

Article

The Treachery of Images: Redefining the Structural System of Havana's National Art Schools

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Abstract: This paper illustrates the contribution that on-site survey and graphical documentation offer to the structural comprehension of 20th century architectural and civil engineering heritage and, therefore, to its sustainable conservation. The research herein presented has identified the true structural system of Havana's National Art Schools, an internationally well-known architectural masterpiece that was recently investigated within the drafting of a comprehensive conservation management plan. This iconic complex was built right after the Castro's revolution and was meant to embody Cuba's newfound freedom. To this end, the complex was supposed to be built using Catalan vaulting, a technique loaded with significance due to its provenance, affordability, and flexibility. While most of the literature, the architectural features, and the very designers assert that no concrete nor steel were employed during construction, recent studies suggested that a reinforced concrete core might be hidden behind the masonry-like appearance of the five buildings. The structural analysis performed in order to draft a conservation and management plan for the school site thus became a hermeneutic opportunity to address this topic. Combining direct observation, documentary research, and nondestructive analyses (infrared thermography and magnetometer testing), it was possible to finally redefine the structural nature of these notorious architectures, which are indeed mostly made of reinforced concrete.

Keywords: Havana's National Art Schools; hidden structure; reinforced concrete; documentary analysis; graphical documentation; infrared thermography



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1. Introduction

Through the case study of Havana's National Art Schools, this paper aims to underline the role of graphical documentation within the process of knowledge, which sets the foundations for any conservation activity. Indeed, images "visible" (buildings in their current conditions), "beyond the visible" (thermographs), and "no-more visible" (photographs of the construction site and original blueprints) are hereby combined to redefine the structural system of this 20th century architectural icon. Contrary to what was commonly believed, the whole architectural complex was hardly built employing the Catalan vaulting technique, as the five school buildings were instead found to have a reinforced concrete core hidden behind the masonry-like appearance.

Therefore, the presented research also configured as an occasion to re-evaluate the relationship between the field of construction history and restoration, demonstrating how in architecture, the hands-on conservation activity may increase knowledge together with literature study. The analyses and trials performed on the buildings to develop a conservation and management plan unexpectedly brought to light clues that denied what had been acknowledged by previous literature.

After a brief overview of the history of the National Art Schools (Section 1.1), the paper thus examines the state of the art (Section 1.2), considering both the single case study and related literature, and, in broad terms, concrete architectures and their changing

perception over time. A further paragraph is dedicated to the description of the adopted methodology (2), which mainly resorted to three analysis techniques: namely, documentary research, direct observation, and noninvasive testing such as infrared thermography and magnetometer survey. The outcomes of the study are presented in Section 3, which provides a step-by-step description of the process that led to the concrete discovery in each one of the four analyzed buildings. Finally, the results are reconsidered with reference to a broader context (4), highlighting how conservation and restoration activities always contribute to increasing the knowledge, even when dealing with notorious and widely studied buildings.

1.1. The Case Study

Havana's National Art Schools are a highly iconic example of modern architecture. Built between 1961 and 1965, they were made to embody the very ideals of the Cuban revolution, conveying a sense of novelty and freedom. Such ambition was entrusted to three young architects—namely Vittorio Garatti, Roberto Gottardi, and Ricardo Porro—who designed and constructed their masterpieces on the golf course of Havana's former Country Club. In particular, the plan was to build five pavilions devoted to the teaching of just as many art disciplines: music, ballet, modern dance, plastic arts, and dramatic arts (Figure 1).



Figure 1. Satellite map of the campus and overview of the five schools: (a) School of Ballet; (b) School of Modern Dance; (c) School of Dramatic Arts; (d) School of Plastic Arts; (e) School of Music (photos by the authors).

Given the extent of the task and the limited time available, work was split between the three architects, and each one of them was put in charge of one or two buildings: Garatti oversaw the construction of the Schools of Ballet (Figure 1a) and Music (Figure 1e), Gottardi of the School of Dramatic Arts (Figure 1c), and Porro of the Schools of Plastic Arts (Figure 1d) and Modern Dance (Figure 1b). As the aim was however to create a homogeneous complex, to overcome physical distance between the pavilions and style differences owed to the architects' diverse education, the designers sought unity in architectural and structural features. From the very beginning, they identified a few shared principles to follow throughout construction, such as formal freedom, integration with nature, and the employment of the same construction systems and building materials. With regard to the latter, they also agreed to avoid the use of concrete and steel, arguing that such materials were lacking in the postrevolution phase, in favor of locally sourced materials and workmanship and, especially, of bricks and Catalan vaulting [1,2].

This technique, then unknown to Cuban builders, was originally developed in the Mediterranean area and, especially, in Spain [3]. The construction method consists in the overlaying of several layers of thin tiles (typically no less than two) bound together by mortar. The peculiarity of Catalan vaults is that they find stability in their own geometry: their light weight and calibrated shape enable them to avoid the use of reinforcements of any kind as well as to limit the use of fixed centering during construction [4,5]. Both these features contributed to making this technique particularly inexpensive.

Thin-tile vaulting (or Catalan vaulting) landed in North America at the end of the XIX century with Spanish architect Rafael Moreno Guastavino [6,7]. While quickly catching on in the United States, it appears that by the 1960s, this construction technique still had not reached Cuba, making it a perfect fit for the construction of the National Art Schools: new, flexible, and low cost. Moreover, the arrival of Spanish mason Gumersindo on the island provided the chance to overcome the lack of expertise of local constructors. Both experiments to test the functioning of the structural system, and classes to supply the know-how were organized, as confirmed by several photographs (Figure 2). The Cuban Ministry of Construction (MiCons) even issued a booklet on tile constructions, including a few pages containing detailed instructions on how to build Catalan vaults [8].

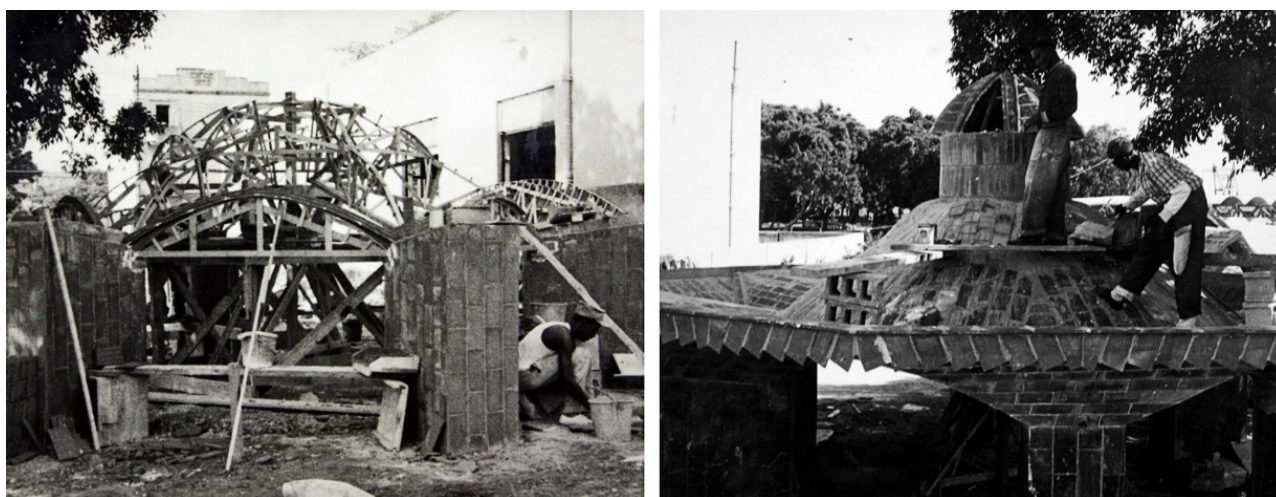


Figure 2. Photographs stored in the Universidad de las Artes de Cuba (ISA) archive showing a teaching workshop and small-scale testing of the Catalan vaulting technique. The original caption by José Mosquera reads: “Banco de pruebas. Escuela para aprender la tecnica constructiva” [“Test bed. School for learning the building technique”].

As a result, although different from one another, the five schools look somewhat alike: they all display organic shapes and appear to be mostly made of masonry, and seemingly thin-tile vaults.

Given these premises, for several decades the schools were believed to be outstanding examples of this peculiar building technique. This is widely asserted in literature [1,2,9,10] and confirmed by the very architects, who repeatedly failed to clear up the misunderstanding, when asked to talk about the schools [11–13]. Although they admitted to the use of iron tie rods [14], they never explicitly mentioned that the five buildings have a hidden reinforced concrete core, as pointed out by the results hereinafter presented.

The abrupt interruption of the construction site occurred in 1965 left three out of the five pavilions uncompleted and thus unable to fulfill their original functional requirements. While Porro's schools have been up and running since 1964, the Schools of Ballet, Music, and Dramatic Arts were soon dismissed and left to perish for several decades. Despite physical abandonment, the utopian genesis of the National Art Schools was never forgotten, and the revolutionary facet of these iconic architectures was frequently analyzed in literature [2,15–17]. If the formal and cultural-related aspects of the schools have been widely debated through the years, little has been said about more technical matters, such as the construction methods adopted or the structural behavior of these peculiar pavilions. In fact, the first truly scientific study on the topic was conducted by John Loomis in the 1990s: his book, *A Revolution of Forms* [9], offers a systematic description of the five buildings based on both historical documentation and direct observation.

1.2. The State of the Art

While representing an important milestone, Loomis' book contributed to feeding the myth that the architectures were indeed masonry structures. The international influence of the publication brought growing attention to the schools, finally reaching the engineering community. Picking up on the exceptional features of these buildings, Princeton University's Department of Civil and Environmental Engineering started an investigation aimed at clarifying the organization and behavior of these impressive thin-shell structures [18]. The study mainly focused on the domed pavilions of the School of Ballet, whose shape and dimensions appear particularly daring from a structural point of view, especially since, at the time, they were thought to be built employing the Catalan vaulting technique [9]. However, during an on-site inspection occurred in 2016, Princeton's former student Isabella Douglas detected some anomalies that allowed her to uncover the true structural system of the building. While analyzing the dance pavilions, she noticed recurrent delamination which had resulted in the fall-off of large portions of the outermost layer of tiles. Based on the knowledge of the construction process, the substratum was initially assumed to be a layer of mortar connecting two adjoining layers of tiles, but upon closer examination, it was revealed to be a rather thick layer of reinforced concrete [19–22]. Such a conclusion was drawn from two relevant observations: the first one being the presence of exposed reinforcing steel on one of the pendentives supporting the dome of the dance pavilions, and the second one the fact that tile delamination could most easily be explained as a consequence of concrete spalling. Indeed, rebar only became visible due to the detachment of a consistent block of concrete, which generated a 7 cm deep hole at the bottom of which it is possible to see tie wire (Figure 3).

Seeking further validation of these new findings, Princeton's scholars turned to the historical documentation at their disposal. In particular, they resorted to the oral testimony and photographic albums of school's builder José Mosquera, who carefully documented nearly all stages of the construction site. Piecing together information collected from direct and indirect sources, Douglas was finally able to redefine the construction system of Vittorio Garatti's School of Ballet, whose bearing structure turned out to be mostly made of reinforced concrete. The deceptive appearance of the building, which actually suggests otherwise, comes as a direct result of the construction process.

