ADVANCES IN BUILDING EDUCATION
INNOVACIÓN EDUCATIVA EN EDIFICACIÓN

A Service-Learning proposal for Architecture, Building and Urbanism Students: getting involved in Education Tours in Madrid

Una propuesta de Aprendizaje-Servicio para estudiantes de Arquitectura, Edificación y Urbanismo: implicación en rutas educativas en Madrid

Gabriel Pinto [1*], Victoria Alcázar [2], María M. Conde [3], Ángel Agüero [4], Marina P. Arrieta [5], Freddys R. Beltrán [6], Patricia García-Muñoz [7], Javiera A. Sepúlveda [8]

[1,] Escuela Técnica Superior de Ingenieros Industriales, Universidad Politécnica de Madrid, Calle José Gutiérrez Abascal 2, 28006 Madrid, Spain. Phone number: +34 910677302. gabriel.pinto@upm.es*
[2] E. T. S. de Ingenieros Industriales, Universidad Politécnica de Madrid, Spain. mariavictoria.alcazar@upm.es
[3] E. T. S. de Ingenieros Industriales, Universidad Politécnica de Madrid, Spain. maria.mconde@upm.es
[4] Instituto Universitario de Tecnología de Materiales, Universitat Politècnica de València, Spain. anagrod@upv.es
[5] E. T. S. de Ingenieros Industriales, Universidad Politécnica de Madrid, Spain. m.arrieta@upm.es
[6] E. T. S. de Ingenieros Industriales, Universidad Politécnica de Madrid, Spain. f.beltran@upm.es
[7] E. T. S. de Ingenieros Industriales, Universidad Politécnica de Madrid, Spain. patricia.gmunoz@upm.es
[8] E. T. S. de Ingenieros Industriales, Universidad Politécnica de Madrid, Spain. javiera.sepulveda@upm.es

Received: 21/02/2025 |Accepted: 08/04/2025| Publication date: 02/05/2025
DOI:https://doi.org/10.20868/abe.2025.1.5450

TITULARES

- Se empleó la metodología de Aprendizaje-Servicio para diseñar e implementar dos paseos educativos.
- Alumnos y profesores de la UPM se formaron en competencias, tanto transversales como específicas.
- Se abordaron temas que vinculan historia, arte, ciencia y arquitectura.
- Se resalta la contribución española al descubrimiento de tres elementos químicos durante la Ilustración (siglo XVIII).
- Se ponen en valor los logros de la Edad de Plata de la cultura española (finales del siglo XIX y primer tercio del XX).
- La actividad fue muy bien valorada por un público diverso en edad y formación.

HIGHLIGHTS

- The Service-Learning methodology was applied to design and implement educational walking tours.
- Students and faculty from the UPM developed both transversal and subject-specific competencies.
- The tours explored interdisciplinary connections between history, art, science and architecture.
- Particular emphasis was placed on Spain's contribution to the discovery of three chemical elements during the Enlightenment (18th century).
- The achievements of Spain's Silver Age (late 19th century to the early 20th century) were highlighted.
- The activity received highly positive feedback from a diverse audience.

RESUMEN

Se ha empleado una metodología de Aprendizaje-Servicio por parte de profesores y estudiantes de la Universidad Politécnica de Madrid, para diseñar y llevar a cabo dos paseos educativos: "La Ilustración española y el descubrimiento de tres elementos químicos" (siglo XVIII) y "Los 'altos del hipódromo', una zona emblemática de la 'Edad de Plata' de la cultura española" (finales del siglo XIX y primer tercio del siglo XX). Los objetivos incluyen: promover una educación holística que integre la ciencia con el arte, la historia y la arquitectura; fomentar habilidades como investigación de datos, trabajo en equipo, presentación oral y creatividad; difundir contenido cultural al público en general; y profundizar en la comprensión del patrimonio arquitectónico y cultural de Madrid. Diseñados para público diverso, de distinta edad y formación —incluidos asistentes a congresos científicos y estudiantes—, estos recorridos también involucran a alumnos y docentes universitarios de arquitectura, edificación y urbanismo. Se reflexiona sobre la experiencia, abordando temas como la evolución urbana de Madrid, cartografía histórica, estilos arquitectónicos (neoclásico, funcional, neomudéjar…), evolución de los edificios históricos, vidas de arquitectos destacados y la relación del patrimonio arquitectónico con el turismo.

Palabras clave: *Aprendizaje-servicio; Arquitectos españoles; Arquitectura de los siglos XVIII, XIX y XX; Edificios históricos en Madrid; Iniciativas de divulgación; Patrimonio arquitectónico.*

ABSTRACT

A Service-Learning methodology has been employed by professors and students at the Universidad Politécnica de Madrid to design and conduct two educational tours: "Spanish Enlightenment and the discovery of three chemical elements" and "The 'altos del hipódromo', a significant area during the 'Silver Age' of Spanish culture (1868-1936)". The objectives include: providing a holistic education integrating science with art, history, and architecture; nurturing skills such as data research, teamwork, oral presentation, and creativity; disseminating cultural content widely to the general people; and deepening the understanding of Madrid's architectural and cultural heritage. Tailored for diverse audiences including international participants, scientific conference attendees, and students from specific areas, these tours also involve students and faculty from architecture, building, and urban planning backgrounds. This article reflects on these experiences, evolving into discussion of topics such as Madrid's urban development, historical cartography, architectural styles (Neoclassical, Iron, Functionalism, Neo-Mudéjar…), the progression of historical buildings, the lives and works of prominent architects, and the intersection between architectural heritage and tourism.

Keywords: *Architectural heritage; Architecture from the 18th, 19th and 20th centuries; Historic buildings in Madrid; Outreach initiatives; Service-learning; Spanish architects.*

1. INTRODUCTION

The need for society in general, and young people in particular, to understand and appreciate the relationships between science, technology, and society is widely acknowledged. These relationships are part of what is currently known as STEM education, which stands for Science, Technology, Engineering, and Mathematics, or STEAM education, where the Arts are included [1]. This type of education is part of a broad spectrum of educational methodologies that, in recent decades, have aimed to increase student involvement, foster meaningful motivation, and significant learning in various educational stages and contexts.

In 2019, a Service-Learning (SL) Office was established within the Universidad Politécnica de Madrid (UPM), with the primary goal of promoting learning through the practical experience provided by volunteering. Apart from introducing the subject matter of SL, highlighting the roles of the involved groups (students, educators, and organizations), promoting projects, and providing resources and news, this office has developed an interesting guide on this educational methodology [2]. The guide emphasizes that SL requires the relationship of two fundamental aspects: the existence of both learning and a service that addresses a real need. Furthermore, it is noted as a key aspect for cultivating individual talents and fostering social commitment. SL is a well-established strategy that has been successfully implemented in universities [3, 4]. Salam et al. examined its application in higher education, addressing, among other aspects, the theoretical framework, methodologies, integration across various disciplines, implementation challenges, pedagogical outcomes, and associated benefits [5]. In addition, Madrid is the capital city of a nation that has participated in the scientific development over the past centuries, which unfortunately is not widely known by the general public. Therefore, it is necessary to disseminate achievements in this regard.

Between 2022 and 2024, two educational projects were carried out with the aim of leveraging the SL methodology to develop two informative scientific routes. In these projects, volunteer students from UPM, who act as guides, in collaboration with a group of professors, not only contributed to the design of these guided walks but also presented and encouraged questioning among the general public about significant contextualized facts, buildings, and historical events related to scientific and technological advancement. Thus, while providing a service to the community, students learn concepts from science, technology, art, and history.

The first project, titled "*Madrid a Ciencia Cierta*: design and implementation of guided routes with STEAM topics", was funded by UPM under the "Service-Learning Projects" call of 2022 [6, 7]. The designed routes were: "Spanish Enlightenment and the discovery of three chemical elements" and "The *'altos del hipódromo' (racecourse heights)*: a landmark area of the 'Silver Age' of Spanish culture". The other project, titled "'*Madrid con Ciencia' (Madrid with Science)*: Walks to discover our scientific past", was granted the following year (2023) within a similar call; the project aimed to deepen the previously designed walks, promote their dissemination, and target them towards specific profile audiences. Specifically, the work presented here focuses on the adaptation of these routes for university students in architecture, building, and urban planning. It is considered to be particularly inspiring for educators involved in these knowledge areas, their students, and anyone curious and eager to learn about the involved topics.

