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An approach to the convent of Santa Clara de Asís in Havana. Study of its conservation status and intervention proposals

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ABSTRACT
Santa Clara de Asis Convent High Choir timber truss has been victim of humidity and attack of abiotic and biotic agents which have caused its gradual degradation. For the identification of pathological processes associated with these agents and because of its patrimonial character, a diagnosis study based on an organoleptic inspection and superficial tests was carried out with the available instruments, which allowed identifying the causes. By modeling the structure with SAP 2000 program, we obtained the results that were used to calculate the solutions proposed for the identified pathologies, mainly for the loss of connection between the wall plate and the tie rod beam.
Keywords: pathological processes; patrimonial character; organoleptic inspection; superficial tests; modeling.

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Un acercamiento al convento de Santa Clara de Asís de La Habana. Estudio de su estado de conservación y propuestas de intervención

RESUMEN

La armadura del Coro alto del Convento de Santa Clara de Asís ha sido víctima de la humedad, y del ataque de agentes bióticos y abióticos que han provocado su paulatina degradación. Para la identificación de los procesos patológicos asociados a estos agentes y por su carácter patrimonial se realizó un estudio de diagnóstico basado en una inspección organoléptica y en ensayos superficiales con el instrumental disponible, que permitieron identificar las causas. Mediante la modelación de la estructura en el programa SAP 2000 se obtuvieron las solicitaciones a las que se encuentran sometidos los elementos a intervenir y con el resultado se calcularon las soluciones propuestas para las patologías identificadas, fundamentalmente para la pérdida del vínculo entre la solera y el tirante.

Palabras clave: procesos patológicos; carácter patrimonial; inspección organoléptica; ensayos superficiales: modelación.

Inspeção ao convento de Santa Clara de Asís em Havana. Estudo do seu estado de conservação e propostas de intervenção

RESUMO

As treliças do Coro alto do Convento de Santa Clara de Assis têm sido vítimas da umidade, do ataque de agentes bióticos e abióticos que causaram sua degradação gradual. Para a identificação dos processos patológicos associados a esses agentes e pelo seu caráter patrimonial, foi realizado um estudo diagnóstico baseado em inspeção organoléptica e ensaios superficiais com os instrumentos disponíveis, que permitiram identificar o problema e fazer um diagnóstico. Modelando a estrutura no programa SAP 2000, foram encontradas as solicitações as quais os elementos estruturais estão submetidos. Com isso foi proposta a solução dos problemas patológicos, principalmente a intervenção para corrigir a perda do vínculo entre a viga e o tirante.

Palavras-chave: processos patológicos; caráter patrimonial; inspeção organoléptica; ensaios superficiais; modelar.

1. INTRODUCTION

A project to recover the Santa Clara de Asis Convent in La Habana Vieja has begun with the purpose of rescuing this ancient building to preserve its past, its present and its future, through a process of renovation, preservation and restoration of the heritage inherited by mankind so that it becomes part of contemporary life.
The convent, which is located in the old part of the capital of Cuba, Havana, with its High Choir as shown in “Figure 1” was, according to Pedro Herrera, “the first non-army structure on a monumental scale built in Havana; that is why the urban scene of the old villa experimented a definite transformation”. (López, 2006).

Figure 1. High Choir in Santa Clara Convent Church

Santa Clara Convent timber truss of the first cloister is considered the oldest timber truss preserved in La Habana Vieja. This type of roof is the best exponent because of its dissimilar solution. This composition of the structure has been exposed to the attack of external agents, both biotic and abiotic, which act in an aggressive way causing its degradation.
A study on this topic was carried out as part of the research to determine the state of deterioration of the timber truss High Choir Convent at present. This study resulted in the proposals of intervention techniques, both traditional and current ones. The techniques were aimed at recovering and improving the structural capacity of the timber truss at Santa Clara de Asis Convent, which was built in the 17th century and is considered a World Cultural Heritage with a protection 1 level, granted by the urban regulations in La Habana Vieja. The building constructive system represents a valuable heritage, so to preserve it means to rescue the cultural identity of the nation.

2. SANTA CLARA DE ASIS CONVENT: THE OLDEST TIMBER TRUSS EXPONENT PRESERVED IN LA HABANA VIEJA

The famous architect Felicia Chateloin, in her article called "Timber Truss in La Habana Vieja. The Privilege of its Preservation" stated that "Santa Clara Convent can be considered the most important example of a construction in Havana where timber truss has been used. The study of the convent is important not only because of its ancient construction, quality and variety of its roofs but also because of the number of elements that make up the roofs which is the same in any other construction" (Santiesteban, 2007).
"The coffered wood ceiling**s** cover most of the premises on the top floor of the first cloister and are distinguished by their elegance as well as the size of the main elements, the ones in the church nave and its choir" (Espiniella, 2001; Arduengo and Cruz, 2012).
In Cuba, most of the sloping wooden roofs from the colonial times are descendant from Mudejar timber truss. For a long time, authors like Joaquin Weiss (Weiss, 1978) referred to this type of timber truss as carved ceiling, but Felicia Chateloin makes emphasis on the error in using this term in the timber truss, "today we recognize that this term must be restricted to decorated flat ceilings. They should be correctly called 'timber trusses' for their structural system. The timber truss, not the carved ceiling, was the one which characterized the roofs and ceilings of colonial Havana in the 17th and 18th centuries" (Santiesteban, 2007).