Michele Paradiso had come to similar conclusions, after examining the very same pictures. In a paper published in 2014 [23], he stated that the extensive use of reinforced concrete shown by the building site's photographs testified to the use of a mixed technique, rather than Catalan vaulting. Moreover, the scholar had had the opportunity to participate

to a meeting occurred at the Cuban Ministry of Construction (MICONS) in 2008, in the presence of some of the engineers and architects who had originally taken part to the construction of the schools. In that occasion, Arch. José Mosquera and Arch. Regino A. Gayoso Blanco affirmed that, in order to ensure the stability of the complex architectural shapes designed by the architects, it was decided to use reinforced concrete. Indeed, although rarely acknowledged, several structural engineers participated in the project. Among others, Edoardo Esenarro and Isabelita Wittmarch worked side by side with Vittorio Garatti and Ilda Fernandez with Ricardo Porro.



Figure 3. The pendentives of the dance pavilion's dome. The loss of the outermost layer of tiles unveiled the presence of reinforced concrete. The picture on the right shows the visible tie wire.

As emerged from an attentive study of Mosquera's pictures, the main criterion adopted throughout the building site was that of covering the inside of the wooden formworks with one or more layers of clay tiles before placing rebar and pouring the concrete inside of them (Figure 4).



Figure 4. The School of Ballet's choreography theater during construction. The photograph depicts the wooden formworks for the casting of the dome's concrete ribs and rings (ISA archive).

This way, once the concrete had set, the wooden formwork could be dismantled, leaving the tile coating in sight while hiding the core structure underneath. To complete the job, the extrados was also tiled, so that it would in fact appear as a thin-tile vaulted structure [22]. The side finishing of the arches is particularly misleading as it shows the typical pattern of this construction technique: alternating layers of tiles and mortar (Figure 5).



Figure 5. The deceptive appearance of the side finishing of the domes and vaults of the School of Ballet, displaying alternating layers of clay tiles and mortar (photo by the authors).

Overcoming appearances, Michele Paradiso was the first to point out the use of a mixed technique within the National Art Schools complex. Later on, Princeton's work group was able to confirm Paradiso's argument by identifying the structural system of the domes of the School of Ballet as concrete grid shells with adobe tile covering. The work hereby presented takes a further step forward, demonstrating how all five schools conceal concrete and steel reinforcements.

As proven by the aforementioned works, since John Loomis' book, studies on Havana's National Schools of Art have consistently increased [24–31] and so have international recognitions of their significance. Starting from 2000, they have repeatedly been included in the World Monuments Fund's Watch List (2000, 2002, 2016) [32]; in 2003, they were listed in the UNESCO tentative list [33], and in 2010, they were declared a National Monument by the Cuban Government. The newfound prominence of the Schools of Art also highlighted the need for an improved management of the whole complex, fostering further initiatives aimed at preserving the site. In particular, in 2018, the schools were awarded a grant within the frame of the Getty Foundation's Keeping It Modern initiative [34], which was devoted to the development of a conservation management plan. The project, led by Politecnico di Milano, saw the participation of Assorestauro, Princeton University, Università di Parma and Universidad de las Artes de Cuba (ISA) and addressed several issues, taking into account the multiple aspects contributing to architectural heritage preservation. Picking up from where Princeton's studies left off, the occasion also offered a chance to further clarify the structural features of the five buildings, and thus to verify whether the use of reinforced concrete was limited to the School of Ballet or spread also to the other schools, configuring as the main construction system employed despite the original premises.

The International Context: An Overview

The vicissitudes of the National Art Schools should however also be considered in light of the contemporary international context. The construction of the schools occurred at a time of debate, when the architects' community had not yet taken a firm position toward reinforced concrete architectures. Indeed, if the use of reinforced stone—somewhat the ancestor of reinforced concrete—had been used for several centuries, it was not until a hundred years later that reinforced concrete (as currently intended) made its first appearance. For a few decades, however, its use was mostly limited to industrial or civil engineering applications. The tables turned with the advent of Auguste Perret (1874–1954), whose work legitimized the use of concrete for architectural purposes.

In the following years, and until the 1960s, architecture critics found themselves divided on how to approach the extensive use of reinforced concrete: some defended classicism, whilst others supported modernism. In particular, Peter Collins sought for a continuity of classicism [35,36], showing his entanglement in the past. Reyner Banham and Robert Venturi also addressed the question. According to Colin Rowe, they represented “the polar extremes between which architecture now [1960s] oscillates” [37]. If on the one hand Banham wished for a functional and upfront architecture [38,39], on the other, Venturi made “ambiguity” his very motto, praising the richness of “nonstraightforward architecture” [40].

In this controversial panorama, it is rather easy to imagine how the three young architects of the National Art Schools might have had some difficulties deciding on how to proceed. After their plan to employ pure Catalan vaulting flunked, possibly due to structural engineers' concerns, they found themselves having to choose between form and significance.

While reinforced concrete was “invented” as a building material at the end of the 19th century, the issue of its conservation only developed in recent years. In fact, the need to preserve the architectural heritage of the 20th century poses specific conservation challenges that need careful addressing. The literature in this regard has been flourishing over the last 20 years, encompassing many aspects of reinforced concrete damages and conservation [41–55].

Having the opportunity to participate to the Keeping It Modern initiative, it was interesting to examine how the topic of concrete conservation had been dealt with in other studies but also to check whether cases of “hidden concrete structures” had previously been recorded. While some of the developed conservation and management plans primarily focused on concrete pathologies [56–58], others provided all-round structural analyses of the architectures in question [59,60]. This of course entailed the need for a thorough interpretative process, comprising on-site inspections, documentary research, and instrumental investigations.

The case of the Uruguayan Iglesia de la Parroquia de Cristo Obrero [60] has proven particularly interesting as it displayed astonishing similarities to the schools of Havana. The engineer who designed the church, Eladio Dieste, employed a technique he called “*c ramica armada*”, which basically combined the properties of Catalan vaults with those of steel reinforcement and, occasionally, concrete (or extremely thick layers of mortar). Unlike the case of the National Art Schools, however, Dieste was always quite transparent about the structural system of the church [60] (p. 48).

Even though other conservation plans did not highlight discrepancies as consistent as those emerged for the Cuban case, they all provided compelling strategies, offering helpful suggestions to address the question of concrete analysis and preservation.

2. Materials and Methods

As mentioned, the presented study configures as a (so to speak) accidental consequence of a broader research, aimed at drafting a conservation and management plan to safeguard the whole National Art Schools complex. In the process, one of the primary objectives was the assessment of the stability of the buildings, which, to that end, could not

be left aside. To correctly interpret the structural behavior of these peculiar architectures, an in-depth analysis of each construction element was however necessary. The efforts made to define their stratigraphy and construction technique, ended up uncovering unexpected data concerning the buildings' structural system.

The original conservation purpose thus became a hermeneutic opportunity which enabled one to update the historic evaluation of the schools' site, providing an enhanced understanding of its buildings. This, however, is not an isolated case: while construction history upholds its prominent role in restoration, it is by now clear that there is a certain reciprocity between the two disciplines. As a matter of fact, conservation activities often bring to light forgotten pieces of information which, integrated with data collected before the intervention, allow one to refine the global discernment of the asset [61].

With regard to the specific topic addressed by this paper, the amendment of the structural knowledge of the buildings was achieved by adopting a combined approach which took into account several different sources of information. Direct observation, documentary research, and noninvasive analyses, all resulting in some sort of graphical documentation, equally contributed to the identification of the technique employed in the construction of the National Art Schools. In fact, it was only by fitting together evidence emerged from these three activities (original drawings, pictures of the construction site, and infrared thermographs) that reliable results were obtained.

Due to the lack of archival documents regarding the Schools of Dramatic Arts, Plastic Arts, and Modern Dance, the described method was only adopted for the Schools of Ballet and Music. Nonetheless, infrared thermography was also used as the primary tool to collect information regarding the structural system of the Schools of Plastic Arts and Dramatic Arts. Because of its rather straightforward appearance, the School of Modern Dance was not included in the presented study. Indeed, the concrete ribs supporting the vaults are clearly visible here, even highlighted by the chromatic contrast between bricks and white-painted concrete. The structural layout of this specific building was hence one of the clues that motivated the research.

Ultimately, the research employed a comparative method combining direct and indirect sources, and more specifically images from the past, and "visible" and "beyond the visible" images of the present that was able to reveal, once and for all, the true structural nature of Havana's National Schools of Art. The main techniques adopted throughout the study will be further described in the following subsections.

2.1. Direct Observation

The first step consisted of the observation of the architectural object, which, as well known, is the first document of itself [62,63]. In particular, the severe decay affecting these long-time neglected architectures has uncovered features that were intended to stay hidden.

On the one hand, the diffused loss of the finishing layers or of even more significant portions of material proved quite helpful in order to define the stratigraphy of the construction elements without resorting to microdestructive investigations. This was, for instance, the case for Douglas' studies [19–22], as she realized that the domes of the School of Ballet were not Catalan vaults by visually noticing the presence of concrete and steel rebar in one of the pendentives.

On the other hand, the interpretation of the deterioration phenomena, intended as visible manifestation of internal actions (and interactions), also provided useful hints to define the construction system of the buildings. In particular, the analysis of crack patterns and deformations allowed one to clarify their structural behavior and hence to evaluate its compatibility with the supposed building technique and materials.

Each of the four schools considered by the research was thus preliminary examined, searching for clues to either confirm or deny the use of reinforced concrete instead of Catalan vaulting. However, since mere visual inspection was not sufficient to dispel the doubts raised by Princeton's research, further studies were carried out.

2.2. Documentary Research

The close examination of the historical documents describing the construction process of the schools was also configured as a valuable source of information. In fact, within the Keeping It Modern initiative, one of the main objectives was the collection and reorganization of the heterogeneous materials regarding the site. The research uncovered a large number of documents of different typology, origin, format, and medium. The whole documentary heritage concerning the National Art Schools (from construction to present days) was estimated to comprise tens of thousands of items.

This brought to the institution of a dedicated archival fond (ISA archive) which guaranteed greater access to documentation, thus allowing one to both reconsider the photographs that had already been taken into account by previous studies and to analyze yet unreleased evidence. It should however be noted that most of the gathered materials concern the work of Vittorio Garatti and hence mainly offer data about the Schools of Music and Ballet. Two types of documents proved fundamental to the scope of the research: the original blueprints by the architects and the pictures taken during construction.

2.2.1. Original Blueprints

The 1960s drawings allowed one to better understand the architects' original conception, and thus whether the idea of integrating or fully replacing the Catalan vaults with reinforced concrete arose from possible criticalities emerged during construction or, on the contrary, had been the builders' intention all along. The examined blueprints lean toward the latter option, leading to the hypothesis that the principle of using the Catalan Vaulting technique never materialized, not even on paper.

About 509 digital copies of the 1960s blueprints for the Schools of Music and Ballet were collected thanks to the documentary research. Such files mainly consist of scans of the paper drawings and heliographies from the original designs, dating from 1961 to 1965. At the time of the scan, most of the drawing appeared to be in a fair state of repair, despite the presence of a few rips around the edges. Architect Vittorio Garatti is the author of most of the designs, although helped by several different draughtsmen. The drawings have different paper sizes and scales of representation, as they concern many aspects, ranging from the general architectural layout of the buildings (plans and sections) to more technical issues such as construction details, plant design, and finishing. Most measurements are expressed according to the metric system, but in some cases, the US system was also used.