2. OBJECTIVES

The educational and cultural needs identified for the two specified educational projects are as follows:

- Provide a more holistic education for engineering students and other degrees (such as physics and architecture), creating new teaching tools to relate science and technology to issues of art, history, and architecture. Conventional teaching, often characterized by its compartmentalized view of subjects, needs to be supplemented with broader and contextualized perspectives.

- Develop competencies such as data research, teamwork, oral presentation, creativity, etc., in undergraduate, master's, and doctoral students, as well as postdoctoral researchers.

- Facilitate new avenues for the dissemination of activities for the Madrid City Council, such as designing walks that offer contents from Madrid's scientific and historical heritage, which is not as well-known as its historical and artistic heritage.

- Provide greater knowledge of science, art, and history topics for diverse audiences: students and teachers of all educational stages, citizens interested in culture, visitors to Madrid for various reasons (leisure, scientific congresses, events, etc.). In an era where the public has increasing access to information, it is essential for universities to develop rigorous explanations that combine entertainment and education.

- Increase awareness of the architectural heritage of the Universidad Politécnica de Madrid.

- Improve knowledge of the architectural and cultural heritage of a historic city like Madrid. The first route is part of the *Paseo del Prado y el Buen Retiro, paisaje de las artes y las ciencias* (also known as "*Paisaje de la Luz"*), declared a UNESCO World Heritage Site in 2021, that enriches it from a lesser-known perspective: Spain's significant involvement in the discovery of three chemical elements, among other scientific milestones. The second route highlights some scientific achievements and personalities of the "Silver Age" of the Spanish culture (late 19th and early 20th centuries).

To address these needs, the following objectives were proposed:

1. Promote understanding of the relationships between Science, Technology, and Society (STS). For instance, many students acting as guides on the routes were initially unfamiliar with the content they explained later to others.

2. Develop and explore specific topics in the history of science and technology.

3. Deepen understanding of the achievements of four Spaniards (Antonio de Ulloa, the Elhuyar brothers - Juan José and Fausto- and Andrés Manuel del Río) who discovered three chemical elements (platinum, tungsten, and vanadium, respectively), as well as scientists, engineers, and architects from the relevant periods.

4. Highlight the contributions of these scientists and engineers in the city of Madrid, focusing particularly on del Río as the only Madrilenian scientist to have discovered a chemical element.

5. Emphasize the foundation and importance of the periodic table as a milestone in science: some of the mentioned figures contributed to its genesis without being fully aware of it.

6. Promote awareness of the rich historical, cultural, and social relationships in Spain and Spanish America, covering the contexts spanning the 18th, 19th, and early 20th centuries.

7. Address specific topics in geodesy and other areas of science and technology.

8. Contribute to promoting Madrid as a tourist destination of scientific interest.

9. Engage university students from various disciplines in achieving these objectives.

10. Foster the acquisition of personal and social competencies by students, such as empathy, public speaking skills, ability to explain scientific topics to both experts and laypeople, satisfaction in delivering quality work, and learning while serving the community.

These overarching objectives have been expanded to cater to groups with specific characteristics. To date, specific route programs (either as guides or as recipients of information and participants) have been developed for specific groups of students and teachers from various fields of knowledge (engineering, chemistry, physics, and science education) and backgrounds (different educational stages, general public, high schools in rural areas, foreign students, among others). The specific main objective of the work presented here has been to propose ideas to adapt the two didactic and informative routes prepared to students and teachers in architecture, building, and urban planning. This approach encourages reflection on these profiles, adding to the aforementioned objectives by delving into topics such as: urban development in Madrid from the 18th century to the present day; exploration of historical maps; architectural styles (specifically observing diverse styles such as Neoclassical, Iron architecture, Functionalism, and Neo-Mudéjar); evolution and reuse of historical buildings; life and work of iconic architects from the 18th to the 20th centuries; and the relationship between architectural heritage and tourism, among others. Additionally, these routes may serve as inspiration for creating new routes in Madrid and other cities.

3. METHODOLOGY

In terms of content (academic competencies), the routes include a multitude of concepts and tools:

- Science-Technology-Society (S-T-S) relationships: Museums were visited, and various resources such as books, articles, archives, and websites were consulted.

- Exploration of specific topics in the history of science and technology: This included discussions on the discovery of platinum, tungsten, and vanadium within the context of the Spanish Enlightenment in route 1, and discussions on physics, chemistry, architecture, and engineering from the late 19th century to the early 20th century in Spain in route 2. In the development of the first route, fascinating data were uncovered regarding the execution of the *Geodesic Mission*, an emblematic scientific expedition of the 18th century. Another aspect to be explored was the birth and development of the engineering studies in Spain, stemming from research on the *Palace of Industry and Arts*.

- Fundamentals and importance of the periodic table: This topic, although popular in basic studies, is often poorly understood. Leveraging route 1, which highlights the three elements discovered by Spaniards, research was conducted on the genesis and significance of the periodic table as a paradigm of human knowledge, and related topics such as the implications of discovering a chemical element [8].

- Reflections on society and culture in interwar Europe: The uniqueness of society and the evolution of science during the 1920s and 1930s were recurrent themes.

- Study of gardens and buildings in the routes: This involved examining the architects implicated, architectural styles, building refurbishments, urban planning, etc.

Regarding personal and social competencies, aspects such as the following were encouraged for the involved students:

(a) Fostering empathy: Considering, for example, the audience targeted by the routes, which is not always knowledgeable about the topics discussed.

(b) Improving public speaking skills: Enhancing the ability to speak effectively in public.

(c) Developing explanations of scientific topics for diverse audiences: Tailoring explanations for individuals with different educational backgrounds.

(d) Promoting and valuing a sense of service: Emphasizing the importance of contributing to and valuing the service aspect of their roles.

The teaching methodologies and learning activities implemented to develop the project were:

- Learning by Doing: Activities were carried out with a strong practical approach (research, creating posters and presentations, meetings, designing and developing routes, making videos, etc.), which served to "learn" and overcome challenges as they arose.

- Challenge-based Learning: The main challenge initially was to develop two informative routes (thematic content, time management, design, etc.), but as the project progressed, new challenges emerged. For example, in this work, a challenge was to adapt the routes to include aspects related to architecture and related areas.

- Research-based Learning: Engaging students in building their own knowledge through an active process of inquiry and interaction with other students, researchers, and professors.

- Cooperative Learning: Collaboration between students and teachers was the foundation of the project. For instance, interactions were established with students from other countries who were not yet proficient in Spanish, organizing specific visits where they learned about their center's environment and cultural aspects of Spain. They were guided by Spanish students, who also improved their English communication skills.

4. RESULTS

4.1 Designing informative tours

The generated routes, which are subject to slight changes in implementation depending on the nature of the audience and scheduling availability (the standard time for each is about 2 hours), are illustrated in Figure 1 and summarized in the following sections. The idea is to make them dynamic and as relaxed as possible. In the case presented here, themes related to chemistry and physics have been omitted or abbreviated to emphasize architectural and urbanistic implications.

To enhance the educational nature of the routes, a set of images were prepared to be used during the tours, displayed either on tablets or in a folder with colour photocopies. In some cases, the routes were not physically conducted but rather explained in conferences (congresses, science weeks, events, etc.). This approach also proved to be motivating in practice.

