Applications of Non-Destructive Techniques in the study of a Caribbean historic timber house

Applications of Non-Destructive Techniques in the study of a Caribbean historic timber house

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Abstract. The aims of this research is to analysis a Caribbean historic timber house using non-destructive techniques (NDT). The high cultural and historic value that have the timber buildings in the Caribbean and the necessity to preserve them as intact as possible, make NDTs to gain importance at the moment to selected the method to preserver and assess a historical structures in order to survive damages arising from several reasons including damaged by time. The selected techniques concern the measurement of some physical/mechanical properties and condition. The NDT analyses have been grouped under four major: visual inspection, optical, ultrasound, and electromagnetic. For analysis was used: Rinntech Resistograph model R650-ED, FLIR System model T420 for Infrared thermography (IRT), ARBOTOM for tomography, Electrical Resistance Measuring (ERM) with DELMHORST BD-2100 pin moisture meter (Protimeter) and MASTERGRIP Digital Thermometer with Laser for superficial temperature. These techniques can be applied “in situ”, without destroying the heritage and do not require to take big samples. Also, are the most appropriate tool for the evaluation the structure, materials and decorative elements of Cultural heritage.

1. Introduction

A historic building not only has value for its physical appearance or its architectural forms, volumes or styles, it is also important to known and preserved its construction systems, materials and finishes. The historic building is a system where each part is a testimony of its time and events. To preserve it requires a processes where it is essential to have a complete understanding of the building, including its history, construction system, material properties and the pathology, to achieve quality interventions, with awareness and to obtain enough information before rehabilitation tasks.

In a historic building one of the most susceptible materials to be replaced by a new one is wood, regardless of whether it is in good or bad condition due to a lack of knowledge of its characteristics and by being carried away only by physical appearance. With the systematic elimination of wood in a few years, it will be impossible to make a moderately correct and serious reading of our historic architectures. However, wooden structures after several centuries have proven to be resistant and durable, except for specific moisture or xylophagus problems. Unlike other materials that already show deterioration with only a hundred years or less.

Today, the possibilities offered sciences in improving research and conservation of cultural property are immense. It is appropriate to use Non-destructive Testing (NDT) because can evaluate the properties of a material and determine the state of preservation or the degree of the integrity of the materials without causing damage to cultural heritage. The NDT can be defined as those which identify physical and mechanical properties of materials without changing its capacity for future use

[1]. Choosing the least invasive and the most appropriate way of intervening in a historic building require a careful decision that always takes into account its historical significance and their values, as well as bearing in mind other concerns. For this reason the aim of this research is to analysis the wood using non-destructive techniques (NDT) and determinate the construction system of a wooden Caribbean historic house.

Used NDT is not new for timber house. In the second half of the 20th century, a series of scientific articles on NDT in wood were published and since 1963, Washington State University and the USDA Forest Products Laboratory (FPL) begins to hold a series of international Nondestructive Testing and Evaluation of Wood Symposiums, for the exchange of technical information [2]. Now the symposium represents the full spectrum of technical interests, from basic and applied science to the use of various methods in industrial and field applications. During the past 30 years, forest products researchers and the forest products industry have developed and used NDT tools for a wide range of applications-from the grading of structural lumber to the in-place evaluation of the mechanical properties of individual members in wood structures [3] [4].

In 2003, a methodology for evaluate wood structure was published which proposes that three components should be taken into account: diagnosis, evaluation and restoration treatments [5]. In 2009, Basterra proposes, visual recognition techniques and other NDT and pseudo non-destructive methods were used such as microphotography, xilohigrometry, ultrasound velocity measurements, screw extraction and resistography [6]. The structural assessment starts with the identification of the original wood species, characterization of the wood and identification of damage and lesions.

Analysis of resistography profiles obtained from wood samples and extraction of pieces of wooden structures with an age of 80-120 years were performed, and the close relationship between the resistography variables and the density of the wood was observed (R2> 90%) [7]. Also, some researchers have used infrared thermography (IRT) in the inspection of historic timber structures to analysis the thermodynamic behaviour of timber as a function of its density [8]. In situs assessment with NDT techniques are relatively easy to use, and have low equipment costs.