To our purpose, the most relevant drawings were those concerning structural features. Indications regarding the stratigraphy of the main construction elements were later verified by means of on-site investigations. In particular, blueprints showing the intended position and dimensions of steel rebar proved fundamental to define a targeted diagnostic plan leading to concrete discovering and pinpointing.

It should however be noted that the original drawings do not offer any certainty concerning the actual realization of the designs, since changes might have occurred throughout the building site.

2.2.2. Photographic Materials

The rich photographic apparatus, on the other hand, enabled it to partly overcome such uncertainties, offering more reliable data. In fact, the intrinsic documentary nature of photography contributed to the elevation of the camera to a scientific tool soon after its invention [64,65]. It was probably with this purpose that José Mosquera took frequent pictures of the building site of the School of Ballet, recounting the entire construction process through a sequence of images. Unfortunately, since Mosquera was mainly involved in the design and realization of the School of Ballet, photographs concerning the other buildings are sporadic and do not allow one to retrace the building activities in their continuity. While Princeton's scholars already had the chance to see Mosquera's albums, further pictures were found among the ISA archive, which includes about 300 photographs taken by different authors between 1961 and 2020. In particular, the pictures concerning the

construction phase were mostly taken by José Mosquera and Vittorio Garatti. The archive also stores the shots taken by photographer Paolo Gasparini after the schools' completion. This photographic survey, which had more of a celebratory purpose [66], somehow ended up fomenting the idealistic facet of these architectures and, along with it, the Catalan vaulting myth. After all, right after the construction site shut down, the appearance of the schools was impeccably deceitful, hiding all the clues that recently unveiled the presence of reinforced concrete. Several authorial and amateur surveys followed the one by Gasparini, documenting the gradual changes and decay of the schools, and, therefore, the slow resurfacing of the concrete core.

Among these materials, the most relevant information was deduced from the building site's pictures by Vittorio Garatti, which had never been examined before. Indeed, a few of his photographs captured details that do not appear in Mosquera's albums (and viceversa). Such images offered new data that helped complete and refine previous theories, with particular reference to the extensive use of reinforced concrete in the School of Ballet.

2.3. Noninvasive Analyses

The technical details deduced from the iconographic records were crosschecked with information emerged from direct observation as well as with the outcome of few non-invasive on-site analyses, such as infrared thermography (IRT) and magnetometer testing.

The former method has been widely adopted in cultural heritage preservation since the 1980s, as it enables one to highlight possible discontinuities and anomalies (e.g., cracks and delamination), in the substrate [67,68], even when they are not visible to the naked eye. In fact, IRT is a contactless test method that uses an infrared imaging system to measure the distribution of the emissive power of different surfaces at various temperature ranges [69,70]. The outcome is a series of two-dimensional images (thermographs), in which each color identifies a different surface's apparent temperature (ISO 6781:1983; ISO 18434-1:2008; UNI EN 13187:2000) [69].

The surveys were conducted using a FLIR T1020 thermal camera, while the IR inspection's acquisitions were processed through Grayess Stritch software. Finally, the resulting thermographic mosaics were composed using Adobe Photoshop.

The second investigation technique adopted to identify the structural system of the buildings was magnetometer testing, which is broadly used to locate and estimate the diameter of steel rebar (BS 1881-204:1988). Of course, in the specific case, the aim was rather to verify whether rebar was present or not, than to determine its geometry and distribution. Since pure Catalan vaulting does not include metallic reinforcement, the detection of any iron elements would have implied the use of a different construction system, or—at least—of a mixed one. Pachometer testing was only carried out on the vaults and domes of the School of Ballet, using a HILTI PS 200 Ferrosan, whose maximum detection depth for object localization is approximately 18 cm.

3. Results

The following subsections illustrate the outcomes of the study, providing a detailed description of the aforementioned comparative method as applied to each one of the four analyzed schools.

3.1. School of Ballet

3.1.1. Choreography Theater and Dance Pavilions

Moving from Princeton scholars' findings, the present work was able to further clarify the constructive system of the main domes of the School of Ballet. Thanks to targeted analyses and new pieces of information that emerged from the historical documentation, it was possible to highlight an even more extensive use of concrete than expected.

In particular, the present research was able to retrace step by step the building process of the school. According to the ascertained criterion that work forms would be made—or at least covered—with clay tiles, the first stage of construction was the setting up of the

wooden scaffoldings, which, given the dimensions of the pavilions, ended up being rather complex structures (Figure 6).

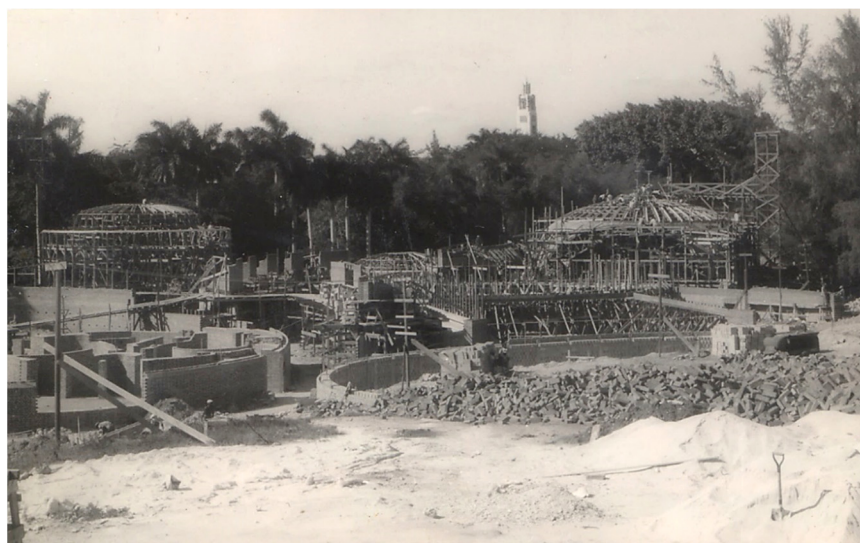


Figure 6. The wooden scaffoldings installed for the construction of the School of Ballet's dance pavilions (ISA archive).

Once the scaffoldings were in place, masons proceeded to lay one or more layers of clay tiles to build the work forms. In particular, for the pendentives of the dance pavilions and the annular sector at the base of the choreography theater's dome, the intrados was shaped following the geometry of the supporting centering (Figure 7). On the other hand, the work form of the rings and ribs composing the grid of the upper spherical cap were basically made of wood and were then coated with tiles on the inside (Figure 8). Reinforcing bars were subsequently positioned (Figure 9) and finally the concrete was poured to create the main bearing framework (Figure 10). The next step was to fill the gaps of the concrete grid, which was achieved through the construction of narrow tile vaults.



Figure 7. One of the pendentives of the dance pavilions' domes during construction. As can be noticed, the tiled intrados of the pendentive was configured as a work form for the subsequent concrete casting (ISA archive).



Figure 8. The wooden formworks of the ribs and rings of the choreography theater while being coated with clay tiles on the inside (ISA archive).



(a)



(b)

Figure 9. (a) The reinforcing bars positioned in the domes' ribs and rings before the pouring of the concrete. (b) The rebar grid located at the intrados of the pendentives of the dance pavilions before the concrete casting. An analogous reinforcement was placed around the annular sector at the base of the choreography theater (ISA archive).

Although the “filling vaults”, due to their limited span, could reasonably be taken for actual Catalan vaults, a newfound drawing by Garatti (Figure 11) and a picture from the construction site (Figure 12) prove otherwise, showing how even these elements were intended as work forms.



Figure 10. One of the dance pavilions after the concrete casting. The picture clearly shows the concrete framework hidden beneath the current clay tile covering (ISA archive).

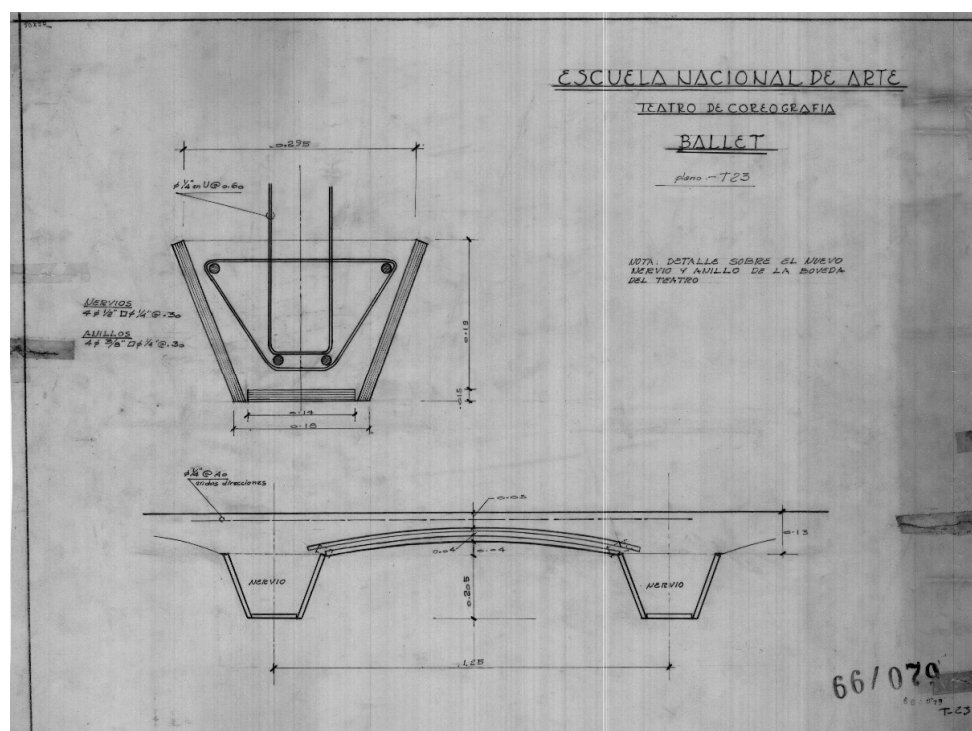


Figure 11. A drawing from the original 1960s project showing the intention of covering the narrow tile vaults between the ribs with a further layer of reinforced concrete (ISA archive).

Figure 12 displays a reinforcing steel net positioned above the ribbed cap of the choreography theater, indicating the intention of casting a further concrete layer, just as illustrated by the architect's original design. While no further pictures documenting the next stages of construction of the choreography theater were found, some photographs of the dance pavilions suggest that the same technique was adopted there. Figure 13 shows

one of the latter after the second concrete casting, which covers the entire surface of the dome, creating a smooth and continuous shell. Although there are no records to confirm that the reinforcing net was also used in the dance pavilions, the upward steel connections linked to the ribs and rings' rebar seem to validate this theory (Figure 14). Finally, the extradoses of the domes were covered with clay tiles, hiding the reinforced concrete from the sight and definitely simulating a masonry structure (Figure 15).



Figure 12. The reinforcing steel net positioned above the ribbed cap of the choreography theater before the second concrete casting (ISA archive).

