IDENTIFICATION AND CHARACTERIZATION OF THE FOYER OF THE NATIONAL THEATER OF COSTA RICA AS PART OF THE METHODOLOGICAL STRATEGY FOR THE THREE-DIMENSIONAL MODELING OF THE FUTURE DIGITAL TWIN

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ABSTRACT:

This paper summarizes the first results of the third specific objective of the research project: Digital Twin (DT) as a management tool for the programmed conservation plan (PCP), case study: Foyer and Smokers of the National Theater of Costa Rica (TNCR, by its Spanish acronym), developed with the support of the Vice Rectory of Research and Extension of the Technological Institute of Costa Rica. This objective aims to integrate graphic, non-graphic and linked information from the diagnostic stages of the PCP, through three-dimensional modeling, for the definition of conservation actions and future visualization of the DT. However, prior to modeling it was necessary to understand the composition of the structural system of the first body of the TNCR.

The project has the information of the building systematized in documents and plans, both original and from subsequent studies and interventions, as well as a three-dimensional model made in 2021. However, there is no "as built" information after the construction or the interventions that have been carried out; in addition, the structural information of foundations, mezzanines and roofs is not integrated with the ornamental and pictorial information; that is, prior to this research there was no precise documentation of the structural elements that make up the study area and that support the heritage with artistic value of the building. Therefore, this paper presents the work carried out between June 2022 and March 2023 to identify and characterize the components of the Foyer and Smokers of the TNCR, using non-invasive techniques.

1. INTRODUCTION

The National Theater of Costa Rica (*Teatro Nacional de Costa Rica* or TNCR by its Spanish acronym) is a building declared historical-architectural heritage and the only building officially recognized as a National Symbol of the Republic. It was inaugurated in 1897 as an opera building of eclectic style, but with a functional design that, according to (Santamaría-Montero, 2017), responds to the archetype of the French theatrical model. This author explains that Engineer Nicolás Chavarría, the professional in charge of the work since 1890 and during the first four years of its construction, justified the final design of the TNCR using arguments based on the technical treatise "The Theater", written by architect Charles Garnier in 1871, as well as other authors of the time. According to this author, the functional organization of the building is clear, with a floor plan of three sections, the first with lobbies and staircases, on the second floor of which is the "great hall" or Foyer (see red area in Figure 1). In the middle is the second body, which corresponds to the great hall together with the stage (see blue area in Figure 1) and, finally, the administrative sector which, in the case of the TNCR, surrounds the square stage on three of its sides, the sides and the back (see yellow area in Figure 1).

To conserve the building, the TNCR has undergone numerous interventions over time, actions that have contemplated the different structural levels of the building, including the preservation of its artistic work. Although there are historical and technical documents of the proposals made, there is no record of "as built" plans. This situation represents a problem because, although the logs indicated the changes made on site, they were not recorded in the plans. This inconvenience has been dragging on since the very beginning of the theater's construction work, since according to (Santamaría-Montero, 2017) the original design of the TNCR changed during construction and, according to the Conservation Department of the building, the final plans of the work are not available. On the other hand, the existing documentation is not integrated, which makes it difficult to manage the building's conservation processes. At the beginning of the investigation, areas such as lobbies, stairways, foyer, and smoking rooms do not have detailed structural information that would allow understanding the construction system of the first body of the building.

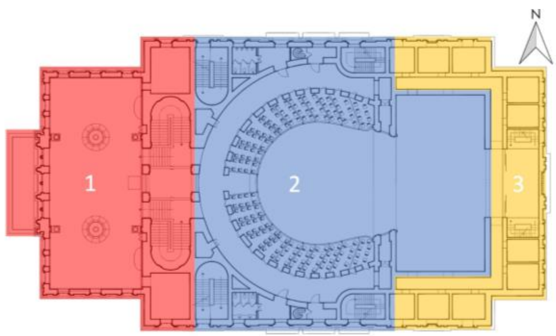

Figure 1. Interpretation of the TNCR bodies, as described by (Santamaria-Montero, 2017), based on the plans of (Cordero-Villalobos, et al., 2022) of the second level floor plan of the TNCR. [1]

[1] 1: First body of the TNCR; 2: second body of the TNCR; 3: third body of the TNCR.

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On the other hand, as is the case in other historic buildings, at the end of the intervention works in the TNCR, mainly corrective maintenance processes have been carried out, focused on addressing specific problems that arise in the building. Authors such as (Della Torre, 2002) have contrasted this concept with that proposed by programmed conservation. It has been concluded that, while maintenance refers to specific actions that are carried out when a problem is detected; programmed conservation responds to an analysis of the building prior to its intervention, which allows understanding the problems it faces from an integral vision.

It contemplates the interventions of the property, as well as the development of a program of preventive, follow-up and control actions whose purpose is the conservation of the heritage work during its entire operational cycle. Understanding the importance of programmed conservation applied to a building such as the TNCR and with the objective of proposing a baseline for the development of a tool that integrates the information and allows continuous monitoring of the property, the Technological Institute of Costa Rica (TEC) has formed a research team composed of the schools of Architecture and Urban Planning, Industrial Design and Computer Engineering. This team includes TNCR professionals, specifically from the Conservation Department, who together with experts from the University of Seville and the University of Liege, proposed the research project: "Digital Twin (DT) as a management tool for the programmed conservation plan (PCP). Case study: foyer and smokers of the National Theater of Costa Rica". The present communication is carried out within the framework of this research and aims to present the first results of the third objective, which consists of integrating the graphic, non-graphic and linked information of the diagnostic stages of the PCP, by means of 3D modeling, for the definition of conservation actions and future visualization of the DT.

This objective is intended to answer the question of how should the DT guarantee the follow-up of the monitoring variables determined in the diagnosis of the PCP? This question involves the visualization of the TNCR by means of digital environments and the challenge of modeling the section of the property under study according to the necessary requirements for the development of the DT, with a level of maturity between an informative DT and a predictive DT.

2. METHODOLOGY

To understand the structural system of the first body of the TNCR, information gathering techniques were used through documentary research, planimetry consultation and a first phase of field work using traditional instruments. Once the first information had been reviewed and systematized, it was necessary to resort to a new phase of fieldwork based on the application of non-invasive techniques, using specialized technology to deepen the knowledge of the first body of the building. Some of the equipment selected for this work are not usually used in the discipline of Architectural Conservation, however, due to the complexity of performing the work in a space in use with constant influx of public and the aesthetic and patrimonial value of the pictorial and ornamental works present, the research team considered them relevant for the identification of the structural elements, due to the low risk of causing alterations in the object of study. It is important to clarify for the reader's understanding that the research techniques were not applied in a linear way, but rather, starting from a first information gathering plan and according to the development of the research itself, the sources were repeatedly consulted, and the data found in each of them were contrasted, in order to faithfully build a first three-dimensional model describing the structural system of the first body of the TNCR.