2. Case of Study

The Bodden Leroux family house, located in the heart of the town of Sanchez in the province of Samana, Dominican Republic. In the beginning it was a small fishing village known as *Las Cañitas*. In 1879 it became a very prosperous city as a result of the construction of a port where many transatlantic ships arrived with imported goods, people and many technological advances that were marketed and distributed throughout the island. By law *Las Cañitas* was renamed *Sanchez*, on May 31, 1886, in honor of Francisco del Rosario Sanchez, one of the Fathers of the Nation [9]. The distribution of the goods was carried out by land, through the railroad or carriage, and by sea, by small vessels such as schooners, sloops and *cayucos* among others. The economic impact generated by the port and the railway stimulated the migration of nationals and foreigners.

In 1886, the city had 1,000 inhabitants and 180 homes, and by 1887 there were about 2,000 people, not taking into account the Scots and English employees of the company that administered the railroad [10]. In 1907 a Dominican diplomat wrote about Sanchez that "...overnight he became the storehouse of the largest, most fertile and laborious valley in the country, and prospered and advanced by great leaps and bounds..."[11]. In 1907 the town had 3,000 inhabitants.

For decades Sanchez was one of the most cosmopolitan centers in the country and the region, it was the presence of so many foreigners. For various reasons, the port and the railways lost importance and activities were gradually reduced. In the early 1970s the railway stopped working and the port began to deteriorate. The city fell into an economic slumber from which it has not yet recovered and began to lose a large number of inhabitants. Their homes and businesses were abandoned.

2.1. Bodden Leroux house

The Bodden Leroux family built their house in Sanchez (fig.1) at the end of the 19th century. They ordered a wooden house from the United States because at that time it was popular and prestigious to have a catalog house. The house is a simple layout with ornate wooden details, often called Farmhouse, National styles or American Foursquares. Was built on a sloping terrain, so it rose on wooden piles which makes it look bigger. It’s a simple farmhouse with rectangular plan, divided into rooms that communicate by a central corridor and has a perimeter gallery where all the doors and windows open. The whole structure is made of wood, with horizontal siding plank pinewood boards of 13.97cm wide (51⁄2 inches). The floor of the house is also made of pinewood boards. The metal roof is hipped with four gabled dormer windows. The house has been modified and expanded. However its appearance has not changed much. Is currently abandoned (fig.2).

Figure.1. Bodden Leroux family house (Prieto, 2018)