Fig. 1: *Guided tours routes (A, B y C: route 1; D: route 2) explained in the text. (Source: Own elaboration based on Google Maps).*

4.1.1 Tour 1: The Spanish Enlightenment and the discovery of three chemical elements

Spain played a prominent role in the research that led to the discovery of the three aforementioned chemical elements [9]. It was the result of a collective effort and one of the consequences of the regeneration impulse carried out during the 18th century, within the context of the Spanish Enlightenment and the consequent Bourbon Reforms [10]. The Enlightenment was a philosophical and cultural movement that emphasized the dominance of reason and represented a cultural globalization [11]. Among other characteristics of its development in Spain, it is worth mentioning a general interest in reforming aspects of public works, administration, communications, education, agriculture, and industry (including economic and technical improvements in sectors such as mining and metallurgy in Spanish America); the formation of "enlightened despotism" governments, for which monarchs relied on well-educated individuals; initiatives to promote scientific and technical training in the armies; efforts to develop a 'national science' that would enable the application of technology for better resource utilization; the creation of scientific and educational institutions such as the *Real Academia de Guardiamarinas* (Royal Academy of Marine Guards, Cádiz) in 1717, the *Real Seminario Patriótico de Vergara* (Royal Patriotic Seminary of Vergara) (Guipúzcoa) in 1777, and the Mining Academy of Almadén, also in 1777; and the funding of scientific expeditions. To achieve this, scientific exchange with foreign countries, especially with Central European countries, was encouraged through actions such as funding "scholars" to expand their studies in major European educational centres, organizing programs for "industrial espionage" or "observation committees", and hiring foreign professionals (Heinrich Störr, Louis Proust, François Chavaneau...) for newly created or revamped centres. In this way, it is considered that Spain effectively joined the Scientific Revolution of the time.

An emblematic example of a prominent personality of the Enlightment, mentioned at the beginning of the route, is Agustín de Betancourt (Puerto de la Cruz, Tenerife, 1758 – Saint Petersburg, 1824) [12], whose bicentennial of his death was commemorated in 2024, leading to multiple initiatives in his honour. As a civil engineer, military strategist, and architect, he made significant contributions in both Spain and Russia, working on diverse topics such as steam engines, hot air balloons, structural engineering, and especially urban planning (overseeing the development of several Russian cities like Saint Petersburg and their transportation systems). The route (see Figure 1 A to C) begins in the southern area of El Retiro Park, continues towards Emperor Charles V Square (also known as Atocha Square) -where there is a statue of Antonio de Ulloa-, and progresses to the San Isidro Secondary School in the Latina district. It passes through the Botanical Garden and the birthplace of Andrés del Río in Lavapiés neighbourhood. During the tour, references are made to the Elhuyar brothers through several buildings. Topics covered include: what are chemical elements, the importance of metals, scientific expeditions, adventures of "navigators and corsairs", industrial espionage, the development of science in the 18th century, and the significance of mining in Spanish America. These topics are generally discussed briefly, aiming to motivate participants to seek more information and to visit these places in detail at another time. The most notable stages of this route are:

- Remains of the former Royal Porcelain Factory of Buen Retiro, popularly known as "La China," located in the current Ángel Caído roundabout within El Retiro Park [13]. Virtually only the remnants of one of the park's waterwheels (see Figure 2), used in the factory and located in the Huerto del Francés (The Frenchman's Garden), were discovered during excavations carried out between 1996 and 2000. The factory (an example of royal manufactures) was founded by Carlos III on the site of an old hermitage,

with artisans from Naples, to produce ceramics used to decorate the Royal Palace and other royal sites using a manufacturing technique that was a state secret. It seems that it was destroyed by English troops in 1812, after defeating the French who had been stationed there. In this first stage, the fundamental ideas of the route are explained, introducing the Enlightenment period. Therefore, support material includes images of some emblematic architects mentioned throughout the tour, painted by Francisco de Goya, another prominent figure of that period (see Figure 3).

Fig. 2: *Waterwheel at the Frenchman's Garden (Gardens of El Retiro, Madrid). (Source: https://www.miradormadrid.com /noria-del-retiro/ CC BY-SA 3.0).*

Fig. 3: *Image used in route 1 to introduce some of the emblematic architects of the Spanish Enlightenment. (Source: Own elaboration based on images collected from Wikimedia Commons. Public domain).*

- Royal Observatory of Madrid. Built also at the initiative of Carlos III, at the suggestion of Jorge Juan, it was inaugurated in 1790. The architect was Juan de Villanueva, and the initial idea was for it to be part of a "Science Axis," along with the Royal Cabinet of Natural History (in the building that would eventually become the Prado Museum) and the Royal Botanical Garden [14]. Currently, it serves as the headquarters of the National Astronomical Observatory, belonging to the National Geographic Institute. Figure 4 shows two images of the building from different periods.

Fig. 4: *Royal Astronomical Observatory of Madrid – Juan Villanueva Building (Sources: Above - Grabado de F. J. Parcerisa y Boada, 1833, Public domain; Below - Fanattig. GNU Free Documentation License).*

- Palacio de Fomento (Development Palace). This building, designed by Ricardo Velázquez Bosco, about whom more information is provided in route 2, was constructed between 1893 and 1897 [15]. Initially planned as the School of Arts and Crafts and Faculty of Sciences, on the grounds of the Botanical Garden, it has served as the headquarters of various ministries, such as Public Works, Public Instruction and Fine Arts, and currently houses the Ministry of Agriculture. Although the building dates after the Enlightenment period and aligns more with the

content of the following route, it is used to discuss the life and work of Antonio de Ulloa [16] due to the presence of a statue of him (created by José Alcoverro) on the main façade, as shown in Figure 5. Antonio de Ulloa y de la Torre Guiral was born in 1716 in Seville. In 1733, he entered the Royal Academy of Marine Guards (Cádiz) and between 1735 and 1734, he participated in the French Geodesic Mission, an emblematic scientific expedition [17]. On the return journey, he was captured by corsairs who took him as a prisoner to England. There, he described platina (resembling silver), previously considered an impurity of gold and silver, identifying it as a new metal and, consequently, a new chemical element which is the only one of Spanish etymology: platinum (Pt). Between 1749 and 1751, he participated in a "secret commission" for several European countries including France, the Netherlands, and Sweden. Besides his main role as a naval officer (he eventually became governor of the vast territory of Louisiana, in present-day United States), he wrote a report on the cleaning of Madrid, proposed the creation of a Cabinet of Natural History in the same city, and designed navigation and irrigation canals for the Kingdoms of Castile and León. In this part of the route, additional time is dedicated to explaining the Geodesic Mission and encouraging participants to visit the Naval Museum (about a ten-minute walk away). This museum displays important relics related to what is discussed in this tour, and its website is also a relevant source of information.

Fig. 5: *Photographs of the building known as the Palace of Fomento, and of a detail of the sculpture of Antonio de Ulloa located on the facade. (Source: Wikimedia Commons. Public domain).*

- Real Jardín Botánico (Royal Botanic Garden) was initially established on the banks of the Manzanares River in 1755, through the initiative of Fernando VI, in the area where the Puerta de Hierro is currently located. It was later relocated to its current location between 1774 and 1781, under the direction of Francesco Sabatini and Juan de Villanueva [18]. Its main purpose was the study and teaching of botany, as well as the organization of scientific expeditions such as the Royal Botanical Expedition of the New Kingdom of Granada led by the botanist, physician, and priest Celestino Mutis (Cádiz, 1732 – Santa Fe de Bogotá, 1808). This expedition was notable for its drawings of plant collections and the description of new species. Figure 6 shows a late 18th-century painting and a current photograph of one of the entrance gates.

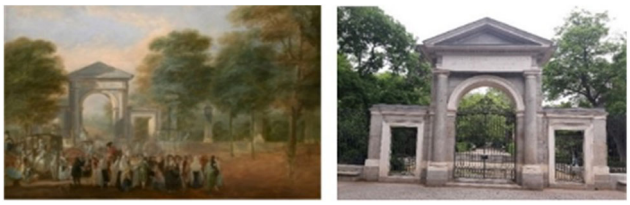

Fig. 6: The Botanical Garden from Paseo del Prado (oil painting *by Luis Paret y Alcázar circa 1790) and a current photograph of the same entrance gate. (Source: Left - Museo Nacional del Prado; Right - Photograph by G. Pinto).*

- The Prado Museum. Its construction began in 1786 under Juan de Villanueva, with the idea of housing the Royal Cabinet of Natural History, the Academy of Sciences, and a large chemistry laboratory. It was devastated during the Napoleonic invasion, serving as a barracks for the invading army, and was inaugurated in 1819 (at the request of Fernando VII and especially his wife, Isabel de Braganza), as the Royal Museum of Paintings, following the model of the Louvre [19]. Figure 7 includes two images of what is now known as the Villanueva Building. Figure 8 shows the original plans of the building's floors, elevations, and profile.

