USE OF ACOUSTIC TOMOGRAPH FOR DETECTING INTERNAL FAULTS IN WOODEN PARTS

USO DE TOMÓGRAFO ACÚSTICO PARA DETECÇÃO DE FALHAS INTERNAS EM PEÇAS DE MADEIRA

USO DE TOMÓGRAFO PARA DETECTAR DEFECTOS INTERNOS EN PIEZAS DE MADERA.

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ABSTRACT
The ArborSonic3D acoustic tomograph is a device that performs analysis of cross sections of wooden elements in a non-destructive way. The present work shows the application of this device as a method of identifying internal flaws in five specimens of four different species of wood, namely Garapa, Pinus, Roxinho, and two elements of Maçaranduba. The use of the tomograph generates results in tomograms and graphs that allow identifying that the visual appearance of the specimens is consistent with their internal state. The compatibility of these results show the potential of using this non-destructive technique to be used on living elements, without the need to fell trees for analysis, thus being able to diagnose trees with structural failures and help in the safety management of public or forest areas.

KEYWORDS
Acoustic tomograph; non-destructive techniques; woods; internal flaws.

RESUMO
O presente trabalho mostra a aplicação de uma técnica não destrutiva como método de identificação de falhas internas em cinco corpos de prova de quatro espécies diferentes de madeira, sendo elas Garapa, Pinus, Roxinho, e dois elementos de Maçaranduba. Esta técnica contemplou o uso de um tomógrafo acústico (ArborSonic 3D) que permitiu a obtenção de tomogramas que possibilitaram analisar a seção transversal dos corpos de prova avaliadas. Os resultados obtidos permitiram identificar que a aparência visual dos corpos de prova é condizente com o seu estado interno. Esses resultados mostram o potencial do uso dessa técnica não destrutiva em corpos de prova, e plantios florestais, contribuindo para a necessidade de caracterização da madeira em pé, para todos os tipos de plantio.

PALAVRAS-CHAVE
Tomógrafo acústico; ensaio não destrutivo; madeiras; falhas internas

RESUMEN
Este trabajo muestra la aplicación de una técnica no destructiva como método de identificación de defectos internos en cinco ejemplares de cuatro especies diferentes de madera: Garapa, Pinus, Roxinho y dos piezas de Maçaranduba. Esta técnica utilizó un tomógrafo acústico (ArborSonic 3D) para obtener tomogramas que permitieron analizar la sección transversal de los ejemplares evaluados. Los resultados obtenidos mostraron que el aspecto visual de los

http://dx.doi.org/10.29183/2447-3073.MIX2023.v9.n5.155-163
ISSN: 2447-0899 (IMPRESSA) | 2447-3073 (ONLINE)

especímenes es coherente con su estado interno. Estos resultados muestran el potencial de la utilización de esta técnica no destructiva en ejemplares y plantaciones forestales, contribuyendo a la necesidad de caracterizar la madera en pie para todo tipo de plantaciones.

PALABRAS CLAVE
Tomografía acústica; ensayos no destructivos; madera; defectos internos.

http://dx.doi.org/10.29183/2447-3073.MIX2023.v9.n5.155-163
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Mix Sustentável | Florianópolis | v.9 | n.5 | p.155-163 | OUT. | 2023

1. INTRODUCTION

The presence of trees in an urban environment offers a range of environmental, economic, health, and well-being advantages. Trees play a role in filtering air pollution, absorbing oxygen, regulating air temperature, controlling humidity, as well as mitigating rainwater runoff and absorbing sound noise. Studies confirm that the presence of trees can reduce energy consumption for fans and air conditioners, extend the lifespan of asphalt, and increase property values. Trees are also associated with leisure, stress reduction, and social well-being (TZOULAS; JAMES, 2004). These benefits are enhanced by the tree's structure: the more mature and developed the tree, the more beneficial it is, and consequently, the greater the damage in case of structural failures and branch or tree falls (DURYEA; MALAVASI, 2021).