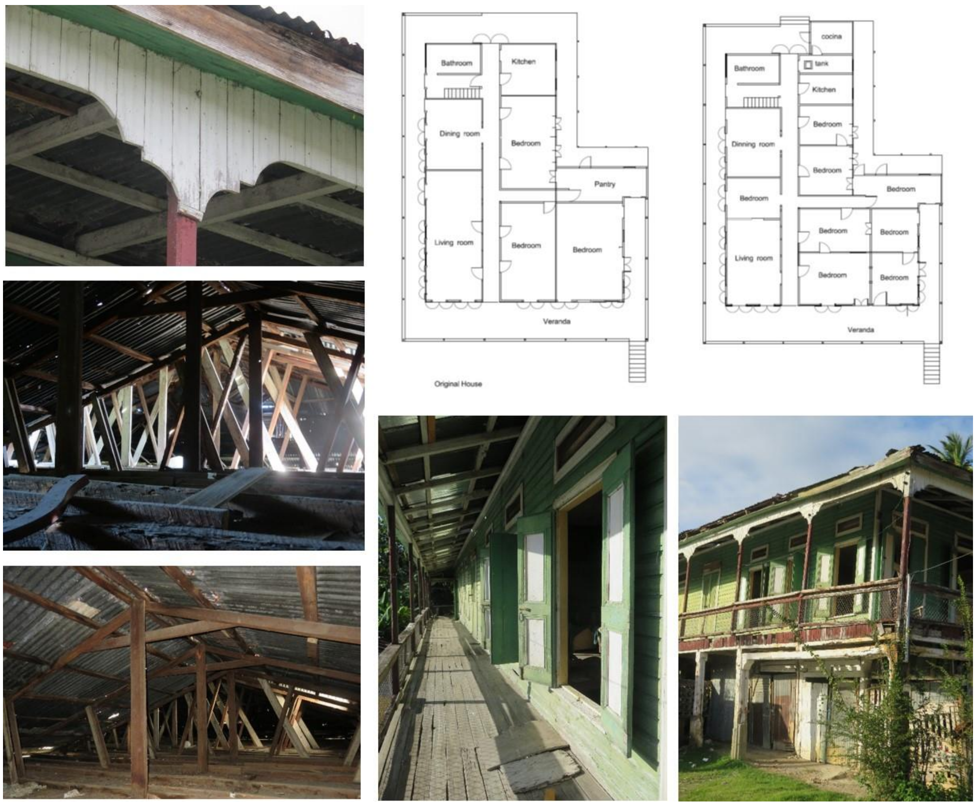

Figure.2. Details of Bodden Leroux’s house (Prieto, 2018)

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2.2. Environment condition. Sanchez, Province of Samana

The Dominican Republic is in the Caribbean, located in the tropical zone of the northern hemisphere. at latitude 18.735693 and longitude -70.1626511. The geographic coordinates, using format Degrees and Decimal Minutes (DDM) is latitude 18°44.142' N and longitude 70°9.759' W. In general the geography of the country has created two types of climate: tropical rainforest climate (Af) and tropical savanna climate (Aw). Sanchez is in front of the bay and surrounded by mountains, having a humid tropical rainforest climate.

The average annual minimum temperature is 22.13°C and maximum 31.18°C, average precipitation at 172.09 mm, average relative humidity 80% and average wind speed 2.22 m/s. Average monthly hours of sunshine over the year is 9 hours.

The environmental conditions consist in measuring air temperature and surrounding relative humidity (T/RH) with air speed of the external and internal conditions of the historic building. For thermo-hygrometric parameters were used a Tpi 1010a a portable equipment that provide the measurements to monitor and adjust to the air handling devices. In addition, it was used a Pyle PMA90 Digital Anemometer/Thermometer to measure air speed, air flow and temperature. The Weather Channel was also consulted.

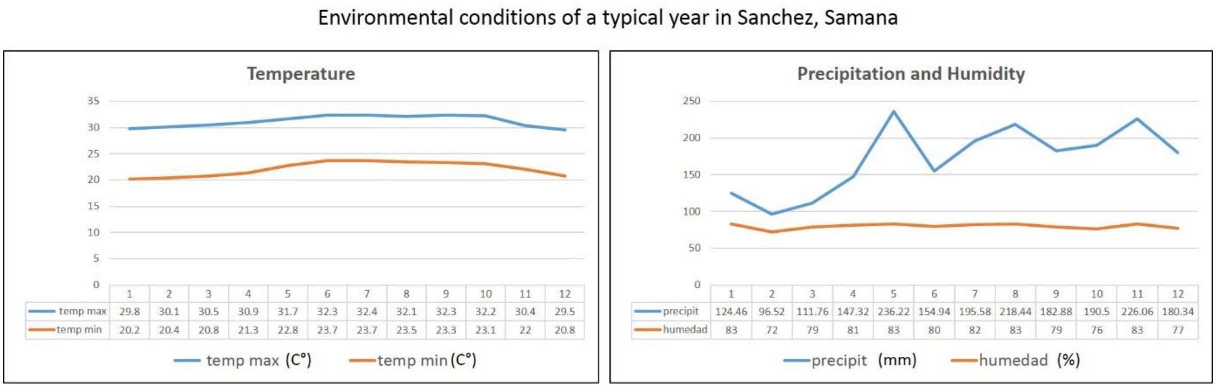

Fig.1 Environmental condition in a year in Sanchez (Flores, 2019)

3. Materials and Methods

To proceed with the assessment of the state of conservation, is necessary gain knowledge of the building, determine the environment condition and analyses the current conditions of the building. Archives and desk work were doing to obtain historical information about the house. In addition, a photographic survey of the current state was do it. For the analyses we used non-destructive techniques (NDT): visual inspection, ultrasound, optical and electromagnetic.

