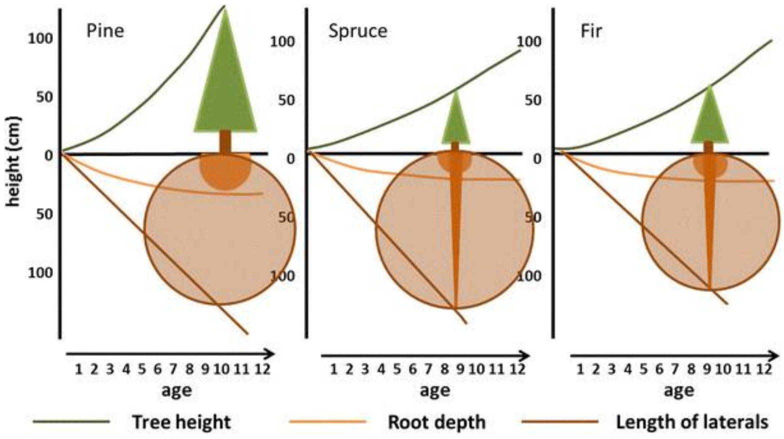

Figure 9. Tree height, root depth and the development of lateral roots (Eis, 1970)

4.2. Which Plant Types Should Not Be Preferred?

The following table (Table 1) includes plants not recommended for use in landscape architecture projects near structures.

Table 1. Plants that are not recommended for use in landscape architecture projects near structures

Taxus baccata	*Yew Tree*	Highly popular ornamental plant in gardens. However, it is not only known for its toxic properties but is also characterized by a deep-rooted nature. As a coniferous tree, it can reach heights of up to 20 meters and possesses a taproot system that can extend to at least two meters, and depending on its location, it can penetrate even deeper. In its mature stage, the yew tree develops numerous fine roots near the surface.
Quercus robur	*Oak Tree*	Develops a robust root system that extends to approximately 30 to 40 centimeters in depth below the surface.
Pinus nigra	*Black Pine*	Botanically, black pines, which can grow up to 50 meters in height, can develop a taproot system that extends up to two meters in depth, making them not recommended for planting near structures.
Tilia tomentosa	*Silver Linden*	The taproots of silver linden trees can reach approximately two meters in depth.
Robinia pseudoacacia	*Black Locust*	Originally from North America, black locust trees can grow up to 40 meters in height and their main roots can dig down to three meters in soil layers.
Juniperus communis	*Common Juniper*	Junipers develop taproots that extend up to six meters in depth, making their removal quite challenging.
Eucalyptus globulus Labill.	*Eucalyptus*	Eucalyptus, which is not a native plant of Turkey, particularly the large-sized ones planted in wetlands, can absorb around 400 liters of water from the soil daily, leading to a decrease in groundwater levels. Therefore, they are not recommended for planting as they can adversely affect the local water table.

Salix babylonica	*Weeping Willow*	The roots of weeping willows planted very close to buildings generally do not exert enough pressure to cause damage to the foundation. However, very fine roots can work their way into cracks or small openings in the foundations to find water. The most harmful effect of tree roots is in buildings where there is soil filled between the foundation walls.
Populus tremula	*European Aspen*	Aspen tree roots typically have shallow and deep components. If there is a small crack in the foundation, an aspen tree root can find it and enter by widening the crack. Additionally, aspen trees are known to have high water demand.

4.3. What Is The Monitoring of Tree Root Growth with Remote Sensing Technologies?

Monitoring tree root development with remote sensing technologies has an essential place in urban planning. With these technologies, the development and orientation of plant roots under the ground can be detected by remote sensors, imaging systems, and data analysis methods. Among the various methods used, the most frequently used one is ground radar (Ground Penetrating Radar - GPR).

GPR technology enables the examination of tree roots under the ground without damaging or interfering with the roots. GPR detects objects under the ground using electromagnetic waves. The device sends electromagnetic waves to the ground through antennas placed on the ground surface. When these waves hit objects of different densities under the ground, some are reflected and returned to the antennas. By detecting and analyzing these reflections, GPR guides in determining the position and shape of underground objects (Figure 10) (Stover et al., 2007). Detection of tree roots with GPR is of great importance in determining the distribution, depth, and size of the root systems of trees. This information provides information about the trees' roots' health, water intake, and feeding habits. Utilizing the information obtained, revealing the root structures that may create risks, and taking precautions will play an essential role in the tree-structure relationship.

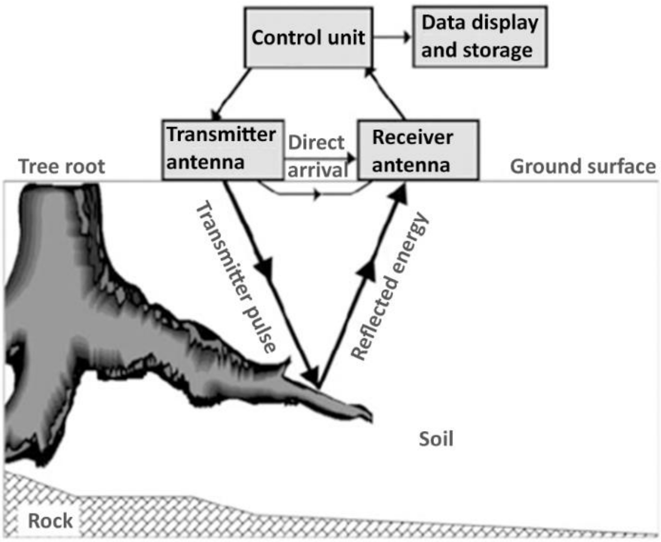

Figure 10. Working principle of GPR (Stover et al., 2007)

It is necessary to monitor tree root development in cities exposed to earthquakes. This monitoring is important not only for earthquake countermeasures but also for preventing infrastructure damage caused by floods. Root development in the existing structure area can be followed with GPR tools. However, before that, creating possible risk maps will prevent the loss of time, personnel, and budget in the urban fabric covering a large area.

In light of the foregoing, the roots of trees form a complex network within the soil, playing a crucial role in the growth and development of the plant by absorbing water and nutrients essential for its survival. Additionally, tree roots anchor the tree to the soil. However, the strong structure of roots can occasionally pose a threat to human structures. Therefore, properly planting and managing trees are essential to mitigate potential risks. Moreover, the quality and depth of the soil also influence the spread and impact of tree roots. Consequently, the root systems of trees should be considered as a significant aspect in environmental conservation efforts.

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The article complies with national and international research and publication ethics. Ethics Committee Approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to this manuscript. There is no conflict of interest.

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