2.1 Structural and constructive characterization of the church High Choir timber truss

The High Choir ceiling is made up of rafters or angle rafter, see "Figure 2", in twos, which start from the fastening, which is the perimetric frame of the structure, reaching the ridge beam or ridgepole to form four gables. According to Santiesteban, 2007, in spaces with a design span of more than 10 m long, the rafters will have an approximate section of 14 x 17 cm. The angle braces are connected horizontally, two-thirds from the height, by the collar beams, which determine the ceiling central part, so that the interior perimeter is a trapezoid. Considering the characteristic mentioned, timber truss can be classified as a rafter and a collar beam truss and as a structural set, that works under compression. "On these roofs, the ridgepole is not visible and can or cannot be supported on hips. The collar beam has a section of equal dimensions or very similar to the ones of the rafters of its timber truss" (Santiesteban, 2007).

Figure 2. Structural elements of the Convent High Choir timber truss.

The rafters are supported by the walls by means of the fastening, which is a structural frame of the system. In religious temples, the section can be of 35 x 30 cm or more; the fastenings are the one which receives the horizontal thrust that the rafters transmit (Santiesteban, 2007). For stiffening the structure, the fastening is fastened by transverse beams or tie rod beams which work by traction and form a triangle together with the rafters. These section beams are 15 x 20 cm approximately and are joined by short pieces called links, thus forming what is called tie rod beams. See "Figure 3", in the space between the links and halfway of the design span, there is a starred polygon with a decorative function. The objective of the tie rod beams is generally to join the wall plates which are made up by sections.


Figure 3. Tie rod beams on corbels**.**

It is noted that in the space angles, "Figure 4", the 'angle braces' are assembled to the fastening. They have a stiffening action and like the tie rod beam**,** they work by traction (Santiesteban, 2007). The angle braces are placed at 45° supported by corbels in skew (Matauco, 2000). The corbels on which the angle braces are supported and parallel to the contiguous walls, thus making the front parts more visible.

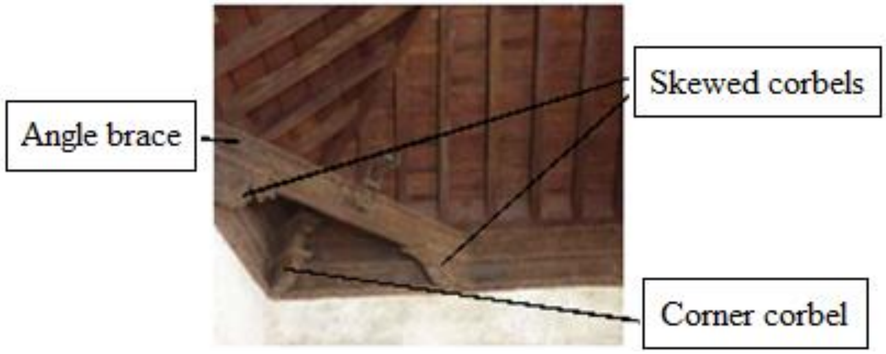


Figure 4. Angle brace, skewed corbels and corner corbel.

3. METHODOLOGICAL APPROACH FOR THE DIAGNOSIS.

The methodology used for the analysis of the pathologies on the timber truss was done by studying the methodologies proposed by different authors (Álvarez et al., 2005); (Basterra et al., 2005); (Garófalo, 2000); (Otaño, 2002); (Rodríguez, 2006). "A comprehensive analysis of the problem will always take the study of the environment next to the building, the lesions and their strainal signs and their casuistic effects. The preservation or necessary protection goes from the building to the city and vice versa, like every process that works like a system" (Otaño, 2002).

The diagnosis methodology which the above authors define, has three fundamental stages, first, characterization of the object of study; second, organoleptic inspection and third, superficial examinations. In the first stage, a search and a bibliographic inspection to gather information about the history of the building unit as well as a description of the characteristics of the system and its components were carried out. The second stage consists of the inspection of the building and its environment, based on a rigorous and detailed organoleptic inspection which allows establishing the general state of conservation of the structure. The inspection will include a sketch where coordinate axis was drawn with the objective of better delimiting the areas of the space and facilitate the future description and representation of the identified pathologies. This will also be accompanied by a photographic documentation to provide evidence of the pathology referred to. In the third stage, the techniques and instruments used for carrying out non-destructive tests which allow doing a more detailed analysis of the pathological processes taking place on the structure are defined. In this stage, the environment parameters that can have an influence on the observed pathologies are assessed by applying tests in situ to check the temperature and the amount of environmental and superficial humidity of the elements. The anatomical identification of the species and xylophagous organisms is carried out in the laboratory. This final diagnosis has the purpose of confirming or rejecting the hypothesis developed in the second stage.

In diagnosing, the sketches which appear in "Figure 5", the numbers of the elements which make up the structure of the High Choir are shown. The enumeration of the rafters was made in an independent way in each gable, whereas the components of the planking were defined according to the right joint in each case and they were numbered starting up from the timber truss on the walls in the direction of the ridgepole. The corbels, the angle braces, the hips and the tie rod beams (elements which can be seen in "Figure 6") were numbered in a consecutive way, starting from the elements located at the intersection of the axes B'-1, and in a clockwise direction, see "Figure 5".