3.1. Visual Inspection (VI)

The visual inspection provides a preliminary indication of the condition of the wood and the degree of damage. Starts from the observation of an occurred failure or pre-acknowledgement of damage. For that, the visual inspection is the simplest way to evaluate and assessment a building and a very important component of any analysis. Includes naked-eye observations and can provide information about the stages of deterioration.

3.2. Ultrasound

To detect and quantify wood internal decay was used the Rinntech ARBOTOM, an impulse tomography unit that enables an inside view of condition of timbers and trees. These methods generates ultra-high frequency sound waves through the material and when a discontinuity such as a crack or any other imperfection is encountered, part of the sonic energy is reflected. It is then measured and displayed on a screen. A series of sensors are placed around the structural elements, each one connected to the next and then to a computer. Each sensor is tapped, which sends a stress wave across the wood to the other sensors, and produce an image. The Image analysis software was used to quantify the proportions of undamaged and damage wood, with Species-specific algorithms, and optional colour schemes allow for detailed analysis of decay data. The structural pieces were measured different heights and width. Tests were performed on different structural elements as: bean, column, board, post and piles.

3.3. *Optical.*

To identify wood 0.5 cm to 1cm cubic blocks were extracted, to be processed and identified by the Comparative Wood Anatomy method. Cross-sectional observations were made at the Digital Microscope at 20-250X magnification and photographed. Thin sheets of radial sections were manually extracted to be mounted on fixed optical microscopy preparations with Herter DPX resin. The observations were made in Omano optical microscope (OM 118-B4) at 40X and 400X and photographed with an Amscope MC 1000 camera. The fields that presented diagnostic characteristics for the identification of the samples.

Infrared camera FLIR SYSTEMS model T420, FOL 18mm lens and 240 × 320 pixels IR resolution was used for Infrared thermography (IRT). The camera having a spectral range 7.5 to 13µm, has a field of view (FOV) of 25°x19°/0.4 meters, spatial resolution (IFOV) of 1.36 mrad, and has an adjustable thermal range from -20°C to 650°C. For this project was set at -20°C to 120°C. The IRT offers a thermal image with different temperatures that is interpreted as moisture area, and with that can detect levels of moisture content in wood. This dynamic difference (i.e., the thermal contrast) provides information about location and shape of defects. Thermography is a widely used NDT for the examination of the internal structure of the materials.

3.4. *Electromagnetic*

Rinntech Resistograph model R650-ED, is an electronically controlled, drill that provides unsurpassed accuracy in measuring the relative density of wood in trees and timber structures. A resistance drill for detecting decay in woods. The equipment use DECOM software to analyses the data and produce credible charts that properly reflect actual wood conditions. The drill direction was radial to the grain and the drillings were performed relative to the tangential direction at angle 90°. Different parts of the structure were sampled and each sample was drilled three times to obtain a mean drill resistances of these measurements were averaged to form the average mean drill resistance. The sample are: the pile (P-1, P-2, P-3); column (C-1, C-2, C-3); bean (B-1, B-2, B-3); joist (J-1, J-2, J-3). The piles are circular, the columns are square, the beams and joists are rectangular.

The wood-water relationship cannot be described by a single behavior from 0 to 100% moisture content; rather it involves two successive and to some extent simultaneous behaviors. The stages are explained starting from dry wood, with 0% moisture content up to 'green wood' after felling with a moisture content exceeding 100%. To measure, assess and monitor the relative the moisture content of timbers was used the Electrical Resistance Measuring (ERM) with DELMHORST BD-2100 pin moisture meter (Protimeter). Also, the MASTERGRIP Digital Thermometer with Laser for superficial temperature, is used to assess the material external temperature.

4. Results and Discussion

4.1. *Visual Inspection (VI)*

The visual inspection indicated that the siding plank and the veranda presence area of deterioration. Only 20% of the rafter beam, joist, brace, and pile presence deterioration or damage. The 50% of the post columns present damage. The 30% of the floor presence large area of deterioration and 50% presence some kind of damage. The 65% of the roof presence damage. The 80% of doors and windows presence damage and deterioration. In general, visually the 80% of the house presence damage (Table 1).