McPherson et al. (2005), in their study, address the benefits and costs of urban forests, including trees in cities, emphasizing the importance of assessing the phytosanitary and structural condition of urban trees to ensure public safety and the maintenance of environmental and social benefits. Specifically, it is noted that urban trees can provide environmental, economic, and well-being benefits but can also pose risks, such as falling branches or entire trees, which can be dangerous to people and nearby properties.

The management of risks involving urban trees increasingly demands the adoption of technologies to analyze and prevent the risk of falling. Urban trees reach significant sizes, and over the years, the risk of rot and insect infestation increases, exacerbated by interference from urban equipment. Therefore, it is necessary to take measures to assess trees in public spaces to investigate their phytosanitary and structural condition, developing a risk assessment and mitigation plan (CHIESURA, 2010).

To carry out such assessment measures, it is possible to use devices that monitor wood from planting and allow the detection of defects during growth, such as knots, cracks, internal, and external faults. Currently, acoustic instruments are being used to estimate the internal properties of tree trunks. Among the most commonly used equipment for non-destructive assessment is the acoustic tomograph (Arbosonic 3D), which can detect invisible holes, rot, or deterioration inside the trunk of a standing tree from images called tomograms. The main advantages of using non-destructive methods in assessing wood properties compared to conventional methods are the speed of application, reliability of results, reduction of losses in the evaluated material, and cost reduction (ANGULO-RUIZ et al., 2021).

In this sense, this study focuses on the use of an acoustic tomograph on specimens of various wood species to verify internal faults. The non-destructive assessment technique can be used in various areas, including the furniture industry, construction, paper, and pulp production, as well as cultural heritage preservation. Additionally, the research can contribute to improving the management of risks involving urban trees, ensuring greater safety and well-being for the population.

2. MATERIALS AND METHODS

All tests were conducted in the Laboratory of Architecture and Urbanism Technology located at the School of Architecture and Urbanism of the Federal University of Minas Gerais in Belo Horizonte, Minas Gerais, Brazil.

2.1. Acoustic Tomograph

The study utilized an ArborSonic 3D acoustic tomograph. This equipment is composed of several components: sensors for positioning around the circumference of trees or test specimens, amplifier boxes that enable the interconnection between the sensors, connecting cables, and a battery that allows the amplifier boxes to be connected to a computer (ANGULO-RUIZ et al., 2021).

The ArborSonic 3D acoustic tomograph is used in practice to diagnose latent, internal damage in living trees and wood samples. The method is non-destructive, meaning it involves minimal interventions in the wood. The process involves measuring the time interval required for sound waves to travel through the wood of a tree component or wooden element, providing information about its structural and mechanical properties. A longer propagation time of sound waves indicates the presence of internal biotic damage, such as cavities in a tree trunk, which can be detected by analyzing variations in the temporal profile of the propagated acoustic waves.

The sensors are steel nails hammered into a wooden element around its perimeter at regular intervals. Hammering a sensor creates sound waves whose speed is recorded by another sensor (Figure 1). The sensors are hammered to a depth of about 15 mm, meaning the sonic scan of a specific section of the measured element is miniaturized when compared to its actual dimension (MAKÝŠ et al., 2018).

In general, the denser the wood, the higher the sound

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velocity. If the wood's moisture content is higher, sound waves pass through it more slowly because the capillaries contain water instead of air. This results in greater resistance to sound waves. The velocity of sound waves within healthy wood depends on its species, moisture content, and measurement direction.

Figure 1: Path followed by the sound wave inside the wood.
Source: Fakopp (2020).

For the device to operate correctly, it is necessary to position the sensors correctly and establish the shape of the element to be measured. There are possibilities for circular, elliptical, rectangular, and irregular shapes. After this information, the software provides the positioning of the sensors and the distance of each one from sensor 1 in a counterclockwise direction. The sensors are connected to their respective amplifier boxes, which are numbered and connected to each other through connecting cables. The last box is connected to the battery, which is connected to the computer via a USB cable or Bluetooth (Figure 2). The next step is to enter data about the material to be examined into the software interface (FAKOPP, 2020).