Fig. 7: *Original appearance of the north facade of the Prado Museum, in a painting by Ferdinando Brambilla and a current photograph (Source: Own elaboration based on images collected from Wikimedia Commons. Public domain).*

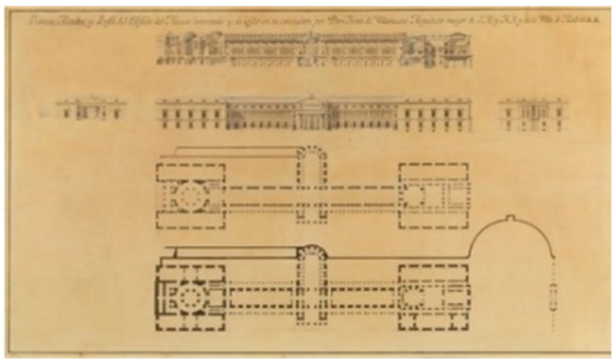

Fig. 8: *Plans, elevations, and profile of the building of the Museum, conceived and directed in its execution by Don Juan de Villanueva, Chief Architect of His Majesty and of the Royal Academy and of the City of Madrid, 1796 (Source: Museo Nacional del Prado).*

- Casa de la Platina (The House of Platina), located at Hortaleza Street, block 330 (current number 87), was renovated by Juan de Villanueva, mentioned several times previously, between 1787 and 1791. It housed the Royal Platinum Factory and the School of Physics, Chemistry, and Mineralogy. Later, it became the Lithographic Establishment of the Hydrographic Deposit (between 1819 and 1825) and the Santa Bárbara brewery. Construction of the Santa Bárbara Palace, located in the square that currently bears the same name, began in 1862.

As it is somewhat far from the route followed, participants are shown its location through photographs of old maps. In 1791, the House of Platina, under the direction of French chemists Chavaneau (between 1791 and 1797) and Proust (between 1799 and 1806), played a crucial role in the study and commercialization of platinum [20]. It was initially located on De los Jardines Street, later renamed Del Turco Street (where General Prim was fatally attacked in 1870), and is now known as Marqués de Cubas Street. This last location is usually visited in the designed route; it currently houses the School of Applied Arts and Artistic Crafts.

- Palacio de las Cortes (Palace of the Courts). This building was constructed between 1843 and 1850 according to the project by architect Narciso Pascual y Colomer (Madrid, 1801 - Lisbon, 1870; besides many constructions in Madrid, he became the director of the Superior School of Architecture of this city), after the demolition of the Convent of the Holy Spirit [21]. It is relevant on the route because in a neighbouring building (see Figure 9), Fausto de Elhuyar lived his last years and passed away. At that time, it was the Palace of the Duke of San Pedro, on Florín Street (a unique house), now Fernanflor, which housed the General Directorate of Mines and the School of Mining Engineers, both directed by Elhuyar.

Fausto de Elhuyar y Lubice was born in 1755 in Logroño and between 1773 and 1777 studied surgery, mathematics, and natural history in Paris. Over the next three years, he continued his education in other European institutions. Between 1781 and 1785, he was a professor of Mineralogy and Metallurgy at the Royal Seminary of Vergara (Laboratorium Chemicum), where he coincided with Chavaneau, and they collaborated on the purification of platinum. There, in 1783, he obtained tungsten with his brother Juan José [22].

Fausto was appointed to Mexico, where he became the Director General of Mining of the Viceroyalty of New Spain and founded the Mining College (1792) and the Mining Palace (1813). He returned to Spain in 1821, passing away in 1833. His brother Juan José, one year older than him, had a similar education, although he became the Director of Mines (mainly of silver) of Santa Fe de Bogotá (current Bogotá,

Colombia, in the then Viceroyalty of New Granada) in 1784, where he passed away in 1796.

Fig. 9: *Church and Convent of the Holy Spirit, demolished in 1842, and the Palacio de las Cortes in 1853. (Source: Above- Wikimedia Commons; Below - Pinterest. Public domain).*

- Andrés Manuel del Río's Birthplace. Del Río was born in 1745, in Ave María Street in the Lavapiés neighbourhood. Concretely, he was born at house number 17, which was later demolished and rebuilt to the current number 23 (see Figure 10) [23]. The route also passes by the Church of San Sebastián (at Atocha Street No. 39), where he was baptized, and by the current San Isidro High School, formerly known as the Royal Studies of San Isidro on Toledo Street, where he studied. After studying mining and chemistry in several Central European countries, he was appointed in 1793 as a professor at the Royal Seminary of Mining in Mexico, teaching Mineralogy and Mining Labour. After 26 years in Mexican lands, he returned to Spain as a representative of New Spain in the Parliament during the liberal triennium (1820-1823), located in the current Senate building. Between 1829 and 1835, he was in the United States and passed away in Mexico in 1849. The story of the discovery of vanadium, which he called “eritronio” (erythronium), is an interesting and curious example of how scientific knowledge develops [24].

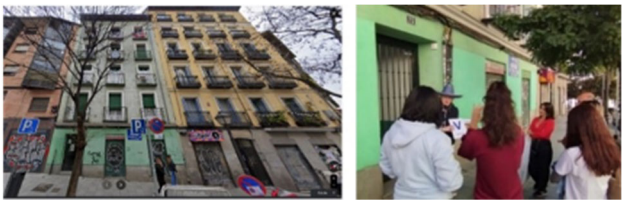

Fig. 10: *The facade of the current building of Andrés del Río's birth home and a photograph from one of the visits made there (Source: Left - Own elaboration base don Google Maps; Right - Photographs taken by authors).*

This final stage of the route is complemented by showing participants a map of Madrid from the mid-18th century to contextualize the era in a city much smaller than today's. Additionally, participants are usually shown a photograph of the imposing Mining Palace of Mexico City (see Figure 11), built in 1813 by Valencian architect Manuel Tolsá (Enguera, Valencia, 1757 - Mexico City, 1816) —another example of a prominent personality of the Enlightment— to house the Mining Tribunal and the Mining College. There, Fausto de Elhuyar and Andrés Manuel del Río carried out extensive teaching and research work.

Fig. 11: *Palacio de Minería (Palace of Mining) in Mexico City: Lithograph by Casimiro Castro in the 19th century and current photograph (Source: Wikimedia Commons. Public domain).*

A reproduction of the Independence Mural, a work by Juan O'Gorman from 1961, is also shown to participants, depicting portraits of these two scientists and their mutual friend, Alexander von Humboldt, among several dozen characters [25]. As

an example, and among other possible visits, within the interest of the participating group and the available time, the route includes a stop at the Neptune Fountain, designed by Ventura Rodríguez and inaugurated in 1786. Not only does it allow the visualization of a work that del Río saw constructed before his first trip to Mexico, but it also illustrates the "Neptunism" theory about the origin of minerals by his admired professor, Abraham Gottlob Werner (1749-1817).

4.1.2 Tour 2. The 'Altos del Hipódromo' (Racecourse Heights): An emblematic area of the 'Silver Age' of Spanish culture (1868-1936)

By analogy with the "Golden Age", which took place between the early 16th century and the late 17th century, marking the peak of Spanish culture between the Renaissance and the Baroque periods, there is also talk of a "Silver Age" of Spanish culture for the period between 1875 (start of the *Bourbon Restoration*) or 1898 (known as the "*Disaster of 98"*) and 1936 (start of the Spanish Civil War) [26]. It was a period of modernization that encompassed multiple facets across literature (including writers from the generations known as 1868, 1898, 1914, 1927, and 1936), music, cinema, architecture, sports, radio, press, science, and technology. Additionally, new concepts emerged for women during this time, illustrated by the creation of the *Residencia de Señoritas* (Young Women's Residence) and the Women's *Lyceum Club*.