Table 1. VISUAL INSPECTION OF THE DEGREE OF DAMAGE IN WOOD

DEGREE OF DAMAGE IN WOOD	Sheathing	Rafter beam	Joist	Post Column	Brace	Floor	Ceiling	Pile	Door	Window	Veranda
Decay / Rotting	II	N/D	N/D	N/D	N/D	II	I	N/D	I	I	II
Crack or Split	I	N/D	N/D	N/D	N/D	II	I	N/D	I	I	II
Deformation	I	I	I	I	I	III	II	N/D	I	I	III
Knot or knothole	I	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	I
Bending	I	N/D	N/D	N/D	N/D	II	I	N/D	I	I	II
Swelling/ dryness contraction	I	N/D	N/D	N/D	N/D	I	I	I	I	I	I
Shrinkage/ moisture growth	I	I	N/D	I	N/D	N/D	N/D	N/D	N/D	N/D	I
Soft and spongy	I	N/D	N/D	N/D	N/D	II	N/D	N/D	I	I	III
Moisture	I	I	N/D	I	N/D	I	III	I	I	I	III
Dry rot	I	N/D	N/D	I	N/D	I	N/D	N/D	II	II	III
Broken member	III	N/D	I	N/D	I	III	II	N/D	II	II	III
Improper repair	II	I	I	I	I	III	III	I	III	III	III
Loose joints and connection	I	I	I	I	I	III	III	N/D	I	II	III
Missing wood	II	I	I	I	I	III	III	N/D	II	III	III
Presence of xylophage insect	I	N/D	N/D	I	N/D	N/D	N/D	N/D	N/D	I	II
Vegetation, Fungi and lichen	I	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	I
Color loose or change	II	I	N/D	I	N/D	I	I	I	I	I	III

Degree I: Poor presence or area of deterioration. No danger of falling.
Degree II: Medium presence or area of deterioration. Danger to falling.
Degree III: Large presence or area of deterioration. Danger to falling.
N/D: No sign of damage or presence.

4.2. *Ultrasound*

The ultrasonic testing enabled detection of deep and extremely small flaws within the material. In the Ultrasonic diagrams (Fig.2) can observed that all the piles are in very good conditions (P-1), the column in the veranda (C-2) has some crack and deterioration due to humidity, a bean (B-1) in a roof has deteriorated and the joist present some deterioration. Even though some columns look dry when the tomography is carried out, it could be determined that they are in good condition inside. The same thing happened with the beams. The same thing happened with the elements that conform the frame of the building structure.

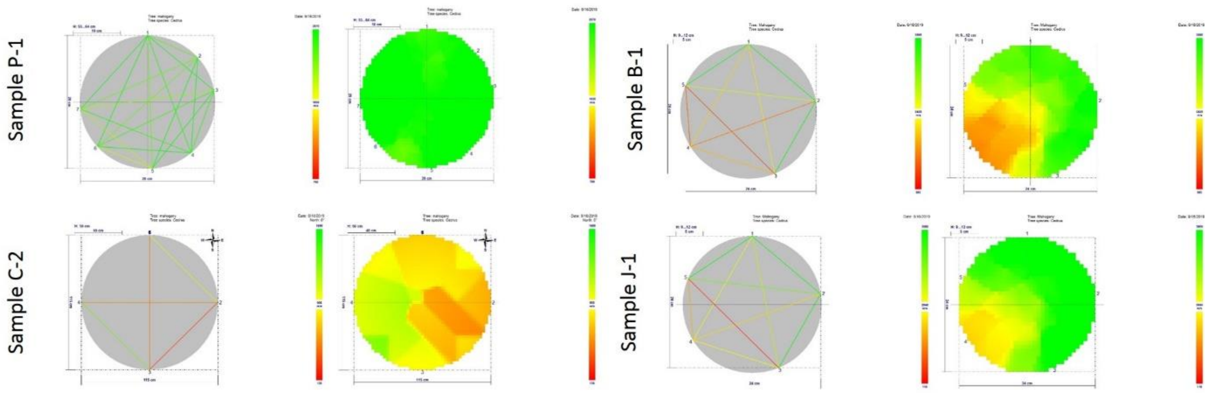

Fig.2. Ultrasonic diagrams of the samples P-1, C-2, B-1 and J-1.