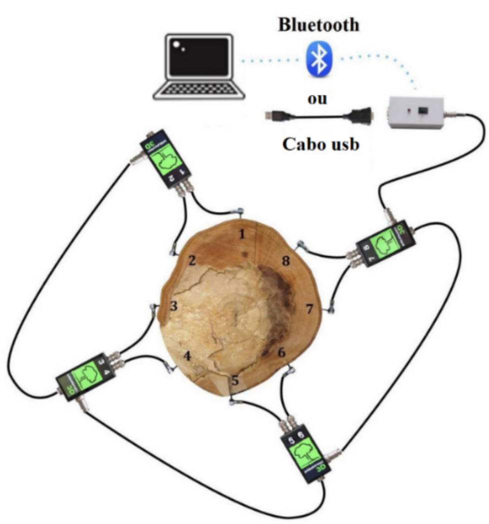

Figure 2: Acoustic Tomograph Setup Diagram.
Source: Fakopp (2020).

2.1. Acoustic Tomograph

The elements used in the development of this study consisted of 5 test specimens of different wood species, divided as follows: Garapa, Roxinho, Pinus, and two units of Maçaranduba. All test specimens have dimensions of approximately 15 cm (15 cm length x 15 cm width x 15 cm height), as shown in figure 3.

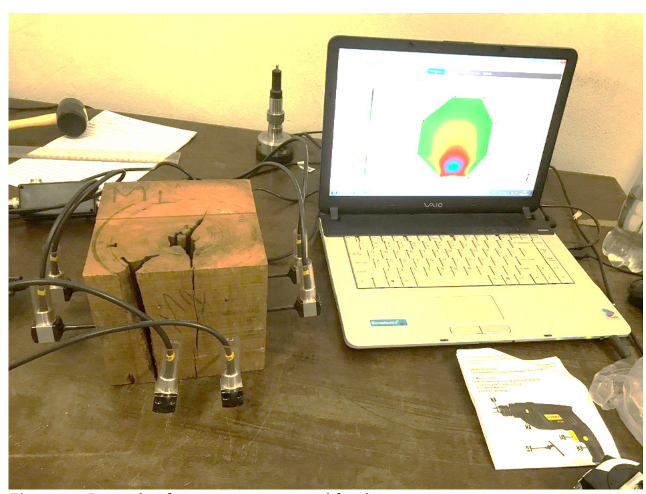

Figure 3: Example of a test specimen used for the test.
Source: Image of authors (2022).

3. RESULTS AND DISCUSSIONS

The test specimens used in the experiments exhibit some flaws and were chosen with the intention of confirming whether the acoustic tomograph is capable of accurately providing information about the internal state of pieces

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that can be visually observed.

All five test specimens were drilled at a height of 12 cm from the base to accommodate the sensor placement. When launching the software and specifying the dimensions and shape of the pieces to be examined, the software provides the measurements at which each sensor should be positioned. Figure 4 illustrates the sensor distribution on the Maçaranduba piece.

The first field, titled "Layer Name," allows for an analysis of various heights of pieces. In the case of living trees, for this study, an analysis of only one layer was conducted. The field called "Plane" refers to the specific height from the base of the analyzed piece. In this study, a height of 12 cm was defined.

The "Sensor Distances" field specifies, starting from sensor 1 marked as the initial point, the distance at which each sensor should be placed counterclockwise. For example, sensor 2 is located 4.8 cm from sensor 1, sensor 3 is located 14.2 cm from sensor 1, and so on.

In the other fields located vertically on the left side of the screen, you can specify the shape of the element to be analyzed. In this case, a rectangular shape was chosen, and 8 sensors were used. For analyses of trees and samples with larger diameters, it's possible to increase the number of sensors to achieve better spatial and temporal resolution of the physical and mechanical properties of the object under examination.