One of the first steps to follow was the analysis of original plans elaborated by (Reitz-Eggers, 1890-1897), the review of the thesis of (Santamaría-Montero, 2017) and the study of the documents and structural reinforcement plans of (Gutiérrez-Gutiérrez and Quirós-Lara, 1991). In addition, the Final Graduation Work of (Romero-López, 2021) from the School of Civil Engineering of the University of Costa Rica, the three-dimensional model generated by this author and the Foyer plans elaborated by (Cordero-Villalobos et al., 2022) were also analyzed. Only the model of (Romero-López, 2021) and the plans of (Cordero-Villalobos et al., 2022) can be considered as final surveys of the architectural work, since both what was proposed by (Reitz-Eggers, 1890-1897) and (Gutiérrez-Gutiérrez and Quirós-Lara 1991) underwent modifications on site that were not recorded. As a result of these determinations, the research team was not sure of the exact location of the structural pieces, both the original ones and those installed during the interventions in the 1940s and 1990s.

Based on the documentary information, the first phase of field work was developed, which included a photographic survey, corroboration of dimensions and identification of lesions in the Foyer and Smokers, using as a basis the existing plans of the internal facades of the Foyer, provided by personnel from the Conservation Department of the TNCR. Prior to the development of this phase, it was necessary to propose a codification of the constructive and ornamental elements of the object of study. The Foyer space was divided into three blocks, A for the north sector, B for the central sector and C for the south sector. The "Smoking area for men" was called block D and "Smoking area for women" block E. From this division, a coding by construction or ornamental element was established, consisting of the first letter of the name of each element (two letters in the case of elements with the same initial letter) and a number, which was assigned in two ways: counterclockwise in plan and counterclockwise in elevation in order from right to left. The coding was systematized in the survey plans and, in a database, shared with the entire research team. Once this task was completed, scheduled visits were made to the site to corroborate dimensions, detect differences in the survey plans and take detailed photographs of each element and block. In addition, an initial identification of lesions was made to allow the team to determine risks and degrees of conservation.

After the survey work, it was determined necessary to deepen the knowledge of the construction system of the object of study. To carry out this task, non-invasive techniques were used to determine the structural system of the mezzanine between the main lobby (first level) and the Foyer (second level), as well as the ceiling and roof of the first body of the TNCR. The first step was the observation using an endoscopic camera, with the objective of identifying the structural elements described in the documents, among these components the beams and the joist system of the mezzanine. These observations were made through incisions made at two points in the ceiling of a room adjacent to the lobby, known as "Salón de las Musas"; in addition, the presence of electrical boxes was used to observe the structural elements. To determine the location of the metallic structural components of the mezzanine, the collaboration of TEC's Center for Research in Housing and Construction (CIVCO) was requested, who provided the equipment to carry out this task. The recommendation of the CIVCO staff was to carry out two types of tests. The first was the use of a Profometer 650

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AI pachometer or coating gauge, commonly used in civil engineering to locate the reinforcing bars or rods of a structure, specifying the thickness of the coating (usually concrete) by measuring the disturbance of a magnetic field generated on the surface of the coating itself. The second type of test suggested was with a Ground Penetrating Radar or Georadar GPR Proceq GP8000, used to detect objects or disturbances below ground. This detection is based on the transmission of ultra-wideband electromagnetic (EM) waves from materials (in a range of 10 MHz to 2.6 GHz), a part of the electromagnetic wave is reflected when a boundary is reached between two materials with different electrical properties, the signal that is reflected is recorded on the EM wave source and shown to the operator, to be recorded and analyzed later. Although both types of tests were suggested, there was no certainty that either would work because the conditions in which the equipment would be used were different from those for which they were designed, i.e., the instruments would be used at the mezzanine level to detect metallic elements covered by layers of wood and not in concrete or natural ground, as they are usually used. On the other hand, a Leica BLK360 laser scanner was used to record the information of the roof and sky structure, with which a series of surveys were taken, joined and processed using the Cyclone Register 360 program. As a result, a base point cloud was obtained to elaborate the structural elements of the roof of the first body of the TNCR.

3. RESULTS

The results are presented below according to the different sources and methods of data collection.

3.1 Information from documentary sources

After reviewing the different documentary sources, it is possible to make a preliminary description of the structural composition of the first body of the TNCR. This description is based on the plans of (Reitz-Eggers, 1890-1897) and (Gutiérrez-Gutiérrez and Quirós-Lara, 1991), which show the original approach to build and intervene the building; however, they do not show the result; that is, they are not "as built" plans. On the other hand, we resorted to the three-dimensional model produced by the Final Graduation Project of (Romero-López, 2021), which, although it is only architectural, was a basic reference to locate in an abstract way the structural elements identified in the other documents. The construction system of the TNCR can be described as a mixed system combining masonry walls with steel frames.

According to the plans of (Reitz-Eggers, 1890-1897), the masonry walls are made of fired brick with thicknesses between 0.85 and 0.95 m, depending on their location. The foundations are cyclopean type, with river stones, with a thickness between 1.00 and 1.20 m, according to the width of the wall they support. These foundations start at a depth of 0.50 m according to the level of Second Avenue and 3rd Street (south and east sector) of the City of San José and reach 1.30 m in the first body of the TNCR. The depth increases towards the eastern sector to adapt to the topography, reaching approximately 4.00 m in the area corresponding to the stage, in the second body.

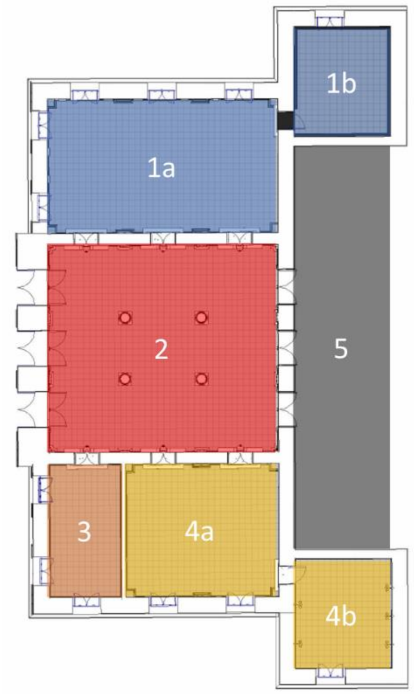

Figure 2. Functional composition of the second floor of the first body of the TNCR, based on the model developed by (Romero-López, 2021).

The second floor of the first body of the TNCR is polygonal in shape and consists of a first rectangle of approximately 13.65 m wide by 27.65 m long. This section is located to the west and contains to the north the current cafeteria (see Figure 2, element 1a), in the center the main lobby (see Figure 2, element 2) and to the south the souvenir store (see Figure 2, element 3) and the "*Salón de las Musas*" (see Figure 2, element 4a). To the east of this section is another rectangular space measuring approximately 5.85 m wide by 35.10 m long, following the symmetry axis of the building. In this area are located from north to south, a cafeteria room or support space (see Figure 2, element 1b), the internal lobby and first development of the stairs (see Figure 2, element 5) and a room adjacent to the "*Salón de la Musas*", which formerly served as the office of the Theater Management (see Figure 2, element 4b).