4.3. Optical

It was identified that all the piles are *Copaifera officinalis L*. (Amacey o Cabima), the beans, joist, decorative elements, some boards, the wood frame are *Pinus Strobus L*. (White Pine, Northern White Pine), the boards in the house extension and the repair woods are *Pinus taeda* (southern yellow pine). This indicates that the house was brought from the north of the United States, which was very common in the late 19th century (Fig.3). The piles are made of local wood. This was also very common, as the level of the house was resolved on site. The extension of the house and the repairs are

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made in the middle of the 20th century and at that time the wood that came to the country came from Louisiana, so it is not strange that it is southern pine.

Fig.3. Wood of structure of the house (*Pinus Strobus L.*) (Carreras, 2019)

The thermography indicates that the thermal conductivity of wood is relatively low due to its porosity. As the humidity of the wood increases, so does its thermal conductivity. As the temperature of the wood drops, its strength increases (Fig.4).

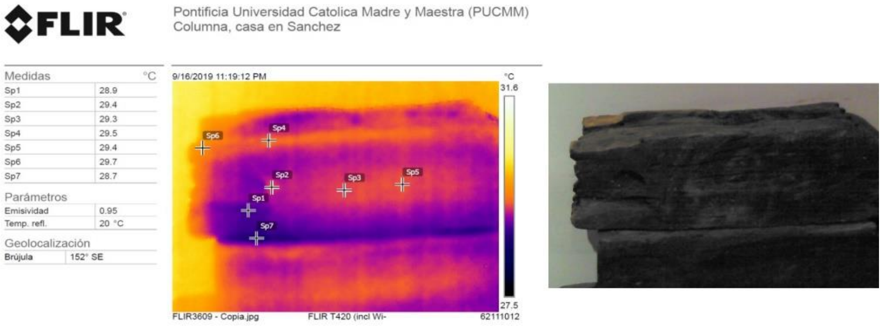

Fig.4. Thermography of a piece of columns.

4.4. Electromagnetic

The Measurements were taken on January 9th, 2019, between 10:39h to 14:39h. The average temperature was 27.69°C, with a maximum 30.8°C and minimum 22.5°C. The relative humidity average was 53.12%, with maximum 64.9% and minimum 41.0% (Fig.5).

The equilibrium moisture content of the wood in these environmental conditions is between 9 -9.6 %. All the samples had a higher than normal level of humidity, because the metal cover is broken allowing water to pass through when it rains and constantly allowing the environmental humidity of the place to penetrate which is high. In some cases, such as verandas, the wood is exposed to climatic conditions and these are affected by humidity, weakening the pieces. All mechanical properties showed a decrease upon increasing the moisture content from above 12%.

With the resistograph three drillings were performed in all these 12 pieces (Fig.6). The normal density values of *Pinus Strobus L* is 350-510 kg/m3, *Pinus taeda* is 450-550 kg/m3 and the *Copaifera officinalis L.* is 601-810 kg/m3. The averaged form the average Mean drill resistance [rel] of the samples indicated that the density of the pile are higher than the normal value, the C-1 and C-2 are within the normal range but C-3 is higher. The density of the samples of the beams and joist are higher (Table 2).

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Table 2. Characteristics of the samples at 27.69°C and 53.12% humidity