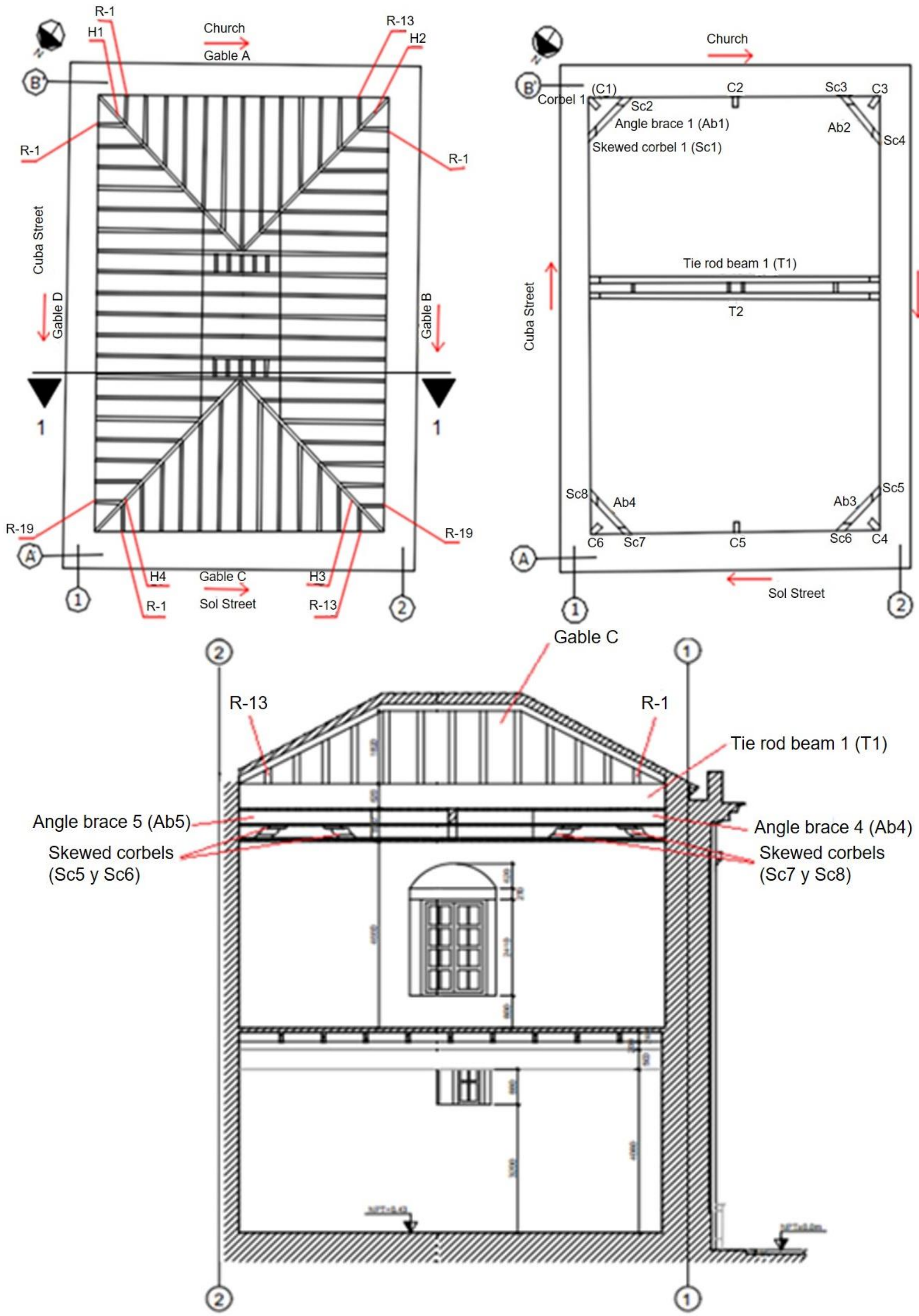


Figure 5. Nomenclature and numbering of the elements at the High Choir in an architectonic plant and in a cross section 1-1.