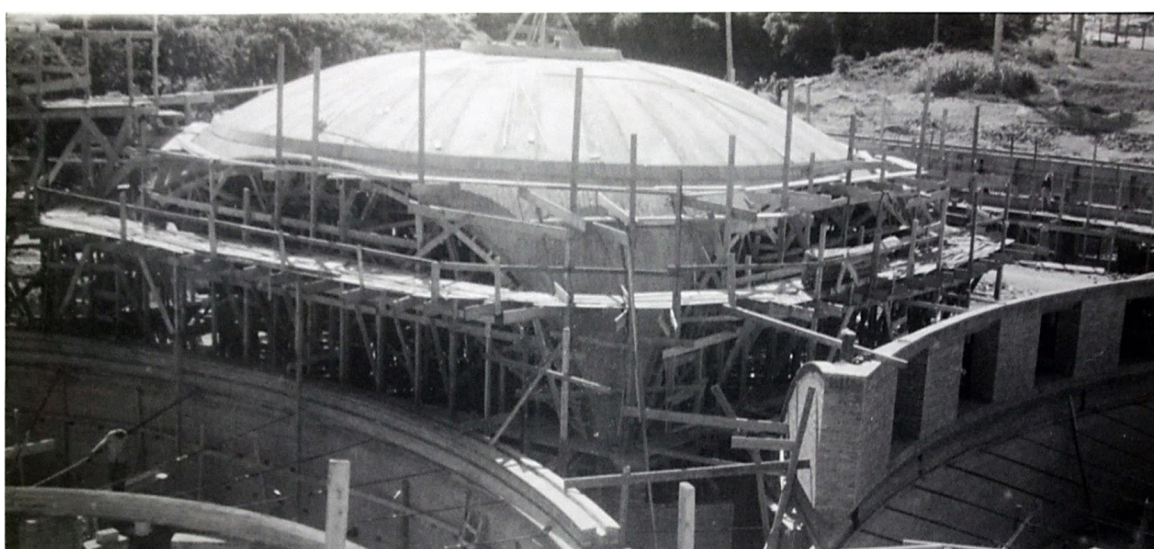


Figure 13. One of the dance pavilions after the second concrete casting (ISA archive).

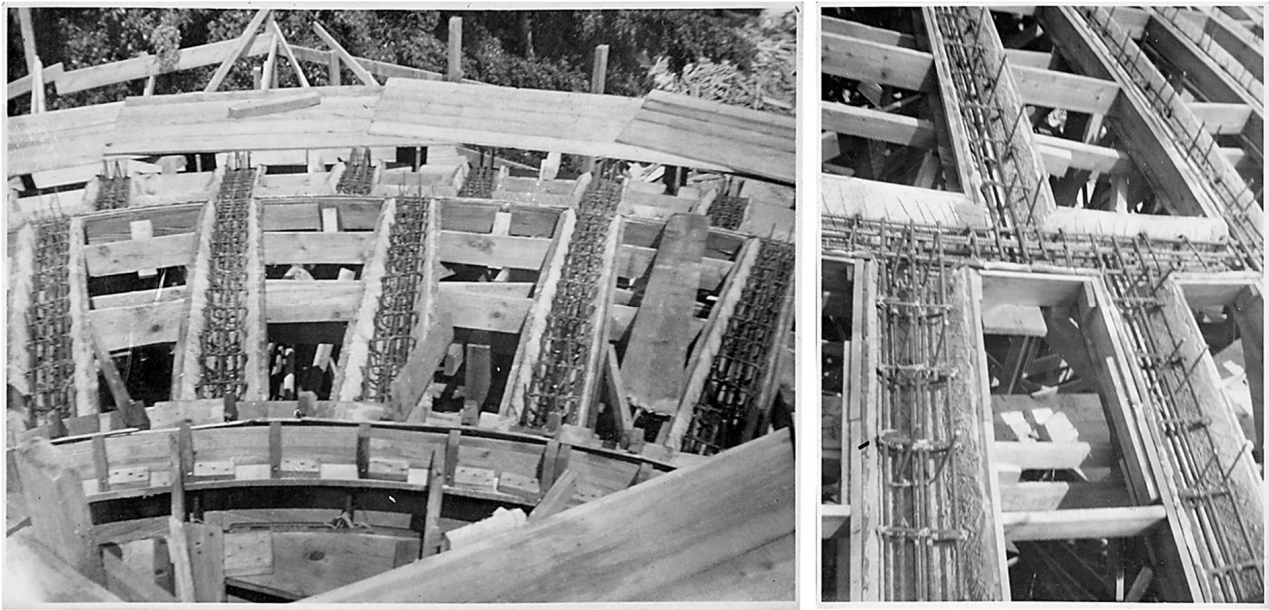


Figure 14. Two photos of the construction site, showing the upward steel connections protruding from the dance pavilions' ribs (ISA archive).

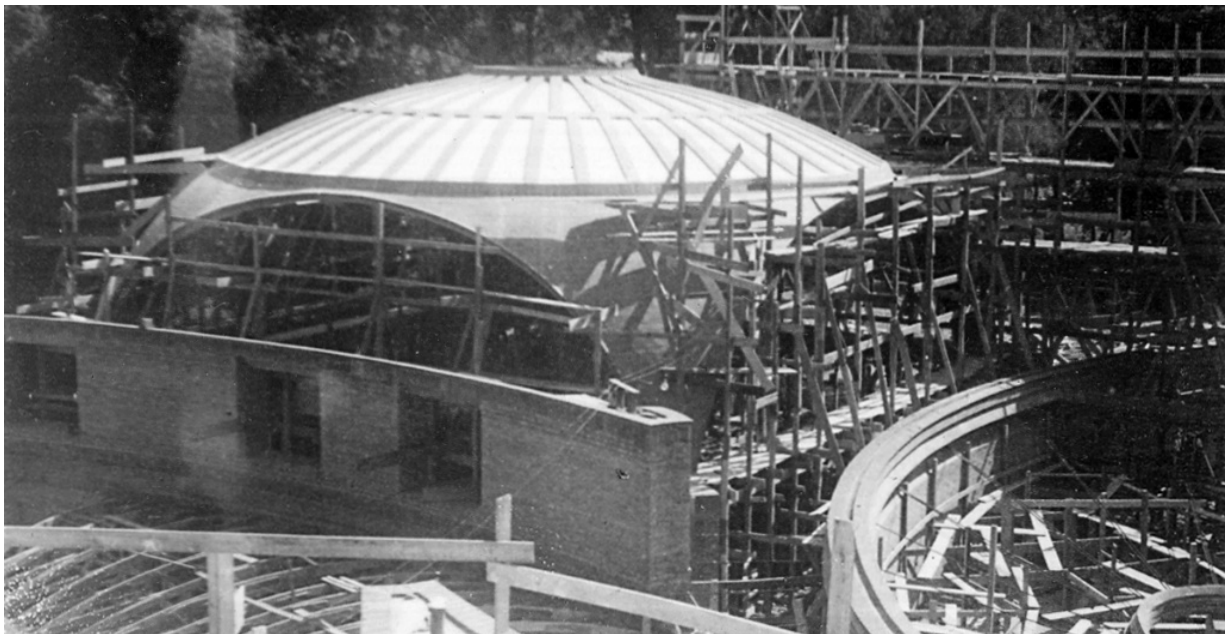


Figure 15. One of the dance pavilions right after completion: the concrete has been completely hidden from sight thanks to a covering layer of clay tiles (ISA archive).

The study of the construction process of the School of Ballet allowed one to further validate and slightly rectify Princeton's findings, contributing to the redefinition of the construction system of this iconic architecture. In particular, while Douglas and her work team had already identified the general method adopted in the construction of the school, the present research was able to pin down, one by one, the main phases of the building site. This methodical approach ended up highlighting the use of an additional layer of concrete casted above the concrete grid that had been previously discovered.

3.1.2. Pasillo

The sinuous corridor connecting the rooms of the School of Ballet (pasillo) was also taken into account. After a thorough examination, we can affirm that all its covering vaults include some kind of reinforcement. Indeed, even in the vaults that do not have a plain reinforced concrete slab, steel rebar was inserted to strengthen the masonry (like Dieste's *ceramica armada* [60]). As for the larger vaults, hiding a concrete core, the building process might have actually been quite similar to that of the above-described domes: laying a few layers of tiles to build the intrados and the sides of the vault in order to create a work form to set rebar and pour the concrete and finally covering the extrados with another layer of clay tiles. A few hints were taken from direct observation: Figure 16 shows the cavities left on the analyzed vaults by prior core testing, which confirm the presence of a concrete layer hidden below the extrados tile covering. The holes are about 10 cm deep, and within this depth, there is no sign of rebar.



Figure 16. (a) The 10 cm hole left by previous core testing, proving the presence of a concrete slab (photos by the authors). (b) Pachometer testing performed to detect possible rebar in the same vault.

Further verification of rebar absence was offered by the outcomes of the pachometer testing performed at the extrados of the vault (Figure 16b), which did not highlight any iron presence within the detection range. These results do not come as a surprise since, as observed in the construction process of the previously described domes, rebar should be located in proximity of the intrados. Finally, a drawing by Vittorio Garatti reveals that the original intent of the architect was in fact to strengthen the pasillo's vaults with reinforced concrete (Figure 17). Even though the blueprint only focuses on the vaults covering the main entrance of the building, it is reasonable to think that the same technique was to be applied to all the larger vaults covering the pasillo.

The thermographic survey performed on vaults with smaller spans also highlighted the presence of rebar (Figure 18). Although in this case the actual structural system is not reinforced concrete, it is still not possible to talk about pure Catalan vaulting but rather of a mixed technique, as suggested by Michele Paradiso [23]. The outcomes of the thermographic survey were also confirmed by visual inspection: Figure 19 shows a reinforcing bar located above the lower layer of tiles of the pasillo's intrados, which was made visible by current decay.

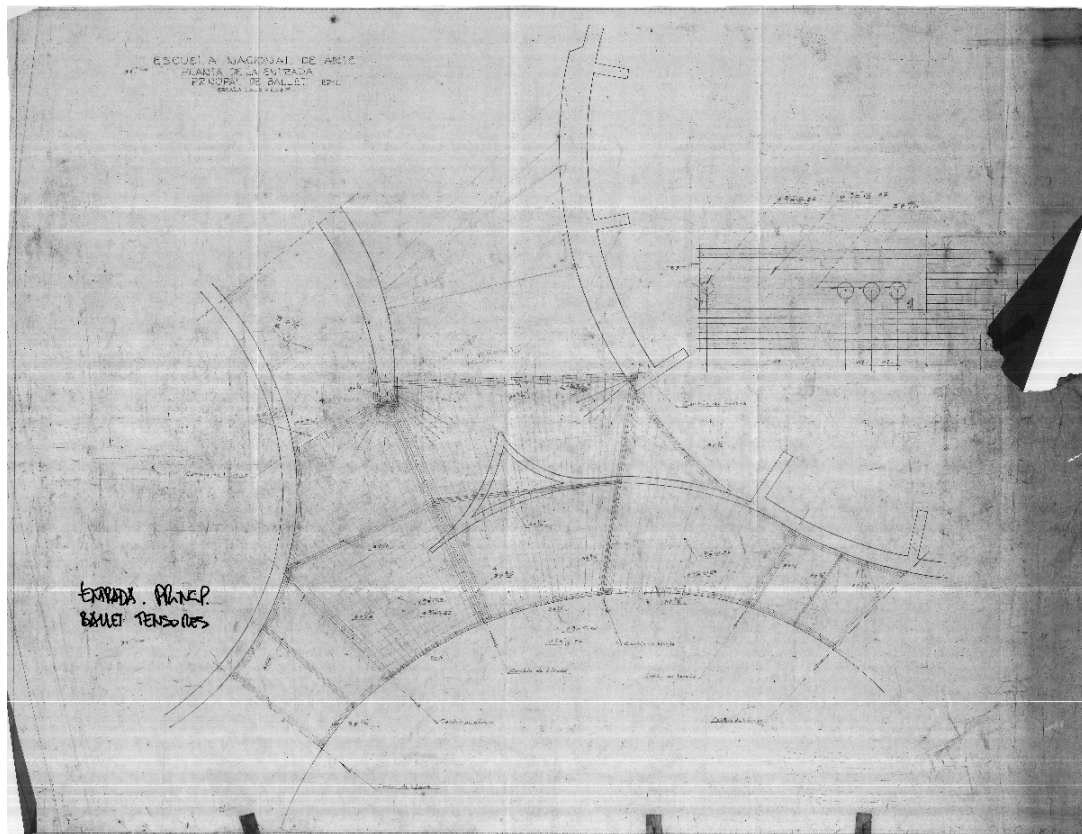


Figure 17. Drawing from the 1960s blueprints, highlighting the intention of using reinforced concrete for the vaults of the pasillo located nearby the main entrance of the building (ISA archive).