In the "Valid Spatial Data" field, the length and width dimensions (A and B) are provided, along with the number of sensors on each side, which is 2 (ASC and BSC). The "PD" field requires you to input the penetration depth of each sensor used; in this case, a depth of 1.5 cm was used. Finally, the "BT" field requests the approximate bark thickness of the tree. Since these tests were conducted on sawn wood test specimens, the bark thickness was 0.0.

After distributing the sensors and inputting the data into the software, the next step is to strike each sensor with a hammer. These strikes transmit sound waves that are captured by the opposite sensors. Three uniform strikes are required on each sensor. The result of the analyzed tomogram can be represented in a graph or 2D and 3D maps. Since this is a single-layer evaluation, the visualization in a 2D map makes it easier to observe internal flaws in each analyzed element.

The result maps present a graphical representation with colors ranging from light blue to dark green. The vertical chart on the left side of figure 5 provides information about the wave travel velocity inside the piece. The green portions represent healthy and compact wood, where waves travel at higher speeds. In contrast, the red and blue areas represent lower speeds, indicating where the sound wave encountered difficulties in traveling, which may represent hollow spaces or internal wear.

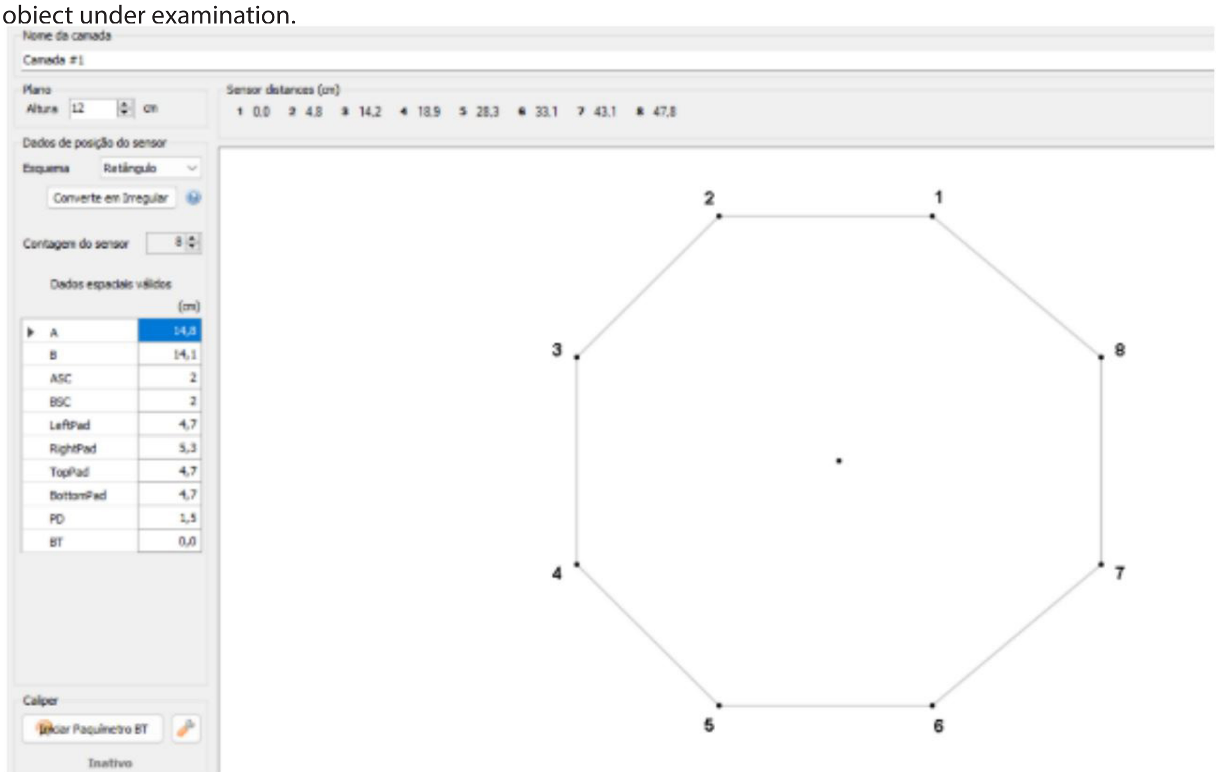

Figure 4: Software Interface Demonstration.
Source: Test realized by software Arborsonic3D (2022).