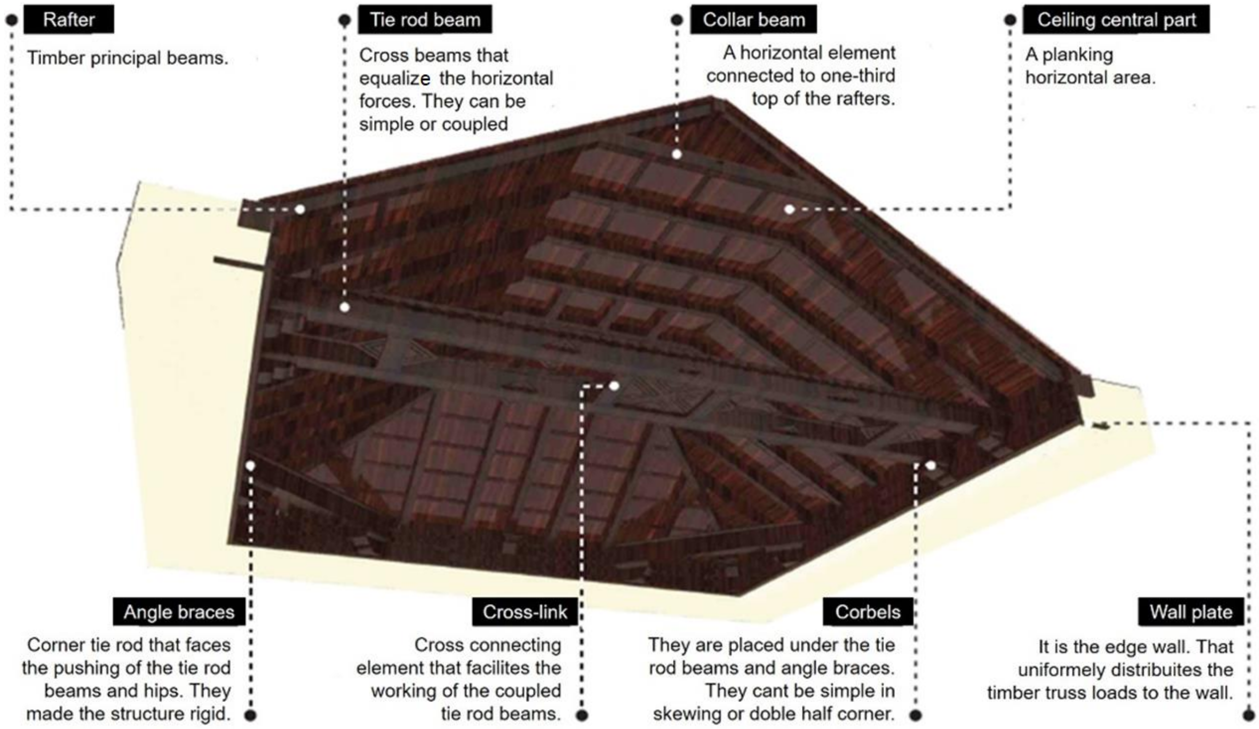


Figure 6. High Choir elements forming the timber truss. (Authors: Dayana Espinosa Ruiz, Arch; Lillian Potts Rodriguez, Arch. and Linnet Valdés Rivero, Arch.)

3.1 Visual inspection of the High Choir.

The first approach to the structure showed the evident state of abandoning and the level of deterioration due to the lack of maintenance. Dirtiness is visible on the walls as a result of the accumulation of dust, soot and organic matter because of the nearness to the Harbor Avenue and the passing of vehicles along the neighboring streets.

A high environmental humidity can be perceived in the place. On the other hand, the building has been exposed to an excess of water for long periods of time, as there are a lot of seepages coming from the roof, which are evident for the green patinas and rain wash patches on the walls, see "Figures 7-10". These seepages can cause severe damages in the wood, accelerating the process of rottenness, as well as on the mud walls; these types of constructions tend to retain much humidity.



Figures 7 and 8. Patinas on gallery wall to axis 2 of the Choir.

Figure 9. Wall with rain wash in axis A

Figure 10. Top wall green patinas in axis 2.

Because of the proliferation of feeder plants on the roof, there are visible developed systems of roots which penetrate the mud walls, see “Figure 11”, and can cause fissures in the wall.

Figure 11. Roots in axis A from the feeder plants on the roof.

The groups of bats in the roof of the building (see “Figure 12”) have contributed with their excrements and remains of food to the dirtiness of the walls and the deterioration of the building in general, see “Figure 13”. Although in some situations, these chiropterans are beneficial to man, like in the maintenance and regeneration of forests in the dispersion of seeds. However, they can become a plague when they install in places that do not constitute their normal habitat.
The bats' stools contain acids, which cause problems of an esthetics nature in the walls due to the accumulation of black excrements. They can also affect people's health, by creating a propitious environment for the development of an ecological succession of microorganisms, starting with the growing of bacteria, fungi and finally the proliferation of xylophagous insects.

Figure 12. Presence of bats.

Figure 13. Dirtiness on the walls and in the building because of bat excrements and food remains.

Fissures and vertical cracks, which range between 1-2 cm thick and 3-4 cm deep, mainly in the joints of the walls, see "Figure 14". These cracks can be the result of an inclination, caused by the thrust of the timber truss, since there are also horizontal cracks in the lower part of the wall, see "Figure 15".

Figure 14. Crack 1-2 cm thick at the intersection of axes A-1.

Figure 15. Horizontal cracks in the lower part of the wall (axis 1).

As the ceiling is made of an organic material, the wood is exposed to the attack of different agents, both biotic and abiotic, which contribute to its degradation, and loss of its resistance in most cases. The abiotic agents are of chemical or physical type and are caused by meteorological or climatic phenomena like solar radiation, environmental humidity, the rain, the wind, among others (Group of authors, 1998).

According to the Wood Chilean Corporation (CORMA, its abbreviation in Spanish), certain conditions are needed for the growth and subsistence of biological agents like the existence of a source of food material to take nourishment, an interval of ideal temperature for their growth (between 3º and 50ºC), being optimum about 37ºC. Wood becomes sensitive to the attack of fungi, when humidity ranges between 20% and 140%, since below 20%, the fungus cannot grow, and above 140% humidity, there is not enough oxygen to be able to live. With the conditions mentioned above, the wood is exposed to the biological attack, thus creating alterations of great importance in the wood mechanical resistance or on its external aspect.