The second level of the first body of the TNCR is an extrusion of the first; however, it is functionally less complex, since, on the west section or first rectangle, is the Great Hall or Foyer (see Figure 3, element 1) of free plan, while, in the east section are located from north to south, the room known as "Smokers for gentlemen", stairs, and the room known as "Smokers for ladies" (see Figure 3, element 2, 3 and 4 respectively).

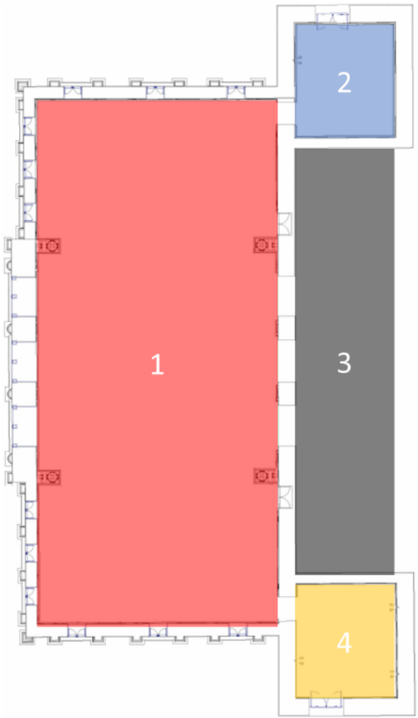

Figure 3. Composición funcional de la segunda planta del primer cuerpo TNCR, basado en el modelo elaborado por de (Romero-López, 2021)

According to the plans of (Gutiérrez-Gutiérrez and Quirós-Lara, 1991), immersed in the east wall of the main lobby, between the accesses to the interior lobby and stairs, there are four W-type steel columns, approximately 0.80 m high and 0.25 m wide, which end at the height of the Foyer mezzanine (see Figure 4); these are the only steel reinforcements found in this body of the TNCR. This situation is contrary to what happens in the internal walls of the Great Hall and the stage, where in addition to the four steel reinforcements, parallel to the east wall of the main lobby, pieces of the same section are located every 2.00 m that serve as reinforcement to the structure along its development in plan and height. The difference in the amount of reinforcing steel found in the first body of the TNCR in relation to the other construction sections of the building indicates that this is the most structurally vulnerable sector of the entire building.

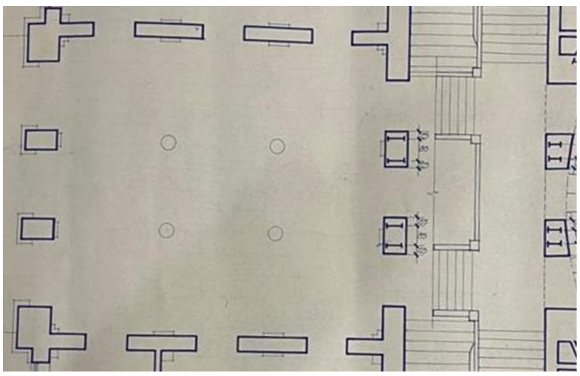

Figure 4. Detail of plan E13-38 from (Gutiérrez-Gutiérrez and Quirós-Lara, 1991). Source: National Theater of Costa Rica.

As can be seen in all the plans of the TNCR, in the main lobby there are four columns with a circular base, with a diameter of approximately 0.50 cm; however, according to (Reitz-Eggers, 1890-1897), they are columns composed of two steel beams of type W, 0.20 m high and approximately 0.10 m wide, joined by zigzag-shaped plates. These elements are hidden behind a wooden drum covered with marble sheets, whose base and capital are made of copper (see Figure 5).

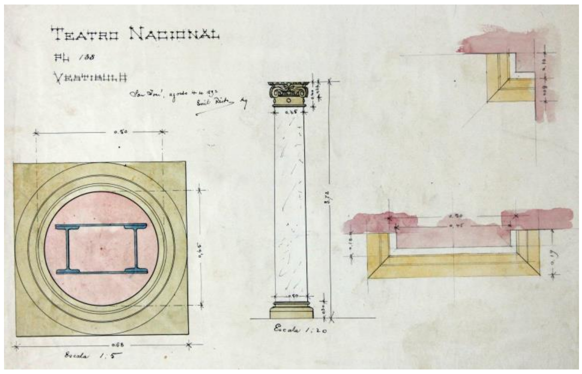

Figure 5. Detail of lobby column according to (Reitz-Eggers, 1890-1897). Source: National Theater of Costa Rica.

According to the plans of (Gutiérrez-Gutiérrez and Quirós-Lara, 1991), on top of these columns, at a height of 3.70 m, there are two W beams of 0.30 m height and 0.13 m wide, which run transversely from east to west and are supported by the walls. In addition, similar beams are shown attached to the walls dividing the east and west sections of the rectangle. On the other hand, there are no records in the plans of transverse reinforcements in a north-south direction, neither attached to the walls nor on the columns. Finally, (Gutiérrez-Gutiérrez and Quirós-Lara, 1991) locate a series of W type joists of 0.16 m height and 0.08 cm wide, with an east-west direction separated by approximately 0.70 m and 0.80 m, completing the structure of the mezzanine.

According to the structural details of (Reitz-Eggers, 1890-1897), below the floor joists there are two beams in perpendicular direction, this fact suggests that over the columns there is a transversal and longitudinal framework of double beams (see Figure 6). Another detail shows a W beam attached to a wall and a joist above it (see Figure 7); in addition, the attached beam is perpendicular to the joist of the mezzanine, so it is assumed that there are also attached beams in the north and south walls. Other elements that can be seen in this detail and that are not reflected in the 1991 plans are the wooden chains on the joists, the planks on them that form the support of the parquet floor and the planks under the joists that correspond to the ceiling.

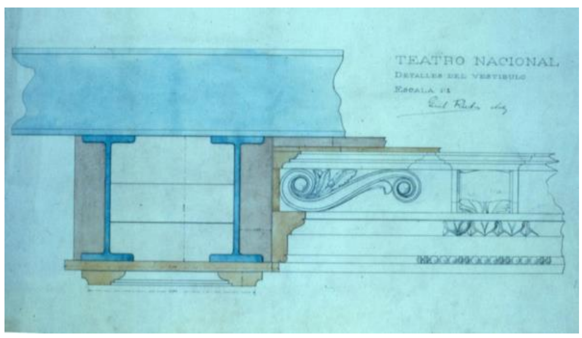

Figure 6. Detail of longitudinal beams below floor joists according to (Reitz-Eggers, 1890-1897). Source: National Theater of Costa Rica.

