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The Astronomical Observatory of Lisbon: It's Patrimonial, Social and Scientific Heritages

1. History

a. The Initiative

In the mid-nineteenth century astronomers were concerned with the accurate mapping of the skies and the measurement of the size of the Universe[1]. The mechanical precision of the new telescopes was allowing astronomers to determine the sub-arcsecond changes in the sky's position of nearby stars (induced by the Earth's motion), called 'parallax'. William Bessel published in 1838 the parallax of 61 Cygni. Some years later, Faye presented in the Paris' Academy of Science the parallax of Argelander's star to be 1.08". That same year, a new value of 0,22" was presented by Peters (working at Pulkova). Using an equatorial telescope Otto Struve got a value of 0.034" and Wichman[2] obtained a parallax of 0.183" with the Koenigsberg heliometer.

The stage was set and the debate getting very lively since the star seemed to be not so close to the sun but fast moving. Faye, who had invented a new zenithal telescope, vigorously debates the different results, particularly with Wilhelm Struve, director at Pulkova,

[1] A.W. Hirshfeld, *Parallax, the race to measure the Cosmos*, New York, W.H. Freeman and Company, 2001.

[2] M.L.G. Wichmann, 1847, *Investigations on the Parallax of 1830 Groombridge*, Astronomische Nachrichten, nº 843.

who took defence of the values obtained at his observatory. In order to settle the growing controversy, by now including the different values obtained for 61 Cygni and Vega, Faye proposes, in a meeting held in the Paris' Academy in 1850, to make new observations using his zenithal telescope, on a latitude where all three stars passed near the zenith: Lisbon was the only appropriate place and the measurements should be carried out by Faye plus Wilhelm and Otto Struve[3].

At that time Portugal was living a progressive state of mind, politicians were very receptive to the innovations undertaken by Science and Faye's proposal was welcomed in the Lord's Chamber (1850), however, it was considered of utmost importance to have the observations regarding that star performed by Portuguese astronomers, with a modern instrument which had to be bought for such a task.

The first intention was to improve the Navy Observatory in Lisbon, by providing it with a zenithal telescope by Faye, since it had a Repsold meridian circle (73 cm horizontal axis, 10 cm diameter and focal length of 1.36 m), a small transit instrument by Dollond (33 cm horizontal axis, 4 cm diameter) plus some theodolites. Its location on the seashore of Lisbon (with frequent mists), along with the poorness of the building, made it inappropriate for these observations. This problem was recognized by the Navy and a committee was chosen to study the issue and find a solution. Several locations were suggested and even building plans were drawn but, together with other obstacles, it was impossible to raise funds to cover the costs of a new building. In 1855 Filipe Folque, a member of that Navy committee and a well known geographer (former Mathematics teacher of King Pedro V), was appointed director of the Navy Observatory. In the meantime the Parliament selected an internal committee to inquire about the Navy institutions. Filipe Folque was called to testify before that committee (that same year) and stated very clearly that the Navy Observatory had no conditions whatsoever for modern astronomy and, therefore, a new one was absolutely needed. One of the Parliament Committee members, José Silvestre Ribeiro, took heart to defend such a view and put forward that proposal before the Government and the Parliament Chamber.

In January 1857, after a very generous fund offered by King Pedro V that covered the initial budget, the regulations for the construction of the new observatory of Lisbon were approved in Parliament and a new *ad hoc* Committee was formed to implement it. This Committee was presided by Marechal José Feliciano da Costa, and included some significant characters of the Portuguese culture of the second half of the nineteenth century, namely Filipe Folque.

b. The Designing Process

Wilhelm Struve seems to have followed the "new observatory" matter since the controversy with Faye, in 1847–1849. In a report made by Filipe Folque (December 1861) it is stated that Struve offered his services to the Portuguese Government and was considered the leading adviser of the Committee. After the Government's decision, Struve played a major role in the process.

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[3] P. Raposo, *A vida e obra do Almirante Campos Rodrigues*, Master's Thesis in History and Philosophy of Science. Departamento de Física da Faculdade de Ciências da Universidade de Lisboa, 2006, p. 34–36.

When Faye was asked to supervise the acquisition of the instruments for the Portuguese Observatory, he kindly accepts but states that he wanted to discuss the matter with Struve. Very significant is the fact that the Committee decides to give Struve full control over the choice and production of the main instruments which ends up deciding what the new observatory is going to be: Struve's personal conviction is that it should be a modern Sidereal Observatory at the forefront of astronomy, rather than a Planetary one (i.e., an observatory focused on the modern research of stars and nebulae, rather than Solar System bodies), an Observatory with which Pulkova could compare results and share tasks.

A few months after the approval of the new observatory by the Parliament, in 1857, Struve sends a report to the Portuguese Committee, with information regarding the building and a lay-out sketch (picture 2). Later on he also sends to the Committee his detailed book on the Pulkova Observatory: *Description de l'Observatoire astronomique central de Poulkova*[4].

Meanwhile the Committee had to choose the place and the architect. After several studies the place elected was in Ajuda, in the king hunting grounds. When asked about it, King Pedro V, very keen on the scientific progress of Portugal, offered the grounds to the observatory and also more money to start the building (his previous donation was spent on the instruments), as well as the sand and water for the construction[5].

The chosen architect was Jean Colson – a French architect working in Portugal for the Ministry of Public Affairs, since 1856, who, although he had never got to built anything, had made some relevant projects (adaptation of The Monastery of Saint Benedict into a Parliament, adaptation of Monastery of Jieronimus, one of Portugal most important monuments, so as to incorporate the headquarters of Casa Pia, a public institution for orphans; a Chapel in the Royal Palace of Necessidades, the Customs building at Oporto, Vilalva Palace)[6].

Presumably the Committee gave Colson the report and layout sent by Struve, as well the book about Pulkova. Colson made three studies that gradually evolved from a very simple building to a monumental one. The first study (picture 3) is from 1859. It follows Struve's layout but it introduces a third wing, probably to achieve symmetry or to accommodate a fourth major telescope. The Committee corrects it, asking for more monumentality (sic) and the re-orientation of the building, so to avoid the ugly wooden sunshade over the northern wing[7].

The second study (picture 4), consigned in November 1859, refers directly to the central room of Pulkova, keeping the shape of the observation rooms, like they were

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[4] Published in 1845.

[5] The King will only ask that the new observatory shall be called 'Royal': *Royal* Astronomical Observatory of Lisbon. Unfortunately it was a pre-republican period, and the title didn't endure much.

[6] About Jean Colson we know almost nothing priory to his arrival in Portugal, and nothing after his went back to France. We don't even know his exact name. We know that he was born in 1814 at Paris, that he was student of Auguste Chatillon, and that he worked as inspector on the works of junction between the Louvre and Tuileries, under the supervision of Louis Visconti, between 1852 and 1856. He lived in Portugal between 1856 and March 1860.

[7] The main entrance of Pulkova faces north and the opposite room faces south. To protect the southern telescope from the sun it was built a wooden sunshade. At Lisbon the main entrance faces south and the opposite wing faces north, so the telescope on this room is protected from the sun by the projected shadow of the central tower.

designed in the first study. The Committee generally agrees to this study, although it asks again for more monumentality (not explicitly, this time): higher ceilings and platbands (instead of tiles in the edge of the roof).

On the 23rd of April 1860 the contract bill between Colson and the Committee is signed. Colson returns to Paris in July and sends the Execution Plan in August: with drawings and Project Specifications. (In these Project Specifications he explains the whole process, with the corrections of the Committee. He also frequently mentions Pulkova as the paramount model to the Lisbon observatory). The Execution Plan (picture 5) follows the orientations given before but, in spite of this much participated architectonic process, the Committee still makes some corrections to Colson's last Plan. And what an awkward and meaningful correction that is!

The Committee corrects Colson's Plan increasing the central building radius by 0,44m, beyond the predicted 4m[8]. The oddity of this measure took us to question its reason: was it due to a particular functional cause (e.g., an instrument that needed such a space extension?); or was it a geometrical matter with esoteric connotations...?! We ended up verifying that this was due to the desire of absolute coincidence of dimensions between the Lisbon and the Pulkova Observatories. Pulkova had been built according to a regional measuring system and *3 sajène* (in Russian, *sàzhen*) was the radius of its central room, corresponding exactly to 4,44m. This fact expresses undoubtedly the desire by the Committee of a stressed affiliation between Lisbon and Pulkova.

After the consignment of the Execution Plan the construction works won't start immediately. Presumably this period was used to study thoroughly the whole project and make the last corrections.

c. The Building Process

The first stone was laid on the 11th March 1861, under the supervision of master builder José Pedro Bento Rodrigues (of an agency of the Ministry of Public Works), but, during the first two years the construction doesn't progress much.

Only when Frederico Augusto Oom returns from Pulkova will the construction works advance strongly. On that date – 1863 – the building was still in its foundations.