The joint between the tie rod beam and the wall plate is the most critical point, since its malfunction brings about problems to the roof and the inflow of water (Garófalo, 2000; Rodríguez, 2003). At the same time, the thrust on the wall are created by the detached tie rod beam, causing horizontal cracks which come up at a certain height, more visible on the internal face, accompanied by a displacement outward of the highest course. "Figures 16-19" show the drop of the corbels on which the tie rod beams and angle braces are supported. The cause of this deterioration can be associated with the presence of humidity which is caused by the putrefaction of the supporting elements in the interior of the wall, that is why the elements stopped working like they used to do it and started to give way. In the case of the corbels on which the tie rod beams lean, they are associated to the force exerted by the tie rod beams.

Figure 16. Dropping of corbel under tie rod beam 2 (T2), on axis 2.

Figure 17. Dropping of corbels under tie rod beam**s** 1 and 2 (T1 and T2), on axis 1.

Figures 18 and 19. Dropping of skewed corbels (Sc7 and Sc8) under angle brace 4 (Ab4).

3.2 Superficial examination of the High Choir timber truss.

We had the support of the Historian Office Diagnosis Group for carrying out the tests, levels I and II (Rodríguez, 2006) which complemented the organoleptic study done and it allowed a closer approach to the real state of preservation of the structure. As part of this study, the following tests were done: measurement of dimensions of the elements which form the ceiling (level I), measurement of superficial humidity, environmental humidity and temperature (level I), punching of the wooden elements (level I), identification of plants (level I) and anatomical identification of wood (level II, in the laboratory).

Dimensions of the elements.

For determining the squaring of the rafters that form the timber truss and the spacing between them, since we do not have the original plans, a metallic tape was used as a measuring element. The measurements were taken on the lower and lateral face of the elements. The spacing measurement was taken internally from face to face of the rafters. The sketch of measurements taken to these elements is shown in "Figure 20".

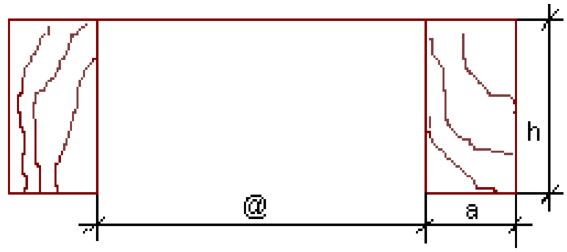


Figure 20. Rafters form of measurement.

Table 1 shows all the elements contained in the timber truss, as well as the dimensions of transverse sections according to the type of piece and its spacing.

Table 1. Dimensions of the elements of the High Choir timber truss.

Element	Quantity		Sections: Width (a)	Sections: Depth of beam (h)	(@) Spacing
Hips	4		17 cm	20-22 cm	-
Rafters	64		17 cm	20-22 cm	45-58 cm
Angle braces	4		23-24 cm	30-31 cm	-
Corbels	10		-	-	-
Skewed corbels	8		-	-	-
Simple tie rod beams	2	T1	24.5 cm	31.5 cm	80 cm
		T2	22.5 cm	31.5 cm	

<u>Relative humidity and environmental temperature.</u>

The levels of humidity were measured with the thermo-hygrometer, see “Figure 21”; they were measured in different points of the building and were controlled during three months (March-May of 2018), so that we could get the possible variations in the readings done as the evidence in atmospheric differences inside the same building. The levels measured in every case are higher than 65% and the thermohygrometic conditions are convenient, that is, inside the building, there are temperatures ranging between 20ºC and 30ºC, which help to the development of biodegradation agents and contribute to accelerate the vital cycles of a number of microorganisms and xylophagous insects which degrade the wood.

<u>Superficial humidity.</u>

The test of superficial humidity allows knowing the content of humidity kept on the fibers of the material, since its value has an influence on the physical properties of it. The instrument used to carry out the test was the Hygrometer *Protimeter Surveymaster SM*, see “Figures 22 and 23”.

Figure 21. Thermo-hygrometer.

Figure 22. Hygrometer *Protimeter Surveymaster SM*.

Figure 23. Measurement of superficial humidity on elements.

The instrument has two ways of measuring: by the color of the bar LED and by the reading of the percentage (%) of humidity kept in wood. According to the color of the bar, it is green when it is in a safe state of drying in the air, yellow represents the boundary line, and red when the wood is in an unfavorable condition. The classification of the levels of saturation established by the manufacturer is shown in Table 2.

Table 2. Levels of saturation established by the manufacturer.

Color	Level of saturation of superficial humidity.	Range of values (%)
Green (G)	Semi-dry	6-8-10
Yellow (Y)	Admissible humidity	12-14
Red (R)	Humid	16-18-20
	Saturated	= 20

The measurements were made on the rafters, in the areas close to the support and on the elements, which were more exposed to humidity. Five settings were registered in each measurement. To execute them, the equipment is pressed to a nominal depth of 5-15 mm on the element studied and this gives relative settings of humidity kept inside the material.
Values higher than 18% were detected in specific areas. This confirms the presence of humidity due to seepages in the roof which is one of the main causes of damage. Humidity ranging from 18 to 20% and higher than this value creates a favorable environment for the proliferation of fungi from rottenness and other xylophagous organisms which can affect the mechanical properties of wood.
In the case of the elements where damages have been found and are not above this range, we can infer that there are stages where there is a considerable increase of humidity, thus allowing the appearance of wood-degrading agents.