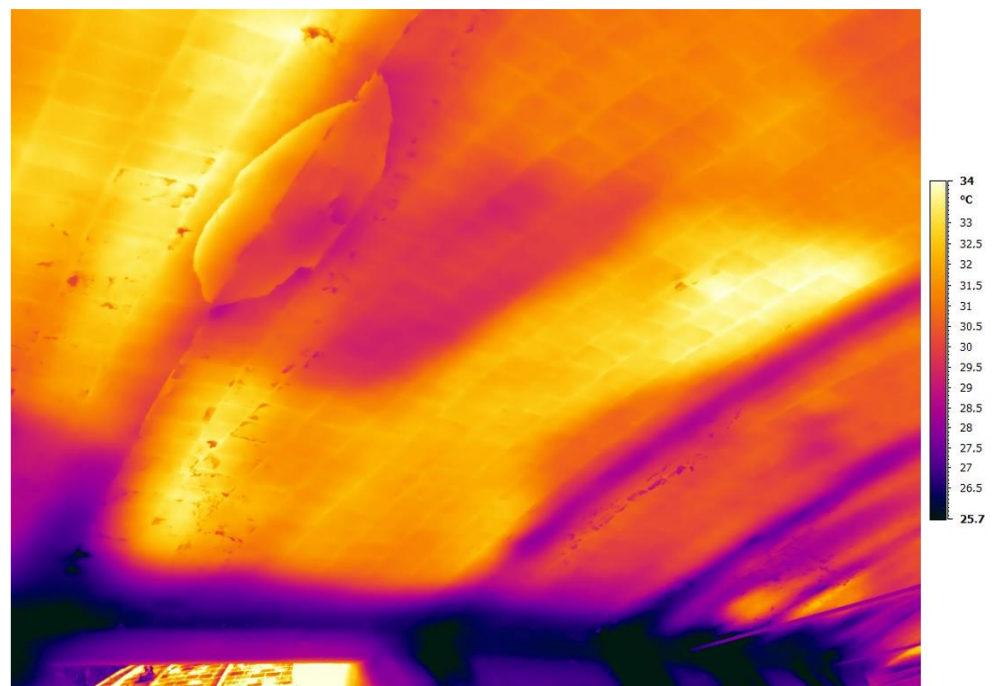


Figure 18. Thermograph of the pasillo (thermal range 25.7–34.0 °C). The survey was performed on 13 February 2020. Environmental parameters at 1:00 PM: 28.2 °C—Relative Humidity (RH) 75.0% (image by Luca Valisi).



Figure 19. Exposed steel rebar at the intrados of the pasillo (photograph by the authors).

3.2. School of Music

Despite the large amount of documentation concerning the original design of the School of Music, detailed information regarding the building technique to be employed in its construction is scarce. The most significant drawing in this regard is the cross-section reported in Figure 20, where the global organization of the structure can be observed. The same pattern repeats on two different levels with slight differences in terms of span, but seemingly identical stratigraphy. The illustration clearly distinguishes elements that are made of bricks from elements that are made of reinforced concrete, even providing a rather precise representation of rebar distribution. According to this drawing, the vaults are clear of any concrete or steel reinforcements, truly resembling the Catalan technique. The arches appear to be composed of three different layers, of which the middle one is by far the thickest, while the extrados one appears to be roughly half of the intrados one.

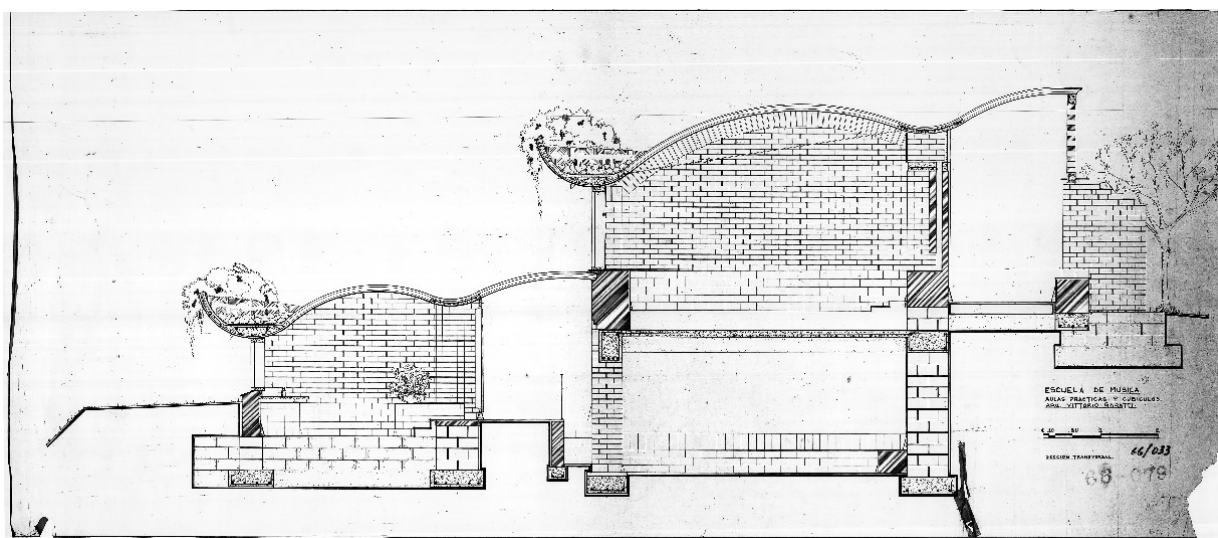


Figure 20. Cross-section of the *gusano* building taken from the 1960s original drawings (ISA archive).

The described ratio is faithfully reflected by the real building, as the vaults comprise, from top to bottom, one layer of clay tiles, one layer of cement, and three further layers of clay tiles held together by layers of mortar (Figure 21). The consistency between the original design and the current situation seems to suggest that, at least in the School of Music, the principle of favoring Catalan vaulting over reinforced concrete was actually put into action [1,2]. Nonetheless, further analyses were carried out to validate this hypothesis.



Figure 21. Current stratigraphy of the vault covering the lower corridor of the gusano building (photo by the authors).

Infrared thermography was fundamental here to visualize what could not be seen by the naked eye. The outcomes of the survey seem in fact to indicate the presence of reinforcing bars hidden in the vaults covering the classrooms of the higher level (Figure 22). It should be noted that such classrooms, designed to host group rehearsals, are much bigger than the individual rooms located on the ground floor, as well as than the corridors. The larger span of the vaults (approximately 5 m) clearly worried the structural engineers who promptly decided to install solid metallic tie rods to avoid their collapse (Figure 20). It was probably for the same reason that the builders saw fit to strengthen the tile vaults with the rebars identified by means of thermal imaging. Although no surveys were conducted on the vaults of the cubicles on the ground floor, their good state of repair (no crack patterns were found, despite the absence of tie rods [71]) suggests that iron rebar might also have been used on the lower level. Unluckily, there are no photographic records of this stage of construction, and we were thus unable to further analyze this aspect.

While we had to acknowledge that, regardless of the original designs, some of the vaults were not built according to the Catalan technique, uncertainties still remained with regard to the structural system of the corridors' covering, with particular reference to the one on the upper floor. The direct inspection of the building offered some helpful insights on the topic: firstly, it was understood that some sectors of the vault, which had probably collapsed, were completely replaced with similarly shaped reinforced concrete ones. However, the poor quality of the materials employed caused their quick deterioration, and today, due to the diffused delamination of the intrados tiles (which could very well be a consequence of concrete spalling), rebar is largely visible (Figure 23).

On the other hand, the vaults that were not substituted are not affected by delamination phenomena but consistently show cracking along the crown (Figure 24). The latter represents the typical crack pattern of segmental masonry vaults [72], leading one to believe that the external hallway could in fact be covered—at least in the authentic portions—by true Catalan vaults. This hypothesis is however denied by the outcomes

of the thermographic survey, which seem to display the presence of steel rebar along the vaults (Figure 25). The structural system should thus be similar to that of the smaller vaults of the pasillo of the School of Ballet, which, although not made of reinforced concrete, are strengthened by metallic bars, mostly located in proximity of the joints between adjacent sectors.