Struve had asked the Committee that someone educated should be sent for training at Pulkova to learn the procedures of the new Sidereal Astronomy and the use of the instruments. Frederico Augusto Oom was a Portuguese Navy Lieutenant and a Hydrographical Engineer, with a degree on the Lisbon École Polytèchnique, where he had studied Mathematics, Astronomy and Geography. Filipe Folque, a former teacher of Oom, acknowledge him as his top student and eventually suggested his name to the Committee. Oom went to Pulkova in October 1858, and stayed there, under the supervision of Otto Struve, until June 1863. When he returns the Committee assigns him the chief responsibility for the new observatory process. Eventually he will become its first director.

Oom played a major role in the construction process of the Observatory. He run the construction, the implanting of the instruments; he even designed some Observa-

[8] Some other minor corrections were made: the main stair switched place with the battery room, two small rooms with down access stairs were built on the East and West ends of the building; on the northern room was opened a window facing north.

tory parts, namely the Spinning Tower. He also requested the assistance of an architect, professor of the Lisbon *Ecole de Beaux Arts*: José da Costa Sequeira, to help him with specifically architectonic aspects.

We believe it is due to Sequeira much of the architectonic quality the Lisbon Observatory still exhibits today (he might have been responsible for the 0,44m extension of the main room.) Although some historians declare that Sequeira only starts working in the Lisbon Observatory after 1864[9], it is plausible that he had been in the advising team since the beginning. Sequeira was known by several members of the Committee and he worked for the Ministry of Public Works, so he could have been called to oversee the process from the architectonic point of view. One of the reports of the Committee states exactly that: it is said that Sequeira had been appointed to supervise "the architectonic part of the construction", but, unfortunately, it doesn't say since when. There is also some documental evidence suggesting an active participation of Sequeira from the beginning of the whole process[10].

Professionally Sequeira was mainly a teacher: he translated works of well known architects (as Vignola) and wrote considerably about architecture, but he has not left us much of buildings. Although we know that he worked in several important public buildings like the Ajuda Palace, Saint Peters of Alcântara Garden, Cascais Headquarters, Navy Headquarters at Alcântara, the Crypt of the Church of Our Lady of the Rock and produced some designs to the Royal Pantheon, he never saw one of his plans executed from beginning to end. The only buildings that are certain to be of his total authorship are two small tumuli. Therefore, it is very difficult to define his own style or to identify it in the AOL's building and so, to understand his degree of intervention in the AOL's architecture. Nevertheless, the final execution of the building reveals some substantial differences from Colson's plan – namely on the cupola and on the pediment – which we can only ascribe to Sequeira.

In 1867 the AOL was already (partially) functional. The first astronomical observations with a small zenithal telescope in the East Observing Room started that same year. In 1869 the first observations were made with the transit circle in the West Observing Room.

The final chapter of the AOL's construction will be the great Spinning Tower. As we have said, Oom conceived its final design (rejecting Colson's proposal[11]) following the classical shape of Pulkova's domes. He first intended to have a Portuguese firm doing the construction of this huge metallic dome weighting 35 tons, capable of rotating 360º around and to open 12 heavy shutters (overlapping doors) that give access to the night sky in any direction. After troubles of all kind for producing the big parts and central

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[9] M. Calado – Quadro Cronológico in *José da Costa Sequeira – Noções teóricas de Arquitectura Civil, Breve tratado das Cinco Ordens de Arquitectura de Jacomo Barozzio de Vignola.* Lisboa: Faculdade de Arquitectura, 1993; p. 20–21.

[10] A small piece of paper (from the AOL's Archive) – a note of the master builder – where is mentioned the correction of the radius of the central room (so, that piece of paper has to be of a very early date, because that kind of correction interferes with the laying of the foundations), mentions Sequeira's authorship in some other changes on the Execution Plan, although those changes concern parts of the building that are done after the founding (so, in theory, those specific notes could have been written years later, not in the same time that the correction of the radius, although it seems rather unlikely that a small piece of paper with five lines handwritten used in the construction grounds was used buy a period of 2 to 3 years – between the laying of the foundations, in 61, and the presumed arrival of Sequeira in 64).

[11] Oom's design is not at all original: he inscribes the mechanical system of Pulkova into Colson's design.

pieces with all these wheels, gears and cranks, Oom gave the execution to a firm of iron ship construction in Gaarden: Norddeutsche Schiffbau. The contract bill was signed in June 1870 with the shipyard director, Georg Hosvaldt. The tower was produced in Germany and brought in pieces, by ship, to Lisbon. It arrived in March 1872 and was assembled by German workers. It was ready for inspection on the 23rd December 1872.

Now, to the complete end of the building process, some details were still missing: coal-gas lightening, fire-fighting facilities, a clock and instruments repair-shop, a botanical garden... The definitive conclusion of all the works in the main building of AOL will be achieved in 1878.

d. Some Scientific Production and Social Impact

The AOL will produce some very relevant astronomical research and will be considered by Struve (in a private report) one of the four major European Observatories (along with Paris, Greenwich, and Pulkova) by the end of the XIX century. Some highlights are given here.

The director Campos Rodrigues and astronomer Augusto Oom participated in the campaign (conducted by the US Naval Observatory in Washington) to use the opposition of Mars in 1892 to determine a better value of the Astronomical Unit (AU). From the results obtained with the Repsold meridian circle they derived the first absolute measurement of the equatorial diameter of Mars[12] as 6564+–319 km, a great matching with the modern value measured by spacecrafts: 6794 km. The next international campaign in 1900–1901 to improve the AU value, uses the opposition of the (recently found) asteroid Eros. The participation of Campos Rodrigues and other AOL astronomers was for producing a high quality catalogue of reference stars. As a result, Campos Rodrigues receives the Valz prize in 1904 from the Académie Française des Sciences (the judges board included Henri Poincaré as president and Guillaume Bigourdan) for the excellence of the work being done at Lisbon.

By 1870 the observatory buys a small (117 mm) equatorial solar telescope made by Repsold-Merz to observe solar eclipses. The annular eclipse in 1912 is observed by Campos Rodrigues who takes 237 plates[13] with the fast revolve-camera he had invented and built to picture the Venus transit of 1882 (unfortunately not observed due to bad weather).

The debate on the General Theory of Relativity gets a push when the astronomer Sir Frank Tyson (1917) points out the upcoming total solar eclipse in April 1919 as a great opportunity to test the theory. At the same time, Frederico Oom (son of the first director) realizing the importance of such research, computes and writes[14] about the visibility of the coming total eclipse in the island of Príncipe (Cape Verde, Portugal at the time). Finally, the physicist and astronomer Arthur Eddington leads the British expedition to Príncipe and exchanges letters[15] with Oom to make arrangements to help them out while

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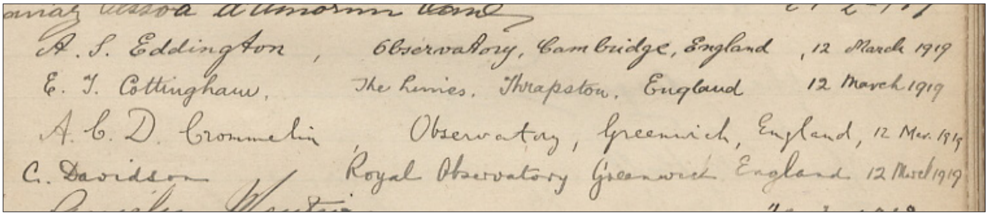
[12] T.F.F. See, 1901, „Astronomische Nachrichten", nº 3750, 109.

[13] Documental Archives of the AOL.

[14] F. Oom, 1917, *O Eclipse Total do Sol em 29 de Maio de 1919 visível na Ilha do Príncipe*, „O Instituto", 64, 97–98.

[15] Documental Archives of the AOL. Ref. C-240 (1918/1919): Letters to/from Eddington.


A. S. Eddington, Observatory, Cambridge, England, 12 March 1919
E. T. Cottingham, The Limes, Thrapston, England 12 March 1919
A. C. D. Crommelin, Observatory, Greenwich, England, 12 Mar. 1919
C. Davidson Royal Observatory Greenwich England 12 March 1919

in Portugal and in the island. On the journey to Príncipe they stop over in Lisbon and Eddington plus other expedition members visit the AOL on March 12th, 1919, as the Visitor's Book eloquently shows.

The impact of such enterprise on the Portuguese astronomical community was diversified[16]. Although there were no local astronomers present in Principe, Melo e Simas (AOL's principal astronomer and a promoter of the Theory of Relativity in Portugal[15]) makes observations of the gravitational effect of Jupiter on the light path of nearby stars, in May of 1923. With an extensive experience on lunar occultations he knew that the telescope would be working beyond its limits, leading to a failure, which he reports in a session of the Lisbon's Academy of Sciences in 1924.

Melo e Simas is the astronomer that gave most use to the great equatorial installed in 1875, a Repsold refractor with 38.1 cm of aperture and 6.83 m of focal length. He conducted an extensive program on the observation and orbit calculation of comets, planets (particularly Mars), double stars and an intensive program of lunar occultations after 1940, which was extremely important for the computation of ephemeris time.

The telescope on the northern observing room is a zenithal instrument for observations at the first vertical. With a design by W. Struve and built by Repsold, it allowed the determination of latitude by Struve's method which was used until 1960, when Baptista dos Santos modifies the instrument to hold a photographic camera for taking zenithal pictures, to be measured and analysed by Horrebow-Talcott's method.