Research done with punch in wooden elements.
The objective of this test is to determine the state of conservation of the rafters in the area close to the supports, according to the measure obtained from the penetration of a graduated punch, see "Figure 24". The value depends on the characteristics and the specific hardness of the wooden element being analyzed. When the punch does not penetrate or is superficial, it means that the studied element is in good shape. However, higher values of penetration (from 2-5 cm) are obtained when the elements are rotten and shredded. The result of this test reveals that the commonest identified damages are: shredding in the area of the rafters and angle braces head in the lower part and sides of 70% of the rafters which make up the ceiling gable, as well as other damages like

cracks, putrefaction, splintering and damp patches.

Figure 24. Investigation in wooden elements with graduated punch.

"Figure 25" summarizes the damages detected in the High Choir, placing them in an architectural plan.

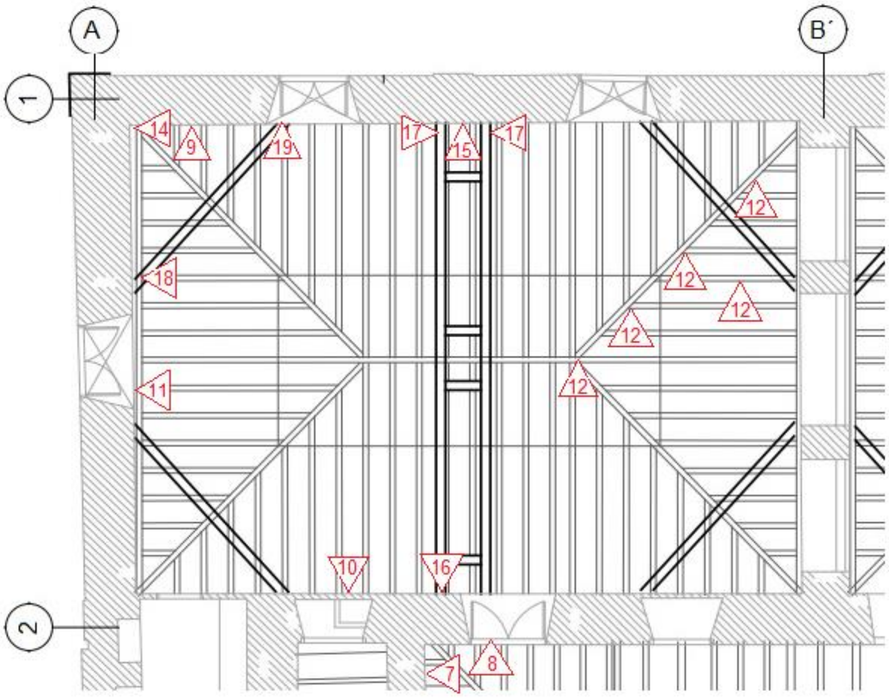


Figure 25. High Choir architectural plan showing the location and association of damages Figures 7-12 and 14-19.

Identification of feeder plants.

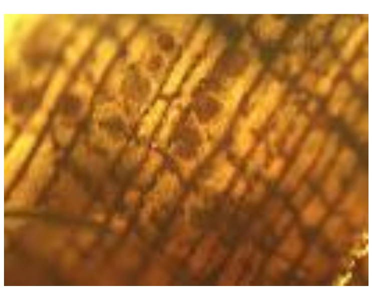
Photographs of parasite plants growing in the roof were taken; see "Figures 26 and 27". The identification of superior plants was carried out by comparing them with specimens present in the herbarium of the Biology laboratory at the Havana Historian Office Diagnosis Group. There, the botanical family, the scientific and vernacular name (Group of authors, 1999); (Roig, 2014) and the biological aspect (Pérez and Rodríguez, 2007); (Pérez, 2010) were obtained.


Figure 26 and Figure 27. Invading plants on roof of the High Choir.

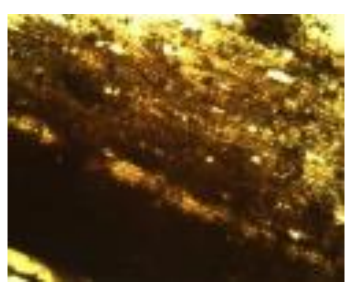
The plants identified are of herbaceous and arborous aspects, the latter has roots which can penetrate the walls and produce cracks which continue developing, widening and creating new internal tensions in the walls (Pérez, 2010).
Although the mechanical action of plants of herbaceous aspect are of less effect than the ones of arboreal aspect, they also play a role in developing damages, contributing to the chemical deterioration of the substratum in which they grow and the retention of humidity; thus, facilitating the growing of other more potential plants. So, it is necessary to know the species or group which the biological agent belongs to, from which are drawn up the strategies for the conservation of the deteriorated substratum.

Identification of timber species.