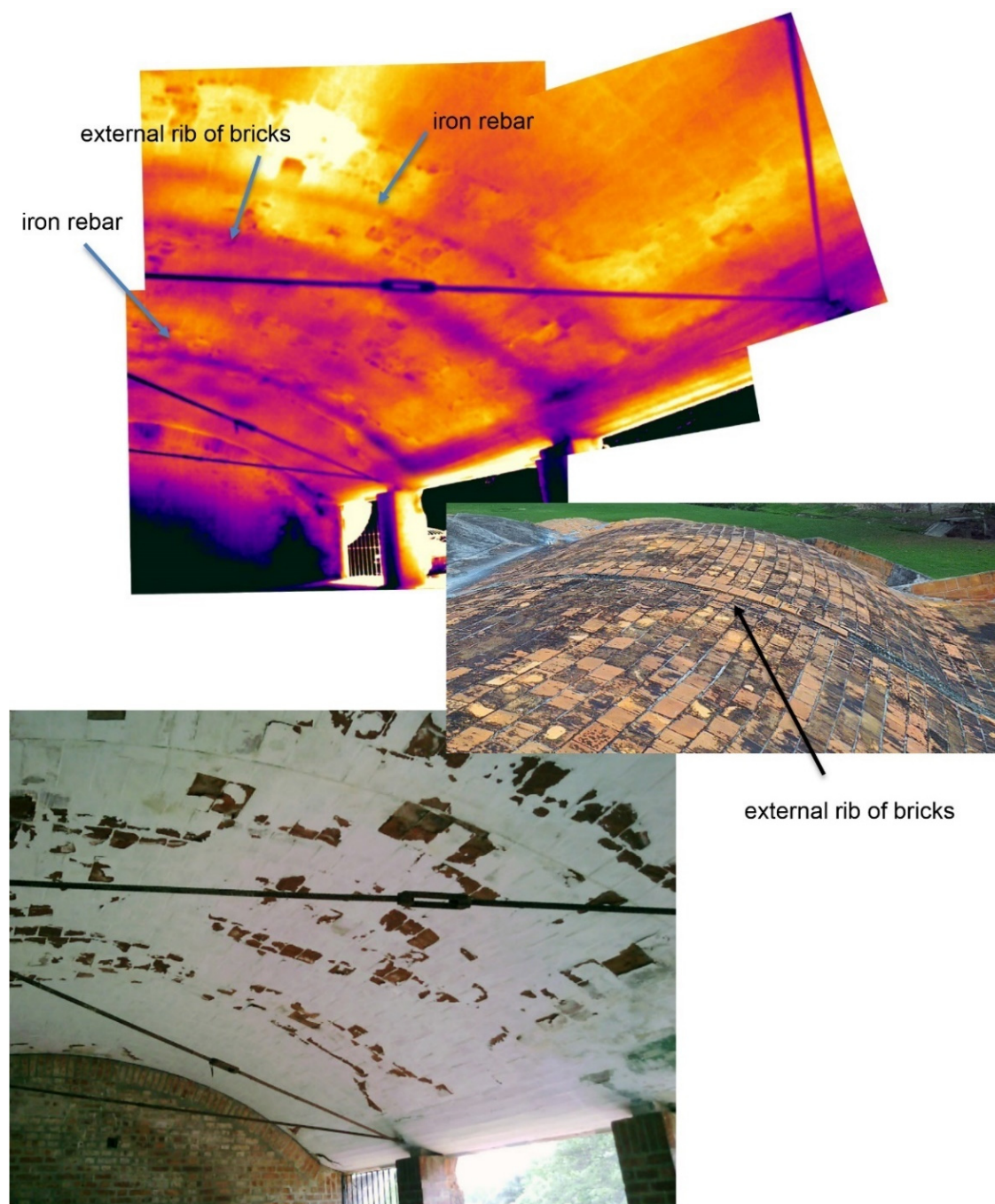


Figure 22. Thermographic survey of one of the vaults covering the classrooms located on the upper floor of the gusano building (thermal range 27.1–28.6 °C). The survey was performed on 20 February 2020. Environmental parameters at 1:00 PM: 28.8 °C—RH 68.2% (images by Luca Valisi).



Figure 23. One of the vaults replaced with plain concrete vaults. The poor quality of the materials employed resulted in delamination and consequent exposure of steel rebar (photo by Luca Valisi).

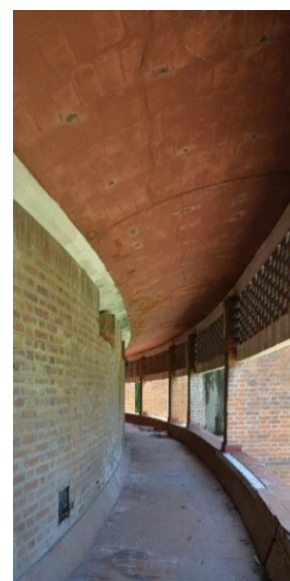


Figure 24. The cracks running along the crown of the vaults covering the upper corridor of the gusano building (photo by the authors).

As mentioned before, Cuban masons were not accustomed to the Catalan vaulting technique [9], and this may partly be read as an explanation to the fact that the construction system was not systematically employed. Indeed, given the large span of the domes and vaults of the five schools, adopting thin-tile vaulting would have been a great risk. Since the gusano is the building with the simplest geometries and most limited span to cover, it appears reasonable that, if somewhere, pure Catalan vaulting was tested here. The lack of expertise of designers and masons may nonetheless have brought the builders to add steel elements with the intention of increasing the structural safety of the building.

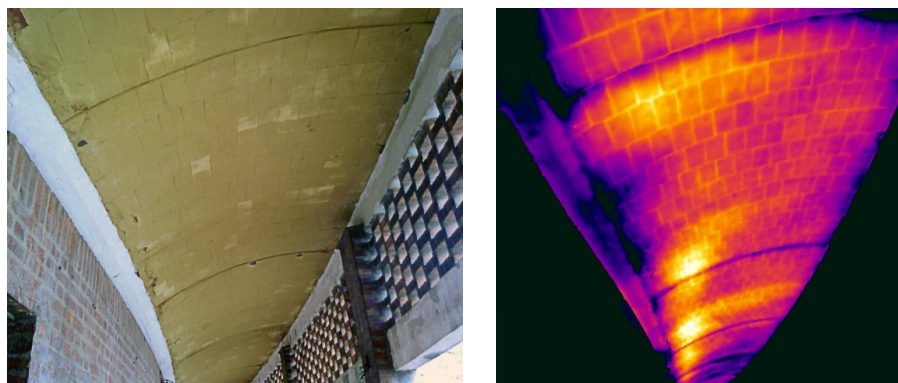


Figure 25. Thermograph of the upper corridor (thermal range 27.2–29.1 °C). Survey performed on 20 February 2020. Environmental parameters at 1:00 pm: 28.8 °C—RH 68.2% (images by Luca Valisi).

3.3. School of Plastic Arts

Ricardo Porro's School of Plastic Arts was also considered by the present research. Despite the lack of archival materials concerning this architecture, the thermographic survey was able to offer an unequivocal reading of the building's construction system.

The first suspicions about the true structural nature of the domes covering the school's classrooms aroused during an on-site inspection. While examining the intrados of one of the smaller cupolas, a rather regular efflorescence pattern was noticed on the tiled surface, resembling a sort of grid (Figure 26). With the aim of further analyzing the phenomenon, the few historical records available were scrutinized seeking for clues. The original blueprint collected, strictly regarding the architectural features of the building, did not provide any technical detail, whereas one of the pictures taken during the construction site (Figure 27) seemed to suggest the presence of a hidden concrete framework supporting the domes. Although quite straightforward, the image was not exhaustive, as it only portrayed the summit portion of the dome. Indeed, the empty work forms that can be seen nearby the top could have been owed to the need to strongly fasten the skylight to the vault below and not expand to the whole structure.



Figure 26. Efflorescence patterns at the intrados of the domed classrooms (photo by the authors).



Figure 27. The domes of the School of Plastic Arts during construction (ISA archive).

As anticipated, the decisive tool to finally identify the construction system of the domes of the School of Plastic Arts was infrared thermography. The concrete grid included in the domes' shells appears neatly in the thermal images (Figure 28), dispelling any residual doubt. The survey was carried out both on the larger and on the smaller domes, detecting the same structural arrangement. However, conversely to what observed in the domes of the School of Ballet, Figure 27 hints at the possibility that the masonry filling the voids of the bearing framework is actually concrete free. As a matter of fact, the photograph seems to indicate that rather than thin tiles, the inner layers were built using full bricks. At the end of the construction process, both the intrados and the extrados of the dome must have been coated with one or more layers of clay tiles, to both hide the concrete ribs and rings to the sight and to increase the overall homogeneity of the structure.

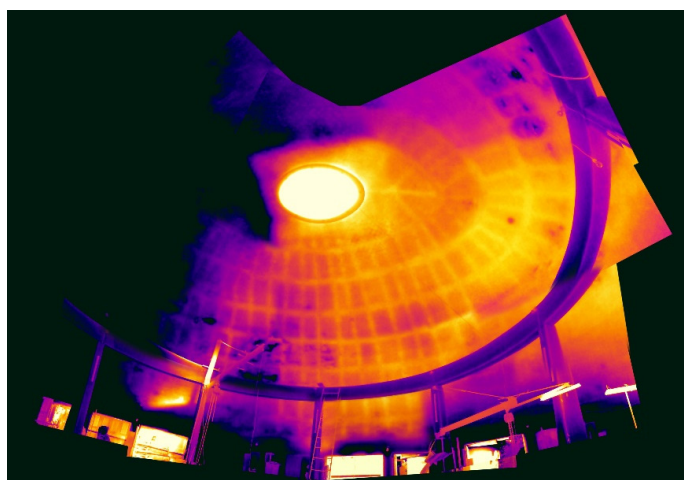


Figure 28. School of Plastic Arts: Thermograph of the dome of the foundry (thermal range 28.5–30.4 °C). 19 February 2020 at 1:00 p.m., 29.1 °C—RH 67.0% (Image by Luca Valisi).

In addition, in this case, the research was hence able to correct previously theories, revealing the true construction system hidden behind the masonry appearance of the building.

3.4. School of Dramatic Arts

Finally, Roberto Gottardi's School of Dramatic Arts was also briefly examined. Given the little availability of archival materials, the analysis mainly consisted in a thermographic survey. As expected, the resulting images highlight the presence of concrete elements supporting the masonry-looking vaults (Figure 29). In particular, the ribs appear to run crossway, delimiting and strengthening the strips of the vault where the skylights are located.



Figure 29. School of Dramatic Arts: Thermograph of a vault (thermal range 28.0–30.0 °C). 19 February 2020 at 1:00 p.m., 29.1 °C—RH 67.0% (Images by Luca Valisi).

4. Discussion and Conclusions

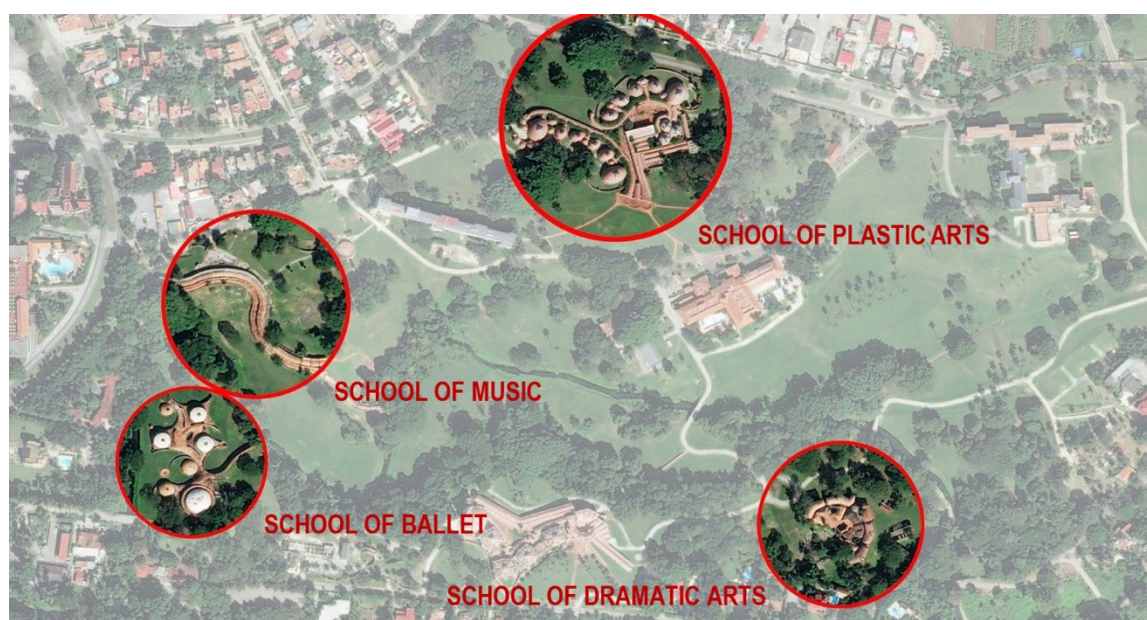
Starting from Princeton's previous findings [19–22], the study was able to finally redefine the structural system employed in the construction of Havana's National Art Schools. Combining direct and indirect sources it was possible to set the record straight, proving that the revolutionary architectures promoted by Che Guevara and Fidel Castro were not built adopting the Catalan vaulting technique as believed for the last sixty years (Table 1) [2,9].