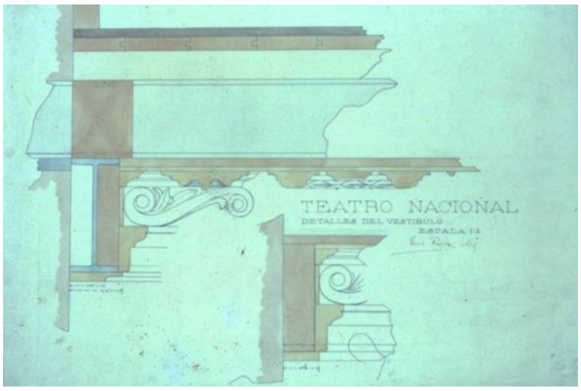

Figure 7. Detail of beams attached to the walls and floor joists according to (Reitz-Eggers, 1890-1897). Source: National Theater of Costa Rica.

On the other hand, according to (Monge-Quesada, W., personal communication, February 17, 2023), at the end of the 1990s it was necessary to carry out a structural reinforcement of the mezzanine of the Foyer in the central section (first rectangle), specifically in the area adjacent to the east wall. The intervention was carried out to provide adequate support for a marble sculpture "Angel of Victory", which was located on the pediment of the main façade of the building and had to be moved to ensure its conservation. These works were not recorded in plans. Another aspect that is not specified in the planimetry of (Reitz-Eggers, 1890-1897) is the type of anchorage of the structural elements. Based on the joints visible in other sectors of the Theater, it is presumed that they are bolted joints; however, there is no specific detail of the joint between the columns of the vestibule and the transverse beams. There are details of the structural reinforcement foreseen by (Gutiérrez-Gutiérrez and Quirós-Lara, 1991), however, at the time of writing, no photographic evidence has been found to confirm the correspondence between the work done and the existing plans. Due to the above, and to the contradictions between the plans of (Reitz-Eggers, 1890-1897) and (Gutiérrez-Gutiérrez and Quirós-Lara, 1991), it was necessary to contrast the information on site using non-invasive techniques.

3.2 Information from architectural surveys

Based on the plans provided by the Conservation Department of the TNCR (Cordero-Villalobos, et al., 2022), a coding process of the architectural and ornamental elements present in the study area was carried out. The objective of this work was to allow the identification of the existing elements in the space of the Foyer and Smokers in order to follow up the conservation processes from the future digital twin, among which are the recording of injuries and intervention works currently or in the future in the object of study. As indicated in the methodology, a division was previously made in plan of the Foyer space into three segments: A, B and C. The northern sector was assigned the letter A, the central sector the letter B and the southern sector the letter C. The Smoking areas were also identified with a letter; Smoking for men was called sector D because of its location to the north of the block and Smoking for women sector E, because of its position in the south wing. Based on this division, each of the architectural and ornamental elements present in each of the interior facades and ceilings of the study area were coded in plan and elevation. Each element was identified with a code composed of the first letter of the name (two letters in case of repetition of the initial letter) and a number. Once the coding was completed, the field work proceeded. Three main activities were defined for this stage: verification of the existing plans in terms of quantity and location of elements (architectural and ornamental), verification of the dimensions of each space and recording of the injuries present. Due to the level of detail required for a predictive digital twin, it was necessary to make 13 visits to the spaces, which were carried out between August and October 2022. For these activities, the work team was divided into subgroups according to the availability of time of each member and had the collaboration of the TNCR Conservation Department, who provided the necessary tools and personnel for data collection and image capture.

Although intervention works have been carried out and recent plans of the internal space of the Foyer are available, the research team was able to identify some gaps in the information recorded in the planimetry. No details of the window frames or the interior volume generated by them (jambs, plinths, arch intradoses) were found. Nor were records found of any of the smoking areas, i.e., it was necessary to carry out a complete survey of each of these areas. Another of the gaps identified was in the information on the ceilings, which although their pictorial works have been analyzed from their composition to their lesions with the support of inter-institutional research and work teams from other disciplines (art, biology and chemistry, among others), they were not included as part of the architectural survey plans provided, therefore, it was necessary to make a complete record of these elements, both in the smoking areas and in the Foyer. The field work allowed the identification of the lesions present in the object of study. Damage was recorded by means of photographs, whose information should subsequently be reflected in the updated plans to be generated with the project for the future digital twin. The main injuries found can be grouped according to the constructive or ornamental element in which they are located and by the material in which they are present or by the extent of the injury and its affectation on the real estate. Lesions were identified in the window frames, mainly damage due to dehydration and the presence of biological agents in the wood, loss of watertightness and dirt deposits due to atmospheric contamination or bird droppings.

As for the interior walls, at a general level in the different sectors of the object of study, there are superficial lesions such as cracks in the coating and dirt deposits. Block C of the Foyer shows chromatic alterations due to particle dragging, which suggests that at some point there have been filtrations from the roof. The presence of lesions in the decorative elements located in the first third of the height of the walls, such as wear and tear, point to handling by visitors as the main factor of deterioration. On the other hand, elements such as cornices, moldings, medallions, and other ornamental pieces show chromatic alterations in their gold leaf finish; these manifestations could respond to the incidence of UV radiation and even to differences in the type of material used in the interventions that the different elements have received over time.

Although all the lesions should be the object of attention, it is the cracks that most concern the research team of the project since they could be indicators of movements of the structure and alterations in the stability of the walls. It was possible to verify the presence of important cracks in the columns located in the division between blocks A and B and blocks B and C of the Foyer. According to the Conservation Department of the TNCR, these lesions are sequels of the damages suffered by the building after the earthquake of April 22, 1991, that had an epicenter in the province of Limón and a magnitude of 7.7 Mw. There are historical records of the time that indicate that the building was closed to the public and underwent several interventions to repair the damage caused by the earthquake; however, it is not known if the cracks have stabilized or if, on the contrary, displacements have continued to occur that could put the building at risk. In this sense, the research team considers it appropriate to prioritize the measurement of the movements in the structure to rule out the need for an intervention in this sector of the building. This task is contemplated within the indicators to be recorded in the future digital twin.

Finally, staff from the TNCR Conservation Department provided an Artec 3D EVA laser scanner that was used to record ornaments on the building. This equipment was used to scan specific decorative objects to obtain point clouds and process them using the Scaniverse application. From the models generated, scale prints were made using the Prusa i3 MK3S 3D printer, owned by the School of Architecture and Urbanism. These test models could be improved, and their usefulness assessed in the future within the needs established in the programmed conservation plan (PCP), however, they allowed the team to know the scope of the Artec 3D EVA model for the generation of point clouds and subsequent obtaining of 3D models.

3.3 Information from thermal camera use

Another piece of equipment used to identify the elements of the structural system of the first body of the TNCR and to study the lesions was a Flir model T530 thermographic camera. This equipment was operated by researchers from the School of Architecture and Urbanism and the field work was carried out in December 2022.

Initially it was expected to detect the beams of the mezzanine and the ceiling framework, however, during the visit it was not possible to visualize the mezzanine system, due to the depth of the pieces and the presence of several layers of materials such as canvas, paint support boards, electrical installation ducts, among others.