Our final word goes to another fundamental parameter for astrometry, in which the AOL excelled: time measurement and keeping. The AOL was created with a secondary goal, but no lesser: to provide a time service to the country. Time had to be measured frequently because all pendulum clocks drifted in time about ½ second per day and, on the other hand, accurate time is needed when astrometric precision is required on final results. Over the years a fair number of accurate pendulum clocks were installed, tested, kept running and their drifts studied with minute details. On top of that, the measurement of the astronomer's reaction time (called the personal equation) was common practice, done with a Kaiser machine, which still exists in good condition.

Resulting from the need of greater accuracy, Campos Rodrigues (CR) creates and builds a new electric switch capable of detecting the pendulum crossing without removing any energy from it, but also providing an excellent and reliable electrical signal. He sent his design (on request) to a number of European observatories. In the central room of OAL was built a Time Console where the electrical wires and signals coming from all clocks, telescopes, Morse keys or time devices around the house, could be selected

[16] E. Mota, P. Crawford, A. Simões, *Einstein in Portugal. Eddington's expedition to Príncipe and reactions of Portuguese astronomers (1917–1925)*, „British Journal for History of Science", in print.

in pairs, graphed on paper tape, interpolated and inter-compared, became the core of all astrometric and time keeping work. The extensive use of the new CR switch, the Kaiser machine, the Time Console, the electric wiring in all used apparatus, allowed the astronomers to publish results with an accuracy of +–0.01 seconds even when only pendulum clocks were available.

The AOL has a rich history and patrimony of all sorts of equipment (clocks, tachometers, chronographs, barometers, thermometers, etc.) always chosen from and made by the most famous companies and makers. However, the funding and modernization of astrometry stopped, the AOL never got a Danjon astrolabe, a spectrograph, neither astrophysicists… and so it begun to decline around the 1960's. No longer significant research will be produced by the old instruments. But, in spite of that (maybe even because of that), those old instruments and rooms will reach us in magnificent conditions: the eastern instruments were operational until the nineties for teaching; the northern instrument was used for relevant research until about the Second World War; the western instrument was used until 1968; and the grand equatorial, in the central cupola, was last used by the seventies.

This is only one side of the story, because, since the beginning, the AOL's has had a social and cultural impact that went far beyond the scientific community. Several old pictures from the late XIX century or early XX century show women and children accompanied by men, that didn't seem to have any specific astronomical interest, walking or wondering around the Observatory facilities. The Visitors' log book confirms it by exhibiting an immense number of entries that we cannot directly correlate with the research done in the observatory. Moreover, several articles were written on the local newspapers about the scientific achievements and cultural importance of the AOL. From the beginning the observatory was shaped to became a symbol of an age and of an ideology. And it still tries to remain so.

The architecture was also preserved – only the Library has changed place. And, between 1998 and 2000, thorough restoration works were completed; these restoration works, although not entirely faithful to authenticity, still managed to keep the essential of the antique atmosphere. Thus the nineteenth century Astronomical Observatory of Lisbon arrives into the XXI century almost like an undisturbed pearl. *Much of this chance might be due to its architectural quality that far exceeds the functional and technical response*.

2. Architecture

a. Elements of architecture

If we compare the ground plans we may notice that the AOL doesn't show anything substantially new (picture 6): the central room is an exact copy of Pulkova's central room, the observation rooms show minor differences from Struve's lay-out (they are slightly bigger) and the three-winged structure is also a copy of Pulkova (although the orientation and the northern wing scheme are original). But if we compare the Elevations and Sections, a whole different picture shows up: there isn't a single match in any of the compartments (picture 7).

If we analyse the ground plans it stands out a sense of a complete affiliation from Lisbon to Pulkova – which is true, in a way. But such a match isn't enough to justify the different quality of the Lisbon space, the different feeling it induces. Although Colson had followed Struve's and Pulkova's plans, he introduced elements of scale, proportion, rhythm and geometry that make the experience of the space in Lisbon quite unique. And afterwards, when the time arrived to choose the ornaments, the colour and the materials, as well as the constructive details, Sequeira inscribed a sensitive atmosphere of discrete, but warm and tender light and textures.

Alexander Brullov, Pulkova's architect, was a descendent of French Calvinists (Huguenots refugees), and a pupil of Durand[17]. He prefers a well balanced and somewhat strict and restrained design – as we can still feel at the Hermitage at Saint Petersburg (namely at the Rotonda room, which has a very similar disposition to the central room of Pulkova). He uses a modular system of geometry by which simple forms, like squares, are added to one another. He prefers the heavier orders (Tuscan and Doric), among the classic architectonic orders. He usually uses white to greyish shades of colour, homogeneous texture materials, normally polished stone or white gypsum... The atmosphere of his architecture is usually sober and straightforward[18], frequently dry and cold. The central room of Pulkova has this set of characteristics. Not so in Lisbon.

At Lisbon the ceilings are higher, the passages wider, (creating a sense of fluidity among the different spaces). In the façade and in the central room (a kind of interior façade) of the Lisbon observatory the arch is preferred to the architrave, producing a more dynamic sensation. The Section proportions are higher and slender in Lisbon (the Golden Section or √2 in Lisbon against √2 and square sections on equivalent locations in Pulkova). The window area is much bigger and the design of the windows is much more articulated with the human scale in Lisbon. The rhythm of openings and closures in the central room is equal in Pulkova, double in Lisbon, from which a monotonous perception results in Pulkova and a vibrant one at Lisbon. The vertical elements on the façade and in the central room are slimmer at Lisbon. The use of wood on the Lisbon floors instead of grey and white stone in Pulkova, as well as the yellow shade of the walls in Lisbon, by contrast with the white walls of Pulkova, smoothes the light and creates a cosy ambience.

The Lisbon Observatory is at the same time – by the characters of its architecture – a monument and a house. His soul is not that of a nineteenth century labouring place: functionally concerned, technically conceived. Lisbon is not even (only) a Science factory. That saved it.

b. The technical and the artistic in the AOL

The outstanding value of the AOL's architecture doesn't imply it didn't respect the technical requirements of an Astronomical observatory. On the contrary, one of the most interesting aspects of the observatory are the mechanisms inserted into the architecture.

[17] French architect and theorist of the eighteen-nineteen century known by his preference for the functional and more sober dispositions, and by his rational approach to architecture.

[18] Even when he uses rich materials, like in the Malaquite Room in the Hermitage, the design is direct and simple, never baroque.

The three wings known as North, East and West, are equipped with metallic trapdoors in the roof. All these rooms possess a covering in wooden boards, creating between these and the exterior walls one space for the air circulation. Interior ceilings are equally covered in wood. The East and West observation rooms have also lateral metallic trapdoors.

The roof trapdoors move individually, using an iron chain coming from a mechanism composed by a ring borne, a horizontal axis and a wheel, installed in a box right next to the plat band. From each side of the trapdoors, there are metallic profiles stabilised by tensioned steel cables. These metallic profiles have two pulleys at different heights. A chain is fixed to the trapdoor next to the hinge, goes to the higher pulley and comes down to the lower one, in order to change direction, lowering parallel to the roof until it goes inside the respective box. The metallic trapdoor of the roof raises itself when the chains are manually operated from the inside.

The rotating tower, on the first floor of the Astronomical Observatory has a circular layout developed in two levels; the upper one includes a circular gallery. Located here several sets of jagged wheels, loops and cranks are fixed to the steel structure of the wall made of steel panels, and are responsible for the opening of the trapdoors from the dome roof. The lateral trapdoors are moved through other chains. The tower has a radial ceiling in steel panels, interrupted at the central part by the dome trapdoors. A space between the exterior stone masonry wall and the wooden structure on one hand and the wooden walls going downstairs on the other hand contains a mechanism with a crank outside[19], which is responsible for the rotating movement of the tower.

Thus in the AOL there are two kinds of space: those with a higher status – a representative function – like the Main Entrance and the Central Room; and those with a technical function, which house the instruments. These two kinds of space are handled architectonically in different ways: the Entrance and the Central Room give the impression of one being inside a temple; the instruments rooms, the impression of one being "inside a barn". Strangely enough this duplicity is not contradictory. As a matter of fact one completes the other: it is the odd hard work done in the Observation Rooms that supports – coherently – the noble, high, mysterious, almost religious atmosphere we breathe in the Central Room; which, reciprocally, stands for the socio-cultural meaning of the astronomers' work, at that time.

3. Instruments

One of the most amazing features in all instruments at AOL is that they still all work, have never been modernized with electrical motors or components or any parts (gears, micrometers, lenses, etc.) or complete systems (tracking, motors, etc.) replaced by better, more modern ones. In a few cases minor changes were introduced but most are from the same epoch of the instrument. Very few are those cases that one can consider modern machinery, like the photographic cameras introduced in the late 60's, attached to the Meridian Circle to take pictures of the declination micrometers readings. There is also the

[19] Nowadays is an electric motor that moves the rotating tower, but the ancient mechanism with the crank is still in use.

new end plate for the great equatorial, with includes a very modern micrometer to study double stars which was (partially) built in Nice in the 1990's. However it is not attached to the telescope. It is true the telescopes are not perfectly aligned or optically collimated, neither the pendulum clocks are kept running and that would have to be done in case one wants to do again some serious observing.