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Figure 5 represents the result obtained for the test of the Garapa wood piece. By examining the shape found in the software, it is possible to observe that the entire internal part of the piece has a high frequency of wave transmission, indicating that there are no internal structural flaws.

Figure 6 represents the tomogram of the Pinus wood, where it is possible to observe a decrease in wave velocity near sensors 5 and 6, represented by the colors red and blue. This representation indicates that the wood is slightly deteriorated at these points. The software indicates that the area represented in red accounts for a total of 5% of the piece.

Figure 7 presents a comparison between the original piece of maçaranduba (element 1) and its respective tomogram. This specimen was intentionally abraded in the central part with a hole made by a drill, to simulate an internal failure. In the software representation, it is possible to observe that the external part presents a green, uniform surface, and in the center where the hole exists, the representation is in red, which is not the most critical state that can be reported by the software. This is because the hole made did not exceed the entire length of the piece, going only from the top to the middle. Therefore, the sound waves can bypass the hole, either on the sides or underneath it. The area in red shows a deterioration percentage of 24% according to the software.

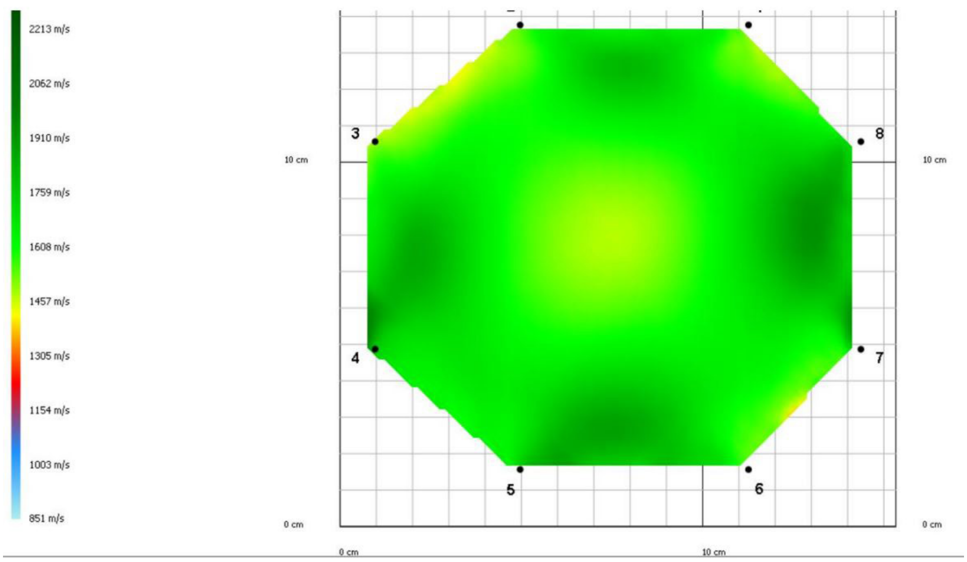

Figure 5: The tomogram result for Garapa wood.
Source: Test realized by software Arborsonic3D (2022).