The cause of this long-lasting misapprehension kept alive by the very architects deserves to be further investigated on the historical and architectural side. In fact, the reason why Vittorio Garatti, Roberto Gottardi, and Ricardo Porro never explicitly admitted to the fundamental role of reinforced concrete is still unclear, although it is evident that without it, those iconic building would simply not exist. It might be a direct outcome of the social and

political context within which the five buildings were conceived. Indeed, in this scenario, Catalan vaulting constituted rather a medium to convey an ideal than a mere construction technique. In the mind of the designers, it represented the maximum expression of novelty and independence, primary ideals of the Cuban revolution. Determined to deliver a message of freedom, the architects created an image of high significance and stuck to that significance for decades. Hence, the title of this paper, a tribute to René Magritte, who with his 1929 painting *The Treachery of Images* (also known as “This is not a pipe”) cautioned about appearances’ mendacity. In the same way, while the sinuous shapes of the coverings of Havana’s iconic architectures look like Catalan vaults, they are not. After all, the story of the National Art Schools deals as much with the physical construction of the school buildings, as it does with the construction of a myth. While hidden concrete allowed the structures to stand, the image of the schools was built with false appearances, captivating pictures [66], and fascinating narrations.

Table 1. Summary of the findings of the presented research. (Original plans: ISA archive; overview photographs: by the authors; thermographs and sketches: arch. Luca Valisi).

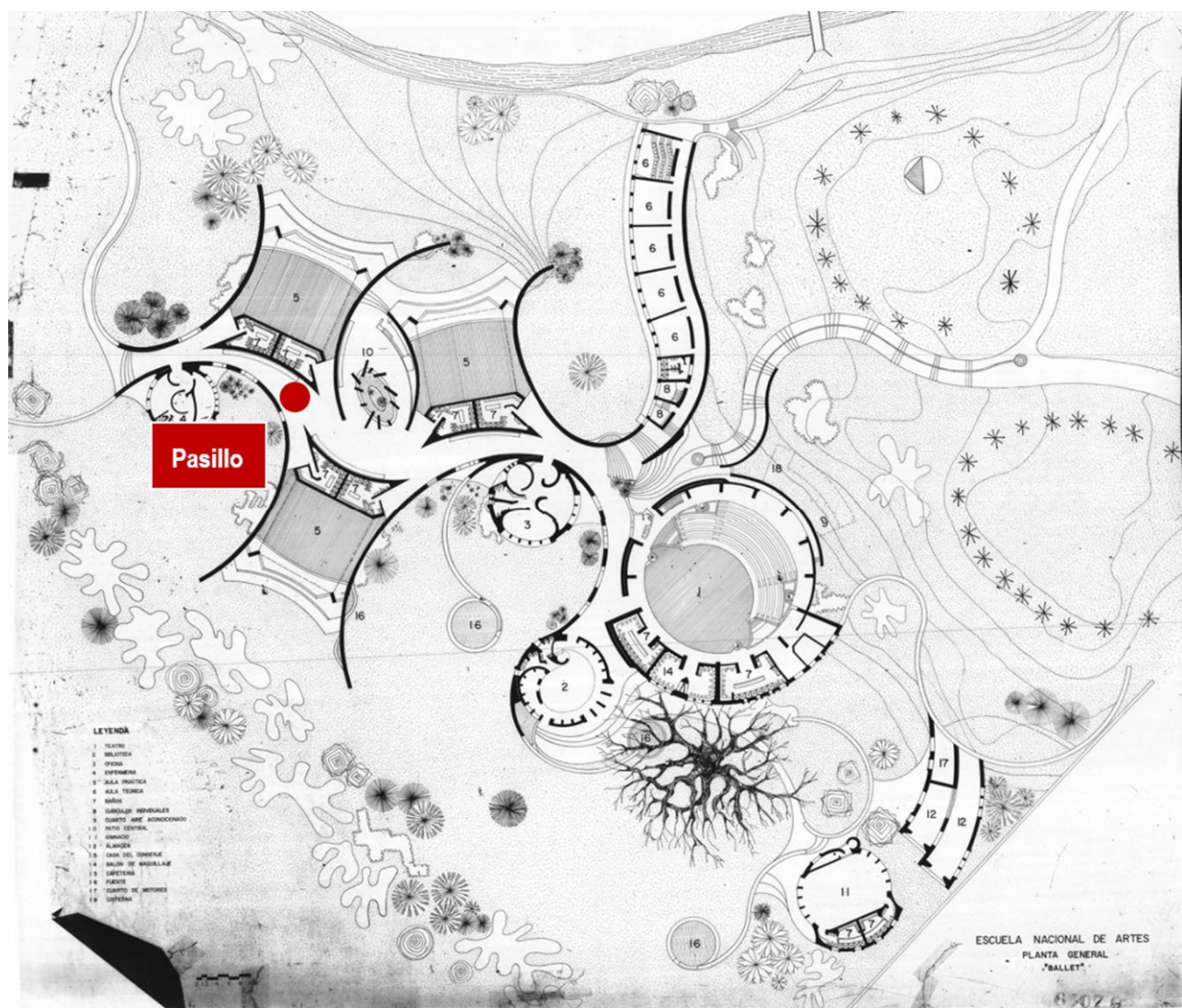
Reinforced Concrete Presence in Havana’s National Art Schools



School of Ballet



Table 1. Cont.



Pasillo

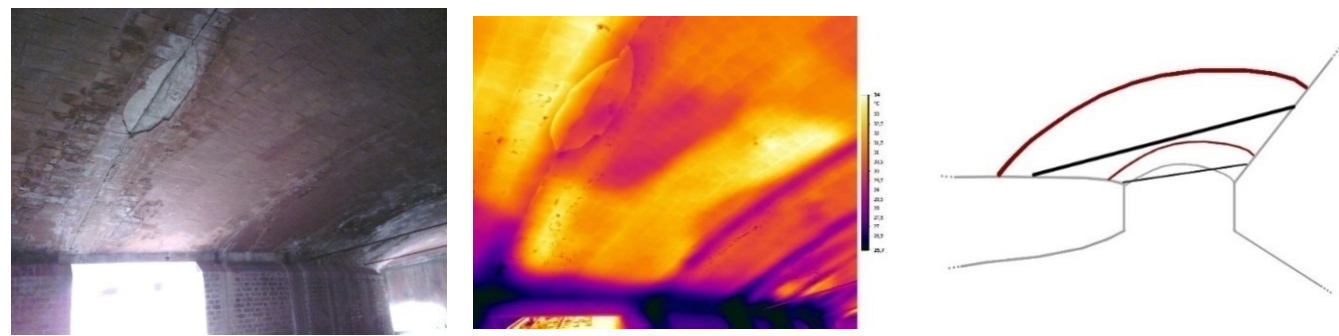
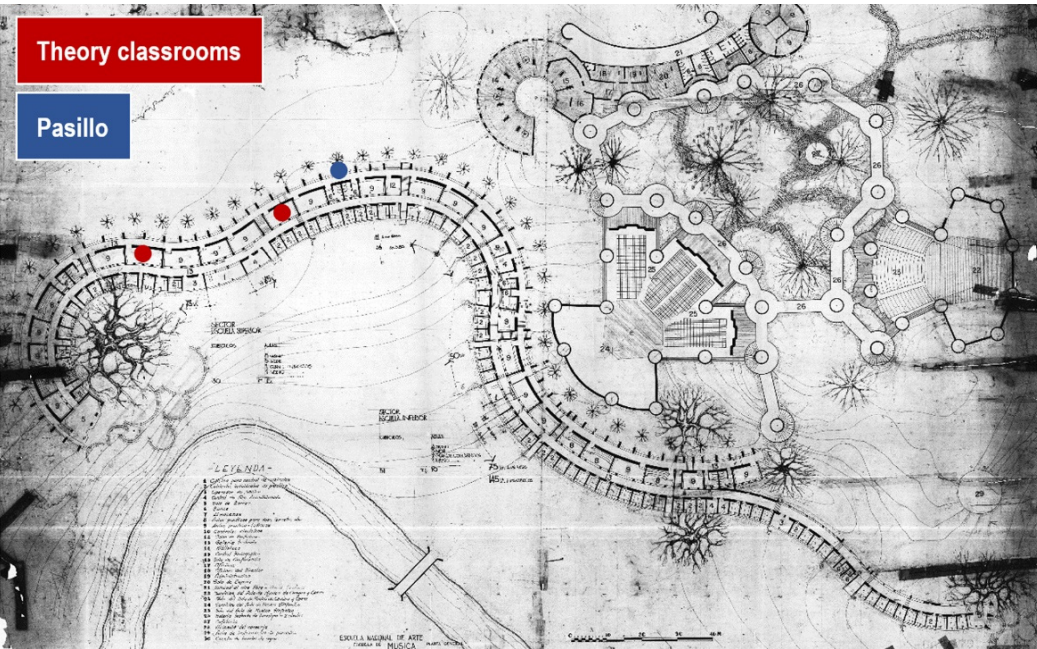


Table 1. Cont.

School of Music



Theory classrooms

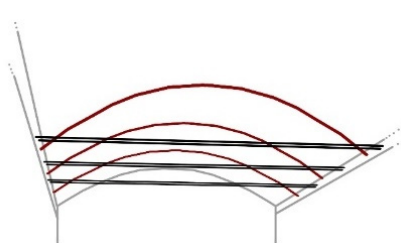
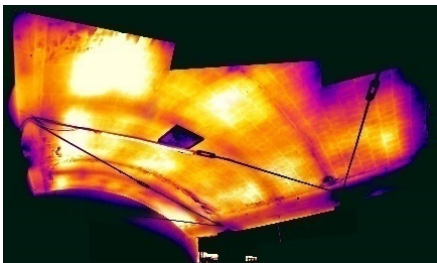
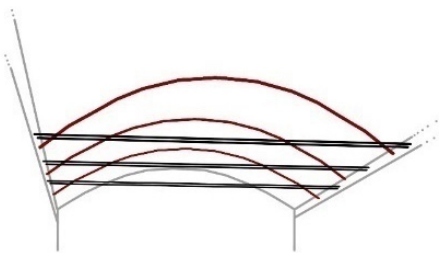
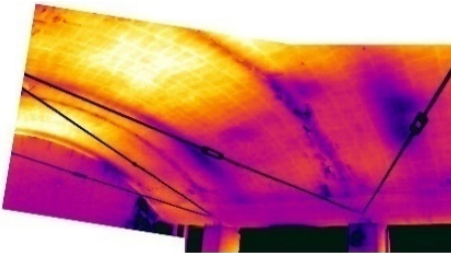
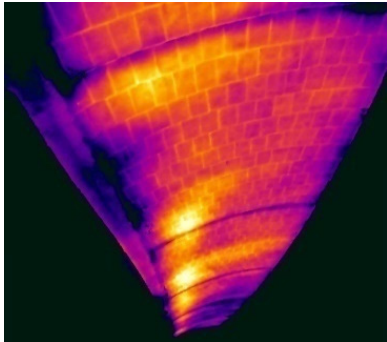


Table 1. Cont.