The same thing can be said about the building: all moving structures still work as the original ones and nothing has been changed, replaced by new solutions or even modern materials. Thus, we still suffer from traditional problems like the leaking in of rain water trough some dome shutters, in windy nights. Unfortunately, the preservation works done in 2000 removed the old electrical wiring including the one associated with the time signals connecting all telescopes with the Time Console, which was a big loss.

The instrument collection is enormous and we'll list only some of them, the ones that stand out in a visit.

The "jewel of the crown" of all telescopes, which is always a subjective statement taking into account the beauty and value off all of them, but considering the AOL as a house of pure astrometry and the recognition it gave to the work done here, must go to the Meridian Circle, considering as well all the auxiliary accessories it still has. One can find a comprehensive description of it in the classical publication on the "Mars Opposition of 1982" book[20], sent to more than 230 institutions and observatories around the whole world.

It was built in bronze by A. & G. Repsold in 1861 with optics by Merz (135 mm of aperture and focal length of 195.5 cm). For aligning it vertically a thin mercury bath was put at the nadir and a procedure developed by Campos Rodrigues became in use after October 1884, that is much like the one described to be used in Paris by Périgaud, in 1888. All alignment collimators rest on their pedestals working, and the large lifter structure that slides on floor rails still works. It lifts and holds the telescope tube in the air, rotates it by 180º and lowers it back into the supports in order to compensate for collimation errors.

The northern observing room has accommodated the large "first vertical" instrument: it has a unique design (the possibility of inversion by two methods) to favour the determination of latitude by Struve's method. He personally suggested that the AOL should have such a telescope, like Pulkowa. This was also considered *one of the most valuable instruments* in house. The telescope was built by Repsold with optics from Steinheil, a 160 mm objective lens with focal length of 231 cm. Is has been used till late 60's and is fully functional (although not aligned or optically collimated) with all its original parts, none of them showing wearing out or oxidation of any kind. The room and instrument are unique and make a cosy atmosphere. Probably very few exist around the world in such a good ("brand new") condition. Besides this instrument there is a "zigómetro", a device used to calibrate linear bubble levels, i.e., to find out the horizontal degree of inclination as a function of a bubble position. Was built in Pulkova by Brauer.

The west observing wing is considered to be the "Time Room", where all time observations were carried out by the two small alt-azimuth transit instruments. The very first observation of Time was performed in June 27th, 1867. It was the real inauguration of the AOL.

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[20] Real Observatório Astronómico de Lisboa (Tapada). *Observations méridiennes de la planète Mars pendant l'opposition de 1892*, Lisbonne, Imprimerie Nationale, 1895.

Both instruments were built by A. & G. Repsold in 1866 (optics by Merz with 69 mm of aperture and focal length of 75 cm) and are capable of inverting the azimuth in order to compensate for collimation errors, i.e., the star is timed crossing the wires (in the reticle) on the left of the meridian, then one rotates the telescope, puts the star back in the field of view and times the star crossing the next wires after the meridian. One of the telescopes was upgraded with an impersonal micrometer, a device invented by Repsold in 1890, to make the timing procedures observer independent.

There was a problem however: when the telescope tube is rotated by 180º in azimuth one looses the star being observed. The procedure was sometimes too long and killed the observation. Hence, Campos Rodrigues invented a new add-on device and method based on the reading of two bubble levels that allowed the astronomer to put back the zenith angle and recover the observed star very rapidly. This device proved to be very efficient and was added to both transit telescopes. The measurement of very accurate right ascentions of fundamental stars[21] became a regular and joint program with Berlin's Observatory, for the annual almanacs.

To improve on the observations data the AOL bought, around 1970, an electric chronometer and chronograph from Longines model A5 with a printer and a number of electric inputs used to receive the electric signals from the observers and inter-compare the pendulum clocks. This chronograph was used in conjunction with the transit instruments and printed a digital value of 0.01s plus a millisecond digit interpolated graphically. Two years later a very sophisticated quartz clock from Patek Philippe came in. It is a voltage controlled quartz clock with a digital display and a converter from mean solar time to sidereal time. An internal radio receiver was tuned to the Rugby time signal that, once decoded, was internally used to self-discipline the quartz oscillator. It had similar external connection capabilities as of the electric Longines but the time read out was at the millisecond level. In the eighties, rubidium and caesium atomic clocks were also bought and became the fundamental time source.

The central room of the AOL was the daily working place where all the clocks, electric keys, thermometers, barometers, hygrometers, calculators and tables were placed. The very important Time Console is here with two fundamental clocks very close to it: a Molineux-Dent for mean solar time with an inscription "*with a new escapement by F. Dent from the famous house of Strand, London*". It has a 24 hours dial with two hour hands, one for Summer time (in pink colour) and the other for Winter time. The correction of the daily drift was done by changing the pendulum length, i.e., the position of its gravity point with a micrometer. The other traditional clock is a Sidereal Time pendulum by Krille, #1647, built in Altona in 1863. It has two different hands in sub-dials for hours (24 divisions) and minutes. These two clocks had a typical daily drift smaller than 0,5 s. The correction of this drift was done by adding or removing small masses on the mechanism.

The next step in time accuracy came with three different types of mechanisms for pendulum clocks, of which Siegmund Riefler of Munich was the first maker to develop one in 1889. He introduced a support of the pendulum upper body that rocks on two knife edges, achieving daily drifts in the hundredth of a second figure, or even lower. Our clock

[21] Rodrigues, César A. de Campos, *Corrections aux Ascensions Droites de quelques étoiles du Berliner Jahrbuch observées à Lisbonne (Tapada)*, Kiel: Druck von C. Schaidt, 1902a.

is from Max-Richter in Berlim and has a pendulum from Riefler in which a electromagnet connected to the upper part and electrically controlled, is used for minute adjustments on the period. Its accuracy on the hundredth of a second has only been surpassed by the quartz clocks, which made it a reference for mean solar time for distribution in Portugal. It also has two different hands in sub-dials for hours (24 divisions) and minutes.

Very interesting is the fact that Campos Rodrigues built a complete double pendulum clock at the clockwork shop of AOL. The two pendulums run in opposition in order to compensate any (possible) period change induced by a small earthquake. The only unfinished part is the main dial that still is in cardboard but, otherwise, is a fine clock.

On the northern wall of the central room we find a pendulum clock for solar mean time from L. Leroy & C^{ie}, serial Nº 1327. The information written on the enamel display shows the address *Paris, nº 7^{éme} Bd de la Madeleine*. It has two large handles (hours and minutes) plus a small one for seconds on a sub-dial.

From the same maker Leroy & C^{ie} in Paris, the AOL possesses the finest high precision pendulum clocks they made, in the beginning of the XX century. With serial Nº 1397 and Nº 1398, labelled as "*Horlogerie de precision*", they are kept in an underground room in the basement, with air pressure tight door, in order to keep the room temperature and atmospheric pressure constant. Moreover, the clocks are hanging on the walls from their external vacuum cylinders, metallic but with a glass dome on the top, whose function is to keep air in low pressure inside the tube (read off by a pressure gage). There are a number of electrical wires that bring outside the clock signals and controls.

Besides a number of small electrical apparatus in the central room there is a large wonderful min-max mercury barometer, built at the Industrial Institute of Lisbon in 1882. It has two small reading telescopes that slide on a vertical bar to measure the height of the mercury column (read off from a vertical scale).

The Time Console was the convergence point of all electric wiring carrying signals from all telescopes, clocks and measuring devices. Besides the switch board that selects the inputs to be compared the time signals were drawn (in a square wave shape) by a double electromagnetic pen holder (made by Campos Rodrigues) on a paper tape running at a controlled speed. This was really the core place of all time measurements, including the comparison between the sidereal time observations (which had to be reduced the next morning) and the fundamental pendulum clocks to compute their time delays. This was performed regularly every morning at 11:00 and followed for the other clocks.

In the outside small dome at southwest in the garden, there was a refractor with an equatorial mounting by Repsold, a wooden tube with optics by Merz (117 mm diameter and focal length of 195 cm) that was bought for the solar eclipse in December of 1870. Later it was used in, at least, the eclipses of 1900, in which was carried to Serra da Estrela, and in 1912 when was used for the solar eclipse photography by Campos Rodrigues. This is the only telescope that had to be recovered since it has been without use for many decades and the small dome outdoors was not completely weather proof. After its recuperation in 2005 has been moved to the inside rooms of AOL and is not fully functional, neither we have all accessories available. So it seems.

There are two small refractors from Utschneider-Fraunhofer (97 mm of aperture and 146 cm of focal distance), at the time borrowed from the Duke of Palmela, and used by Teixeira Bastos for the observation of a solar annular eclipse in April 17th, 1912.

