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Acoustic Tomography as a Supporting Tool in the Sustainable Management of Historic Greenery: Example of the Church Garden in Horostyta (Poland)

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Abstract: Senile trees in historic church gardens have natural, aesthetic, historical, and cultural value. Cutting them down too hastily annihilates the achievements of entire generations. We should try to preserve the greenery surrounding historic churches and integrate it into a clear compositional arrangement with the sacral architecture. The primary purpose of the paper was to describe the process of inventorying 200-year-old trees and to present the revalorization project for the garden around the historic Orthodox church in Horostyta, located in the Lublin Voivodeship, in southeastern Poland. The church complex consists of a wooden 18th-century building, bell tower, garden, and cemetery. Within the church garden's boundaries, there are 15 trees, with two predominant species: *Acer pseudoplatanus* L. and *Tilia cordata* Mill. These trees are of varying ages and health conditions. We used acoustic tomography to perform tree health diagnostics. Three trees, for which the initial visual assessment was disturbing, were examined thanks to detailed tomography tests. Then, through a project adapting the church garden to the health conditions of the ancient trees, they were separated from users by flowerbeds and no small architectural objects were placed around them. The presented development concept forms a compromise between tradition and the modern user's needs. In 2007, a general renovation of the temple building was completed. Currently, the presented project for the church garden is being implemented.

Keywords: acoustic tomography; senile tree; church garden; orthodox church; revalorization; Horostyta Wyryki commune; Poland

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1. Introduction

Academic interest in preserving, maintaining, and restoring historic gardens started in the 1980s when the Florence Charter officially identified historic gardens as "living monuments". Over the last 40 years, garden management methodologies have evolved and become more complex. Historic gardens represent essential nodes in the plots of open-space systems and ecological networks [1]. Gardens are a part of our culture. They "open a window" to the past, and it is hard to rehabilitate or replace the original gardens once they are lost. In Poland, many historic gardens need maintenance, restoration, and conservation, and general improvements in the skills and knowledge of their keepers are also required. The delicate maintenance of senile trees is vital for historic gardens and their conservation.

In some historic gardens, age-old trees can harm people and property. Considering such situations, one should make decisions about the design of the restoration of ancient gardens and the long-term management of vegetation to ensure a functioning, healthy, and safe area for future users [2,3]. Recognition of old and notable tree stands and historic orchards as heritage elements is widely accepted because they are considered valuable elements of "biocultural heritage" [4–6].

Nevertheless, the science of analyzing the stability (statics) of trees makes a vital contribution to public safety by providing, if not perfect, at least an improved method of measuring the stability of trees, thereby increasing the level of comfort from being in their presence [7–9]. Examination of trees using CT scans allows one to look inside the trunk and assess structural changes in the wood much better than only using the VTA method (visual tree assessment). The results show precise information about the size and location of rot, damage, and other defects affecting the tree's stability. The presented acoustic tomography research can be considered innovative in Lublin province.

We carried out observations in the eastern part of the Lubelskie Voivodeship, which borders Ukraine and Belarus. The village of Horostyta is located near Polesie Lubelskie, Łęczyńsko-Włodawskie Lake District, Polesie National Park, Poleski Landscape Park, and Sobiborski Landscape Park. This region is among the least populated in the Lublin region and has one of the highest forestation rates. A natural environment with a wealth of unique fauna and flora specimens, of which various species grow in the adjacent forests, swamps, peat bogs, and vast meadows, surrounds Horostyta. The attractiveness of the place is also influenced by well-preserved architectural monuments associated with a centuries-old tradition, testifying to the cultural and ethnic diversity of the region. In the municipality of Wyryki, these are both secular and sacred objects that testify to the rich and complex history of the area, including the hunting palace of the Zamoyski family, the late Baroque Roman Catholic church in Lubien, residential buildings dating back to the early 20th century, windmills, and the Orthodox church in Horostyta.

Recognizing religion as an essential organizing factor in social life, especially in traditional (rural) communities, various manifestations and forms of religiosity are significantly reflected in the cultural landscape, primarily in material, sacred, landscape elements [10,11]. At present, however, in the landscape of the Polish countryside in connection with the drive to modernize it, some characteristic elements are disappearing, i.e., rural home gardens, church gardens, and small sacred architectures such as shrines and roadside crosses.

Temples, monasteries, necropolises, and other smaller religious objects and symbols characteristic of different cultures differ in form, architectural style, location rules and orientation, and content and symbolism. They are an essential source (carrier) of meaning related to the emotional, intellectual, and utilitarian spheres, which, however, cannot be read without knowledge of specific cultural codes [12,13]. Religious objects are not only places of worship or rituals; they also perform other essential social functions, such as integrating a community, commemorating significant events, and figuring out landmarks. They are also a peculiar expression of the need to "mark" space, "tame" it, and thus define the belonging of an area [14].

One example of interesting buildings in the rural landscape is churches and wooden orthodox churches. These serve as religious buildings and are a crucial element of cultural heritage. The gardens in their surroundings need to be recognized, thoroughly analyzed, and, in further proceedings, revalorized and protected, and recommendations should be developed about how to care for and maintain the old stands [15].

This study set the following research tasks:

1. The primary purpose of this study was to investigate the usefulness of sound tomography for assessing the health of a stand of trees in a historic church garden.
2. Uncertainty about the health of trees can lead to erroneous decisions about stand management. We developed a conservation plan for valuable tree stands and garden projects based on a visual assessment supported by sound tomography surveys. In this way, one can avoid the felling of low-risk trees and prevent possible accidents by removing high-risk specimens.
3. The collected data provided a database of information on the stand's resources and served as the basis for designing the church's surroundings.

The primary purpose of the work was to show the process of taking inventory and revalorizing the surroundings of a historic religious building. While diagnosing the health of the dendroflora, the latest computer techniques, i.e., acoustic tomography, were used. The results made it possible to carry out a revalorization project tailored to the health of the aged trees growing on the property. The critical problem was to develop a plan to develop and maintain a properly functioning garden so that it would be possible to preserve as many trees as possible that are valuable to the environment while adapting the site for safe use. Moreover, while restoring such objects, we must understand the features of the church landscape design, which has been formed and improved over the centuries.

The Stages of the Design Process

We organized the design process in three stages. Firstly, we reviewed the scientific literature and papers. We presented the church's history in Horostyta, described the main guidelines for designing the church gardens, and explained the symbolism used in these gardens. The next stage of the research consisted of visiting the chosen site for measurements and data gathering and evaluating the site's current garden. The last stage of the research consisted of data processing and the final design proposal based on the findings and insights. We used CorelDraw, Sketchup, and Photoshop software to represent the graphical elements. The stages of the design process are presented below (Figure 1).

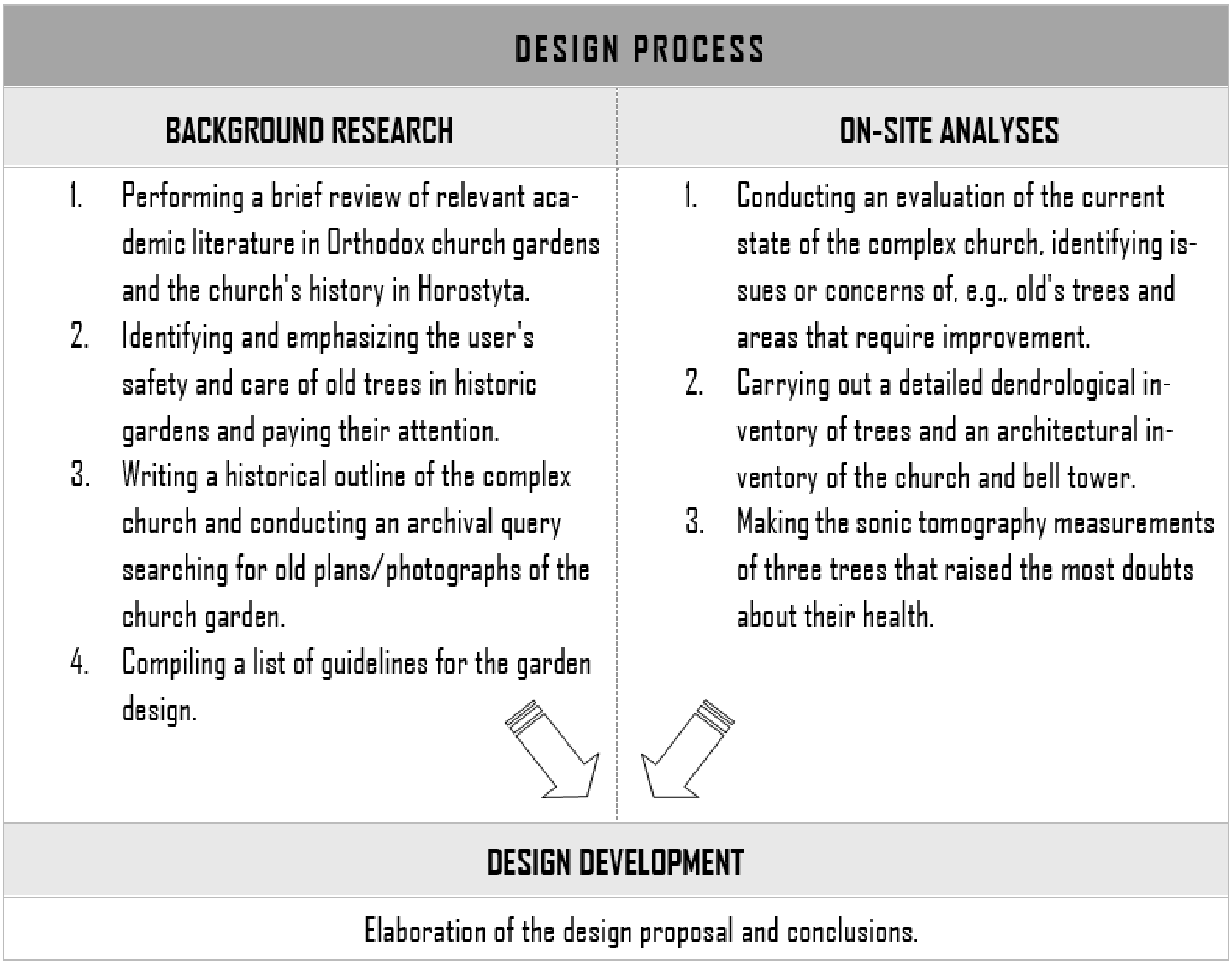


Figure 1. Process of the revalorization project for a historic church garden.

