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THE TEACHING OF ACOUSTICS AT THE HIGHER TECHNICAL SCHOOL OF ARCHITECTURE OF MADRID IN 1855

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ABSTRACT

The Madrid "Escuela Especial Preparatoria de Arquitectura" was created in 1844, with a holistic educational model, which required the reinforcement of technical training to achieve an appropriate balance with the artistic part of the curriculum. In 1848, with the creation of the Preparatory School for Civil Engineers, Mining Engineers and Architects, the scientific-technical training for architectural studies was reinforced. In 1855 a new curriculum was approved for the Architecture degree program, which among its novelties introduced the subject: Notions of acoustics, optics and hygiene applied to architecture. This communication shows the program of this subject, 170 years after the beginning of teaching acoustics in the Higher Technical School of Architecture of Madrid.

Keywords: *History, Architecture, Education in acoustics, Teaching.*

1. INTRODUCTION

The Higher Technical School of Architecture of Madrid is the school of architecture of the Universidad Politécnica de Madrid (Spain) and was created in 1844 under the name of Escuela Especial de Arquitectura de Madrid, being the oldest school of architecture in Spain. Its origins date back to the 18th century.

In Spain, the Royal Academy of the Three Noble Arts (painting, sculpture and architecture) was founded in 1744. In 1752, the Royal Academy of Fine Arts of San Fernando was created. It organized the regulated teaching of architectural studies in that year and its statutes were approved in 1757. Since then, it has been responsible for awarding the title of architect, replacing the old system of guilds [1], [2], [3], [4], [5].

Given the evidence of the lack of technical knowledge of architecture students and their disadvantage compared to engineers, in 1844 the "Escuela Especial Preparatoria de Arquitectura" was created because of the transformation of the teachings of the Royal Academy of Fine Arts of San Fernando, which in 1848 was established as an independent institution understood as a School for the Application of Arts. This Preparatory School was created for the special studies of Architects, Civil Engineers and Mining Engineers, as they all shared a similar scientific background. The duration of studies at the Preparatory School was two years and it was abolished in 1855.

The architecture degree lasted four years and previously required an entrance exam and two years at the Preparatory School. With the Moyano Law of Public Instruction (1857), the School of Architecture came under the university regime as the Higher School of Architecture, dependent on the Central University (currently the Complutense University), and became responsible for awarding the official title of architect.

2. THE NEEDS OF ARCHITECTURE AND THEORETICAL ACOUSTICS IN THE EARLY 19TH CENTURY

Before the 20th century and the development of modern acoustics, there was very little connection between the theoretical knowledge of acoustics and the needs of architects in the design of venues [6]. Architects at that time could not rely on scientific support for their designs.

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The evolution of venues design was slow and gradual, with small architectural milestones throughout history. The Roman architect Vitruvius Polion, author of *De Arquitectura* [7], exhaustively described aspects of the design of theatres and their acoustics, one of his aims being to ensure good vision and hearing for the spectators. The architects of the Renaissance and Baroque periods would place the actors on stages elevated above the lower plane of the audience. In 1580 the first permanent theatre designed by Andrea Palladio, the Teatro Olimpico, was built in Vicenza. It is a covered theatre, the stage in the configuration of the ancient Roman theatres and the audience area was in the shape of a semi-ellipse. In 1628 the Farnese theatre was inaugurated in Parma with a U-shaped audience area. The first Italian opera house in the shape of a horseshoe with overlapping boxes on five levels was built in Venice in 1654, initiating a typology that remained unchanged for almost two centuries, being the most common in the design of theatres in the 18th and 19th centuries.

In the 18th century, musical events took place in different venues, such as palaces, masonic lodges, public gardens and ballrooms. Initial venues, sponsored by royalty or nobility were small. As the acoustic power level of the new musical instruments increased and in response to the demand of larger audiences, concert halls dimensions increased. The new need for larger venues in view of the interest in paid music meant that the audience had to be able to see and hear. During the 18th century, the Italian theatrical model became generalized with different floorplan geometries: elliptical, circular, bell-shaped. In central and northern Europe, concert halls evolved from churches and the rectangular floor plans of ballrooms.

During this period, architects continued designing spaces for music, and the first treatises on the topic appeared, specifying technical solutions that had previously worked and were repeated by designers. Two architects who influenced theatre architecture in their countries were the Frenchman Pierre Patte who in 1782 wrote the book Essai sur l'Architecture théatrale [8], and the Englishman George Saunders who in 1790 wrote A Treatise on Theatres, [9]. In 1880, the architect Jean Louis Charles Garnier, designer of the Paris Opera House, [10] expressed his disappointment at not finding any help from the theoretical knowledge of acoustics.

Today, in the subjective ranking of the acoustic quality of opera houses and auditoriums carried out by conductors and acousticians, many of the considered as best halls were built before any scientific knowledge of the behavior of sound in a venue was applied, such as: Teatro La Scala, Milan, 1778; Teatro San Carlo, Naples, 1737; Grosser Musikvereinsaal, Vienna, 1870; Opera Garnier, Paris, 1875; Concertgebouw, Amsterdam,1888; Carnegie Hall, N York, 1891; Teatro Colón, Buenos Aires, 1908, etc.