4. Historical Documentation and Library

Since the year 2000 that we have started the slow recovery of all the documentation available in the AOL. After several renovation works in the other buildings that were being used for housing and office space and depot, that required the moving of many historic documents and small instruments or parts of it, they were still packed in big boxes and out of track. Thus a big effort has resulted in the gathering of all this patrimony, cleaning and separation of different articles, sorting and filing all books on the university database, organizing, sorting and cleaning old historical documents in an archive and finally, with the strong help of the Bureau of National Monuments and Buildings a construction of a clean room with temperature and humidity control.

The collection of old and historical books (astronomical atlases, etc.) whose cataloguing is fairly complete can be accessed on the internet[22]. The documentation has had a first organization, a database was created and is available now for studying, however requiring time for consultation and research by the interested person. Maps, construction plans and diagrams have been treated and filed[23]. There are still old instrument catalogues and manuals that need to be sorted and filed and represent a wonderful source of information on all the instruments we have still to process.

5. The Observatory as a World Heritage

a. Architecture and Science

The marriage between architecture and science takes form, through time, in different ways and conditions. There is a science of construction linked to a technique and an art of conception. Art and technique complement each other, as result, without contradictions. We must not forget that architecture and science lived side by side until very late in Western European History. It is in the eighteenth century that a conceptualization of the architectonic *oeuvre* dissociates from the conceptualization of the world and its related cosmologies. In a way, the architectonic object, until "*le siècle des lumières*", symbolizes the universe through the order from which it has been produced as a constructed form. The progressive independence of engineering science around the eighteenth century announces that disjunction and unveils the formal composition in architecture towards the aesthetic competence domain: as a functional object, the building is produced accordingly to rational and economical principles; yet as work of art pays obedience to the logic of creative intuition. Astronomical Observatories, as works of architecture, may simultaneously be technical objects and aesthetic objects. The nineteenth century will make this duality problematic and give origin to its further annulment, from the twentieth century onwards.

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22 http://ulisses.sibul.ul.pt/ulisses/portal/html/index.htm

23 R.G. Baptista, R. Agostinho, *Documents of the AOL's Architecture* [in:] „2005: Past Meets Present in Astronomy and Astrophysics". Proc. 15th Portuguese National Astronomy Meeting, July 2005 (2006, World Scientific), p. 109.

Curiously, it is this type of building, scientifically determined in its program and construction that allows us to understand how this duality has become a basic contradiction of our time, and simultaneously symbolizes the relation that science holds with architecture.

On the other hand, that rationalism applied to the construction, which will characterise the European XVIIIth century, makes that, in the case of particularly *spacialised* functions attributed to buildings, the technical object becomes progressively autonomous in regard to symbolic and experiential objects, which, in face of that, start being viewed as an "aesthetic" addition.

It doesn't exist a typology of astronomical observatory from the architectonical point of view, just like the case of the object-museum. However, the scientific drive has always found a way to provide the required technical instruments in a spatial context or organization, in what we may call now an "Observatory house". How was that done? We'll have to go back in time in order to answer that question.

In pre-historical ages, the first, may we call, "astronomical observations" were made outside in the open air. We may consider these construction elements as a "spatial mechanism", *id est*, an "instrument spread along the landscape" regulated by the observations' practical demands: orientation, location in relation to observed sky areas or relative positions to the other built elements. These spatial mechanisms got smaller until they had become manageable by the users at the exact human body scale. As soon as the observation conditions demanded other types of facilities and complementary functions, the whole mechanism was enclosed in the interior of a building. The absence of a safe typological reference makes virtually impossible the pretension of symbolizing an institution (Astronomy or even Science itself). Without a model, what is the building to be recognised in its role of "symbol"?

b. The AOL as a technical instrument

The broad understanding of the AOL in its previous functions, including the infrastructures, compelled us to start a comprehensive study concerning the building's architectonical features, relating the science to the architecture, trying to understand how, originally, all the devices (technical or other) were used by the succeeding inhabitants. There is an extra difficulty to consider: from this point of view, the AOL's building shelters a structure, *id est*, the technical instrumentation of the observatory. The building itself becomes, prior to all the rest, a kind of cocoon that protects these devises. It defines the space in which the Observatory "inhabitants" develop their activities. The inner space, while structure of shelter where the gestures are inscribed and where are to be found laying the objects which allow to concretise all use programs, become, altogether, the "scenery" of rituality for which science and scientists confirm their status (that of scientists) and establish the technical operations which provide meaning to the building and identity to the institution it stands for. The two structures – the instrumental one and the construction one – will confound themselves? No, they just co-exist. They cross themselves in the point of definition of those elements – those of construction and those of the instruments – where the position and function interfere in the process of form conception. The need to employ openings on walls, doesn't interfere with the theme, as stylistic manifestation – in this specific case affiliated in a sort of neoclassicism – of the *templum* conception. In fact, the morphology or the inner logic set on the transition space's layout of the room which shelters the instrument(s) whose operation, requires a physical communication with the exterior, in any such way, disguises the relation between the interior and exterior. In order to the technical device exhaustively function, the facades of the building are unstructured with openings "out of place" in the compositional sense.

In the same way, the need to create a stable support for the other structures requiring specific conditions of assemble (the main telescope, for instance, whose supports drop into the solid bedrock) its just going to give origin to adjustments in scale or in the way (increase in pillar's section due to mechanical requirement) it does, oftentimes, these elements acquire disproportionate dimensions relatively to other elements (openings and central space, for instance), not resulting in such manner any revision on the room's geography or the environmental logic it creates.

c. Pulkova and Lisbon

The main building of the observatory is an adapted version, in its performance of the Pulkova Observatory (S. Petersburg). The scale appears changed and some of the infrastructures, which the Saint Petersburg complex possesses, were simplified or are not even present at all. It is on a symbolic level that the variations become significant. To confirm this, one could verify the total absence of vinculum to the place and the imagistic sense of all the exterior arrangement and its ceremonious interior.

The Pulkova Observatory is, nevertheless, the first modern observatory desired to function as a scientific macro-object. When discussing its construction, two proposals were considered: one that explored the stylistic imagery of gothic buildings and another one, which ended up being chosen and that, apparently, with less aesthetic concerns, clearly manifest "*the scientific vocation of the construction*" as admits Wilhelm Struve, its creator. Furthermore, he declares that the program of the set of building was established "entirely according to its various functions". Thus, what guides the project is fundamentally the "astronomical considerations"[24].

In the case of the Royal Astronomical Observatory of Lisbon however, one must stress, it is the architectural quality produced by its past users that lend it a seemingly architectonic "charm" which explains its other possible uses, past and present, on behalf of its visitors. Such is the case, that contrasts with Pulkova, not only in the level of scaling, but also in that of domestic ambiance which it manages to be proportionate, in the inside as the outside. The Astronomical Observatory of Lisbon is a receptacle of the common heritage we find in architecture and science, that's true. But, it's necessary to remember that as scenery of an emerging scientism in the end of the XIXth century it is, to great extent and along with the bibliographical and instrumental estate, in the architectonic substance that it fetches its patrimonial substance.

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[24] F. Le Guet Tully, J. Davoigneau, *The 19th century observatory today: from astronomical instrument to cultural and scientific symbol* [in:] B. Grab, H. Hooijmaijees (eds), *Who needs Scientific Instruments – Conference on scientific instruments and their users 20–22, October 2005*, Leiden: Museum Boerhaave, p. 57.

d. An Astronomy Museum in Lisbon

The undeniable value of the AOL in all vectors of cultural heritage it contains, makes very difficult to take decisions that go against the cultural values it represents. Historical buildings and scientific instruments of the past facilitate the understanding of our own roots, they help us make the bridge between the old and the current days. As long as this bridge keeps a time continuity the past never dies, the recollection of the astronomy of old makes us better understand how much we have learned and also dream the future to come.

The imagery and symbols hidden in the old buildings and instruments crafted by the daily life efforts and research work must be told to the current generations so they get a glimpse of the future to come, their own future. Therefore, the museum we all have in this observatory must be kept alive as a house of story telling and research work, showing the human adventure that points forward. It should not close the door of the future coming by preserving its estate as a self contained crystal, frozen in itself. Only a few are interested in the dying past. Moreover, the only past experiences that ever last are those connected to the future, the human "us". The centennial dragon trees and the china roses in the botanical garden are a blessing and a must to visit because they still blossom today and will do so for generations to come.

Who else is better in telling these stories besides the scientists themselves?