2. Materials and Methods

2.1. Materials

The Orthodox church and belfry, surrounded by centuries-old plantings, are located at the western end of the village of Horostyta (approximately 2100 sqm) (Figure 2). The building of the Orthodox church, together with the interior and exterior furnishings and belfry, is included in the list of monuments of Lubelskie province under No. A/143 [16]. A historic tree stand surrounds the church, which includes 15 trees of various ages and health, including two natural monuments. A brick wall and part of an old fence outline the area. Cast iron, stylized lanterns illuminate the whole area. Within the property's boundaries, along the fence and on the side of the municipal road, there are two wooden crosses and one metal cross. A wooden cross and a stone slab commemorating the January Uprising (1863) are on the church's northern side. A procession road runs around the church, and the temple dominates this small plot. Its architecture fits very well into the rural surroundings of the village, as does the free-standing bell tower. The parish house is on a separate plot north of the church.

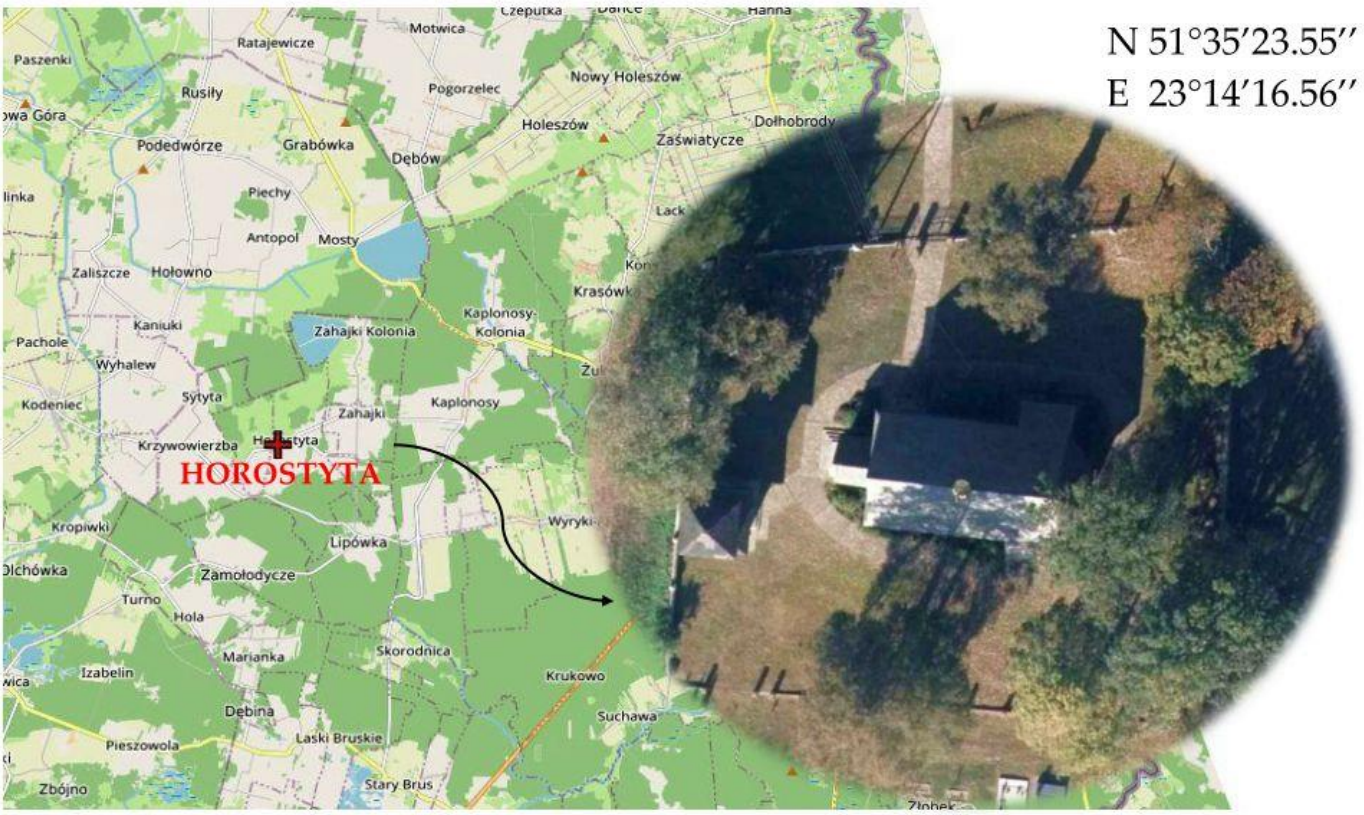


Figure 2. Geographic location of the study area (https://polska.geoportal2.pl/map/www/mapa.php?mapa=polska, accessed on 1 February 2023 (by authors).

Gardens around religious buildings were often created in previously developed areas for cemeteries. However, these necropolises were mainly relocated outside temples in the 18th century for sanitary reasons, among others. The tendency to locate cemeteries within churches dates back to the 10th century, coinciding with concern for burials to occur on consecrated ground [17]. The location of the former church cemetery is also marked around the temple in Horostyta. Today, the burial place is on the south side of the church building, in the cemetery about 100 m from the church.

2.2. Methods of Dendrological Measurements

During the field research, we made a dendrological description of all trees in the study area. The dendrological research consisted of a general description of the tree, which included: inventory number, species name, and general metric data, i.e., trunk circumference at 1.3 m, trunk diameter at 1 m, bark thickness, total height of the tree, range of the tree crown, height of the base of the crown, height of the entire crown, as well as the approximate age, GPS coordinates, and health condition of the assessed tree with comments.

The overall health of the root system, trunk, and crown was important for visual inspection. The visual examination included the characteristics of the trunk's surroundings, the shape of the root neck, and changes and possible damage to the roots. The condition of the trunk essentially determines the health of the entire tree. In the case of fungal infections, the condition of the wood deteriorates, limiting the transport of nutrients and water. During the visual inspection of the trunk, we also considered the base of the crown, in terms of the way the branch fixing might affect the tree's static strength in the future. Assessing a tree's vitality also depends on the amount of downy growth, branch damage, crown asymmetry, or parasitic organisms such as fungi or mistletoe. To determine the vitality of the trees, it was also essential to assess the mechanical, physical, and biological damage (cavities, hollows, and sprouts; signs of insect feeding, fungal fruiting bodies, or exudates). We also paid attention to the leaning of the trunk and other external signs.

We examined trees from all sides, from roots to crown. Visual assessment is always qualitative and sometimes subject to errors depending on the assessor's experience, which should be considered when interpreting the results [18–20]. Of the 15 trees examined, we classified 10 as healthy with no visible damage. The remaining 5 specimens showed noticeable weakness (excessive branch drift, diminished leaves, and falling bark). Three specimens were subjected to detailed acoustic tomography examination for final confirmation of their health status.

We performed tree measurements using a measuring tape and mechanical caliper. The circumference of the trunks was measured using a measuring tape with an accuracy of 1 cm at 130 cm above the ground and the diameter was measured using the caliper at 100 cm above the ground. We measured the crown's reach using the Leica DISTO D5 rangefinder in two directions, N–S and E–W, and we averaged the obtained results. The height of the tree was measured using a Nikon Forestry Pro laser rangefinder. We performed photographic documentation using a NIKON D5300 camera. We also used specialized diagnostic equipment, such as the PiCUS 3 acoustic tomograph by Argus-Electronic GmbH.

The ages of the trees were estimated using several methods: age tables by Majdecki (1980–86) [21], age tables by Mydłowska (2014) [22], a tree age calculator [http://www.tree-guide.com/tree-age-calculator, accessed on 11 April 2023] [23], and a tree size guide [https://wdvta.org.uk/veteran_trees.php, accessed on 11 April 2023] [24]. The additional file contains Majdecki's and Mydłowska's age tables. Significant deviations between methods are often visible when assessing the age of trees. However, there are no better non-invasive methods for determining the age of trees. A more accurate assessment of the age of standing trees can be made using a Pressler probe or a resistograph. However, these are invasive methods. It is worth noting that, in addition to differences in the calculation methodology, the result may be affected by many factors (environmental conditions, substrate abundance, soil moisture, growth rate, or genetic factors); therefore, plantings even from the same period may differ significantly in terms of measured age.

Based on the conducted dendrological inventory and literature review, we created a revalorization concept for the garden around the temple.