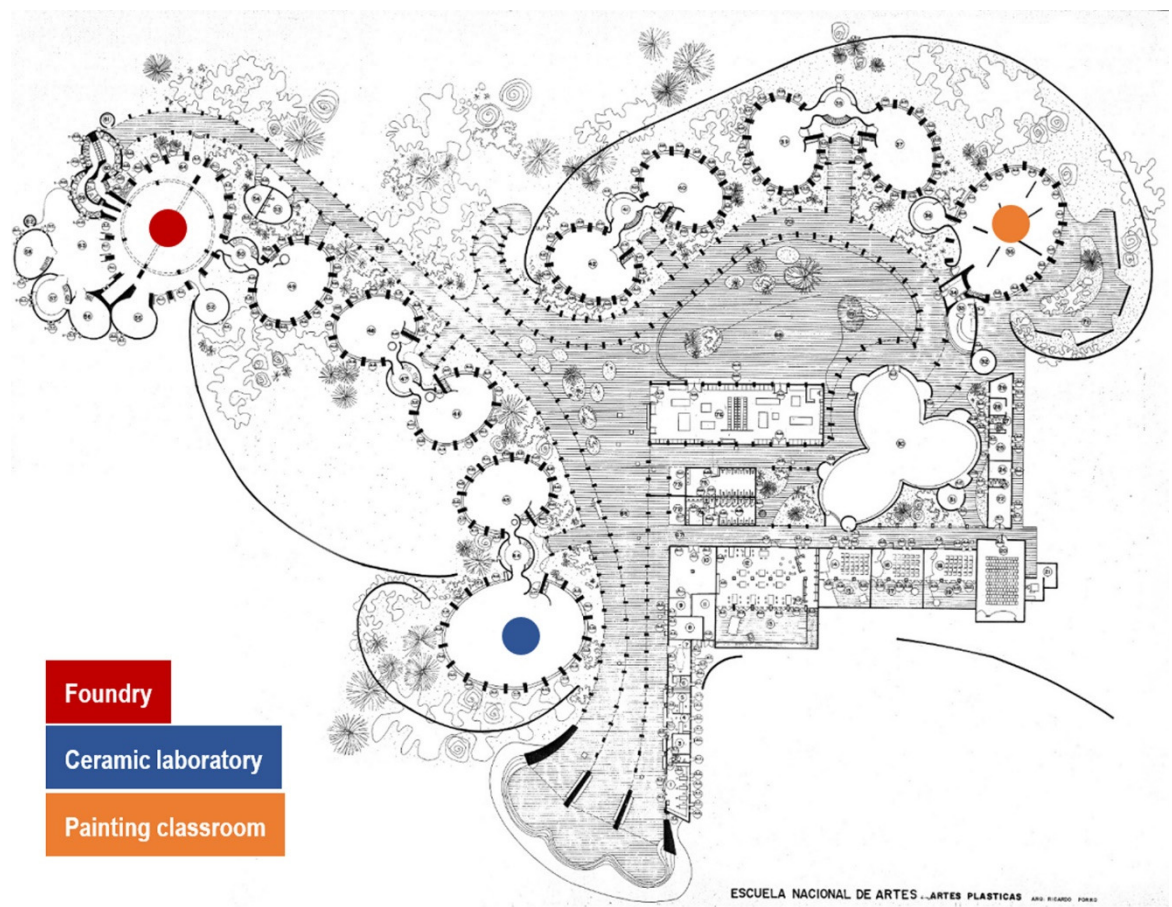
Pasillo (porticoed corridor)



School of Plastic Arts



Table 1. Cont.



Foundry



Ceramic laboratory

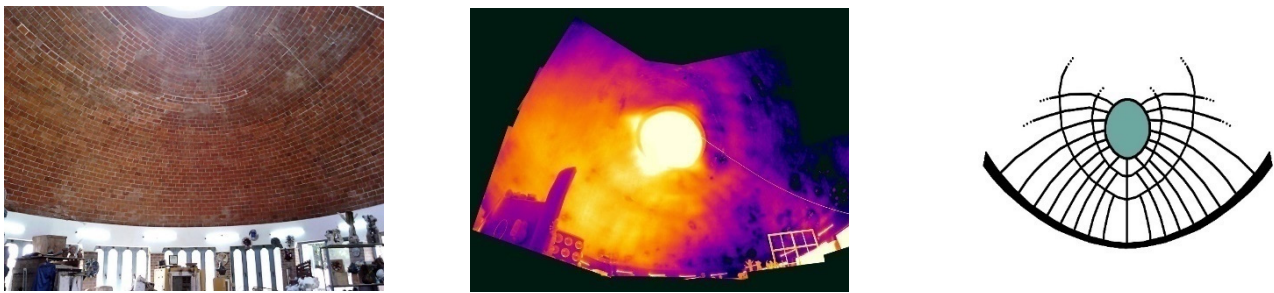
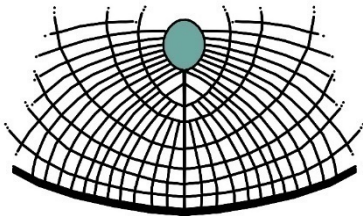
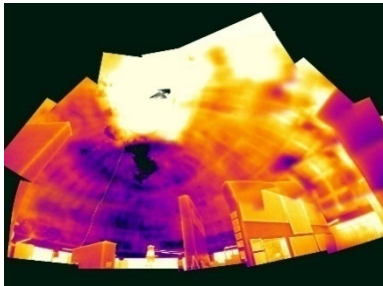


Table 1. Cont.

Painting classroom



School of Dramatic Arts

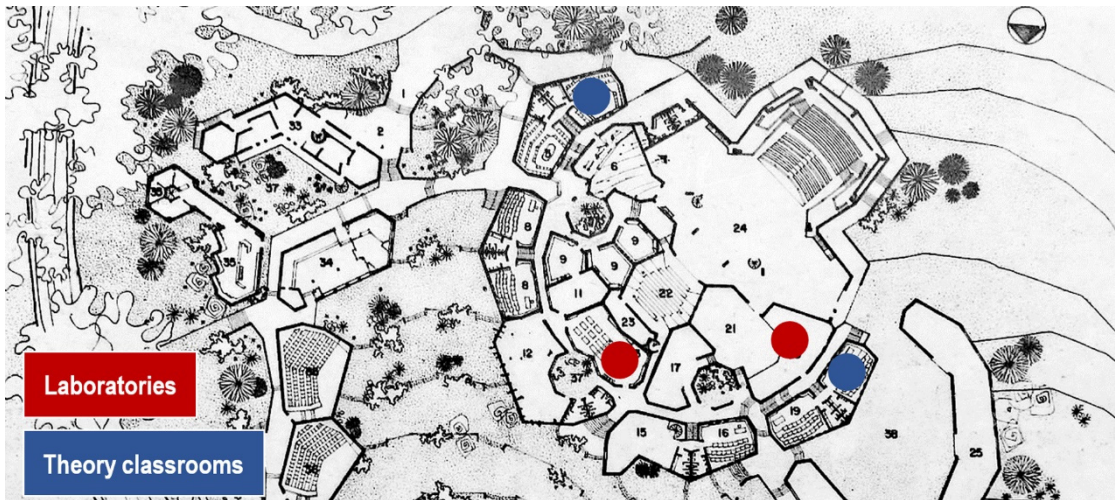


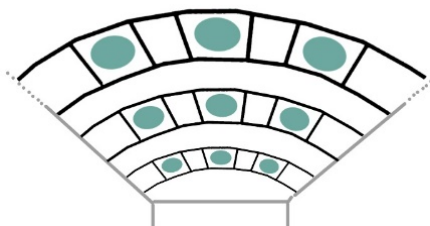

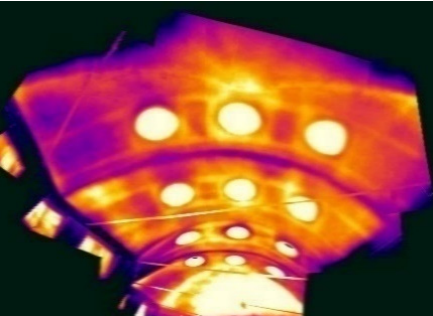
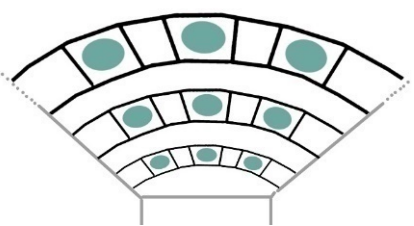

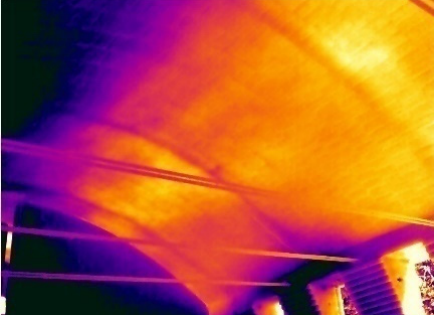
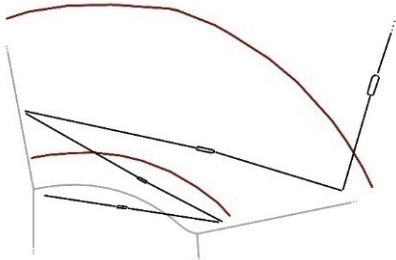

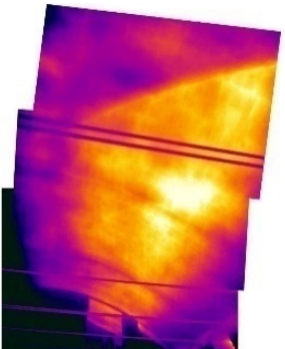
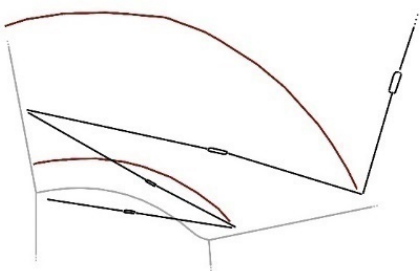


Table 1. Cont.

Laboratories		
		
		
Theory classrooms		
		
		

In this respect, Jorge Otero-Pailos offers two hints [73] which could help explain the unfolding of events concerning this iconic example of Modern Architecture. On the one hand, he reminds us that 1960s and 1970s architecture critiques, while aiming to demonstrate how architecture is more than just a building, ended up overshadowing its

materiality. This is somehow what happened to the National Art Schools, where, for a long time, the literature focused on the contextual discourse rather than on the physical structure, nourishing the rhetoric of the architectures. On the other hand, he underlines that every work of architecture results from co-authorship, even though some of the co-authors remain hidden. Perhaps, future archival research will further clarify the role of the other designers who took part in the making of the National Art Schools. In particular, it would be interesting to assess the influence of the engineering component on the construction process and its turning to reinforced concrete. Edoardo Esenarro, Isabelita Wittmarc, and Ilda Fernandez are only a few of the actors involved, who contributed to the project by conceiving and calculating this ingenious “invisible concrete” [23]. Although silent and soon forgotten, they also played a relevant role in this story, and their authorship should be recognized [74].

In this scenario, the outcomes herein presented confirm the hermeneutic power of conservation and restoration activities, providing new, unexpected (and possibly unasked for) details to reinterpret the whole picture. This somehow recalls the quest for intertextuality, suggested by Bruno Reichlin [75]: the dismantling and reassembling of evidence to increase the understanding and knowledge of architecture.

In the end, after a superficial use of images largely contributed to spreading the idea that the National Art Schools were an extraordinary example of Catalan vaulting, it is again through images that this belief is coming undone. This proves the high potential of graphic documentation when used in an aware and comparative way, to both recount architecture and investigate it, with relevant implications for conservation and restoration activities. Indeed, ensuring usability and safety is the way to a sustainable preservation of these iconic architectures. A thorough understanding of the structural system is essential, and, to this end, graphical documentation proved to play a central role.

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