Samples	Pile			Column			Bean			Joist		
	P-1	P-2	P-3	C-1	C-2	C-3	B-1	B-2	B-3	J-1	J-2	J-3
Density (Kg/m³)	1402	1490	1102	495	291	676	610	712	612	558	495	600
Size (mm) (inch)	Ø 308 12 1/4''	Ø 319 12 9/16''	Ø 327 12 7/8''	111 x 111 4 3/8 x 4 3/8	111 x 111 4 3/8 x 4 3/8	111 x 111 4 3/8 x 4 3/8	41 x 143 1 5/8 x 5 5/8	41 x 143 1 5/8 x 5 5/8	41 x 143 1 5/8 x 5 5/8	41 x 92 1 5/8 x 3 5/8	41 x 92 1 5/8 x 3 5/8	41 x 92 1 5/8 x 3 5/8
Nominal lumber (inch)	N/A	N/A	N/A	5 x 5	5 x 5	5 x 5	2 x 6	2 x 6	2 x 6	2 x 4	2 x 4	2 x 4
Moisture content (%)	19.4	16.7	15.1	15.5	20.5	14.2	13.4	14.2	14.1	13.1	14.5	13.0
Temperature of wood (°C)	25.0	24.9	25.0	28.9	26.00	28.5	26.1	26.0	26.0	26.5	26.0	26.5
Wood species	Copaifera sp.	Copaifera sp.	Copaifera sp.	Pinus strobus	Pinus strobus	Pinus strobus	Pinus strobus	Pinus strobus	Pinus strobus	Pinus strobus	Pinus strobus	Pinus strobus

In some columns, the effect of the moisture content could be observed by finding little resistance with the drill of the resistograph. The permanence of moisture in the wood could be confirmed visually by the presence of fungi. This is important to know because it influences the mechanical properties of the wood.

Figure 6. Using the resistograph in a rafter under the floor (Flores, 2018)

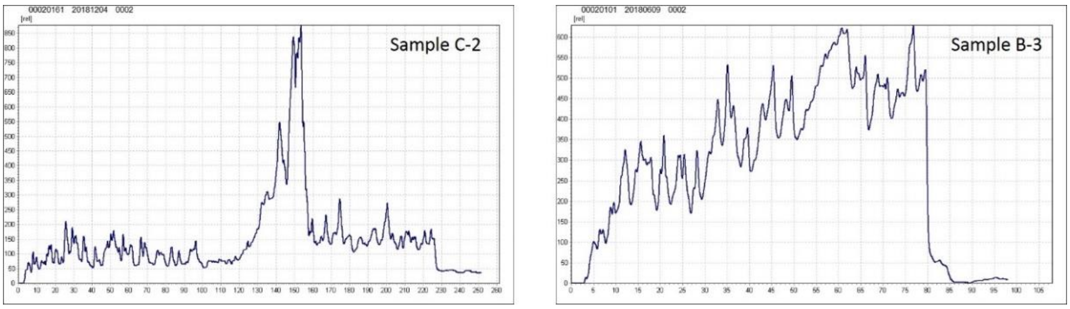

Figure 4. Resistance graphs. On y-axis measured quantity [rel] and on the x-axis the depth (mm).

5. Conclusion

Through visual inspection it was determined that in general the structure of the house is in good condition. The main injuries are in the enclosures, floors, ceilings and veranda, which show an advanced deterioration, mainly caused by moisture. Also, improper repair, lose joint and connection, missing wood and color change are some of the damage that can appreciate by visual inspection.

Ultrasonic tomography, coupled with image analysis and the resistograph provides an efficient, noninvasive approach to evaluate the condition of the internal decay of the timber and the structural.

In general, the ARBOTOM indicated that some structural elements had internal lesions although they were not visually appreciated. Gaps and soft areas were detected in some columns while in others can observed the good state in which they are.

The resistograph affirmed the data obtained with the ultrasound and also indicated the resistance of the samples. The thermographic inspection allowed to know the presence of moisture on the pieces, detect insects and anomalies. The moisture level was tested with thermos-hygrometer and as the wood dries, its strength properties improve significantly when the moisture content falls below the saturation point of the grain. The wood begins to suffer damage if its moisture content remains above 20 % for long periods of time. The heat capacity of wood depends on its density, moisture content, temperature and direction of the grain.

In conclusion, some of the non-destructive testing can be used for investigation of historical structures. The benefit to used NDT is that can applied “in situ”, do not require to take big samples to destroy and to obtain such information. In addition, they are the most appropriate tools for the evaluation of external and internal wood structures and for assessing and analyzing the quality of materials in cultural heritage. However, long-term monitoring using the same device by one experienced team is very appropriate and the results are reliable.

6. Acknowledgment

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