2.3. Measurements with the PICUS 3 Acoustic Tomograph

In recent years, the number of tools and methods used in tree surveys has steadily increased [25–27]. Non-destructive testing can be divided into global techniques (ultrasound waves, stress waves, and resonance) and local techniques (probing, coring, and drilling) [28]. Among the methods used here were mechanical acoustic waves [28–30] and several others [31–33]. Using modern examination techniques based on acoustic tomography gives promising results compared to basic visual assessments [34–36]. Qiu et al. developed a tomographic technique using mechanical waves (i.e., stress and acoustic waves) and electromagnetic waves (i.e., laser beams) to evaluate tree trunk defects. In their experimental work, they used the tomographic technique to inspect a tree trunk with an air hole fabricated at the centric position and air gaps made at 5–50 mm near the surface. The results indicated that the internal air hole and air gaps at 5–20 mm below the tree surface could be effectively detected and quantified. Compared to the results using conventional sonic tomography, the presented tomographic technique achieved more accurate and reliable detection of internal defects in tree systems, especially if the internal defects were close to the free surface (i.e., critical defects associated with bending failure) [37].

In addition to the accuracy of the results, the measurement time is also essential. The Balas team evaluated the time needed for measurement and proposed an optimal workflow in 2020 [38]. The results of their work suggested that the scanning of one average-difficulty tree by SoT and ERT resistance tomography took an average of approximately 52 min when one operator measured one scan and approx. 37 min when two operators measured a queue of trees. Working in a two-person team was moderately more efficient. Typically, the overall cost of one scan is approximately EUR 25–30, depending on many variables.

Sonic tomography is a technique broadly applied for detecting defects and voids within several kinds of elements. Sonic pulse velocity tests (SPV tests) are widely applied for detecting the morphology, hidden defects, and voids within structural elements. This technique, broadly applied because it is non-invasive and easy to perform, is remarkably adaptable to ancient buildings, in which no damage is tolerated due to historic preservation requirements. Moreover, SPV tests were recently applied with tomography technology to obtain images of sonic speeds from which it was possible to rapidly reconstruct the morphology of the internal elements [39].

Camassa et al. (2019) proposed some improvements to ultrasonic tomography for masonry constructions, based on the implementation of advanced inversion algorithms, the use of information about wave attenuation (attenuation tomography), and acoustic wave time-of-flight measurements, and enhancements to the experimental setup concerning the coupling between probes and masonry [40].

The topographic measuring apparatus comprised a central unit, sensors deployed around the trunk, and specialized software (Figure 3). Before deploying the sensors, the trunk was tapped with a rubber mallet to pick up deafening noises, suggesting potential changes inside the trunk's internal structure. Only then was the correct measurement level established, and pins were placed around the trunk, at equal distances. Then, the pins were shallowly driven into the bark, on which the sensors receiving the acoustic waves were then attached.

Figure 3. Acoustic tomograph CT scanner on a tree trunk (photo by M. Dudkiewicz).

The number of sensors installed depended on the circumference and shape of the trunk mapped using a specialized PiCUS caliper (Figure 4).

Figure 4. Measuring the geometry of the tree trunk using the PiCUS caliper (photo by M. Dudkiewicz).

The first measurement point was always located on the north side to facilitate the interpretation of the results.

Acoustic tomography is based on measuring sound waves passing through the tree trunk between installed sensors. The sound waves are excited by tapping the individual sensors with an electronic hammer. The measurement process results in a color tomogram illustrating the sound velocity distribution over a trunk cross-section. The default color code for interpreting the results obtained using the included software is as follows: brown and black areas indicate high sound wave velocities corresponding to healthy wood; green corresponds to medium velocities, indicating a transition area between solid and nonsolid wood, but in some cases, it can also suggest problems inside the trunk; and purple, blue, and white areas indicate low sound velocities, characteristic of damage or voids inside the trunk. The processed sound velocity map (tomogram) can be used as a basis for making a scientific and knowledge-based decision on the viability of a tree without felling it. Yellow lines on the cross-section of the trunk suggest the occurrence of internal cracks, which often do not give apparent external symptoms. The thicker the line, the greater the risk of such an occurrence. In contrast, a red line on the tomogram indicates the limiting wall thickness, which allows the determination of the minimum mechanical strength of the tree trunk [41].

3. Results

3.1. Historical Outline of the Village

The founders of the village, the name of which is derived from ‘chworost’, meaning overgrown wilderness, were royal starosts in the early 16th century. Fr. Ivan Sopoćko, the Orthodox dean of Wlodawa and Brest, wrote in 1521 in his chronicle: “Okromie togo podaju kaplicu w siele Khorostyta, siemuż otcu Ignatiju Siergiewiczu fundacji ich miłosti panov Koptiow. Pri niejże i wołok dwa gruntu nadleżaszczich do tojże kaplica chramu założenija Czesnego Kresta.” The temple’s founder was a courtier of Sigismund the Old, Mikhail Vasilevich Kopeć, a hospodar marshal, advisor, and spokesman for Ruthenian affairs in the chancellery of the Grand Duchy of Lithuania. The first historical mention of an independent Horostytsya parish dates back to 1699. In 1702, the owners of the Opole estate, the Kopci family, founded a wooden, single-domed Orthodox church. In 1756, they sold the estate and Horostyta to Józef Sierakowski. Toward the end of the 18th century, the chamberlain of Lusk, Józef Szlubowski, a Sejm member, acquired the estate in 1790. In 1793–1794, the temple underwent extensive renovation, the presbytery was rebuilt, and another general renovation was carried out in 1848. In 1861, a wooden bell tower was erected, which survived. Another estate owner in Horostyta was Bronisław Deskur, a local heir who led the January Uprising in Podlasie. In the Horostyta Orthodox church, insurgents under his command swore allegiance to Poland. In 1875, the Orthodox Diocese of Chełm incorporated the parish, and from then on, it belonged to the second district of the Włodawa deanery. In 1915–1917, the clergy did not use the temple. At the beginning of 1923, a formal decision was made to reopen the church in Horostyta. According to estimates, the parish then had more than 5000 believers. Horostyta was a Ukrainian ukaz village, meaning the Tsar exempted the residents from serfdom by granting them land for ownership. However, the population faced various adversities, including as many as three displacement actions. The first of these was the great evacuation in 1915, known as the bieżeńżeń, the second was the displacement in 1945 deep into eastern Ukraine, and the third was during Operation Vistula in 1947, when the inhabitants of Horosyta were mostly deported and the parish was liquidated. In the 1960s, the population partially returned and regained their lands. The parish in Horostyta was reactivated in 1953 and incorporated into the Lublin deanery. By the end of the 1970s, the community had 360 believers; today, there are approximately 150 [42–44].

3.2. Symbolism in Orthodox Church Architecture

The founders of the village, the name of which is derived from 'chworost', meaning overgrown wilderness, were royal starosts in the early 16th century. Fr. Ivan Sopoćko, the Orthodox dean of Wlodawa and Brest, wrote in 1521 in his chronicle: "Okromie togo podaju kaplicu w siele Khorostyta, siemuż otcu Ignatiju Siergiewiczu fundacji ich miłosti panov Koptiow. Pri niejże i wołok dwa gruntu nadleżaszczich do tojże kaplica chramu założenija Czesnego Kresta." The temple's founder was a courtier of Sigismund the Old, Mikhail Vasilevich Kopeć, a hospodar marshal, advisor, and spokesman for Ruthenian affairs in the chancellery of the Grand Duchy of Lithuania. The first historical mention of an independent Horostytsya parish dates back to 1699. In 1702, the owners of the Opole estate, the Kopci family, founded a wooden, single-domed Orthodox church. In 1756, they sold the estate and Horostyta to Józef Sierakowski. Toward the end of the 18th century, the chamberlain of Lusk, Józef Szlubowski, a Sejm member, acquired the estate in 1790. In 1793–1794, the temple underwent extensive renovation, the presbytery was rebuilt, and another general renovation was carried out in 1848. In 1861, a wooden bell tower was erected, which survived. Another estate owner in Horostyta was Bronisław Deskur, a local heir who led the January Uprising in Podlasie. In the Horostyta Orthodox church, insurgents under his command swore allegiance to Poland. In 1875, the Orthodox Diocese of Chełm incorporated the parish, and from then on, it belonged to the second district of the Włodawa deanery. In 1915–1917, the clergy did not use the temple. At the beginning of 1923, a formal decision was made to reopen the church in Horostyta. According to estimates, the parish then had more than five thousand believers. Horostyta was a Ukrainian ukaz village, meaning the Tsar exempted the residents from serfdom by granting them land for ownership. However, the population faced various adversities, including as many as three displacement actions. The first of these was the great evacuation in 1915, known as the bieżeńżeń, and the second was the displacement in 1945 deep into eastern Ukraine, and the third was during Operation Vistula in 1947, when the inhabitants of Horosyta were mostly deported and the parish was liquidated. In the 1960s, the population partially returned and regained their lands. The parish in Horostyta was reactivated in 1953 and incorporated into the Lublin deanery. By the end of the 1970s, the community had 360 believers; today, there are approximately 150 [42–44].

3.3. Architectural Description of the Building

The church in Horostyta is oriented with the apse and altar facing east, and the entrance is in the opposite western wall. It is built of wood with a log structure on foundations, planked outside and inside, and reinforced with foxholes (Figures 5 and 6). On a rectangular plan, the nave has a newer babiniec added to the west and a slightly narrower, short chancel to the east. Adjoining the chancel to the north and south are rectangular, lower annexes housing the sacristy and treasury. The interior, once tripartite, is now a hall, with a newer music choir in the western part. The windows are rectangular, with semicircular closed windows in the chancel and transverse windows in the sacristy and treasury. The nave is accessed from the north by a stave door with a diamond studded pattern. The roof over the body was once tripartite, with a cupola over the central part. Today, it is five-pitched, shared by the nave and chancel, ending at the bottom with wide eaves with a lambrequin. The side slopes of the roof extend over the sacristy and vault. However, an onion-shaped signature tower rises in the middle of the ridge. Above the granary, the roof has a gabled form. All roofs are covered with shingles [45,46].

Figure 5. View of the church from the side of the municipal road (by M. Dudkiewicz).