Some notable initiatives during this period include the establishment of the *Institución Libre de Enseñanza* (Free Institution of Education), ILE (1876) —which remained active until 1939—, the *Palacio de las Artes y la Industria* (Palace of Arts and Industry) (1887), the *Junta para la Ampliación de Estudios e Investigaciones Científicas* (Board for the Expansion of Studies and Scientific Research), JAE (1907) —within the framework of the ILE— and the *Residencia de Estudiantes* (Student Residence) (1910). The era and its impact on the development of science and technology are showcased during a route (see Figure 1.D) that passes through areas adjacent to a racecourse —inaugurated in 1887 and lasting until 1933— in the space currently occupied by the architectural complex known as *Nuevos Ministerios* (*New Ministries*) and part of *Paseo de la Castellana*. Apart from its conventional use in equestrian activities and as a meeting point for the nobility and bourgeoisie, it was also used for aerial exhibitions and the practice of a sport that was becoming popular: football.

The ILE, inspired by the Krausist philosophy, was inaugurated by professors such as Francisco Giner de los Ríos (Ronda, Málaga, 1839 - Madrid, 1915), Gumersindo de Azcárate y Menéndez (León, 1840 - Madrid, 1917), and Nicolás Salmerón (Alhama la Seca, Almería, 1838 - Pau, France, 1908), who were separated from the Central University of Madrid for advocating academic freedom. Throughout its existence, it involved many intellectuals such as Joaquín Costa, José Ortega y Gasset, Gregorio Marañón, Ramón Menéndez Pidal, Antonio Machado, Joaquín Sorolla, and Santiago Ramón y Cajal. It was a significant centre of culture and the introduction of modern pedagogical theories, extending from university to primary and secondary education. On the other hand, the JAE was created to promote research and scientific education in Spain, presided over by Ramón y Cajal until his death in 1934. In its own Royal Decree of foundation, it is stated that: *"The intellectual work during the reigns of Carlos III and Carlos IV, which resulted in most of our current centers of culture, had as its starting point the end of the isolation into which we had previously fallen, forgetting our enviable tradition, and restored communication with European science. This communication, interrupted later by various causes, now only preserves isolated manifestations."* [27] With this text, participants are suggested a connection between the two routes discussed in this work. This connection can also be described

practically and in a relaxed tone, referring to the popular expression "*ir al quinto pino"* (literally "go to the fifth pine tree", meaning go to the middle of nowhere). This expression refers to the fact that of the five pine trees planted by Felipe V in the first half of the 18th century, from the Paseo del Prado along the Paseo de la Castellana, the furthest from the city centre was located at the current *Nuevos Ministerios*.

The JAE promoted exchange programs for teachers, scientists, and students, as well as scholarships for studying abroad [28]. It also established new centres and laboratories in both sciences and humanities, along with new facilities (such as laboratories and libraries) for existing institutions such as the Museum of Natural Sciences, the Anthropological Museum, the Royal Botanical Garden of Madrid, or the Biological Station of Santander. Furthermore, it coordinated laboratories such as the Alpine Biology Station of Guadarrama, the Biological Mission of Galicia, or the Commission of Paleontological and Prehistoric Investigations, and created the Institute-School (its buildings now house the Ramiro de Maeztu and Isabel La Católica Secondary Education Institutes). In 1939, it was dismantled, like the ILE, and some of its buildings and resources became part of the Higher Council for Scientific Research (CSIC).

The painter Joaquín Sorolla (Valencia, 1863 - Cercedilla, Madrid, 1923), whose Museum-House is near the visited area, was an emblematic artist of the Silver Age. Besides his well-known landscapes, he portrayed other prominent intellectuals of this period, as illustrated with images along the route. One of them is José de Echegaray y Eizaguirre (Madrid, 1832 - Madrid, 1916), Civil Engineer, professor, minister of Public Works and Finance, founder of the Progressive Republican Party, and Nobel Prize in Literature.

Following the stages indicated in Figure 1.D for this walk, some of the most emblematic buildings that are passed by are briefly described, along with some of the comments made during the visits:

- The School of Mining Engineers had its origins in the Almadén Mining Academy, as mentioned earlier. After being located in various places in Madrid, it settled in its current location at 21 Ríos Rosas Street in 1884 [29]. The building, designed by architect Ricardo Velázquez Bosco, was completed that same year and stands out for its harmonious use of different decorative materials such as iron, brick, wood, glass, and stone. The facade features ceramics designed by Daniel Zuloaga, the uncle of the famous painter Ignacio Zuloaga. Figure 12 shows the building with its corner towers and sculptures added in the early 20th century. Inside the building, there is a central courtyard, the Don Felipe de Borbón y Grecia Mining History Museum, and the Marcelo Jorissen Mine-Museum (which can be visited on certain occasions). Jorissen is an example of the era: born in Brussels in 1897, he moved to Spain during World War I and studied at the School of Mining Engineers in Madrid between 1917 and 1922. He later worked in the mining industry and also taught at the same school, where he became its director. He died in 1984. Given the significance of the building and its architect in this narrative, its visualization is an excellent opportunity to discuss with participants the life and work of Ricardo Velázquez (see Figure 13). Born in Burgos in 1843, Velázquez stood out from a young age as an artist and later as an architect. He built several iconic buildings in Madrid, such as the Velázquez Palace in Retiro Park and the Crystal Palace, originally a greenhouse. He is also credited with important constructions such as the Ministry of Development, the School for the Deaf, and the Ministry of Education on Alcalá Street, among others. In addition to his architectural work, he carried out restoration projects at Burgos Cathedral and the Mosque-Cathedral of Córdoba, leaving a significant legacy in Madrid's architectural history before his death in 1923.

• The Geological and Mining Institute of Spain, founded in 1910, traces its origins to the Geological Survey Commission of Madrid and the General Kingdom, established in 1849, which had several locations. The current building, notable for its interior (see Figure 14), which can be accessed free of charge, was completed in 1910 and designed by architect Francisco Javier de Luque López in 1921 (see Figure 13).

Fig. 12: Building of the School of Mining Engineering at the end of the 19th century and presently (Source: Left - Wikimedia Commons. Public domain; Right - https://short.upm.es/ti0n0 CC BY-SA 3.0).

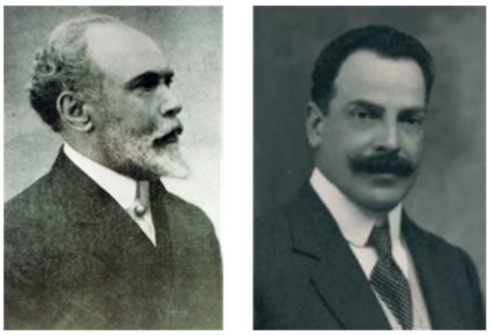

***Fig. 13:** Portraits of architects Ricardo Velázquez Bosco (left) and Francisco Javier de Luque López (right) (Source: Wikimedia Commons. Public domain).*

De Luque was born in Seville in 1872, where he earned degrees in Physical-Mathematical Sciences. In 1899, he graduated in architecture from Madrid and, after residing in Vitoria between 1909 and 1914, he became a professor of Applied Mechanics at the School of Industrial Engineers of Bilbao in 1906. In 1914, he became a professor at the School of Architecture in Madrid. Among his notable works in Madrid, in addition to the Geological and Mining Institute building, are the Jesús y María School, the Parish of the Twelve Apostles, and Pavilion 4 of the *Residencia de Estudiantes*, which is discussed later. His other works include the Spanish Pavilion at the Venice Biennale and the restoration and completion of the facade of the Seville Cathedral. De Luque passed away in Madrid in 1941.

Fig. 14: Various views of the Geological and Mining Institute of Spain (*Source*: Wikimedia Commons. Public domain).