Despite the difficulties in identifying the pieces, images were obtained in the *"Salón de las Musas".* The thermographic photographs showed the type of support used for the paintings, which consisted of wide wooden planks on which the canvases with the paintings were placed. In addition, it was possible to know the direction in which they were placed and to evidence the presence of some humidity in areas of the ceiling and cornices (see Figure 8).

3.4 Information from the use of endoscopic camera

In the "*Salón de Musas*", two incisions were made in the decorative cornices of the ceiling to observe the structure of the mezzanine using an endoscopic camera. For the first incision, this technique made it possible to verify the presence of one of the beams attached to the wall separating the Salon from the Souvenir Shop, in a north-south direction. In the second incision, made in the cornice adjacent to the wall separating the Salon from the Main Hall, the same type of beam was observed attached in an east-west direction. As a result of this work, the existence of W type beams of 0.30 m height and 0.13 m wide located at a height of 3.70 m, attached to the walls on the perimeter of each space was corroborated.

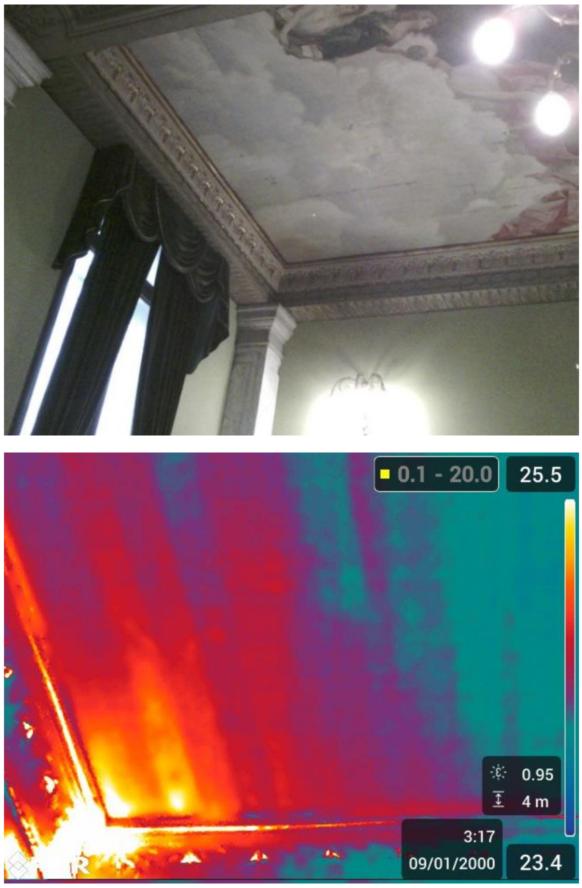

Figure 8. Photographs taken by thermographic camera of the sky in the *"Salón de Musas*", in the first body of the TNCR.

On the other hand, from the electrical registers located in the Foyer, it was possible to appreciate the joists that make up the mezzanine, as well as the wooden chain on top of them. These are W-type steel joists with a depth of 0.185 m and a width of 0.127 m, while the chain plates are made of wood and have a dimension of 0.045 m by 0.045 m. In addition, from the endoscopic camera observation, the presence of wooden joists located between the steel joists was detected. These elements have a dimension of 0.23 m in height by 0.045 m in width and are separated from the steel joists by approximately 0.30 m to 0.35 m. Finally, transverse timber chains were observed, perpendicular to the metal joists, which presumably serve to stiffen the structure (see Figure 9).

Figure 9. Photograph taken by endoscopic camera of the mezzanine of the first body of the TNCR.

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3.5 Information from the pachometer test

To locate the metal structural elements of the mezzanine, pachometer tests were carried out, which, as indicated, are based on the technology of inducing an electromagnetic pulse to detect reinforcing bars inside concrete elements. The test was carried out on November 30, 2022, by laboratory technician Luis Carlos Calvo-Navarro, a CIVCO official. This type of test shows differences in coating, therefore, what can be observed are detections of steel with different types of coating. According to the two tests performed, the coverage can be associated with the depth at which the detection is found. The results of these tests were not clear, since, although they evidenced the presence of metallic elements at different heights, it was not possible to discriminate the type of metallic object, so it is not possible to determine whether it is a structural element or part of the TNCR electrical or mechanical system.

3.6 Information from GPR tests

E The objective of the ground penetrating radar or GPR tests was like the one performed with the pachometer. However, since this technology is based on electromagnetic wave transmission, it was possible to identify the location of different elements. Tests were carried out at two specific times, in both cases by laboratory technician Luis Carlos Calvo-Navarro of CIVCO. The first inspection using this equipment was on November 30, 2022, where four tests were performed: three linear detections in three areas of the Foyer and one area detection, at a point of intersection between the mezzanine and column system. The first two tests were longitudinal, i.e., in a north-south direction, and detected two types of elements. Figure 10 shows part of the results of the second test. On the "x" coordinate axis the depth of the object is identified, while on the "y" coordinate axis the linear location between the objects is identified.

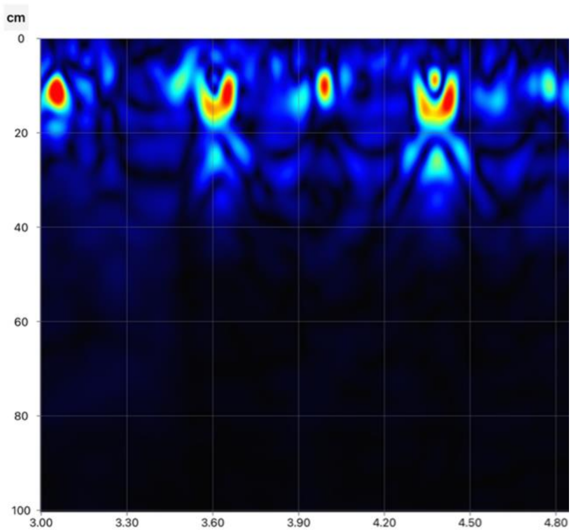

Figure 10. Partial result of GPR test in the TNCR Foyer, November 30, 2022.

The image shows two types of elements, the one that is seen with greater intensity is shown in the form of a "V", in red and orange colors, this is interpreted as the steel joist for being the densest, being the chain on it the one that causes the distortion in the image. The second element, much fainter, is observed as a vertical object, red or yellow in color and is interpreted as the wooden joist. The location identified on the y-axis of the longitudinal linear GPR test is corroborated with the metal and wood joists that are possible to observe through the electrical records of the Foyer. As a result of this technique, it was possible to accurately locate the steel and wood joists that make up the mezzanine of the TNCR Great Hall (see Figure 11).