Figure 6. Orthodox church in Horostyta—south elevation (by M. Dudkiewicz).

In the center of the church is a late-classical, wooden, blue-painted iconostasis from 1880 (Figures 7 and 8). It is single-story and has seven axes, with bronze pilasters decorated with rosettes, and it is enclosed by a cornice. Above the cornice is a finial with three paintings in finely decorated frames. Above the side, the volutes have crosses, while above the central volutes, the volutes are open. The culmination is gilded in bronze, and the fragments are painted blue. The openwork tsarist gates are formed of volutes and acanthus leaves, with crosses and rays. The iconostasis features contemporary icons of St. Nicholas, the Virgin and Child, Archangel Michael, Christ Pantocrator, the Exaltation of the Holy Cross, the Last Supper, the Shepherds' Bow, and the Ascension in the culmination. Representations of the Evangelists and the Annunciation are painted on Tsar's gates. At the iconostasis are two side altars from the first half of the 17th century, with paintings from the old iconostasis painted on boards. On the left altarpiece is the Mother of God and Child, and on the right is the patronal icon of the Exaltation of the Holy Cross (16th/17th century). Surrounding it, nine small scenes of the history of the Holy Cross are visible: Crucifixion, Baptism of St. Paul, Original Sin, Prayer of St. Paul, Empress Helena inquiring about the Holy Cross, Finding of the Holy Cross, Miracle of Resurrection through the Holy Cross, Building of the temple on the site of finding the Holy Cross, and Resurrection [42,43].

Figure 7. Orthodox church in Horostyta—iconostasis (by M. Dudkiewicz).

Figure 8. Orthodox church in Horostyta—elements of the interior (by M. Dudkiewicz).

A wooden two-story belfry, with a square plan of log-and-post construction planked and on a foundation, is located next to the church (Figure 9). Its lower tier is wider, separated by a slanting shingle roof, and the upper tier is narrower, with rectangular slits. The roof is tent-shaped and covered with shingles with a cupola on top [42,43].

In 2006–2007, the Orthodox church and belfry underwent a significant renovation, during which the foundations, damaged walls and roof structural elements, exterior formwork, floors, roof sheathing, windows, and door woodwork were replaced and the iconostasis was restored.

Since 2007, the Orthodox parish in Horostyta has been located on the Horostyta–Hola–Sosnowica–Dratów tourist route, "in the footsteps of the East Slavic Orthodox church tradition in Polesie Lubelskie."

Figure 9. Wooden belfry next to two sycamore maples (by M. Dudkiewicz).

3.4. Results of Detailed Dendrological Inventory

We inventoried 15 trees in the church garden, among which two species dominated: *Acer pseudoplatanus* and *Tilia cordata* (Table 1). Additionally, there are two trees with significant trunk circumferences, registered in 1992 as natural monuments: a small-leaved linden (672 cm in circumference) and sycamore maple (370 cm in circumference).

Table 1. Species and quantity lists of trees around the church in Horostyta, 2020 (authors).

No.	Latin Name	English Name	Number of Trees
1.	*Acer platanoides* L.	Norway maple	2
2.	*Acer pseudoplatanus* L.	sycamore maple	6
3.	*Tilia cordata* Mill.	small-leaved linden	6
4.	*Quercus robur* L.	pedunculate oak	1
			15

The Result of the Tomograph Examination

The fall of an entire tree or branch can cause significant damage to public infrastructure, personal property, and even human life [47]. Sometimes strong winds can also significantly affect the stability of a tree [48]. Aerodynamic drag on all surfaces of aboveground parts of trees—from individual leaves to entire tree crowns—significantly disrupts the airflow inside them [49,50]. The wind load affects the tree crown and generates significant bending moments on the trunk and its root. These are the primary sources of trunk damage and causes of uprooting. At the same time, it is worth noting that when branches move in the wind, they dissipate their energy, reducing the load transferred to the trunk and increasing the tree's mechanical stability. These features can be considered to be self-optimizing tree structures from evolutionary processes [51].

Safety in historic gardens with large trees is critical, and their preservation requires precise diagnostic techniques to detect structural damage to tree trunks caused, for example, by biological or physical factors. Visual tree assessment (VTA) is still the starting point for such studies. However, internal defects in tree trunks often remain out of sight of the arborist or botanist [52,53]. For many years, the Pressler auger was the only tool available for detailed assessment of the internal wood structure of a growing tree. However, this method requires mechanical intervention in the internal tissues of the tree. Its application in the case of valuable historic trees is controversial. At the beginning of the 21st century, surveys of the health of urban stands were conducted using various survey methods (electrical tomography, acoustic, etc.) with varying degrees of success. Of the methods used, acoustic tomography proved to be the most effective tool for detecting the distribution of internal tissues, being the most accurate in locating anomalies and estimating their dimensions and shapes and being the least invasive [54,55]. Compared to other methods, examination by acoustic waves is efficient even in the early stages of wood decay [56,57]. Gilbert and Smiley (2004) estimated that the average accuracy of the device was 89% [29]. Rapidly preventing the degradation of a protected specimen and properly conducting arboricultural work to keep the tree in good condition contribute to preserving the rich biodiversity of parks and gardens.

Additionally, it should be clarified that tree decay is a normal process, not an illness, and belongs to a tree's life, and that there should be decaying parts in old trees. Decaying wood is an essential part of an old tree and it supports other species and biodiversity. Decay is not always a risk, and a professional must conclude by looking carefully at the structure based on VTA and studying the decay using non-invasive methods or microdrill resistance whether structural weaknesses exist and what to do about them.

Many factors can cause decay in trees. Here are some of them: *humidity*—humid conditions support the activity of fungi and bacteria that promote tooth decay. Trees located in places with high humidity, e.g., by a riverbank or pond, are more susceptible to decay; *mechanical damage*—mechanical wounds on tree trunks or branches are places where microorganisms can penetrate; *lack of ventilation and light*—trees that grow in too much density do not have enough light.

Disturbing features and grounds for thoroughly examining a given specimen include peeling bark, holes, cavities in the trunk or branches, dead branches, and mushroom fruiting bodies (Figure 10).

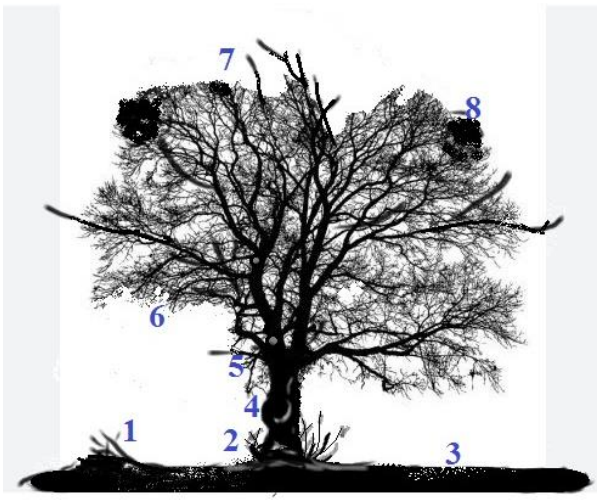


Figure 10. Senile tree. Designations: 1. dry branches under the tree; 2. suckers around the tree's crown; 3. early leaf fall; 4. bumps and mushrooms on the trunk; 5. hollow; 6. asymmetric crown; 7. broken top; 8. mistletoe.

The first thing an arborist may do is use a mallet to strike a tree's trunk and listen to the quality of the sound it makes. The sound of solid or decayed wood that has lost its structural strength sounds different. Next, an arborist may probe cavities with a metal rod to test how easily the cavity's interior gives way when pushed. Sound wood is hard and unyielding when poked, while decaying wood crumbles or allows a tool to pierce it.

We classified 12 of the 15 trees growing around the church as healthy due to the lack of visible damage. The remaining three specimens showed weakness (downy, small leaves, and falling bark). We examined the trees using acoustic tomography (Table 2). Signs of progressive decay were found inside their trunks, qualifying them for detailed observation for the time being but not immediate felling. This decision would depend on the wood's decay rate and the safety of the environment.

Table 2. Results of dendrological expertise (by authors).

No.	Species Name	GPS	Solid Wood	Temporary Wood	Damaged Wood	Conclusions from the VTA	Recommendation
1	small-leaved linden (*Tilia cordata* Mill.)	51°35′23.31″ N 23°14′16.27″ E	82%	11%	7%	suckers at the base of the trunk, dry branches, wilting leaves.	cutting and monitoring, marking the tree with tape, obtain information about possible danger.
2	sycamore maple (*Acer pseudoplatanus* L.)	51°35′23.35″ N 23°14′17.43″ E	62%	7%	31%	tilted tree, many hollows in the trunk, visible decay.	cutting and monitoring, marking the tree with tape, obtain information about possible danger.
3	small-leaved linden (*Tilia cordata* Mill.)	51°35′24.38″ N 23°14′16.83″ E	53%	19%	28%	significant deadwood in the crown, peeling bark, traces of insect feeding in the trunk.	cutting and monitoring, marking the tree with tape, obtain information about possible danger, reconstruction of the foundation of the fence.

Object 1—small-leaved linden (*Tilia cordata* Mill.)

The assessed tree grew on a slight elevation at a distance of 1.5 m from the fence separating the church from the cemetery. The distance from the walls of the church building was 14 m, and it was 1 m from the neighboring tree (Figure 11). In the tree's crown, the growth of small downy branches was estimated at 20%, with hanging branches and wilting leaves. Traces of the maintenance work carried out were visible, and the areas of cuts were well healed. Based on the tomographic results obtained, small foci characterized by weakened internal wood structures were estimated at 8%, located on the northern side of the trunk section. They did not significantly affect the mechanical strength of the trunk. Technically sound wood occupied 85% of the trunk cross-section, and the remaining part (7%) was so-called transitional wood with a slightly weakened structure but was not yet damaged. The recorded speed of sound inside the trunk ranged from 817 to 1150 m s^{-1}, which suggested the tree was in good condition, especially since, according to the available literature, the average speed of sound waves in healthy linden wood is in the range between 940 and 1183 m s^{-1} [58].