• *Colegio de Sordomudos* (The College for the Deaf and Dumb) (see Figure 15). The land on which it is located was purchased by the ILE in 1880 to establish its headquarters, but the project did not materialize due to its excessive cost. The state acquired the land and commissioned the design from Ricardo Velázquez, as previously mentioned, to be the headquarters of the National College for the Deaf and Blind, inaugurated in 1887. Between 1901 and 1907, it was also used as classrooms for the School of Industrial Engineers. In 1932, it became known as the Palace of Primary Education, housing the National Pedagogical Museum as well as a Teacher Training School [30]. The objectives of this museum included creating libraries (a fixed central library and others

traveling), publishing a Pedagogical Bulletin, developing a Laboratory of Pedagogical Anthropology, and providing teacher training courses, lecture cycles, and workshops on psycho-pedagogical techniques. The museum also organized School Colonies, which emphasized holistic, non-formal education experiences such as stimulating activities (games, excursions, walks, etc.), where students were required to keep a diary to record what they learned each day.

Fig. 15: *The College for the Deaf and Dumb building at the end of the 19th century and today (Source: Top – Late 19th-century postcard photograph; Bottom - CESEDEN. Public domain).*

Between 1931 and 1939, the building also housed the headquarters of the *Pedagogical Missions*, a cultural solidarity project initiated by the Ministry of Public Instruction and Fine Arts with support from the ILE. More than 600 volunteers (teachers, university students, artists, intellectuals, etc.) participated in these "missions" in over 7,000 villages, establishing 5,500 libraries with more than 600 thousand books. The missions also promoted choir performances, theater and puppet shows, and film screenings in many Spanish villages, along with circulating art exhibitions from the Prado Museum. In 1941, the building became the headquarters of the Superior School of the Army, which eventually became the current CESEDEN (Higher Centre for National Defence Studies).

• Palace of Industry and Arts. It was built between 1882 and 1887 by Fernando de la Torriente (1845-1886) and, after his premature death, completed by Emilio Boix y Merino (Barcelona, 1856-Montevideo, 1904) [31]. The latter, after his work in Spain, worked as a professor and architect in Argentina and Uruguay. The Palace was constructed on a hill near the racetrack, known as Cerro del Viento (Wind Hill). Figure 16 shows its appearance in the early 20th century and today. It has a height of 28.7 meters from the ground and is supported by 24 forged iron arches with vegetal motifs. It stands out as an example of the so-called Iron Architecture, which employs new construction materials made accessible by the Industrial Revolution, highlighting steel and other materials such as glass, reinforced concrete, and brick. Prominent examples of this style include bridges, the Eiffel Tower, and train stations like Atocha, designed and built between 1888 and 1892 by architect Alberto de Palacio Elissague (Sare, France, 1856 – Madrid, 1939), who had known Gustave Eiffel and collaborated with Ricardo Velázquez in building the Velazquez and Crystal Palaces. The dome is especially emblematic, with a diameter of 22.3 meters, a pinnacle with a lightning rod, and a lantern at the bottom. The building in this stage of the route was constructed to be the headquarters of the National Fine Arts and Industry Exhibitions, with the last one held in 1899. Figure 17 shows posters announcing some of the exhibitions held there.

Between 1907 and 1910, the National Museum of Natural Sciences (MNCN) was relocated to this building, with its origins dating back to 1752 in the Royal House of Geography and Cabinet of Natural History, located in the Lavapiés neighborhood. The collection included specimens from many territories and scientific instruments and books purchased by Antonio de Ulloa. In 1771, the Royal Cabinet of Natural History was established when Carlos III acquired Pedro Franco Dávila's collection (Guayaquil, Ecuador, 1711-Madrid, 1786), initially located in the

Royal Academy of Fine Arts. In 1785, Carlos III commissioned Juan de Villanueva to design a new building in the Salón del Prado, which ultimately became the Prado Museum, as mentioned earlier. Since that time, the MNCN shares the building with what is now called the Higher Technical School of Industrial Engineers of the Universidad Politécnica de Madrid. Its origins trace back to the Royal Conservatory of Arts of Madrid and the establishment, in 1850, of the Industrial Engineering program. Initially, it was located at the Royal Industrial Institute, created for this purpose and installed in the former Convent of the Trinity, in the current Jacinto Benavente Square, which was demolished in 1897. The School disappeared in 1867 when the Minister of Public Works (Manuel Orovio) eliminated its budget allocation. In 1901, it reopened by decree of the Minister of Public Instruction (Álvaro de Figueroa), located at Fuencarral Street No. 91, with some classes held on the top floor of the building of the College for the Deaf, as previously mentioned. In 1907, due to the increasing number of students, the Minister of Public Instruction (Rodríguez San Pedro) allocated funds to relocate all classes to the Palace of Exhibitions, where it remains today after significant expansions and renovations. Inside the building, a particularly emblematic feature is a 30-ton steam engine, installed in 1914, which was built in 1852 in London and donated by the Casa de la Moneda (Coinage Mint) at de Colón Square, where it had operated until 1892. As a curiosity, in the years 1889 and 1990, the building was also used as a hospital during the influenza pandemic (see Figure 18).

In 1910, at the initiative of the JAE, the Laboratory of Applied Mechanics (later Automatics) directed by the prominent engineer Leonardo Torres Quevedo (Santa Cruz de Iguña, Molledo, Cantabria, 1852 – Madrid, 1936) and the Laboratory of Physical Research, within the National Institute of Sciences, directed by Blas Cabrera (Arrecife, Lanzarote, 1878 – Mexico City, 1945), were housed there, where Miguel Antonio Catalán Sañudo (Zaragoza 1894 - Madrid 1957) and Enrique Moles Ormella (Barcelona 1883 - Madrid 1953) worked. All of these figures are worth delving into their biographies and achievements, which participants in the route are encouraged to explore.

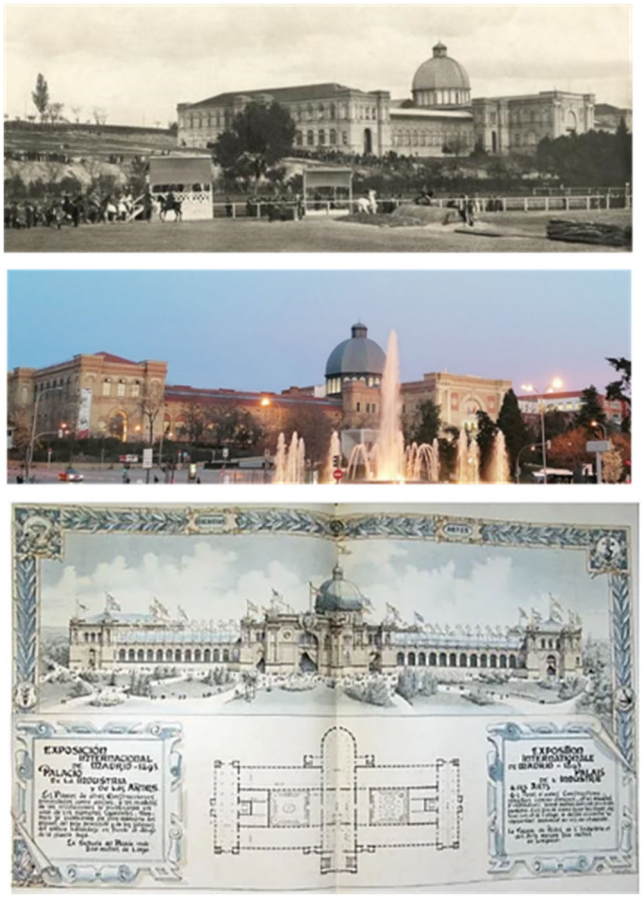

Fig. 16: *From top to bottom: photographs of the Palace of the Industry and Arts in the late 19th century and in present-day, and poster announcing the International Exposition of 1893 (Source from top to bottom: Photograph by G. Laguna and J. Martín at https://www.industriales.upm.es/; https://short.upm.es/umirr; and photograph of original poster. Public domains).*

Fig. 17: *Posters of international exhibitions held at the Palace of Industry and Arts (Source: Photographs of original posters).*

When the racecourse somehow acted as a barrier to Madrid's expansion along *Paseo de la Castellana*, various projects were proposed, such as the one in 1916 by the engineer Director of Madrid's Public Roads, Pedro Núñez Granés (Benavente, Zamora, 1859 – Unknown, 1944) for the urbanization of Madrid's outskirts, including a monumental square dedicated to Alfonso XIII. As an indication of the importance already placed on the development of large cities, Núñez Granes participated in Washington in 1909 in the "City Planning and the Problems of Congestion" Conference, and in 1913 in Dresden at the "International Hygiene Exhibition." His project for the area, illustrated in Figure 18, obviously did not come to fruition.