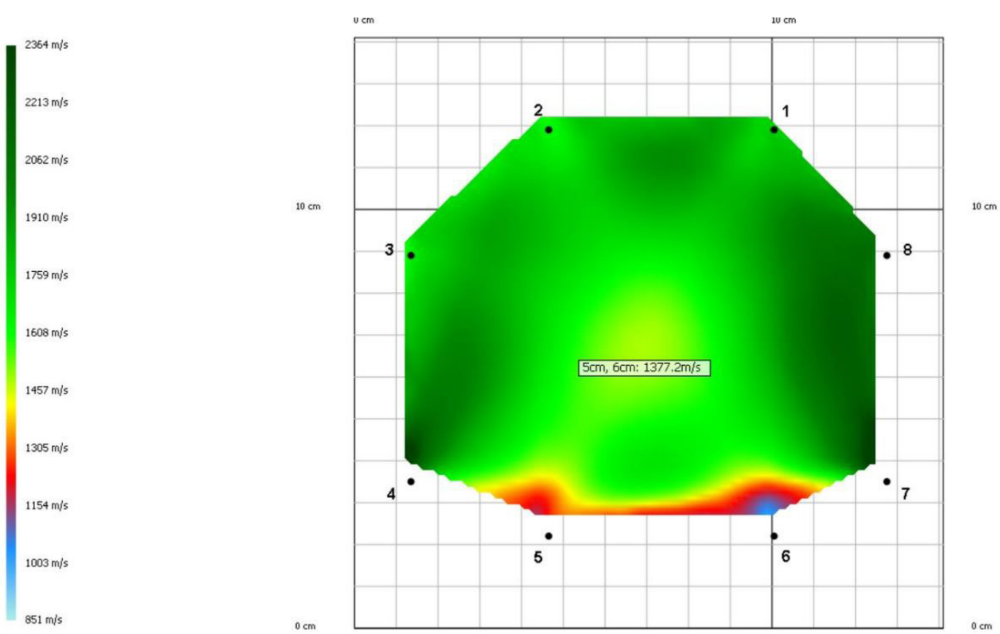

Figure 6: The tomogram result for Pinus wood.
Source: Test realized by software Arborsonic3D (2022).

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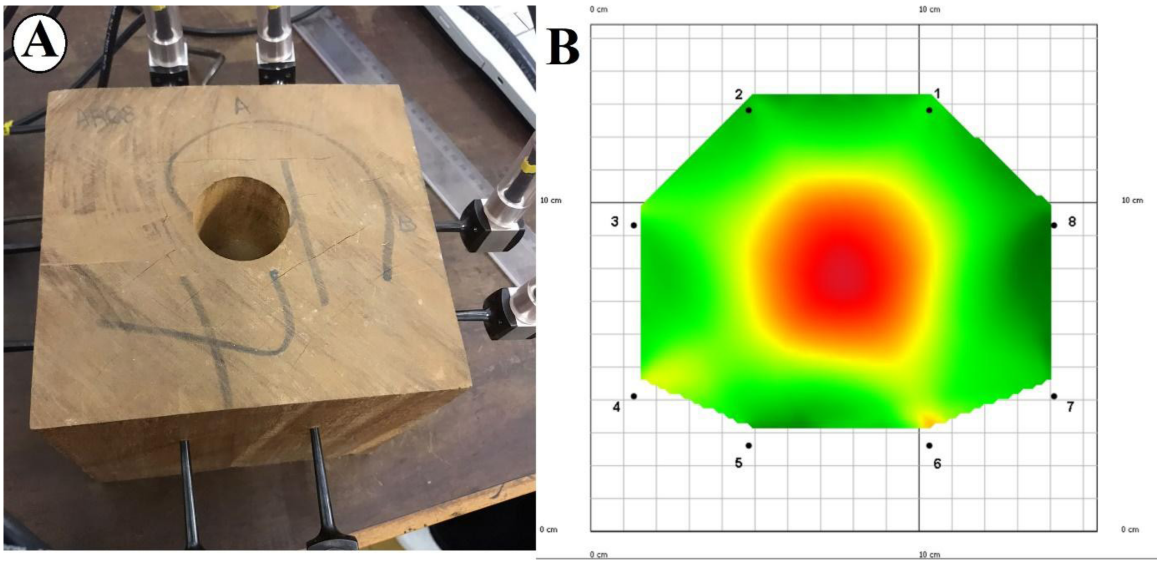

Figure 7: The tomogram result for Maçaranduba wood – Element 1.
Source: a) Image of the authors (2022); b) Test realized by software Arborsonic3D (2022).