STRESZCZENIE

Obserwatorium Astronomiczne w Lizbonie oraz jego dziedzictwo narodowe, społeczne i naukowe

Można powiedzieć, że historia Obserwatorium Astronomicznego w Lizbonie (OAL) rozpoczęła się razem z kontrowersją dotyczącą paralaksy gwiazdy Argelandera między Herve Faye, dyrektorem paryskiego obserwatorium, a Petersem, astronomem obserwatorium rosyjskiego w Pułkowie. Jego budowa miała się stać wyznacznikiem europejskich planów naukowych, punktem odniesienia na mapie kulturalnej Portugalii i opierać się na woli stanowienia wspaniałych instytucji. Korzeniem był rozwój nowej gwiezdnej astronomii, odkrycie i poznanie nieskończonego kosmosu, jego zawiłości i działania jako środka i siły napędowej społecznego rozwoju. Miało urzeczywistniać wartości nowej postawy wobec nauki i kształtować nowe społeczeństwo przez symbol i obraz monumentalnej architektury kształtów i wzorów – jako hymn dla nowoczesnej technologii, zdolnej wyznaczać nowe horyzonty. Instrumenty wybrano spośród najdoskonalszych konstrukcji i nawet wtedy ciągle je polepszano dla większych osiągnięć. Astronomowie ciągle tworzyli lepsze procedury obserwacji, obliczeń, metodologie wykluczające błędy i niedoskonałości instrumentów. Rezultatem było uznanie najwyższej jakości wyników badań na wielorakich międzynarodowych sesjach obserwacji, pomimo że później nie udoskonalano już instrumentów. Zaprzestano

obserwacji dopiero w 1967 roku, ale dziedzictwo obserwatorium jest związane z nowoczesnym centrum badawczym astrofizyki, które wspólnie ze studentami uniwersytetu prowadzi publiczną działalność upowszechniającą. Wiele działań stało się standardem: zwiedzanie starego obserwatorium przez uczniów i inne grupy, comiesięczne publiczne wykłady transmitowane przez Internet, elektroniczny biuletyn informacyjny dla 4000 zainteresowanych, otwarte letnie noce obserwacji, letnia szkoła astronomii dla nauczycieli fizyki, powszechne kursy astronomii, służba narodowa kontroli obowiązującego czasu i synchronizacji przez NTP itp. Zachowanie i przekształcenie w muzeum tego wspaniałego dziedzictwa stało się celem w ostatnich latach, dlatego powstaje specjalny program selekcji, organizacji i odnowy starych ksiąg i dokumentów, astronomicznych katalogów, rejestrów i spisów obserwacji, druków, map i rysunków archtektonicznych etc. Zbudowano i działa specjalny pokój, gdzie kontrolowane są temperatura i wilgotność. Prace renowacyjne rozciągnęły się na zewnątrz i objęły ogród (z rzadkimi gatunkami roślin), aby zachować jego stary, dziewiętnastowieczny charakter. OAL jest tym unikatowym środowiskiem, pomostem między dawną astronomią galaktyki i nowymi granicami nauki łączącej przestrzeń, czas i energię w jedną tkaninę. Zwiedzający może tego wszystkiego dotknąć, może to odczuć i zobaczyć, zaspokoić głód wiedzy od przeszłości do przyszłości.

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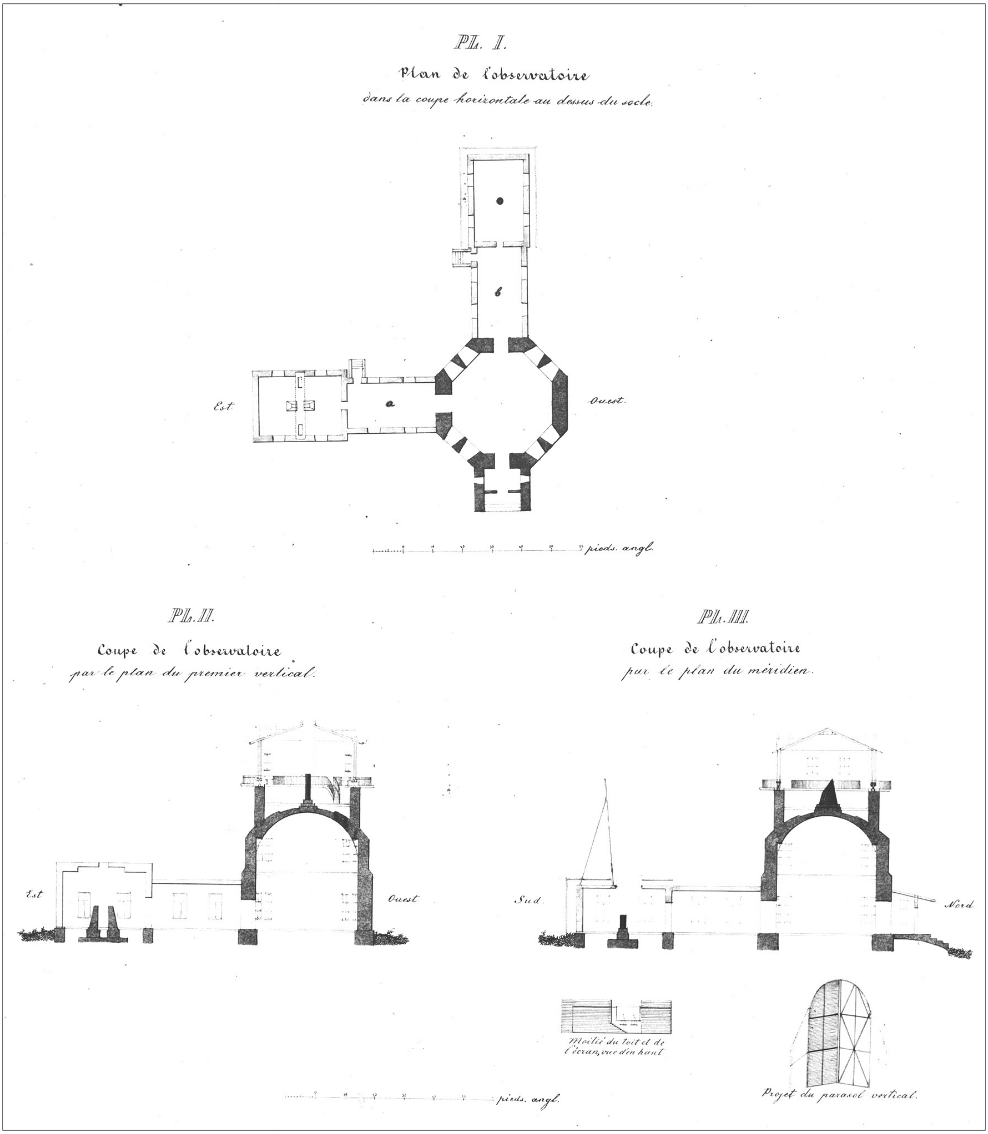
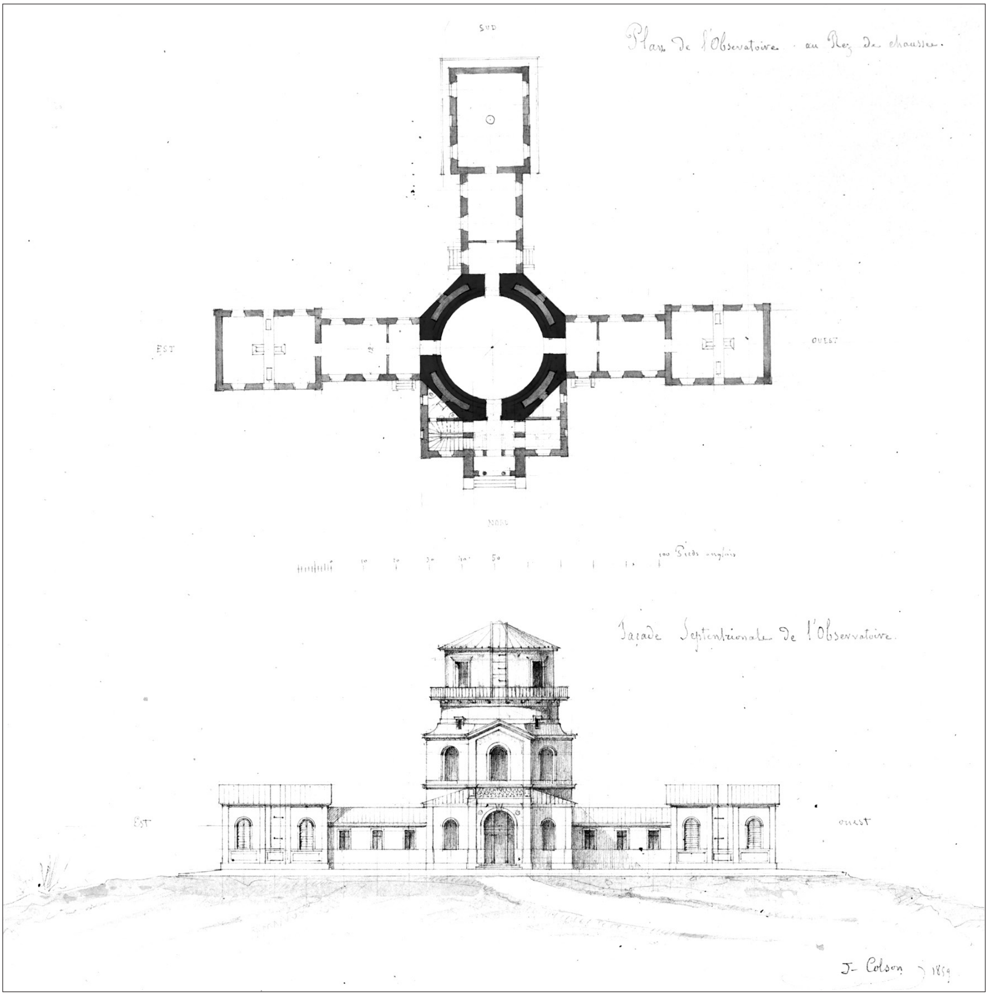
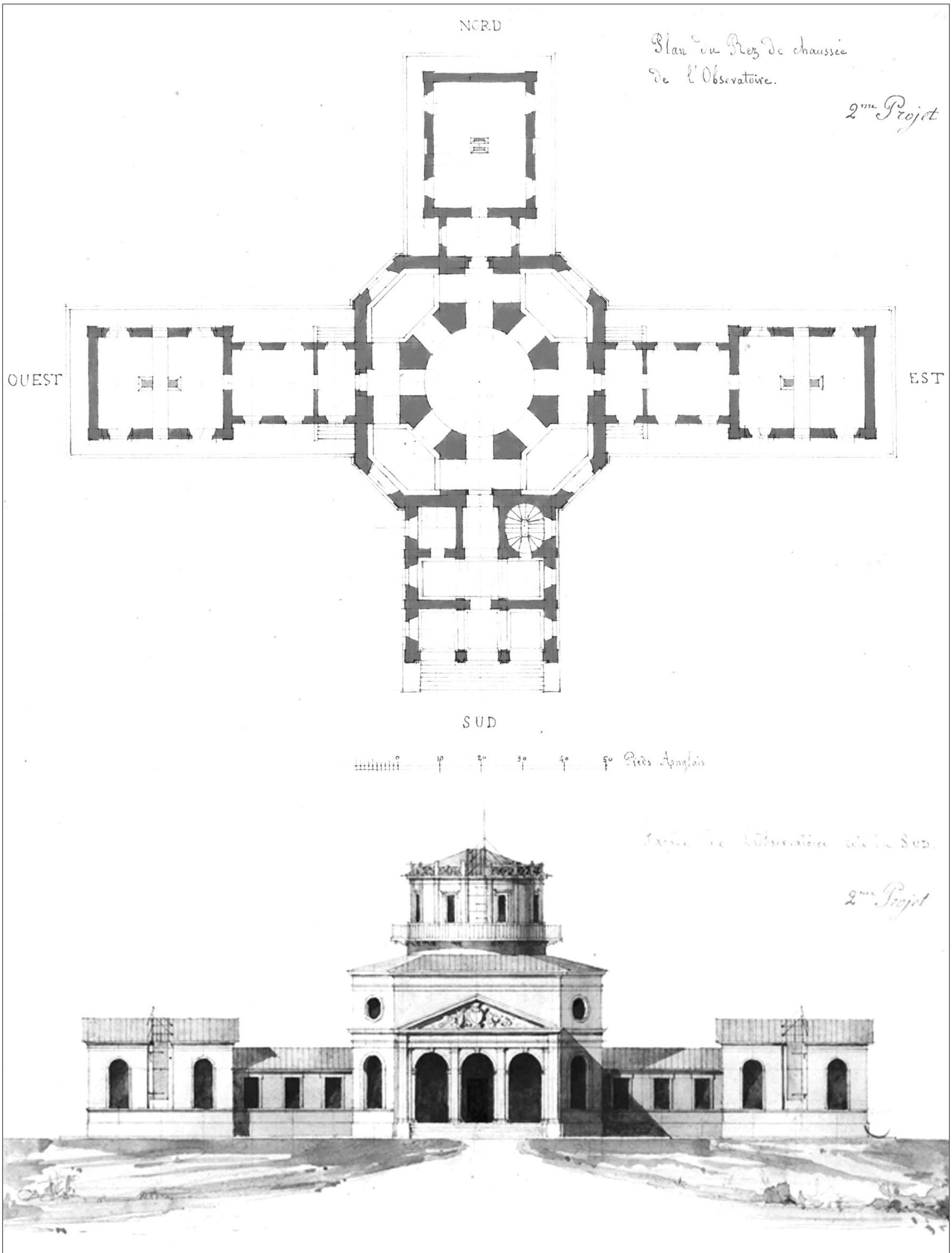
Il. 1. Astronomical Observatory of Lisbon