Fig. 18: *Field hospital in the Palace of Fine Arts to care for the sick from the influenza pandemic 1889-1890, and Project detail for the extension of Paseo de la Castellana, by Pedro Núñez Granes (1916). (Biblioteca Virtual 'Memoria de Madrid'). (Source: Left - La Ilustración Española y Americana; Right: Wikimedia Commons. Public domain).*

Figure 19 shows different images of the current state of the building, with some areas well preserved and others completely transformed at the rear. In turn, Figure 20 shows the transformation carried out in the mid-20th century in the space assigned to the Higher Technical School of Industrial Engineers, to expand classrooms and the library.

Fig. 19: *Details of the back part of the building of the 'Palace of Industry and Fine Arts' at present time (Source: Photographs by G. Pinto).*

Fig. 20: *South side of the 'Palace of Industry and Fine Arts' building in the early 20th century (left) and present day (right) (Source: left - postcard photograph; Right - Photograph by G. Pinto).*

It is worth mentioning that the building housed other facilities throughout its history, such as a Civil Guard barracks and the Institute of Cinematographic Research and Experiments (future Official School of Cinematography), founded and directed by industrial engineer Victoriano López García (Mondoñedo, Lugo, 1910 - Madrid, 1995) in 1947, where many of Spain's most important filmmakers of the second half of the 20th century were trained. The building's various uses and transformations throughout its history are particularly appealing for teachers and students in areas related to architecture.

- *Residencia de Estudiantes* (see Figure 21). Built between 1913 and 1917 as a set of Neo- Mudéjar style brick pavilions [32], it consists of two "twin" buildings separated by a "garden of oleanders," where the rooms were (and are) located—one central (housing the dining room and auditorium) and another called the "transatlantic" building where the laboratories and library were located. Inspired by English colleges, it was expanded between 1931 and 1932 with the Instituto Escuela (Institute-School) —an institution created in 1918 to extend secondary education based on the principles of the ILE and currently occupied by the Ramiro de Maeztu High School— and an auditorium —now the Church of the Holy Spirit designed by Miguel Fisac (Daimiel, Ciudad Real, 1913 – Madrid, 2006)—. From outside, visitors can see a replica of a typical room from that time period, accompanied by a brief description of how poets (García Lorca, Salinas, Guillén, Juan Ramón Jiménez...), painters (Salvador Dalí), filmmakers (Luis Buñuel), scientists (Severo Ochoa, Juan Negrín,

Antonio Madinaveitia, Ignacio Bolívar...), etc., lived and interacted there. Moreover, renowned scientists like Marie Curie and Albert Einstein, as well as economists like John M. Keynes, gave lectures there. It was a leading cultural centre where some of the most vibrant experiences of scientific and artistic creation and exchange in interwar Europe took place. The main purpose of the *Residencia* was to complement university education with an intellectual

Fig. 21: *Top and bottom left: photographs of the Residencia de Estudiantes in the first third of the 20th century; bottom center: recreation of a typical room from that time period; bottom right: current appearance of the central building. Sources: top - https://short.upm.es/1v05e; bottom left - https://short.upm.es/650cn; the other two images - photographs taken by G. Pinto).*

Fig. 22: *To the left, Dalí, García Lorca and "Pepin" Bello in 1926, and Einstein in front of the Museum of Natural Sciences in 1923 and, to the right, current locations of the photographs (Sources: Above to the left - https://short.upm.es/0txgx. Public domain; Below to the left - Archivo General de la Administración, Alcalá de Henares, Madrid [IDD(03)88, F/03198, S10, F45]; Right - photographs taken by G. Pinto).*

and communal environment suitable for students. It featured a library, language classes, and various science laboratories, fostering continuous dialogue between sciences and arts.

During visits, participants are often engaged in identifying traces of buildings seen in certain historical portraits (as depicted in Figure 22). Additionally, to help recreate the atmosphere of the time, photographs like those in Figure 23 are shown, placed in the space between the back of the Palacio de la Industria y de las Artes and the Residencia de Estudiantes. This approach aims to provide a "life" perspective, connecting people who have enjoyed these spaces beyond the buildings themselves.

Fig. 23: *Young people practicing sports between the Palace of Industry and Arts and the Residencia de Estudiantes, in the early 20th century (Source: https://short.upm.es/dwo0m. Public domain).*

- The National Institute of Physics and Chemistry, known as the "Rockefeller Building," was inaugurated in 1932 [33]. It represented an expansion of the Physical Research Laboratory of the JAE, as mentioned earlier, thanks to funding from the Rockefeller Foundation. It is currently the Blas Cabrera Institute of Physical Chemistry (formerly known as Rocasolano) at the CSIC. The architects were Manuel Sánchez Arcas (Madrid, 1897-Berlin, 1970) and Luis Lacasa (Ribadesella, 1899-Moscow, 1966). The first studied architecture in Madrid, with notable constructions such as the San Carlos Clinical Hospital—in collaboration with architect Eduardo Torroja (Madrid, 1899 – Madrid, 1961). After the Civil War, he went into exile in the USSR, Poland, and East Berlin. The second studied architecture in Madrid and was a JAE scholarship recipient in Germany, introducing the rationalist movement in Spain. During the war, he went into exile in Moscow. Prominent scientists such as Blas Cabrera, Miguel

Catalán, and Enrique Moles, already mentioned, worked in this building. Recently, a Laboratory-Museum has been inaugurated that showcases some of Enrique Moles' documents and instruments.

Fig. 24: *Edificio Rockefeller (Rockefeller building) in 1931 (left) and at present (Source: top – An. Quím. 118(4), 2022 p. 278. Public domain; bottom - Photographs taken by G. Pinto).*

4.2 Implementation of informative routes

As already indicated, the described routes have been designed and implemented by students and teachers. Specifically, the students engage in a Service-Learning activity, which is complemented by their role as "guides" during the various visits. Scene from some of the conducted tours is captured in Figure 25.

5. CONCLUSIONS

The experience has been enriching and highly appreciated by the involved groups (teachers and participating students in its development, the public participating in the activities, representatives of collaborating entities, etc.), as expressed in meetings, gatherings, and satisfaction surveys.

Both routes have been successfully carried out in-person as well as in a 'virtual' format (through presentations in various forums and other means). The acceptance from the participating public has been immense, with many individuals leaving their contact information to be notified of similar future activities.

Fig. 25: *Photographs featuring details of participants in some of the educational walks (Source: Photographs taken by authors).*

Directly involved students, as self-assessed and confirmed by the involved educators, have acquired specific and general competencies, making it a good example of Service-Learning. The teachers involved have also gained new insights and have seen the value of their work, appreciated both by the students and the participating audience.

An example of the project's success was the awarding of the first prize for Service-Learning projects carried out at Universidad Politécnica de Madrid in 2023.

With the completion of the project, the routes were established and continue to operate, available upon request. For example, visits have been conducted and conferences organized about them during the celebration of the Science and Innovation Week in the Community of Madrid, as well as for university students from the United States on study trips in Spain.

The idea, regarding future perspectives, is to refine details and tailor them to different profiles. For example, initiatives for dramatization have already been started and are intended to be improved, incorporating period costumes in both cases, which is

particularly appreciated by younger audiences. Additionally, although several visits have been conducted in English, there is an intention to organize them more systematically. There are also plans to develop the visits on web platforms to increase their visibility.

One idea intended to be emphasized with everything involved in this field is collaboration, especially in educating the younger generations, to avoid explaining the past from a present-day standpoint by fostering an appreciation and understanding of the past through admiration for emblematic figures in science, engineering, architecture, and culture overall. The objectives set at the beginning are considered adequately achieved, considering the project's sustainability and future prospects.