The red line illustrated the minimum wall thickness of 12.8 to 13.6 cm (average 13.2 cm), depending on the site, which indicated that the safety limit against trunk fracture was preserved on most of the cross-section. Destructive processes only went beyond this limit on the north side of the trunk.

Calculated for different directions, the trunk section's geometric moment of inertia, measured at the weakest point at the measurement height, ranged from 3.2% to 7.8% of the maximum strength relative to a trunk without defects or damage. The calculations themselves only took into account the trunk's geometry at the measurement level, while the properties of the wood itself may affect the final result of the measurement. Based on the results obtained, one could assume that the tree's mechanical strength and resistance to trunk bending were safe for the environment (Figure 12).

The minimum thickness of a healthy wall relevant to the preservation of tree statics, calculated by the Tree SA method, should be 6.6 cm on average (green line on the attached tomogram). Based on the measurement carried out at the height of 120 cm above ground level, we found that significant weakening of the wood structure occurred only at the height of the 1st and 2nd measurement points in the northern part of the trunk section, and the safety limit was still preserved.

As calculated by the Tree SA method, the wood in the solid trunk required a minimum residual strength of 38%. However, based on the tomographic survey, the percentage of entirely sound wood was 85%. This finding testified to the good statics of the tree (Figure 12).

According to the Roloff scale, the evaluated linden was in the exploration stage (grade 0) [59].

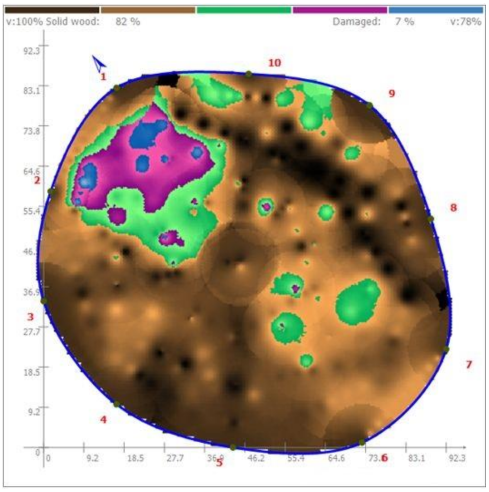
The tree grew very close to another tree, which may have resulted in insufficient sunlight. On the trunk and branches, there were traces of maintenance cuts that may have allowed the penetration of fungi that weakened the tree. The wilting leaves were also evidence of a slight weakening of the plant's vitality.

The project suggested leaving the tree and its surroundings unchanged, i.e., as lawn turf. Planting a floor of shrubs around the trunk or locating small architectural objects under the tree canopy were not planned. The project recommended removing dead branches, and that all work and care procedures should be performed following the rules of arboriculture by a team qualified to care for veteran trees. The condition of the tree should be monitored every 2 years.

Figure 11. General view of small-leaved linden (by M. Dudkiewicz, 2020).

Object 2—sycamore maple (*Acer pseudoplatanus* L.)

The tree grew 0.3 m from the fence wall in the eastern part of the property (Figure 13). The trunk had several cavities, mainly hollows of various sizes. The initially straight trunk from a height of 2.5 m sloped northward at an angle of 30° and revealed several breakages in the crown, resulting in hollows and branch ashes at a level of 15–20%. The topographic examination showed progressive destruction of the trunk's interior in the core, moving to the outer layers on the northeast side at the height of measuring points 7–8. At this point, the minimum wall thickness required to maintain the proper mechanical strength of the trunk, which should have an average thickness of 10.6 cm, was also not maintained. The recorded speed of sound traveling in the wood of the tested maple ranged from 818 m s^{-1} between measurement points 7 and 2 to 1616 m s^{-1} between sensors 4 and 3. Referring to the average speed of sound waves propagating in healthy maple wood, which is on average from 1006 to 1426 m s^{-1} [58], one could conclude that the lower recorded value was slightly lower than the norm while the other was well above the accepted level.



Trunk circumference at the height of 1.3 m: 293cm
Height: 17 m
Crown range: 11.5 m
Approximate age: 121years, 121years, 202years, 97years

Instructions:
1. Tree to keep.
2. Dry branches should be removed following the rules of arboriculture by a team qualified to care for veteran trees.
3. Health monitoring every 2 years.

Figure 12. Tomogram of the interior of small-leaved linden trunk inv. no. 4 (by W. Durlak) [21–24].

Damaged wood on the cross-section of the trunk occupied 30% of the area, and healthy wood occupied 62%. The remaining area was transitional wood (Figure 14). It was most likely that the destructive processes that had begun would worsen in the future. Therefore, monitoring the tree was recommended for the time being in order to prevent possible felling.

The minimum wall thickness indicated by the red line on the tomogram, considered the safety limit before stem fracture, was between 9 and 12.1 cm (average 10.6 cm), depending on the site. It was preserved in most of the cross-section. Destructive processes only went beyond this limit on the northeast side of the trunk (Figure 14).

Calculated for different directions, the geometric moment of inertia for this section of the trunk, measured at the weakest points at the height of the measurement, ranged from 51.3% to 56.7% of the maximum strength compared to a trunk without defects or damage. Based on the results, one could assume that the tree's mechanical strength and resistance to trunk bending were safe for the environment.

The minimum thickness of a healthy wall relevant to the preservation of tree statics, calculated by the Tree SA method, should be 7.15 cm on average (green line on the attached tomogram). Based on the measurement carried out at 80 cm above ground level, significant weakening of the wood structure occurred only in a small area around the 8th measurement point in the northeastern part of the trunk section. In the remaining area, the safety limit was preserved in excess.

As calculated by the Tree SA method, the required minimum residual strength of the solid wood of the trunk of this tree was 48%. On the other hand, based on the tomographic survey, the percentage of utterly sound wood was 62%, which confirmed the good statics of the tree.

According to the Roloff scale, the evaluated linden was in the exploration stage—light degeneration (grade 0–1) [59].

The tree grew close to another tree and right next to a brick fence, which may have resulted in insufficient sunlight. There were hollows in the trunk, broken branches, and deadwood in the crown. The tree's strength was probably weakened by the low amount of light and humid conditions in which the tree grew (by the old brick fence), which resulted in the decay of the trunk.

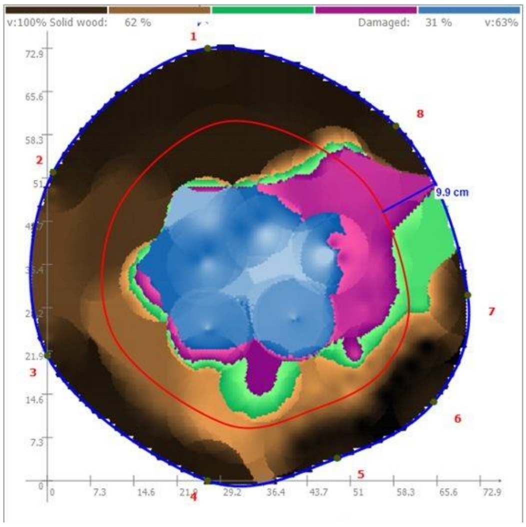
The project suggested planting low turf vegetation around the tree. Locating small architectural objects under the tree crown was not planned. The project suggested removing the dead branches, and that all work and care procedures should be performed following the rules of arboriculture by a team qualified to care for veteran trees. The condition of the tree should be monitored every 2 years.

From the south, a hollow at the height of 0.8 m reaching deep inside the trunk Ø 0.1 m. The second hollow - smaller, at a height of 1.5 m from the south, measuring 0.1×0.02 m. From the west, at the height of 2.8 m, a hollow, probably from a broken branch measuring 0.3×0.15 m. Trunk initially straight up to 2.5 m and then sloping toward the north at an angle of 30°.

Figure 13. General view of sycamore maple (by M. Dudkiewicz, 2020).

Object 3—small-leafed linden (*Tilia cordata* Mill.)

A small-leaved linden grew near the main gate on the northern side of the church (Figure 15). It was characterized by its considerable size and quite downy solid growth in the upper parts of the crown. The crown showed traces of broken branches, and the surgical cuts were partially healed. Numerous heavily leafy outgrowths appeared on the trunk. The crown was asymmetrical, facing north. At the base of the trunk, large root intakes had developed. Traces of insect activity were also visible. The upper part of the tree trunk had numerous hollows. The root system was strongly developed, pushing slightly against the fence's foundation. The CT scan made it possible to determine the health of the trunk's interior (Figure 16). Linden trees are characterized by wood susceptible to biocorrosion; hence, the destruction visible on the tomogram in the core part of the trunk was a common phenomenon. We calculated the limiting wall thickness considered safe for this trunk's mechanical strength to be 16.9 cm on average.



Trunk circumference at the height of 1.3 m: 232 cm
Height: 17 m
Crown range: 18 m
Approximate age: 132years, 132years, 133years, 62 years

Instructions:
1. Tree to keep.
2. Dead branches to be removed. All work and care procedures should follow the rules of arboriculture by a team qualified to care for veteran trees.
3. Health monitoring every 2 years

Figure 14. Tomogram of the interior of sycamore maple inv. no. 11 (by W. Durlak) [21–24].

The recorded speed of the sound wave in the wood of the evaluated linden ranged from 320 m s^{-1} between measurement points 8 and 2 to 1245 m s^{-1} between sensors 4 and 12. The recorded value was much lower than the average, influenced by the movement of sound through the damaged areas slowing down its speed. The upper value, on the other hand, was within the norm and even slightly exceeded it.