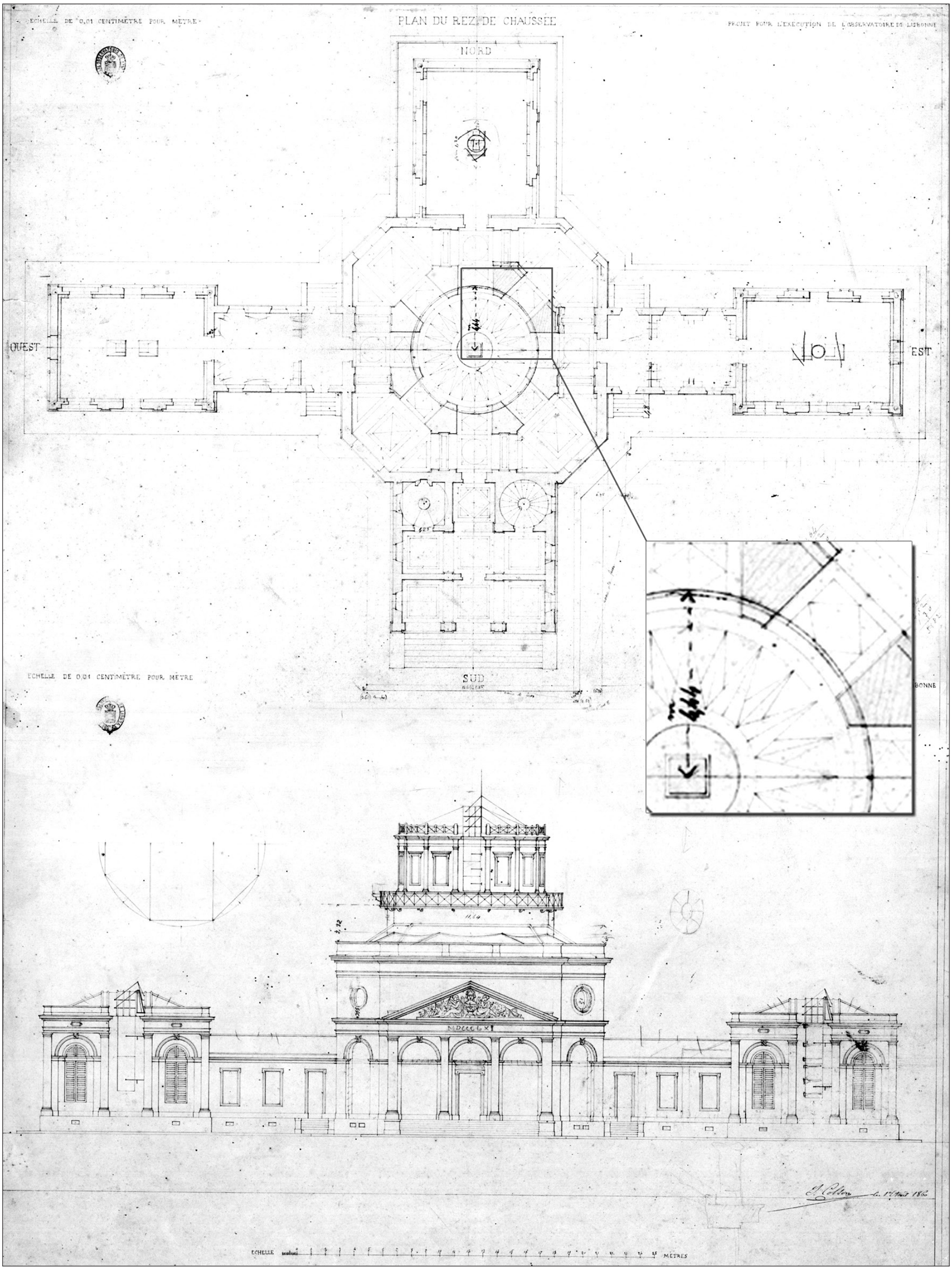
Il. 2. Astronomical Observatory of Lisbon: Struve's sketch