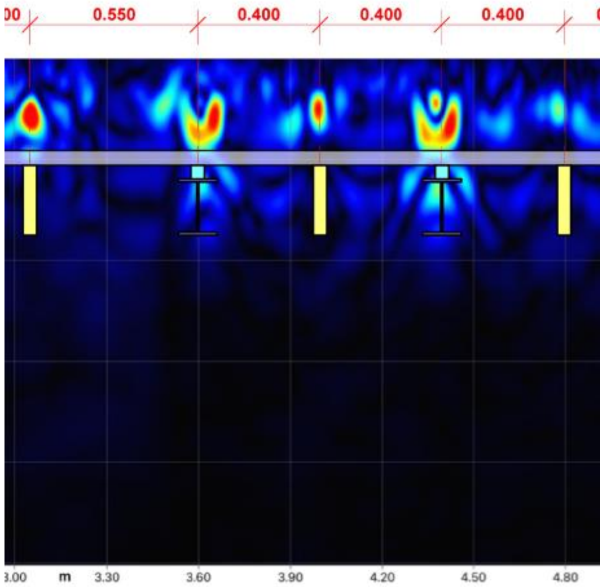

Figure 11 9. Location of steel and wood joists, according to the results of the second longitudinal linear GPR test in the TNCR Foyer, November 30, 2022.

The third test was also linear, but in a transverse direction to the Foyer; that is, from east to west. It was carried out in the south block over the "*Salón de las Musas*". In this test, elements can be seen that are interpreted as W-type beams below the longitudinal joists, which coincide with the axes of the columns of the Main Foyer, as analyzed on site and as shown in Figure 12.

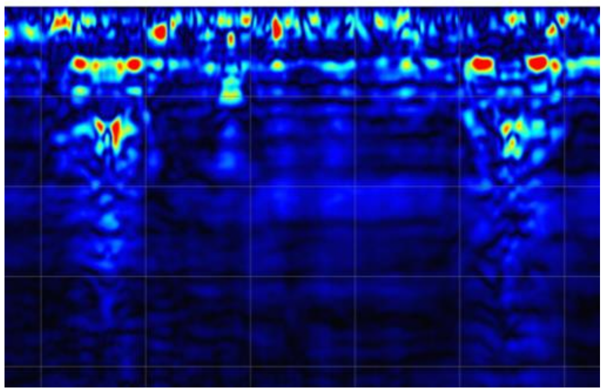

Figure 12 10. Partial result of the third linear cross-sectional GPR trial in the TNCR Foyer, November 30, 2022.

The last and fourth GPR test performed during this first inspection was carried out in the Foyer on the area corresponding to one of the columns of the Main Lobby. This test was of the area type, in an area of 0.60 m by 0.60 m. At the time of the first inspection with non-invasive techniques, we did not have all the details of (Reitz-Eggers, 1890-1897), nor the plans (Gutiérrez-Gutiérrez and Quirós-Lara, 1991), therefore, we were not sure of the number and direction of the beams. The results of this first inspection were interpreted until the second time when new GPR tests were performed.

However, as shown in Figure 13, it was possible to verify the existence of a structural framework. It remained to be determined which elements represented each of the figures present in the image produced by the equipment.

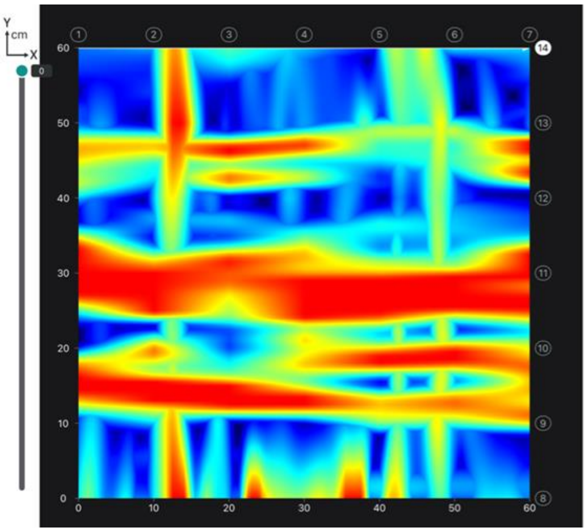

Figure 1311. Result of the area test in the TNCR Foyer, on the column of the Main Lobby, November 30, 2022.

The second time GPR tests were performed was on March 16, 2023, and were also executed by laboratory technician Luis Carlos Calvo-Navarro of CIVCO. On this occasion, having previously conducted an expert consultation with (Monge-Quesada, W., personal communication, February 17, 2023), the inspection was intended to corroborate the information obtained so far. In addition, with the analysis of all the details of (Reitz-Eggers, 1890-1897), and the plans of (Gutiérrez-Gutiérrez and Quirós-Lara, 1991), it was possible to interpret the construction system of the first body of the TNCR, which is described in the conclusions of this paper.

During the second inspection with GPR, four linear tests were carried out in a transversal direction in the central sector of the Foyer, which coincides with the Main Lobby. The purpose of this position was to confirm the presence of longitudinal beams in that area of the west block and to compare the space between them, so that it would be possible to define if there were differences with those detected over the "*Salón de las Musas*". Five linear tests were also carried out at the base of the "Angel of Victory" sculpture, to corroborate the presence of structural reinforcement elements that were described by (Monge-Quesada, W., personal communication, February 17, 2023). Finally, three area revisions were performed with GPR at three points on site: one aligned with the columns of the first level lobby, another outside this line and the last one in the parquet floor that does not have carpet, in the north sector. The purpose of these tests was to interpret the structural framework of beams present under the joists of the mezzanine.

From the first four tests we can confirm the existence of two sets of double longitudinal beams and some other detections in the center (between each pair of beams) that, according to (Calvo-Navarro, L., personal communication, March 17, 2023) it is not possible to determine if it is an element at the same depth of the beams or if it corresponds to a reflection of some upper element that leaves a deeper signal (see Figure 14). In addition, the separation distance between the longitudinal beams in the north-south direction of the central section of the Foyer block is smaller than that of the longitudinal beams located in the north and south sections. The longitudinal beams in the central section are spaced approximately 0.28 m apart and occupy a transverse spacing of approximately 0.54 m (being the same as the transverse beams of this section), while, in the north and south sections, the longitudinal beams are spaced approximately 0.40 m apart, occupying a transverse spacing of approximately 0.66 m.

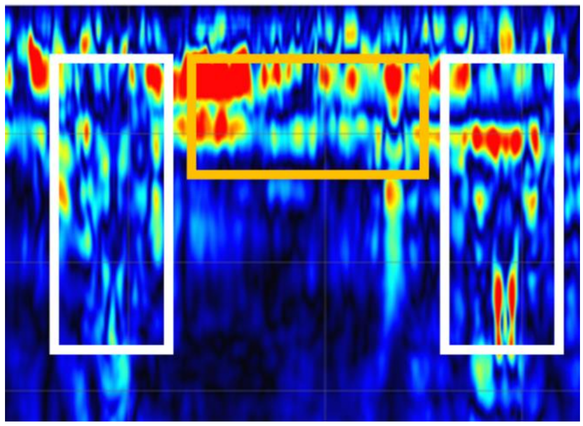

Figure 1412. Resultado parcial de los primeros cuatro ensayos lineales transversales GPR en el Foyer del TNCR, del 16 de marzo, 2023.