Throughout the 19th century, the study of acoustics as a science and its dissemination through books and technical journals began. In 1862 Hermann Helmholtz [11] wrote a treaty on acoustics and hearing, and in 1877 Lord Rayleigh (John William Strutt) [12] published The Theory of Sound, considered the beginning of modern acoustic theory. They established acoustics as a science where observation, experimentation and a mathematical basis led to significant advances. Room acoustics as a scientific discipline can be considered to begin with the work of W.C. Sabine at Harvard University at the end of the 19th century with his experimental work on reverberation time in rooms [6].

3. THE 1855 ACADEMIC CURRICULUM

After becoming independent from the Royal Academy of Fine Arts of San Fernando, the new "Escuela Especial Preparatoria de Arquitectura" adopted a holistic educational model, where it was necessary to reinforce the technical background in order to achieve an appropriate balance with the artistic side. With a model similar to that followed in France, the Preparatory School for Civil Engineers, Mining Engineers and Architects was created in 1848, which improved the scientific-technical training for architectural studies with a two-year plan. Table 1 shows the subjects taken at the Preparatory School. Table 2 shows the subjects of the academic curriculum of the Civil Engineering and Architecture courses.

Table 1. Preparatory School subjects

	Subjects
First Year	- Differential and integral calculus. - Geometry. - Graphical constructions. - Physics and chemistry. - Landscape drawing. - Architectural drawing.
Second Year	- Rational mechanics - Applications of descriptive geometry. - Graphical constructions. - Topography and Geodesy. - Topographical drawing. - Architectural drawing.

Table 2. Comparison between the academic curriculum of the degrees of Civil Engineering (1849) and Architecture (1850).

Civil Engineering	Architecture
First year	
Applied mechanics	Industrial mechanics
Stereotomy	Mineralogy and mineral chemistry
Mineralogy	Extension of stereotomy
Graphical and practical exercises	Graphic exercises and architectural drawing
Second year	
Constructions, part one	General construction theory
Machines	Road construction
Geology	Practical resolution of construction problems
Drawing and practice	Architectural drafting
Third year	
Constructions, part two	General theory of art and decoration.
Civil architecture	Use of water.
Administrative law, Part I	Analysis of ancient and modern buildings.
Drawing and practice	Composition exercises.
Fourth year	
Constructions, Part III	Legal architecture
Water supply	Art practice
Administrative law, Part II	Composition
Drawing and practice	Composition exercises

The disappearance of the Preparatory School in 1855 brought another reorganization of teaching at the School of Architecture. In the same year, a new curriculum was approved in which the architecture degree became a six-year course. Among its changes, it introduced the subject: Notions of acoustics, optics and hygiene applied to architecture. In this subject, the teaching of these three subjects, especially hygiene, began. Table 3 shows the subjects of the 1855 curriculum at the "Escuela Especial Preparatoria de Arquitectura".

In order to gain access to architecture studies, students were required to have a certificate of having successfully passed physics and chemistry in an official center or to take an exam in these subjects at the School of Architecture. They then had to pass entrance exams. Classes were held for six hours a day from 15 September to 30 June.

Table 3. 1855 academic curriculum, Escuela Especial Preparatoria de Arquitectura

	Subjects
First Year	- Integral and differential calculus - Topography - Descriptive geometry - Topographical drawing - Architectural drawing
Second Year	- Rational mechanics. - Industrial mechanics. Part I. - Applications of descriptive geometry to shadows - Gnomonic perspective - Mineralogy - Chemistry applied to architectural uses -Analysis, manipulation and manufacture of materials - Architectural drawing
Third year	- Industrial mechanics Part II: Hydraulics; Mechanics applied to construction - Stereotomy, wood and iron; graphic works of this subject - Architectural drawing
Fourth year	- Civil construction - Hydraulics - Staking out and uprights - Acoustics, optics and hygiene applied to architecture - Theory of art and composition - Elements of composition and 3rd order projects
Fifth year	- History of architecture -Analysis of ancient and modern buildings - Composition
Sixth year	- Legal aspects - Composition

4. ACOUSTICS, OPTICS AND HYGIENE APPLIED TO ARCHITECTURE

The following is the curriculum of the subject which was a pioneer in the teaching of acoustics at Spanish universities. The course consisted of sixteen lessons divided into two blocks: Block I (lessons I to XII) on acoustics and optics and Block II (lessons XII to XVI) on hygiene and health applied to civil constructions. The acoustics and optics program follows the book written in 1848 by Theodore Lachèz [13], a 19th-century French architect, known for his contributions in these fields. His influence extended to the educational field, where he wrote about the teaching of architecture and evaluated institutions such as the *École Impériale et Spéciale des Beaux-Arts* and the *École Centrale d'Architecture* [14].