In order to carry out this test, random samples of the wooden elements for their identification were taken to obtain histological sections in the transverse, tangential and radial directions. The observation of the anatomical characters was taken with the use of the light optical microscope.
The samples were identified by using the compared anatomy method, which is based on the comparison of the macroscopic characters of the samples with pattern woods, previously identified and classified at the Xylotheque biology laboratory of the Historian Office. The characters were assessed are the color, texture, grain, luster, smell (on those that could be measured) and the presence of growth rings (Carreras and Dechamps, 1995). The samples were taken from the angle brace 4, from the wooden frieze, from the skewed corbel 4 and from the frieze from gable D. The results show that the skewed corbel 4, the wooden frieze and the frieze from gable D belong to the Cedrela odorata species, see “Figure 28” and angle brace 4 belongs to the Tectona grandis species, see “Figure 29”.



Transverse section 40x



Tangential longitudinal section 100x

Radial longitudinal section 100x

Figure 28. Anatomical sections of Cedar.

Transverse section 40x Tangential longitudinal section 40x Radial longitudinal section 40x

Figure 29. Teak anatomical sections.

The histological sections of the transverse, tangential-longitudinal, and radial-longitudinal samples were taken (“Figures 28 and 29”), which allow corroborating by the microscope a better observation of the radial parenchyma, making possible to determine that timber species are cedar and teak, according to the parenchyma model of the transverse section.
Once the species have been identified, Table 3 shows their physic mechanical properties, from the information given by the Cuban Institute of Agro forest Researches, which will be used in the structural modeling of the timber truss with the SAP 2000 program and the reinforcement calculations.

Table 3. Main mechanical and physical characteristics of identified woods.

Scientific name	**Common name**	**Density g/cm^3)**	**Elasticity modulus (kg/cm^{2}x1000)**	**Tensile Strength (kg/cm^2)**	**Flexural Strength (kg/cm^2)**	**Compressive Strength (kg/cm^2)**		**Shear Strength (kg/cm^2)**
						Perpendicular to the fibers	**Parallelto the fibers**	
Cedrela odorata	Cedar	0,37-0,75	78.10	690	667	-	302	40
Tectona grandis	Teak	0,61-0,74	110	850	1160-1450	-	513-685	63.2

4. VERIFICATION OF ACTING LOADS ON THE BEAMS

The structure was modeled with the SAP 2000 program, see “Figure 30”, taking the weight of the materials (NC 283: 2003), the roof use load (NC 284: 2003) and the load of wind (NC 285: 2006) for the analysis of the loads combinations according to NC 450: 2006.

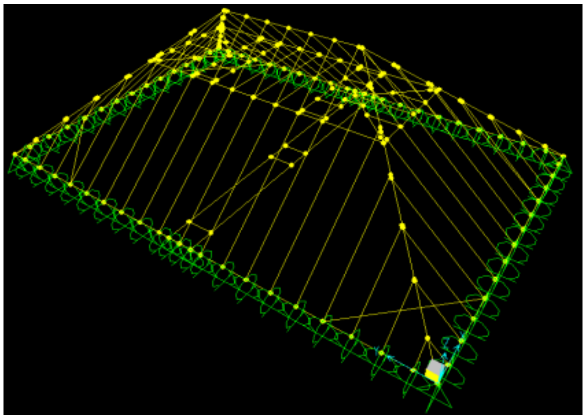


Figure 30. Modeling the structure with the SAP 2000 program.

Results of axial stress modeling in the tie rod beam 1: NT1=60,15kN and in the tie rod beam 2: NT2=52,49kN, obtained from the less favorable combination.

5. INTERVENTION PROPOSALS.

5.1 Solution to tie rod beams with prosthesis.

It involves substituting the retired part of wood by inserting bars (steel ones or FRP- Fiber Reinforced Polymers ones) in drillings done in the wood and gluing the bars so that they adhere well. For the design, it was considered the greater axial solicitation, for both tie rod beams, of less favorable combination obtained from the modeling made with the SAP 2000 program. The diameters of the drillings must be broadening enough to leave a width of 3 to 6 mm around the bar, which will be filled with epoxi.

Process of execution: cut off the degraded part of the head with chain saw or handsaw; drill holes in the original tie rod beam and installation of the bars; selection and conformation of the new wood to be inserted, by mortising to carry out the joint with the wall plate. The holes are drilled in the new insertion and the epoxi resin is applied on the bars. Finally, the new wood to be inserted is placed, which must fulfill the requirements of durability for wood of structural use like the restriction of knots, drying cracks, and control of humidity of hygroscopic balance, among others.

This solution can be applied to products from the Italian company of "Material aids for construction and industry" (MAPEI, its abbreviation in Italian). It consists in applying the epoxy resin first to the wood and holes for the bars. The Mapewood Primer 100 product, which is an epoxy impregnant of fluid consistency is left to be dried and then to apply it later on the bars and wood. The Mapewood Paste 140 product which is an epoxy adhesive of thixotropic consistency is very effective in the restauration of wood structural elements.

5.2 Reinforcement with carbon fibers.

It is a current technique for reinforcing structural elements, which has been used not only for recovering timber structures, but also concrete and masonry ones. It consists in fixing with epoxy resins platens of synthetic material with carbon fiber (approximately 1, 2 mm to 1, 4 mm thick and 60 mm width) to the element to be reinforced. Its use is generally aimed at absorbing the tensile stress, in this case is of 60,15 kN which was obtained as an axial stress less favorable in the modeling carried out, which generate tensile stress because of its high resistance. The fibers have high structural resistance compared to its practically inconsiderable weight and are resistant to corrosion (Morocho, 2014). The disadvantage in applying this method is its high cost.