Damaged wood occupied an area equal to 26% of the cross-sectional area of the trunk, while healthy wood occupied 56%. The remaining 18% was transitional wood (Figure 16). Most likely, the destructive processes that had begun would worsen in the future, but it was unknown at what rate. Therefore, it was worth monitoring the tree and holding off on possible felling.

The minimum wall thickness marked on the tomogram with a red line, considered the safety limit against trunk fracture, was 16 to 17.8 cm (average 16.9 cm), depending on the location. This limit was preserved practically throughout the cross-section, indicating that the trunk's mechanical strength was still good.

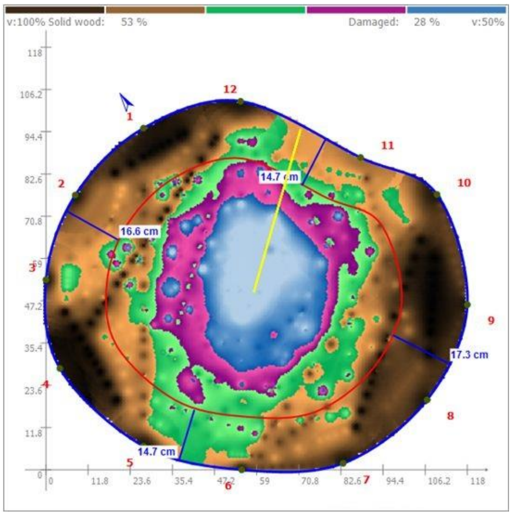
The attached tomogram also shows two yellow lines indicating the possibility of internal cracks, the most likely one oriented to the northeast between measurement points 11 and 12.

Calculated for different directions, the geometric moment of inertia for this section of the trunk, measured at the weakest points at the height of the measurement, was 10.8% to 48.9% of the maximum strength compared to a trunk without defects or damage. Based on the results obtained, one could assume that the tree's mechanical strength and resistance to trunk bending were safe for the environment.

The minimum thickness of a healthy wall relevant to the preservation of tree statics, calculated by the Tree SA method, should average 5.8 cm (green line on the attached tomogram). Based on the measurement carried out at 130 cm above ground level, there was no significant weakening of the wood structure at this trunk section. The required safety limit was maintained in excess.

Numerous broken branches. Large stature in the crown. Crown facing north. Large rooting and regrowth on the trunk. Thick branch cut from the south, as well as from the north and east sides. Roots are pushing the fence foundation outward. Visible hollows in the upper part of the trunk on the north side. Falling bark. Traces of insect feeding in the trunk (exit holes). Nodular growths - remnants of branches - at different heights on each trunk side.

Figure 15. General view of small-leaved linden growing at the entrance of the property (by M. Dudkiewicz, 2020).



Trunk circumference at the height of 1.3 m: 367 cm
Height: 17.8 m
Crown range: 10 m
Approximate age: 152years, 152years, 252years, 123years

Instructions:
1. Tree to keep.
2. Dead branches to be removed. All work and care procedures should follow the rules of arboriculture by a team qualified to care for veteran trees.
3. Modifying the foundation of the fence to allow root growth.
4. Health monitoring every year.

Figure 16. Tomogram of the interior of small-leaved linden inv. No. 15 (by W. Durlak) [21–24].

As calculated by the Tree SA method, the required minimum residual strength of the solid wood of the trunk of this tree was 23%. On the other hand, based on the tomographic survey, the percentage of entirely fine wood was 56%, which indicated good tree statics (Figure 16).

According to the Roloff scale, the evaluated linden was in a borderline stage between degeneration and stagnation (grade 1–2) [59].

The visual condition of the tree was disturbing. Traces of insect activity were visible on the trunk, and the crown was asymmetrical. There was a large dead branch, and the tree put out many root suckers. Modifying the fence's foundation was planned to allow root growth. The tree probably used to grow in a row of trees, and now it was a single object exposed to the wind. It was planned to plant two small trees on both sides of the linden. The project recommended removing the dead branches, and that all work and care procedures should be performed following the rules of arboriculture by a team qualified to care for veteran trees. The condition of the tree should be monitored every year.

The temple walls were shrub beds composed of, among other plants, *Juniperus chinensis* 'Stricta', *Thuja* 'Smaragd', *Spirea japonica*, and *Physocarpus opulifolius*. The selection of species primarily included species of foreign origin and characteristics mainly of home gardens rather than religious establishments. There was no reference to the plant symbolism crucial to the Christian faith.

4. The Problem of Protection of Senile Trees

Old trees are witnesses to history [60,61]. They are not only picturesque elements of the cultural landscape (often painted, photographed, and described) but also a vital part of the natural world. They are the habitat of rich biological and microbial life. According to British data, more than 2000 species of invertebrates (6% of British invertebrate fauna) depend on the habitat of senile trees; therefore, removing such tree canopies seriously affects the biodiversity of cities and villages [62]. Dendroflora is also an essential biodiversity refuge with sometimes rich associated flora. Many species of lichens live on tree trunks, including rare and protected species. Branches are convenient places for bird nesting, and many species of birds (including legally protected birds) live in treetops, such as nightingales, nightjars, blackbirds, grackles, and kestrels.

Dangerous trees pose a significant risk to landowners and those who care for them. It is worth mentioning in this context that the ISA (International Society of Arboriculture) has created a so-called qualification to define the risk assessment of trees (Tree Risk Assessment Qualification—TRAQ). This qualification promotes people's and property's safety by providing a standardized and systematic process for assessing tree risks. The results can provide tree owners and risk managers with information to help them make informed decisions to increase the benefits, health, and longevity of trees [63].

Tree dieback begins with crown thinning, yellowing, and other symptoms on the leaves, a morbid appearance, and the top drying out. Tree branches begin to die from top to bottom. External features include spiral rings in the tree trunk, thin or balding bark, loss of apical dominance, crown dieback, and crowns with few large branches [64]. Pederson described six typical external features of old angiosperm trees. These features include: (1) smooth-textured bark; (2) a reduction in the tree's growth strength; (3) high waviness of shoots; (4) crowns composed of few, thick, and twisted branches; (5) low crown volume; and (6) a low ratio of leaf area to trunk volume [60].

Here, it is worth noting that tree death is a normal process, not a disease, and is part of the tree's life cycle. Decay is one of the crucial processes in old trees and decaying wood supports other species and biodiversity. Decay itself is not always a risk, and the professional must draw conclusions based on proper observations (VTA) and decay testing using non-invasive methods in order to assess whether there is structural weakness and what to do about it.

4.1. Threats Related to the Felling of Ancient Trees

An old-growth tree is a valuable element of tall greenery in urban and rural areas, and, despite its advanced age or significant damage, it is an invaluable element of biodiversity. Any overly hasty decision to remove an aged tree is a considerable loss to the environment, both image-wise, nature-wise, and often historically. In Poland, trees around historic churches are protected as greenery growing on a property entered in the register of monuments. Under this assumption, removing, destroying, or damaging a tree is a crime under Article 108 of the Monuments Act [65]. Unfortunately, we often witness illegal felling or improper care of senior trees (Figures 17–20). Most often, it is topping, i.e., removing the top part of the tree to slow down the growth of the tree, lower the center of gravity, or reduce the size of the crown. "Topping" leads to the destruction of the crown and is a mistake. Due to inefficient tree care, municipalities or parishes have to pay multi-million fines. We must sensitize society and the authorities (secular and ecclesiastical) so that the surroundings of churches are cared for and respected in order to preserve our cultural heritage and their natural value. This research is an example of how carefully each case of a veteran tree should be considered.

Figure 17. Destruction of trees around the Church of St. Marcin Wincenty in Skórzewo near Poznań (Greater Poland Voivodeship) (photo M. Dudkiewicz, 2022).

Figure 18. Destruction of trees around the Church of St. Marcin Wincenty in Skórzewo near Poznań (Greater Poland Voivodeship) (photo M. Dudkiewicz, 2022).

Figure 19. Destruction of trees around the church in Zajezierze near Dęblin (Lubelskie Voivodeship) (photo M. Dudkiewicz, 2022).

Figure 20. Destruction of trees around the church in Zajezierze near Dęblin (Lubelskie Voivodeship) (photo M. Dudkiewicz, 2022).

People hastily remove trees because of the perception of trees as a problem, e.g., threats to the church building. This is primarily due to low social awareness of the importance of trees for biodiversity and ignorance about the principles of their proper care and protection [66]. The fundamental importance of solving the presented problem was to improve the administration and management system of trees in cities, following the example of similarly operating structures in European countries and in America (Table 3). In Germany, urban tree control is a safety assessment, the form of which is defined in the Baumkontrollrichtlinie (Tree Control Policy). The German Association of Landscape Experts (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau) certifies tree care and assessment inspectors. The state registers street trees in a unified cadastral system, and trees over 40 years old are inspected twice a year for traffic hazards. Thanks to constant observation, we can assess how the tree copes with stress factors, whether it produces defense mechanisms, and how the observed defects and diseases progress. International institutions, such as the International Society of Arboriculture, also define standards.

Table 3. Ways of minimizing risk management related to ancient trees based on European and American programs.