Lesson I	Laws of acoustics and general considerations on some of the phenomena to which it refers.
-Acoustics and music -Sound -Propagation, reflections and modifications -The voice -Air, vehicle and instrument of sound -Echoes, resonance, sonority	
Lesson II	Optics, light and distance
-The intensity of light is inversely proportional to the square of the distance	
Lesson III	Classification of theatres
-Theatres and amphitheaters among the ancients and in modern times -Needs they have to satisfy -Differences which characterize them -Their special purposes -Wise acoustic arrangements -Sound vessels -Velarium	
Lesson IV	Modern Theatres and amphitheaters
-Different purposes -Characteristic differences with ancient monuments	
Lesson V	Defects of theatres and amphitheaters, resulting from the non-observance of the laws of acoustics
-Local or general resonances -Echoes -Suppression of sounds or their destroyed intensity -Denomination of vaults, ceilings, niches, semicircles, coffers -Effects of wooden stands, carpets and upholstery -Harmful air volumes in amphitheaters, auditoriums and concert halls	
Lesson VI	Defects resulting from the non-observance of the best optical considerations
-Light poorly distributed and hurting the eyesight -Absorbed by dark colored walls -Chandeliers, steps and handrails poorly arranged -Inconvenience of direct light coming from the south	
Lesson VII	Favorable acoustic conditions for theatres and amphitheaters according to their use
-Speech and chant -Conditions of their sound propagation -Triangular and parabolic amphitheaters. -Particular inclination of the tiers according to a curve -Harmful vibrations of the tiers -Desired modifications in performance halls -Pulpits -Concert halls	
Lesson VIII	Conditions of optics, light and distance
-Conditions of optics, light and distance -Light distribution -Rooms for scenic effects and meeting rooms -Historical theatres -Congress of Deputies	
Lesson IX	Investigation for the most suitable shape for amphitheaters.
-Circle and half circle; Segment or quarter circle -Point of view or place of the scene -Enclosures proportional to the number of spectators -Special circumstances for amphitheaters -Respective position of audience for viewing objects	
Lesson X	Classification of amphitheaters and public assembly halls into five categories
-Rooms satisfying optical conditions -Rooms satisfying acoustic conditions -Mixed music halls for simultaneous seeing and hearing -Demonstrations and experiments	
Lesson XI	Some observations on the inclination of the stands used today in existing halls and amphitheaters

-Poorly used space -Arbitrary inclination of the tiers. -Parallel visual rays instead of rays converging towards the point of view	
Lesson XII	Research and determination of the curve, according to which the benches or floor of public halls and amphitheaters should be laid
-Point of view or proscenium -Average height of the audience -Abscissae and ordinates of the stands -Width and height of seats -Variable vertical distance between successive rows of listeners	

5. CONCLUSIONS

The political and social changes throughout the convulsive 19th century in Spain had an influence on education and, in particular, on the teaching of architecture. It was necessary to go with its *zeitgeist* in terms of progress, social welfare, economic development and, with criteria of technological development that were more pragmatic than artistic. From 1844 to the present day there have been at least 15 academic curriculums until the most recent one in 2010, adapted to the European Higher Education Plan, and an attempt has been made to seek a balance between artistic and scientific-technical subjects.

The teaching of some notions of acoustics at the Higher Technical School of Architecture of Madrid has been changing according to the different study plans; it has never been taught as an independent subject.

For example: it was taught in the 1855 and 1858 curriculum, but then eliminated in the 1864, 1885 and 1932 ones. In the 1875 and 1896 curriculum, it was included under the subject Applications of the physical-natural sciences to Architecture (together with concepts such as ventilation, heating and building services). In 1914 it was offered in the subject of optics and acoustics, as well as in the 1956 curriculum for electrical engineering and acoustics. It was in 1957 when the subject of Acoustics and building services was created, evolving in the curriculum of 1964, 1975 and 1996 within the subject of Building Physics, where it ended up having a marginal presence. In the current plan, curriculum 2010, a series of fundamentals classes are given within the subjects of Physics and Environmental Conditioning and Habitability, and it's also offered as an elective subject, Experimental Workshop in Architectural Acoustics, with 6 ECTS credits.

At present, scientific-technical subjects in architectural studies in Spain continue to represent an important percentage of the subjects on the academic curriculum (they have a greater weight than in other European countries), as the Spanish architect assumes among his competencies some aspects of civil engineering in relation to buildings, which must be preserved as opposed to the figure of an architect who is merely a designer.

In Spain, the architect has a regulated qualification with professional attributions and the curriculum of this qualification have been adapted to the regulatory body of the country. For this reason, some subjects have been modified over the years and new technical subjects have been introduced according to the new requirements of urban planning, construction and building services. Spanish legislation establishes that buildings, including their services, must meet basic safety (structural, fire, usability and accessibility) and habitability (hygiene, health and environmental protection; noise protection; energy saving and thermal insulation) requirements, with the responsibility lying on the architect.

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