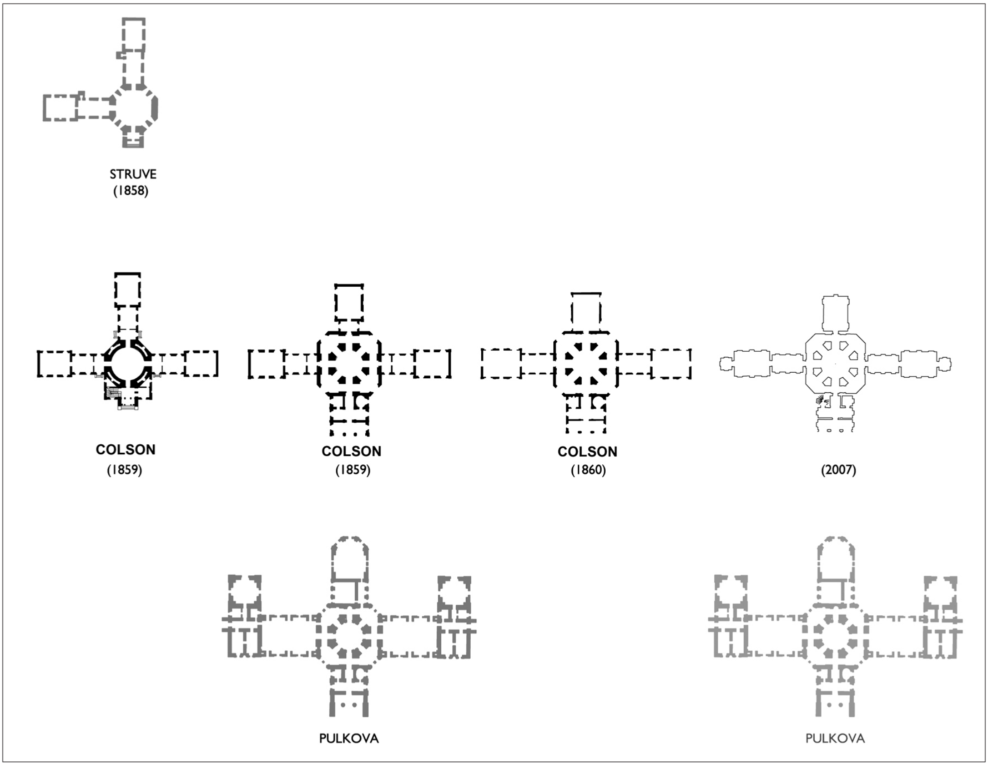
Il. 3. Astronomical Observatory of Lisbon: Colson's 1st study



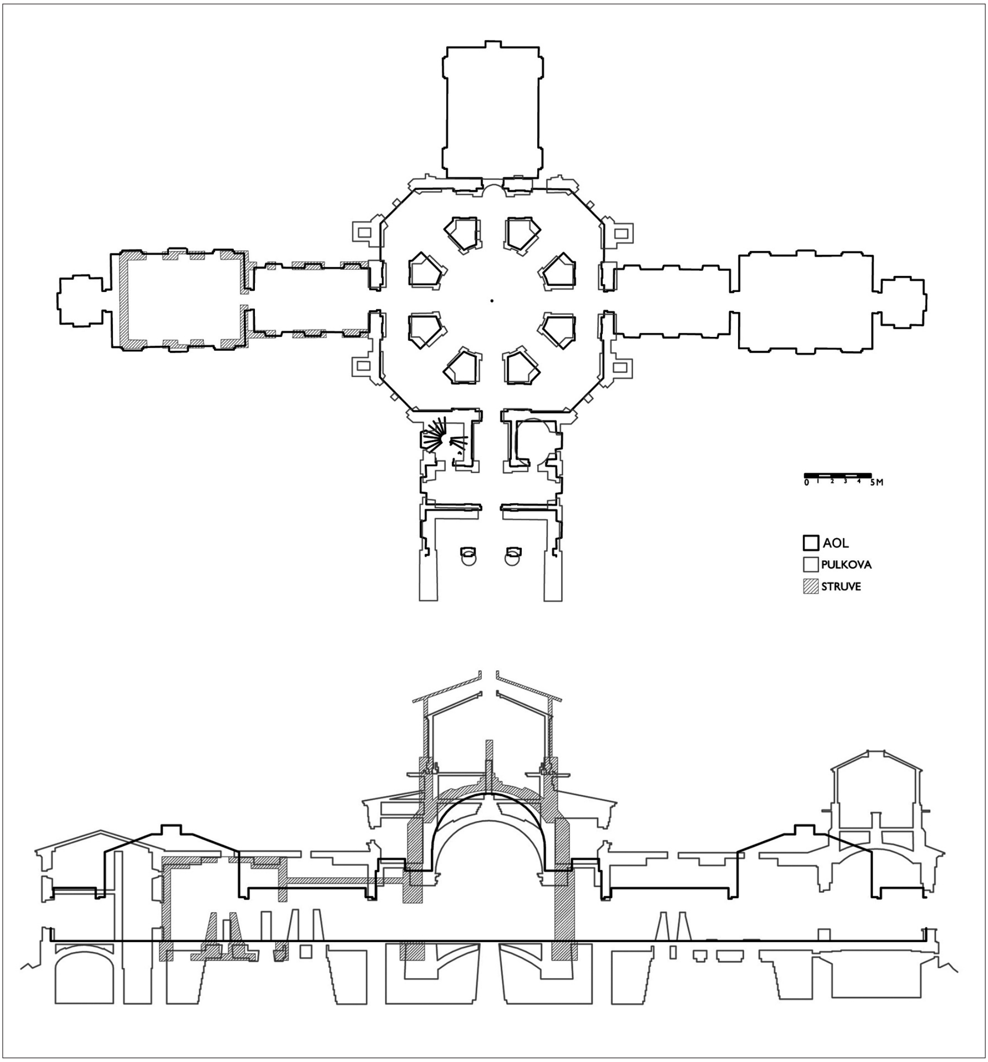
Il. 4. Astronomical Observatory of Lisbon: Colson's 2nd study



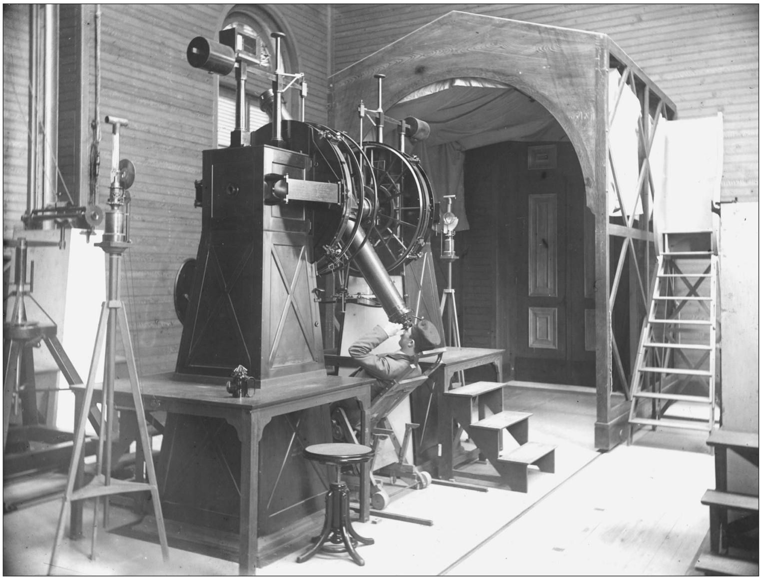
Il. 5. Astronomical Observatory of Lisbon's first Execution plan



Il. 6. Astronomical Observatory of Lisbon and Pulkovo Observatory: ground floor plans

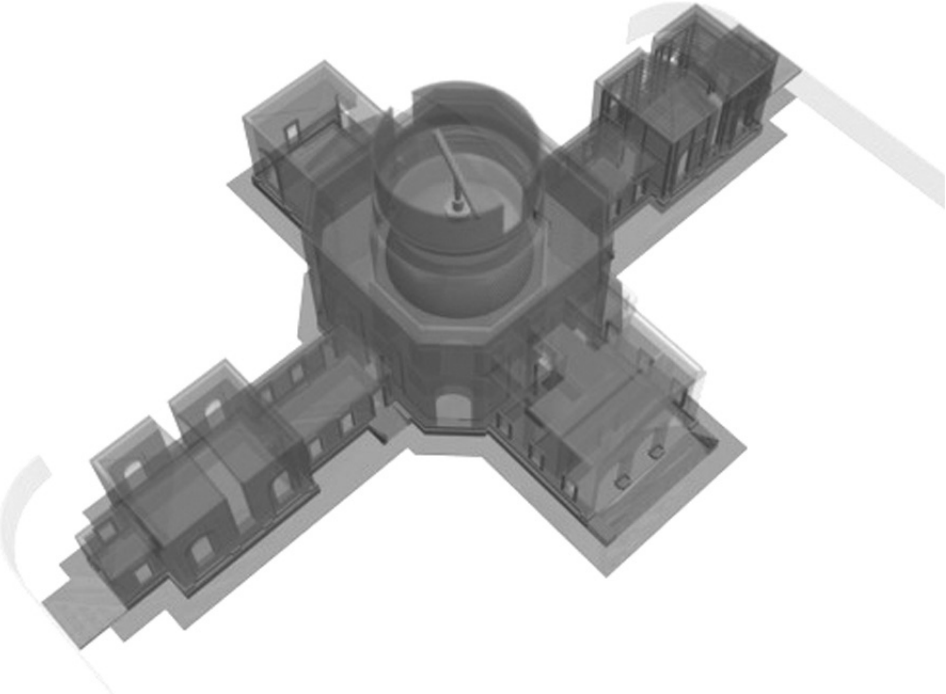


Il. 7. Astronomical Observatory of Lisbon and Pulkovo Observatory: elevations and sections



Il. 8. Astronomical Observatory of Lisbon's Meridian Circle

Il. 9. Astronomical Observatory of Lisbon's first vertical instrument



Il. 10. Astronomical Observatory of Lisbon's 3D model by Hugo Henriques