Risk Prevention	Minimizing and Correcting Threats
1. Rational design of space around ancient trees. Shaping safe compositions (separating trees with shrubs and flowerbeds from sidewalks and benches) (Figure 21). 2. Proper care performed following the principles of arboriculture by a team qualified in the care of veteran trees. 3. Monitoring and objective assessment of trees in terms of safety hazards, allowing for making decisions about dealing with the tree. 4. Education of garden owners and users.	1. Making decisions adequate to the level of risk using minimal to advanced diagnostic methods, e.g., sonic tomography. 2. Closing the tree in the tree protection zone (crown range plus 1 m) from public traffic. 3. Fencing off the projection of the tree crown with string or tape. Placement of warning signs, e.g., bands on the trunk and signs on the lawn (Figures 22–24). 4. Cuts correcting the crown and improving the tree's statistics, using mechanical reinforcements. 5. Improvement of passage conditions, removal of the concrete surface around trees, replacement with air spades, mycorrhiza. 6. If the tree is next to a fence, adaptations of the foundations and fence (Figures 25 and 26).

4.2. Research Limitations in Acoustic Tomography for Senile Trees

It is also worth mentioning the research limitations, which included the sizes of the tree specimens under study. The distance between measuring points (electrodes) on the edges of the tree trunks under study was determined using the PiCUS electronic caliper. Unfortunately, the range of its arms was insufficient to examine trees with a considerable breast height. Therefore, determining the tree cross-section sometimes had to be performed by hand. After hitting the tree trunk with a hammer, an acoustic signal is generated in each electrode, the time is recorded, and the speed of passage of the acoustic waves between each sensor is calculated. In the case of a large internal cavity in a tree of considerable size, some readings were not very precise and required several harder hammer blows. The measurement set consisted of 12 sensors and an electronic device, and a large tree specimen required rearranging the sensors and taking an additional measurement at another 12 points, which increased the time needed for the survey.

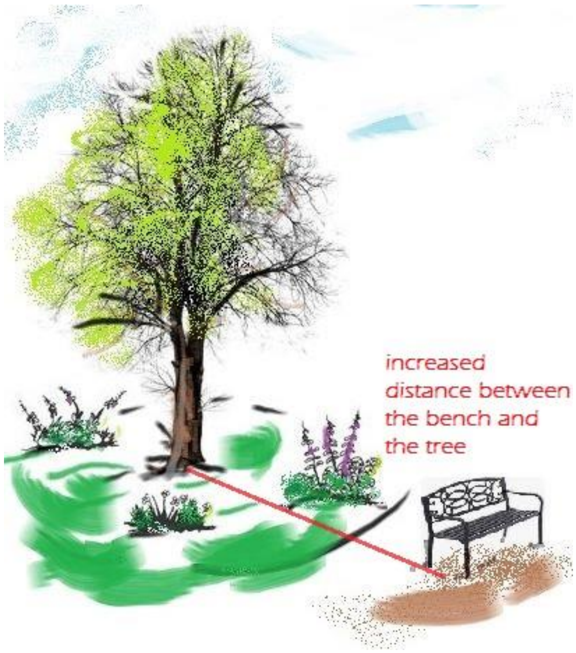


Figure 21. Senile tree in a historic garden—planted perennials can move traffic and benches are located beyond the projection of the tree crown (by M. Dudkiewicz).

Figure 22. Rubber band on the trunk with dendrometric data of the ancient tree and a request to be careful when parking under the tree crown, especially during a storm. Center for Contemporary Art Ujazdowski Castle in Warsaw (photo M. Dudkiewicz, 2022).

(**a**)

(**b**)

Figure 23. (**a**) Rubber band on the trunk with dendrometric data of the ancient tree. Center for Contemporary Art Ujazdowski Castle in Warsaw (photo M. Dudkiewicz, 2022). (**b**) Fencing off an ancient oak with a rope and placing signs warning about falling branches. Ujazdowski Park in Warsaw (photo M. Dudkiewicz, 2022).

Figure 24. A sign with the inscription: Area of an old stand. Danger of falling branches. Staying near old trees is associated with the risk of loss of life and health (photo M. Dudkiewicz, 2022).

Acoustic tomography also has other specific limitations. In some cases, the course of acoustic waves can be disturbed by the internal structure of the wood, such as reaction wood. Interpretation of the tomogram is also sometimes hampered by the presence of cracks or plugs, which tend to occupy a larger area on the tomogram than in reality. A particular case that makes it difficult to correctly read the information in the acoustic tomogram is the occurrence of so-called wet wood in some deciduous trees, mainly elm and poplar. The altered area in the central (core) part of the trunk is depicted on the tomogram in the same way as a cavity caused by rot, whereas the presence of wet wood in the trunk primarily makes the wood immune to rot fungi and has little effect on the stability of the tree. We can conclude that the device provides reliable information on wood density by determining the reason for the presence of low-density wood objects visible on the tomogram. The potential significance of these defects for tree stability and viability requires more profound dendrological knowledge [67].

Figure 25. Planned lack of foundations to protect an ancient linden tree (photo M. Dudkiewicz, 2018).

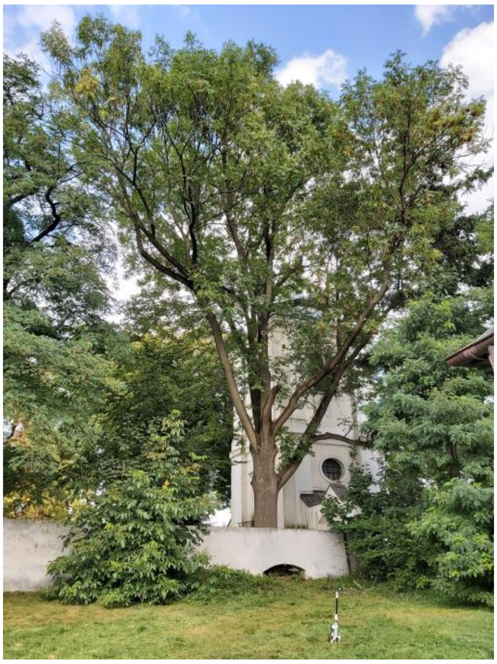


Figure 26. Planned cut-out in the wall to leave room for the development of ancient ash roots at St. Paul in Sandomierz (photo M. Dudkiewicz, 2020).

While advanced decay detection technologies are effective in quantifying internal decay, it is not clear how the additional information provided by these instruments impacts risk assessments concerning the likelihood of failure. Even the once commonly accepted arboricultural rule of thumb, $t/R > 0.3$–0.34 (where t is the radial thickness of sound wood, and R is the trunk radius; Mattheck and Breloer, 1994 [68], has not been spared from debate over its accuracy or widespread applicability [34,68].

5. Guidelines for the Design of Orthodox Gardens

The places where temples were built in the past were not accidental. Orthodox churches were located in places marked by a miracle, a revelation, and the fervent faith of the faithful. People harmoniously integrated the buildings into nature. Today, the surroundings of old churches are often the last refuge of centuries-old tall trees. Amid numerous modern landscape transformations, ancient churches surrounded by greenery remind us of our desire to preserve harmony with the world [69]. In villages, churches were mostly wooden and built in the highest place. If there was a river or lake nearby, then these were also included in the overall composition [70].

The church garden area is an intermediate zone between the sacred (the temple) and the profane (inhabited areas). Orthodox churches and their surroundings have also been burial sites for the faithful for centuries. It was not until the Edict of Nantes of 1777 that the burial of the dead near churches was banned for sanitary reasons. Following France's example, other countries, including Poland, introduced similar regulations. The effect of these changes was to transform the areas of former church cemeteries into landscaped areas, where votive crosses and rows of trees were located, forming a clear boundary in the landscape [71]. Its architectural enclosure gains a landscape dimension with a row of trees along the church's borders. Practical, aesthetic, and symbolic reasons dictated such a solution, thereby accentuating the separation of the sacred and profane zones. Deciduous tree canopies of lindens, oaks, ash, and chestnut trees usually surround temples [72].

In the Orthodox tradition, green is the color of spring and rebirth. In iconography, green is the herald of the Holy Spirit and the color of John the Evangelist and many prophets. Red symbolizes life, beauty, divine love, and power. However, at the same time, it also signifies martyrdom and blood. The color white in the Orthodox church symbolizes God's revelation and glory. White is also used to represent joy and a festive mood and symbolizes purity, innocence, God's wisdom, joy, and happiness. The color brown represents the material world, humility, and poverty [73,74].

Although this manuscript deals with a small rural Orthodox church, it is worth mentioning the basic principles of the spatial composition of an Orthodox monastic complex. Orthodox monastic gardens were characterized by the social and functional specialization of the garden, unity with the surrounding landscape, traditionalism and canonicity, symbolism, and rituals. The garden of the monastery complex was not limited to the inner part of the monastery walls. It was a multilevel system of greenery inside and around the monastery. The central garden, with a specific layout and planting structure, was located inside the monastery walls near the cathedral church. Smaller gardens were located near other buildings. Utility crops grew on the periphery of the monastery complex. By the 14th century in Russia, the concept had taken shape that only primordial nature was sinless, ordered by God Himself and in harmony with it. Monasteries were placed on hillsides, hilltops, and, if on flat terrain, in the bends of rivers, tributaries, or islands. Thus, the monastic complex was dominant in a given landscape within a radius of several miles. The low density of the monastery, high plantings in the monastery courtyard, and the use of native plant species "dissolved" the monastery into the environment, making it an organic part of the natural landscape. One of the main functions of the garden was to replicate the process of creating the world in miniature.

The entire monastery was conceived as "heaven revealed on earth." The placement of the monastery on a hill was seen as an approximation of heaven, God, and Eden. The axis of the main gate and the temple symbolized salvation. The main cathedral's centrality and dominance in space signified the "One God," the microcosm and heaven. Other buildings around the main cathedral embodied the Righteous around the throne of God [74].