Figure 8 represents the second Maçaranduba element and its tomogram performed. Using the color scale fund in the tomogram wich goes from green to blue, it can be conclued that at the points between sensors 5 and 6 the waves have a very low propagation speed, this representation indicates that the part has very serious flaws.

This can be confirmed by looking at the photograph of the piece that shows flaws on the sides with an empty part, close to the center.

The software indicates that this piece has an area of 29% degradation.

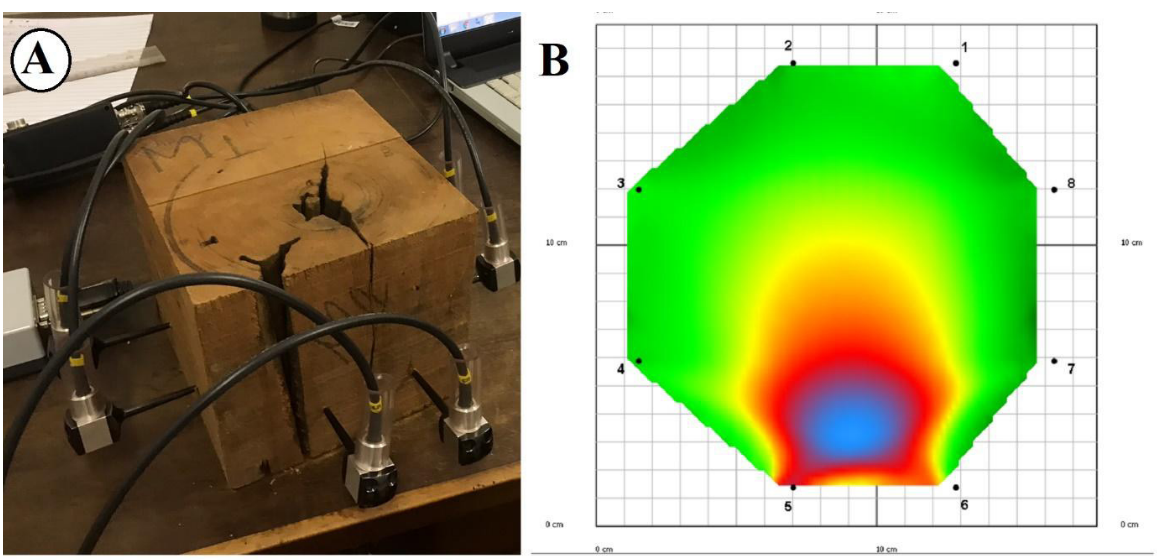

Figure 8: The tomogram result for Maçaranduba wood - Element 2.
Source: a) Image of the authors (2022); b) Test realized by software Arborsonic3D (2022).

Figure 9 shows the Roxinho wood piece and its corresponding tomogram. This piece was also intentionally drilled internally, similar to figure 7, but the hole extends through the entire piece from top to bottom.

In the tomogram, it is possible to observe that the edges remain in green, the middle part in red, and the center of the piece in blue, where the flaw is more pronounced. In practice, this representation is intended to symbolize an area that is hollow inside a tree. The software indicates that this test specimen has a deterioration of 32%.

For all tomography results where situations of more deteriorated wood, as seen in images 7, 8, and 9, it is possible to compare them with the real image of the pieces and conclude that the assessment made by the tomograph is consistent with the actual condition of the piece.

Studies conducted by Kloiber et al. (2016) have demonstrated that broadband acoustic devices, such as the tomograph used in this study, are more suitable for estimating damage to the internal parts of wood than narrowband devices. However, other studies by Cristini et al. (2021) report that there are no statistically significant differences between the speeds measured by different tomograph devices.

Cristini et al. (2021) also point out that for an analysis of living trees, it is necessary to take the tomogram results, such as natural imperfections in the wood, fiber deflection, knots, as well as the quality of the wood surface, including roughness and the presence of microcracks. The correct shape, type, frequency, and orientation of the acoustic sensors also play a significant role in obtaining accurate results.