6. ACKNOWLEDGEMENTS

The help provided by the Universidad Politécnica de Madrid is appreciated, through the projects “Madrid a Ciencia Cierta: Design and implementation of guided routes with STEAM themes” and “Madrid con Ciencia: Walks to discover our scientific past”, within the calls for “Service-Learning Projects” in the years 2022 and 2023, respectively. Also appreciated are the collaborations from the Madrid City Council, through its Project Office, and from the Specialized Group in Didactics and History of Physics and Chemistry (GEDH), common to the Spanish Royal Societies of Physics (RSEF) and Chemistry (RSEQ).

7. REFERENCES

[1] Pinto, G. (2022). Educación STEAM: Análisis de debilidades, amenazas, fortalezas y oportunidades, Anales de la Asociación Química Argentina, vol. 109 (número extra), pp. 114-121.

[2] Servicio de Innovación Educativa de la UPM (2020), Guías para el PDI. https://bit.ly/3JUNL3W (accessed April 14, 2025).

[3] Rodríguez Gallego, M.R. (2014). El Aprendizaje-Servicio como estrategia metodológica en la Universidad, Revista Complutense de Educación, vol. 25(1), pp. 95-113. DOI: https://doi.org/10.5209/rev_RCED.2014.v25.n1.41157.

[4] Bringle, R.G., Hatcher, J. A. (1996). Implementing service learning in higher education, The Journal of Higher Education, vol. 67(2), pp. 221-239. DOI: 10.1080/00221546.1996.11780257.

[5] Salam, M., Iskandar, D.N.A., Ibrahim, D.H.A., Farooq, M.S. (2019). Service learning in higher education: A systematic literature review, Asia Pacific Education Review, vol. 20, pp. 573-593. DOI: 10.1007/s12564-019-09580-6.

[6] Pinto, G., Martín Conde, M., Agüero, A., Alcázar, V., Arabbaseri, N., Arrieta, M.P., Beltrán, F.R., García Muñoz, P., Isar, M., López Hernández, I., Martín, F., Matías, C., Oliet, J., Peponi, L., Ramírez, R., Robustillo, D., Sepúlveda, J.A., Solís, M. (2023). Diseño e implementación de rutas divulgativas STEAM en Madrid: Un proyecto de Aprendizaje-Servicio (No. COMPON-2023-CINAIC-0009). Servicio de Publicaciones, Universidad de Zaragoza.

[7] Pinto, G., Alcázar, V., Martín Conde, M., Agüero, A., Arrieta, M.P., Beltrán, F.R., García Muñoz, P., Sepúlveda, J. A. (2024). “Madrid a Ciencia Cierta”: diseño e implementación de rutas guiadas con temática STEAM, in Experiencias de Aprendizaje-Servicio en la UPM, Universidad Politécnica de Madrid. DOI: 10.20868/UPM.book.81864.

[8] Pinto, G. (2019). La tabla periódica como recurso imprescindible para el aprendizaje y la divulgación de las ciencias, Educación en la Química, vol. 25(2), pp. 17-52. DOI: https://orcid.org/0000-0002-8961-7255.

[9] Pinto, G. (2023). Elementos químicos descubiertos por españoles: Fuente de inspiración y de recursos para una docencia interdisciplinar, in M. González, A.

Herráez (Eds.), Experiencias y estrategias de innovación educativa en ciencia, tecnología, ingeniería y matemáticas (III)", Grupo SM, Madrid.

[10] Kuethe, A. J., Andrien, K.J. (2014). The Spanish Atlantic world in the eighteenth century: War and the Bourbon Reforms, 1713–1796. Cambridge University Press, DOI: https://doi.org/10.18172/brocar.2903.

[11] Outram, D. (2019). The enlightenment, Cambridge University Press, DOI: https://doi.org/10.1017/9781108341233.

[12] Diego, J. A. G., Bogoliubov, A. (1986). Agustín de Betancourt como arquitecto y urbanista, Llull: Revista de la Sociedad Española de Historia de las Ciencias y de las Técnicas, vol. 9(16), pp. 35-54.

[13] Santurtún, C.M. (1999). La porcelana del Buen Retiro. Investigaciones recientes. Boletín de la Sociedad Española de Cerámica y Vidrio, vol. 38(4), pp. 335-344. DOI: 10.3989/cyv.1999.v38.i4.952

[14] Sánchez-Ron, J.M. (2006). The Physical Tourist: Physics in Madrid: Where Science Competed With Art, Physics in Perspective, vol. 8, pp. 318-343. DOI: https://doi.org/10.1007/s00016-005-0261-3.

[15] Navascués Palacio, P. (1973). Arquitectura y arquitectos madrileños del siglo XIX, Instituto de Estudios Madrileños.

[16] Pinto, G. (2017). Antonio de Ulloa and the discovery of platinum, Journal of Chemical Education, vol. 94(7), pp. 970-975. DOI: https://doi.org/10.1021/acs.jchemed.6b01007

[17] Rodríguez, A. (2023). Expediciones científicas españolas del siglo XVIII, Edaf, Madrid.

[18] Añón, C. (1987). Real Jardín Botánico de Madrid: sus orígenes, 1755-1781. Editorial CSIC-CSIC Press.

[19] Rosas, M. (2016). The functions of museums in the construction of urban space: The Paseo del Prado in Madrid. Arte y Ciudad: Revista de Investigación, vol. 10, pp. 129-158.

[20] Capitán Vallvey, L.F. (1999). The transport of platina to Spain in the late eighteenth century, Platinum Metals Review, vol. 43(1), pp. 31-40. DOI: https://doi.org/10.1595/003214099X4313140.

[21] Navascués, P. (2007). El Congreso de los Diputados, in Narciso Pascual y Colomer (1808-1870): arquitecto del Madrid isabelino, pp. 61-99. Ayuntamiento de Madrid.

[22] Puche Riart, O. (2001). Los hermanos Elhúyar, descubridores del volframio, Fundetel, vol. 5, pp. 72-84.

[23] Pinto, G. (2020). Iniciativas del Ayuntamiento de Madrid para resaltar la labor de Andrés Manuel del Río, el madrileño que descubrió el vanadio, Anales de Química de la RSEQ, 2020, vol. 116(1), pp. 38-42.

[24] Pinto, G. (2021). Del Río, descubridor del eritronio, hoy vanadio, ConCIENCIAS.digital: revista de divulgación científica de la Facultad de Ciencias de Zaragoza, vol. 26, pp. 5-25.

[25] Pinto, G. (2022). El Retablo de la Independencia: Obra de arte mexicana donde se homenajea a Andrés Manuel del Río y Fausto Delhuyar, Educación Química, vol. 33(4), pp. 143-155. DOI: https://doi.org/10.22201/fq.18708404e.2022.4.0.82131.

[26] Ibáñez, E.C. (2010). La Edad de Plata española. In Zenobia Camprubí y la Edad de Plata de la cultura española, pp. 11-42. Universidad Internacional de Andalucía.

[27] Residencia de Estudiantes, Decreto de Fundación de la Junta de Ampliación de Estudios. https://short.upm.es/qot6w (accessed April 14, 2025).

[28] Berrio, J.R. (2000). La Junta de Ampliación de Estudios, una agencia de modernización pedagógica en España, Revista de Educación, nº extraordinario, pp. 229-248.

[29] Muñoz Dueñas, D. (1992). La formación de una élite minera: la Escuela de Minas de España (1777-1877), Mélanges de la Casa de Velázquez, vol. 28(3), pp. 21-36.

[30] del Dujo, A.G. (1985). El Museo Pedagógico Nacional y las corrientes pedagógicas contemporáneas, Historia de la Educación. Revista Interuniversitaria, vol. 4, pp. 169-182.

[31] Sejas, J. (1995). Historia de la ETSII a través de la evolución del Palacio de la Industria y las Artes, Proyecto Fin de Carrera, Universidad Politécnica de Madrid.

[32] Guerrero, S. (1999). Arquitectura y arquitectos en la Residencia de Estudiantes, Residencia, vol. 8, pp. 14-16.

[33] Correa, A.B. (2018). El edificio Rockefeller. In Textos de teoría y crítica y bibliografía sobre arquitectura moderna y contemporánea, pp. 18-23. Ediciones Asimétricas.