An essential element in the composition of the church's surroundings was to allow a circular route around the main temple and to form a square in front of it. Additionally, the presence of an Orthodox cross was desired on each building, as well as small architectural forms, i.e., an '*istocznik*' spring and *phiale* (a place for water to shine), flower compositions by the main square, the use of white lilies and white flowers in the garden, and the presence of apple trees. If possible, an avenue of linden trees led to the church. The species selection of plants in gardens was made considering the plants' symbolism and their flowering period during the most important religious holidays. Thus, the Orthodox church garden was, in a sense, a metaphor that tells biblical stories and encourages concentration, prayer, and reflection [74].

Orthodox church garden rituals included processions and sanctification of gifts as a common prayer for God's protection, help, and glory. These included:

1. Grand processions—Velyki Khresni khody (Paschal Way of the Cross, Velyke Vodosvyachennya or Way of the Jordan);
2. Prestol'ni Khresni khody—the days of the patronal feasts of a particular monastery;
3. Church-wide rite of consecration of gifts and small processions around the cathedral (Apple Spas and Nutty Spas, Palm Sunday, Easter);
4. Episodic line processions at meetings of the higher clergy or holy icons in monasteries, monks' burial rank, and others.

All of the above rituals, therefore, required a square where people gathered during the ordination of gifts and a circular avenue around the church as a processional route, highlighting the main avenue leading from the gate to the temple, and side paths to the church cemetery, the '*istochnik*', and '*phiale*'.

In summary, in the case of evaluating the greenery system on the territory of a historic religious site, the basic principle of the development should refer to the historical species selection in such sites and plantings should follow the principles of religious symbolism [75–77]. The churchyard garden should be rich in symbolic colors while having a contemplative atmosphere. The designer should consider the patrons of the church and the iconographic program should also appear on the exterior of the building. Physical and spiritual relaxation, concentration, and reflection should be fostered by elements of small architecture, i.e., benches, and commemorative crosses that are adequately integrated into the entire garden establishment. It is worth using species and varieties of ornamental plants, shrubs, and trees with resinous fragrances or fragrant inflorescences (e.g., lindens, larches, pines, spruces, and roses). As Forstner (1990) notes, all of these stimuli, while stimulating the senses and deepening the scale of the experience, primarily point to something extraordinarily subtle and spiritual [78]. Thanks to the vegetation, the church's immediate and distant surroundings should form a spatial and ecological whole [72]. Trees are commonly used to plant the boundaries of church areas. Thanks to the row of trees along the church's borders, its architectural fencing gains a landscape dimension. Practical, aesthetic, and symbolic considerations dictate this solution, in that it emphasizes the separation of the sacred from the profane.

6. Design Concept of the Church Garden

Finding a balance between natural, historical, and user safety aspects is one of the most critical challenges in the sustainable management of garden monuments. Veteran trees should be provided with adequate living space. Sufficient light and space should reach the trunk and crown, and the extensive root system should have proper soil volume. In this way, the stand should continue to age slowly in peace while remaining in a favorable environment, if possible.

The presented design concept achieved a compromise between tradition and the modern user's needs (Figure 27). The project involved renovation of the fence, the installation of benches, lighting, and construction of a spring. We planted five new trees to supplement the planting in a row along the fence. The senile trees were some distance from the processional road. Flowerbeds surrounded them. This should improve the living conditions of the veteran trees and prevent people from walking under their crowns. We planted shade-loving perennials under the crowns of the trees. The curves of the flowerbeds referred to rural and naturalistic gardens. Considering the plantings used in the project, we suggested their symbolic meaning: periwinkle—fidelity, eternal life; ivy—the permanence of life; boxwood—hope of salvation, immortality; yew—immortality; syringa—kindness; lilac—zeal, diligence; tonsil—vigilance, youth, piety, diligence, new life; quince—marriage; peony—shame; rose—eternal wisdom, martyrdom, transience, mystery, eternity, marriage. In turn, we selected the proposed flower species based on their religious significance and specific symbolism: marigold—penance, abstinence; pansies—timidity of young girls, faithful memory, the Holy Trinity, faithfulness, envy; violet—love, humility, passing, modesty, a widow, a believer, the earth awakening to life after winter; carnation—love, boldness, kindness; iris—suffering, recklessness, the Passion of Christ, forgiveness of sins, sadness; lily of the valley—the salvation of the world; lily—purity, a soul striving for God, a faithful soul, virginity, royal dignity, transience, the word of God, light, spring; mallow—pain, mercy, request for forgiveness; forget-me-not—sincere love, faithful memory, naive simplicity; fern—modesty, daisy—eternal youth; tulip—goodness [79–81].

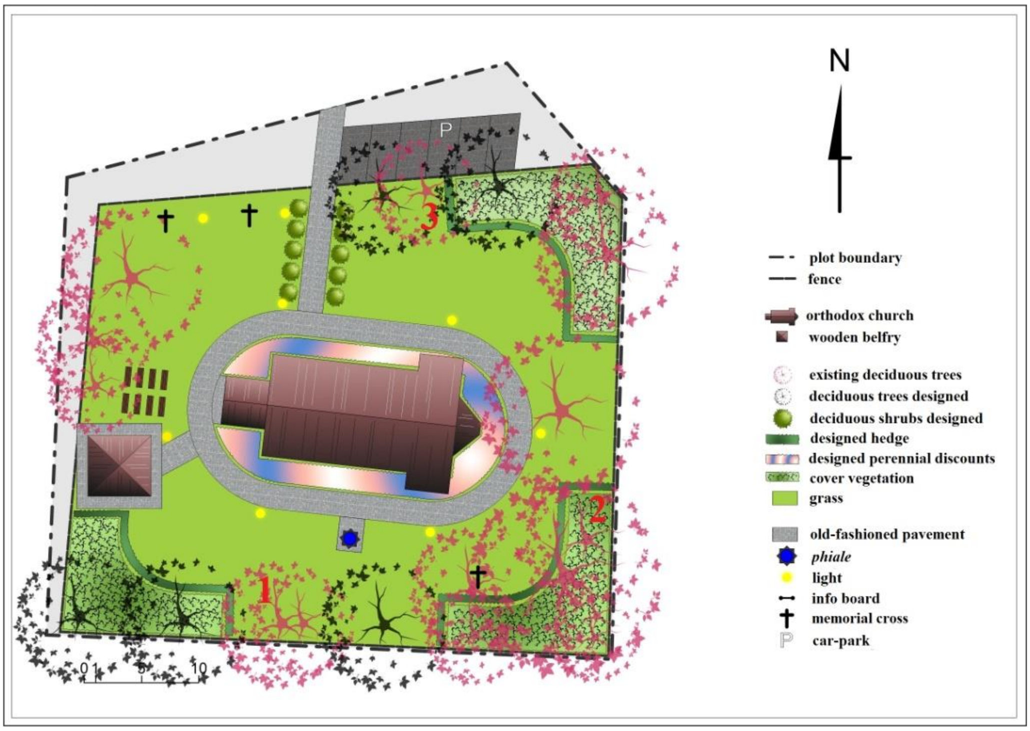


Figure 27. Project for the development of the surroundings around the church in Horostyta (by M. Dudkiewicz).

7. Conclusions

This manuscript presents a case study for the inventory and design of a garden at a historic Orthodox church in Horostyta, a village in southeastern Poland. In the church garden, we inventoried 15 trees, among which two species were predominant (*Acer pseudoplatanus* and *Tilia cordata*) and the most valuable ones were a small-leaved linden with a trunk circumference of 672 cm and a sycamore maple with a trunk circumference of 370 cm, which were about 200–300 years old. Plans to fell three trees with disturbing visual assessments were abandoned thanks to detailed acoustic tomography tests. The CT scans revealed some problems and signs of decay, but they did not indicate cutting.

The obtained results made it possible to design a garden adapted to the health conditions of the ancient trees—they were separated from users by flowerbeds, small architectural objects were not located around them, and their trunks were marked with tape informing users about the possible danger of falling branches.

The presented revalorization concept followed the principles of good conservation practice with the needs of contemporary users in mind. The solutions we applied emphasized the historical and aesthetic value of the whole.

At the moment, according to the recommendations, care work on the trees has already been carried out. Fundraising for the project is underway.

Old-growth trees, an integral part of historic establishments, increase the cultural and historical value of sites and maintain the proper compositional arrangement. Using precise computer techniques that make it possible to detect decay and other types of structural defects inside tree trunks ensures proper safety for people and property in the area where historic trees grow. The need for the above research stemmed from the demands of a Polish conservationist and the landscape architect community for new methods and tools to help shape the space. In this case, acoustic tomography revealed the health status of the interior of the trunks of three selected trees. By gaining a better understanding of the internal structure of the trunks, it was possible to more accurately determine the level of risk generated by and around the trees and then choose the best course of action. The information provided by acoustic tomography made it possible to avoid the felling of trees in favor of regular monitoring. The present study confirmed the validity of the chosen method and the apt choice of tools suitable for the study of sacred gardens.

The authors hope that this publication will fill a severe gap in knowledge about the latest available technology in conserving historic gardens. It was an essential and complicated task in which the needs of three parties—the property owner, the conservationist, and the users and tourists—had to be reconciled. It was interdisciplinary research in which we faced the vast area of diagnostics and arboriculture and the entire thematic and formal complexity of sacred gardens. In the presented research, we drew on various fields of knowledge from the natural, regional, historical, civic, or religious spheres. Our activities can serve as a model for garden conservators in Poland and Europe as part of the sustainable management of historical greenery. The case encourages us to consider situations of hasty cutting, which sometimes occur when we embark on conserving a historic garden. This means that when undertaking any new project, we should first aim to identify the health of the trees with the best possible modern methods and equipment and then reduce felling to a minimum while monitoring trees in weaker conditions and marking them with tape, fences, etc. The proposed measures demonstrate new possibilities in garden maintenance, landscape ecology, or landscape architecture.

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