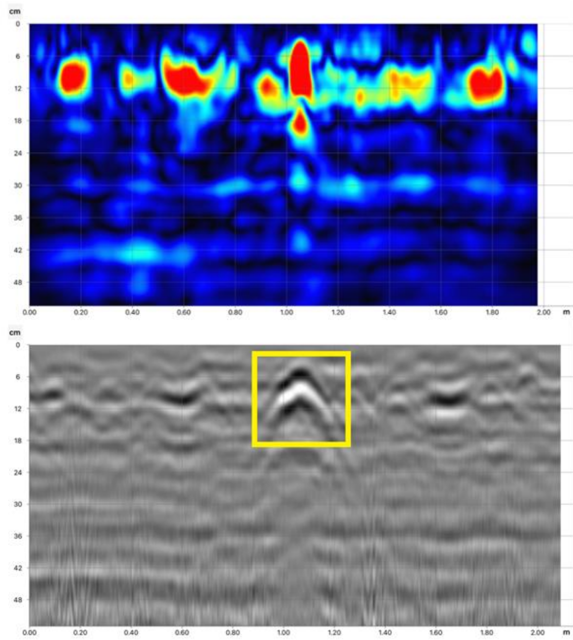

Figure 1513. Result of a linear and radargram test, carried out to the north of the sculpture of the Angel of Victory, located in the Foyer of the TNCR.

With respect to the tests made on the base of the sculpture "Angel of Victory" that corresponds to the central section of the Foyer block (first rectangle) adjacent to the east wall, (Calvo-Navarro, L., personal communication, March 17, 2023) points out that the images show a concave mark that agrees with the possibility of a metal reinforcement to the north (see Figure 15) and south of the base of the sculpture. On the other hand, to the east (back) and west (front) the already known beams are identified and two additional marks are visualized that could coincide with a metallic reinforcement for the installation of the sculpture. Even the radargram seems to show them at a slightly higher level than the previously known beams (see Figure 16).

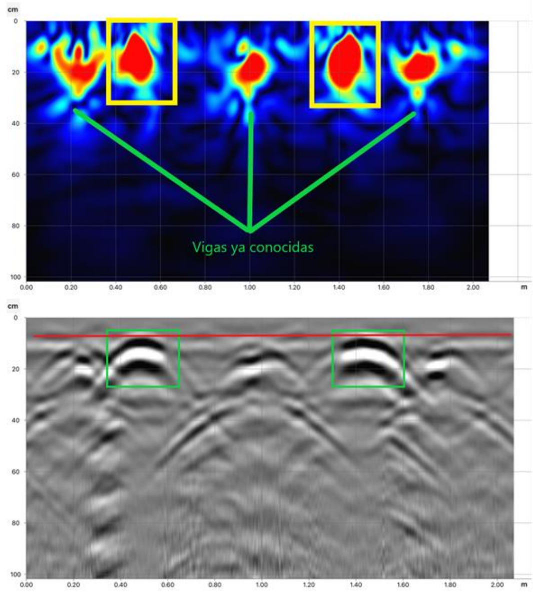

Figure 1614. Result of linear test and radargram, performed to the west (front) of the sculpture "Angel of Victory", located in the Foyer of the TNCR.

Finally, in the three area revisions only the marks of the already recognized beams are observed. This may be due to the number of layers, diversity of materials and depth of the beams present in the object of study, which according to (Calvo-Navarro, L., personal communication, March 17, 2023), may create distortions in the wave impeding a more specific visualization.

3.7 Laser Scanning

Finally, a Leica BLK360 laser scanner was used to record the information of the roof structure. According to the manufacturer's specifications (Leica, Geosystems., 2023), the equipment has a system of four 13-megapixel cameras, which capture spherical images of high dynamic range (HDR). From these images, immersive photospheres and colored point clouds are obtained. With this equipment, a series of surveys were taken and then joined and processed, using the Cyclone Register 360 program, to obtain a sufficiently accurate point cloud for modeling. Autodesk Revit 2023 software was used for the modeling of the structural elements that make up the roof of the first body of the TNCR.

Based on the characteristics of the structural elements present as captured by the point cloud, as well as by the identification of these in the different documents reviewed during the documentary research, it is possible to generate a characterization in the three-dimensional model, identifying the "original" roof elements, i.e. those that correspond to the construction period of the building (prior to 1897) and those that are the product of later interventions, either the one carried out in the 1940s or at the end of the 1990s. As can be seen in Figure 17, the original roof of the Foyer comprises two types of trusses, the first represented with red in the model, corresponds to the main trusses that, according to the original plans, were manufactured abroad; however, the decision was made to increase the slope of the roof and for this purpose a second type of trusses was installed (represented in green in the model) that were placed over the main trusses, allowing a roof slope of approximately 15%. On the other hand, there is also an American type of truss in a horizontal position, located next to the west wall. This element was installed in the 1990s to prevent the collapse of the west wall.

Figure 17 15. Modeling of the roof structure of the central section of the TNCR Foyer block. Prepared by Kevin Hernández-Cervantes.

To identify the stages of construction of the roof and define its age, the type of joint between the structural elements and whether they were assembled on site were taken as characteristics. Under this criterion, bolted joints are the oldest; whereas, those elements that present welded joints between their components, even if they were assembled on site by bolts, are considered to be elements from the 1940s onwards. This criterion is shared by the TNCR Conservation Department, who have their own color coding used to identify the 1897 and 1940s structural elements, which are painted red, while the reinforcing structure placed in the 1990s is painted gray. In addition, the recently placed structure (post-2020) in other TNCR bodies is black. These features were also considered during the three-dimensional modeling to facilitate the identification of the elements.

4. CONCLUSIONS

The conclusions are divided into two types. The first ones are related to the structural system of the building and the following ones show general evaluations in the development of the research project to which the present communication subscribes.

The integration of the information obtained through documentary research, and the contrast of this with the results of the application of non-invasive techniques such as the use of endoscopic camera, tests with ground penetrating radar or GPR and laser scanner, it is possible to identify the structural system the object of study.

1. As illustrated in Figure 18, the columns of the TNCR Main Hall are identified as elements composed of W beams of 0.20 m depth and 0.10 m width approximately. These columns are joined together by means of zig-zag oriented plates.
2. At 3.70 m above the finished floor level of the Main Lobby, a W-beam truss of 0.30 m height and 0.13 m width is located. In the central section of the west block, aligned and above the columns of the Main Lobby, there are two double cross beams that span the space from east to west. They are shown in magenta in Figure 18. Longitudinally in this central section this configuration of the beams is repeated, but with a north-south development, always passing over the metal columns. In Figure 18 they are shown in orange.