5.3 Replacement of wall plate by a one made of wooden.

The wall plate is replaced by a mud sill with the same scantling as the original one with these dimensions (30x35cm); in order to execute the joints in the corners, they will be carried out with a rabbet joint and according to the length of the piece; this will be done every 5 m by means of a key joint. The wood to be used is the Manilkara valenzuelana (a hard-reddish wood, which grows in the island of Cuba) which is a harder wood than the cedar.

Design of the joint along the element.

The joint along the element is based on the key joint**,** which consists in transmitting the tensile stress (Nd) from one piece to another by means of parallel compression to the fiber applied on the front with a b·t surface, see "Figure 31". Besides, the stress generated in the complete section through a longitudinal shear from shearing stress on the b·l surface section, see "Figure 31" (Martitegui et al., 2009).

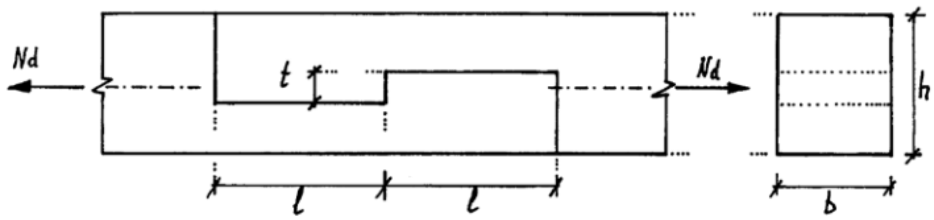


Figure 31. Key joint. Source: (Martitegui et al., 2009)

Joint design on the corner.

The joining of the corners will be done by rabbet joint "Figure 32", which is reinforced with coach-screws as shown in "Figure 33", and have a shank made up of a threaded area on the tip (thread) and a flat area (shank).

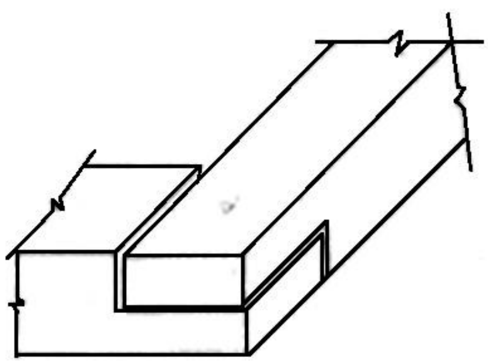


Figure 32. Rabbet joint. Source: (Martitegui et al., 2009).

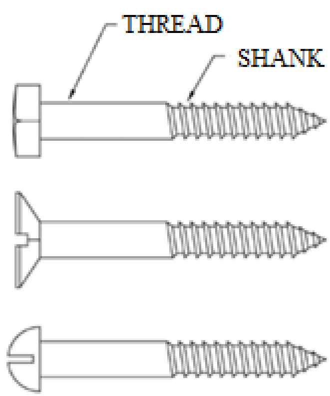


Figure 33. Coach-screws with hexagonal, countersunk, and round heads (up to down). Source: (Martitegui et al., 2009).

5.4 Replacement of tie rod beams with steel tensors.

It consists in placing the steel tensors which will take the stress of the original tie rod beams and will go through the wall plate that is fixed with two nuts and a metal sheet to avoid the crushing of the wood. Thus, using the axial stress obtained from the modeling of the elements with the SAP 2000 program.

The design was done by using bars as members under tension; they can be fixed with threads and

nuts (McCormac, 2002). The nominal stress under tension on threaded little bars when the thread is included in the cutting plane, according to Table J3.2 from Loading and Resistance Factors Designs (LRFD) is equal to 0.75Fu. The failure possibility of these elements is because of fractures due to the area reduction caused by the threads.
The design involved A-36 steel bars with creep stress of Fy=250MPa and last stress of Fu=400MPa. Nominal tensor stresses were analyzed for the most loaded tensor, although two tensors were placed in the same position as the tie rod beams.
It is convenient to limit the minimum diameter of the tensors (McCormac 2002) to 5/8 inches, since tensors with the smallest diameters get damaged frequently during the constructive process. Besides, some designers use diameters not less than 1/500 of the length of tensors, in order to obtain certain rigidity even when the stress calculations allow smaller diameters.

6. CONCLUSIONS

The most probable causes from the pathologies identified are associated with the excess of humidity due to seepages coming from the roof, which have created a favorable atmosphere for the proliferation of xylophagous organisms. The damage which is affecting most the behavior of the structural group is the disjoining or lack of link between the wall plate and the tie rod beam, originated by the putrefaction of these elements in the area of the support on the wall. This causes the thrust of the facade wall and its future collapse which is clearly seen in the vertical cracks at the intersection of axes and horizontal cracks on the wall of axis 1 of the High Choir. Overall, the structure is in a regular state.
The solution suggested to solve the main injury was the replacement of the wall plate by other wood and the tie rod beams by the steel tensors. The last ones will be covered in wood in order to affect as little as possible the esthetic of the building due to its patrimonial value.

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