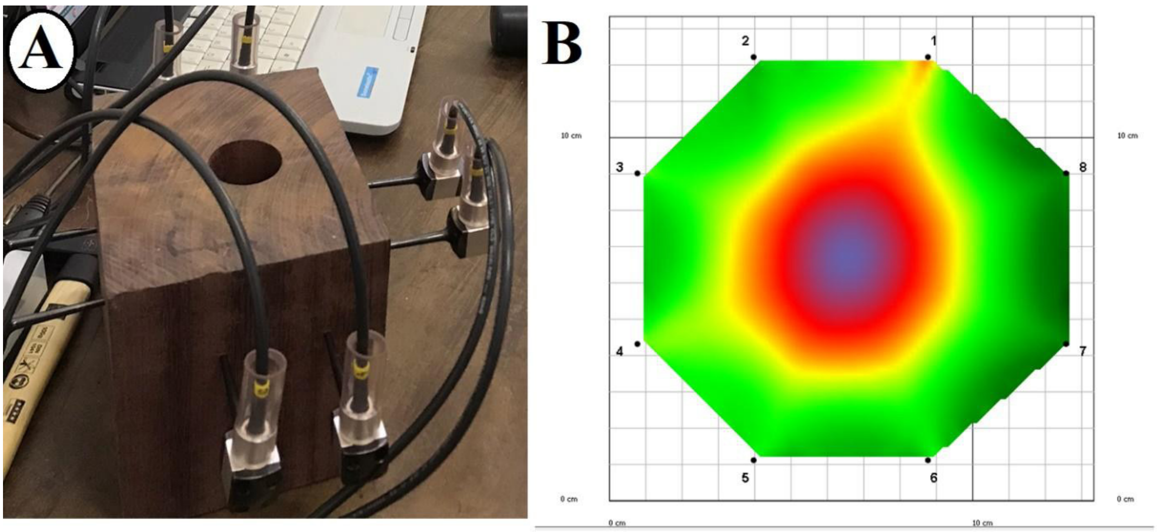

Figure 9: The tomogram result for Roxinho wood
Source: a) Image of the authors (2022); b) Test realized by software Arborsonic3D (2022).

4. CONCLUSION

The knowledge of the technical conditions of wooden elements is crucial to ensure the safety of wooden structures and trees located in public areas. This article discusses the use of acoustic tomography for detecting internal flaws in wooden pieces.

Acoustic evaluation methods provide relatively fast, simple, and accessible results for identifying defects in the examined wood. Their successful application in detecting biologically damaged wood can yield significant results for safety in public areas.

The analysis of test specimens with varying degrees of deterioration demonstrated that the device is efficient in confirming internal flaws in each piece. However, evaluating more complex wood species requires a more comprehensive analysis, taking into account a wider range of factors.

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HOW TO CITE THIS ARTICLE

GÓES, Matheus Barreto de; CARRASCO, Edigar Vladimiro Mantilla; GUIMARÃES, Adriana Braga. Use of acoustic tomograph for detecting internal faults in wooden parts. **MIX Sustentável**, v. 9, n. 5, p. 155-163, 2023. ISSN 244-73073. Available in: <http://www.nexos.ufsc.br/index.php/mixsustentavel>. Access in: DD/MM/YYYY doi: <https://doi.org/10.29183/2447-3073.MIX2023.v9.n5.155-163>.

SUBJECTED IN: 13/01/2023
ACCEPTED IN: 15/09/2023
PUBLISHED IN: 30/10/2023
RESPONSIBLE EDITOR: Lisiane Ilha Librelotto e Paulo Cesar Machado Ferroli

Record of authorship contribution:

MBG: Formal analysis, validation, visualization, writing – original draft and writing – review & editing.

EVMC: Conceptualization, methodology, project administration and supervision.

ABG: Data curation, formal analysis and investigation.

Conflict declaration: nothing has been declared.