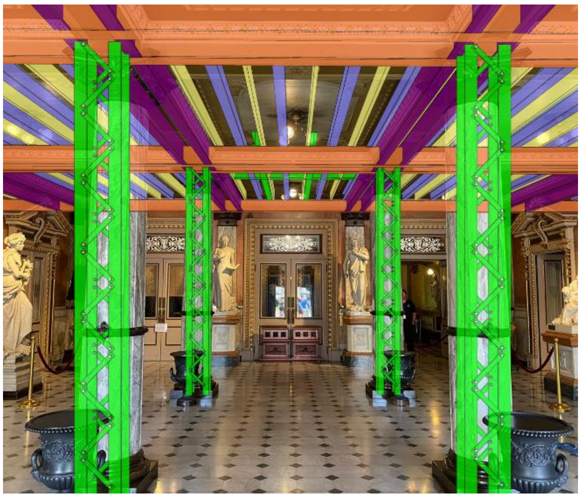

Figure 1816. Metal columns of the Main Foyer and the TNCR Foyer mezzanine framework. Photomontage by Kevin Hernández-Cervantes.

3. As can be seen in Figure 19, in both the north and south sections of the west block, there are also two double longitudinal beams with a north-south development, aligned with those of the central section. On top of these beams, there are a series of W-type metal joists with a camber of 0.185 m and a width of 0.127 m, and on top of these, 35 chains of 0.045 m by 0.045 m, spaced 0.70 m and 0.80 m apart. In addition, between the steel joists there are 35 wooden joists of 0.045 m wide by 0.23 m high, separated from the metal joists by 0.35 m and 0.40 m (see Figure 20).

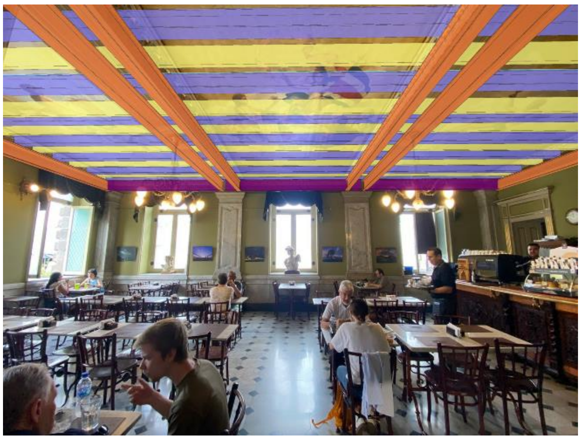

Figure 1917. Longitudinal beams located in the Cafeteria and mezzanine on the north section of the west block of the first body of the TNCR. Photomontage by Kevin Hernández-Cervantes.

4. In the mezzanine of the central section of the west block, adjacent to the east wall and below the "Angel of Victory", structural reinforcements can be identified, one in a north-south direction and two in an east-west direction. Although the location of these reinforcements is known, at the time of writing, it has not been possible to identify their geometric composition, only an approximate camber has been established according to the results of the GPR tests. The geometric re-presentation in the structural modeling is approximate, assuming a continuity in the use of the elements (see Figure 20).

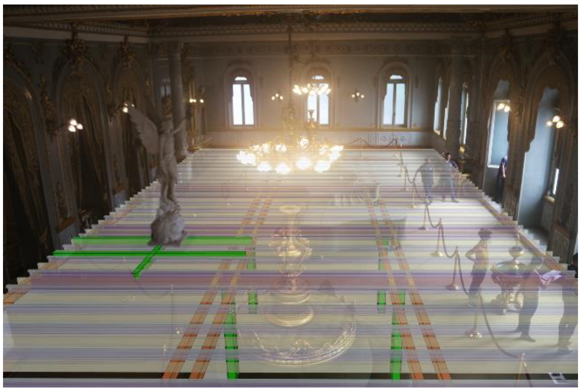

Figure 20. Foyer mezzanine and its structural reinforcement under the Angel of Victory sculpture. Photomontage by Kevin Hernández-Cervantes.

5. Research is required on the basis of photographs from the 1990s, which are on physical support in the TNCR archive, in order to clarify gaps on the geometry of structural elements, as well as on the types of joints present in the mezzanine.
6. In the roof structure of the first body of the TNCR, one type of original trusses is identified according to the plans, and another type of overlapping trusses to increase the slope. Also identified is a metal structure that stabilizes the roof, which is presumed to have been installed in the 1940s. The latter must be confirmed according to documental research. In addition, the re-fortification structure installed in the 1990s is identified. The last two elements described are still in the process of being modeled.

In spite of the importance of this building as a witness of an era, its uniqueness as a representative of the architecture developed in Costa Rica at the end of the 19th century and being the only building declared National Symbol of the country, the National Theater of Costa Rica does not escape the problems faced by many buildings of historical-architectural value in terms of access and integration of the existing information about its construction, interventions and management of its conservation processes. The need for a detailed and unified registry that systematizes all the aspects and processes that are developed in the object of study is evident, in order to achieve an integral management of the building under the concept of programmed conservation. The dispersion of information about the interventions that have been carried out in the building, the incalculable value of its artistic work and the constant use of the building due to the high number of visitors to which it is subject, made it essential to use non-invasive techniques that would allow us to know in detail the structural system of the first body of the TNCR. The use of traditional techniques for the survey, such as photography and verification of measurements in the field, are in themselves insufficient when dealing with buildings with a high degree of detail and mixed construction systems; however, they are valuable techniques that complement the field work carried out with new technologies and allow us to obtain accurate information that later translates into more detailed models similar to the architectural object under analysis.

The integration of different disciplines in the study of architectural heritage is not a new topic, however, it is becoming increasingly evident as a necessity. In the light of programmed conservation, a building is not conceived as a merely architectural or artistic object, but as an asset whose survival is the result of the participation of different types of professionals, who contribute from each area of knowledge for a common goal known and assumed by all as a working team. The research project "Digital Twin (DT) as a management tool for the programmed conservation plan (PCP). Case study: foyer and smoking rooms of the National Theater of Costa Rica" is a first stage in the attempt to improve the management processes of heritage properties in the country. To achieve the proposed scope for this first part, there are still some questions that will need to be resolved before the end of the first semester of 2024 and fulfill the third objective of the project. These questions are:

- How to link the information from 1897, the 1940s and the 1990s to the three-dimensional model?
- What information needs to be linked to the three-dimensional model and the subsequent Digital Twin?
- What information from the models is useful for linking vulnerabilities to the Digital Twin visualization?

Research in the field of cultural heritage is a dynamic process that is continuously evolving. Specialization in intervention techniques and in the use of new technologies must permeate the teams in charge of the important task of conserving our country's heritage. From the different houses of education and institutions related to the subject it is necessary to establish alliances that allow the training and transfer of knowledge that is developed daily, so that every day we have more trained personnel in the best tools for the management of our heritage resources. Research and university extension projects are an opportunity to continue supporting the conservation processes of the important historical, architectural and cultural legacy that we still have in Costa Rica. It is essential that the links continue to strengthen and extend towards their consolidation as part of the strategies to safeguard our heritage.

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