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VII Workshop on Robotic Autonomous Observatories (October 16-20, 2023)
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DEVELOPMENT OF ASTRONOMICAL OBSERVATORIES FROM THE LATE 19TH TO THE 21ST CENTURY

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RESUMEN

Este artículo atiende a la transición desde el observatorio moderno al contemporáneo así como su evolución hasta principios del siglo XXI. Asimismo analiza las variaciones en los diseños de estos edificios hasta que algunas de estas características se consolidan definiendo los rasgos propios del observatorio contemporáneo.

ABSTRACT

This work explores the transition from modern to contemporary astronomical observatories and traces their evolution up to the early 21st century. It examines the gradual changes in architectural and functional designs of these structures, highlighting how certain features evolved and eventually became standardized, shaping the defining characteristics of the contemporary observatory.

Key Words: instrumentation: detectors — methods: observational — techniques: photometric — telescopes

1. INTRODUCTION

The development of the observatories up to the 19th century reached a series of characteristics or constructive solutions that were established as substantial features of the architectural definition of the astronomical observatory. In this sense, several aspects were consolidated, such as the search for the greatest possible structural stability, the independence of the optical instrument supports from the rest of the structure of the complex, the separation of main and secondary uses, attention to thermal stability, the specialisation of the façade and its openings according to the contained use, and the installation of the mobile dome as a roof-covering solution through which the entire sky can be made visible (Castro Tirado 2021a), a solution adopted in many robotical observatories (see for instance Hu et al. 2023).

Beyond the particularities of their construction, the substantial changes in the observatories up to this point range from their genesis to their purpose. In this way, they went from the nobleman or monarch as promoter to the institutions or public benefactors. Likewise, it would progress from the purely scientific interest to its practical application or the incorporation of propagandistic or informative functions. Historically, the enlargement of observatories has been linked to the increase in the number of their instruments and the increase in their size as technical advances made this possible. In the case of royal or state centres, Newcomb stated that "whenever a monarch has wished to associate his name with science, he has designed an observatory commensurate with the magnitude of his ambition, filling it with instruments of the corresponding scaler" (Newcomb 1881). This assertion can be extrapolated to contemporary observatories, regardless of the benefactor or promoter of their foundation, with the qualification that the design and scale of the building will be proportional to the scientific ambition and research project behind it. On the other hand, from the 19th century onwards, the development of cities began to cause problems in some nineteenth-century observatories, which not only began to move away from the large capitals towards smaller towns but also began to consider their situation in environments far from the urban environment as something favourable. This trend would continue and intensify in the following decades, underlining a physical distance from the ordinary citizen that would lead to intellectual dissociation. These astronomical centres with spaces such as lecture halls, classrooms or exhibitions, open to visitors, amateurs and experts, or even public observatories, will gradually lose prominence in favour of highly specialised scientific complexes in which, increasingly, almost exclusively the astronomical function will have its place (Castro Tirado 2019). Both the need to move away from urban centres and the new architectural and structural demands required by the new astronomical instruments were causes of obsolescence of the observatories. As a result, many observatories, especially the more modest ones, which emerged during the previous period, ended up abandoning re-

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search in order to reconvert to another type of use, taking advantage of the construction itself, or they were closed down altogether (Eelsalu 1999).

2. DETACHMENT/DISENGAGEMENT FROM URBAN/CITY

The massive movement from the rural world to the cities that occurred after the Industrial Revolution led to a continuous growth of populations throughout the 19th century. This movement was accompanied by some changes in human activity that already at the beginning of the new century compromised the good performance of observatories (Bourgeois 2017) in urban or peri-urban environments. The emergence of new industry and the increase in motorised transport by land and sea led to an increase in vibrations and pollution. In addition, public street lighting brought with it light pollution that limited the visibility of faint objects. Likewise, this change of century coincided with the transition from refractors, as the paradigm of the telescope typical of any astronomical centre worthy of significance, to large reflectors. This evolution went hand in hand with the rise of astrophysics, although without leaving behind classical astronomy, which relied on meridian circles, transit instruments and astrographs to continue its studies related to the measurement of time or navigation itself (at least until the middle of the 20th century). This meant that the observatories had to attend to different lines of work, which meant that they had to have markedly heterogeneous equipment (Hünsch et al. 2012). Thus, at the end of the 19th century, almost simultaneously in America (near San José, California) and Europe (near Nice, France), the newly-born observatories (both the Lick and Nice ones) presented some of the defining features of what was to become the contemporary observatory. These complexes were to be set up isolated from urban centres, in remote and elevated areas such as mountaintops where, far from the fumes and lights of the city, they would find the best possible conditions for observation.

The boundary between the modern and the contemporary observatory is clearly marked by the ambivalent Lick Observatory (Figure 1). Both its architectural configuration and its main design features are typical of the earlier period, yet it would become the first astronomical centre completely detached from the urban with its permanent mountain installation. The remoteness of the cities meant that the general population was isolated and lost contact with this science. In contrast, during the first part of the 20th century, public observatories were built in large European cities (Berlin, Vienna...) to inform the public about astronomy and the universe (Markkanen 2013). These institutions, being disconnected from the scientific avant-garde, moved away from the new design trends and remained stagnant in the features of the modern observatory. On the other hand, despite their high degree of professionalism and greater secrecy, there are still some astronomical complexes that are occasionally open to an initiated (or at least interested) public, which include guided tours and museum spaces in their complexes. There will even be some centres that consider tourism as a value or recognition (such as the Mount Wilson in the US or the BTA-6 in Russia) and even as a means of financing their research programme (such as the Pic du Midi Observatory or the above mentioned one in Nice, both in France) (Figure 2).

In this regard, the same Director of the Nice Observatory (now the Observatory of the Côte d'Azur) emphasises the natural environment, the panoramic views and the architecture of the complex as values to be highlighted in order to broaden the potential visitor base beyond the amateur public or school excursions, acquiring a national and international tourist vocation (Heudier 2006).

3. FRAGMENTATION

The new needs of science were to lead to some variations in the design principles of buildings devoted to astrophysics, in particular spectroscopy and photometry (Markkanen 2013). While the modern observatory tends to be configured as a unitary building in which a complex programme of heterogeneous uses (observation rooms, offices, libraries, workshops, dwellings...) shares a roof in a single building in which one or more domes and a meridian room that conditioned the orientation of the construction were evidence of its raison d'être, the contemporary observatory will be organised in a less regulated and rigid way (Hünsch et al. 2012). The very size of the new large reflectors, the differences in scale, the different needs intrinsic to the multiple uses or the orography of the mountainous terrain itself, which makes it difficult to have large leveled floors, will be aspects that will cause the segregation of the building into a series of independent constructions. This separation will allow a liberty of layout and orientation in the territory that will favour the conditions for observation, as well as exempting the astronomical function from some of the interferences (vibrations, smoke, light, heating) inherent to other uses.

In addition to being located on a mountain, the Nice Observatory (Figure 3) would be the forerunner

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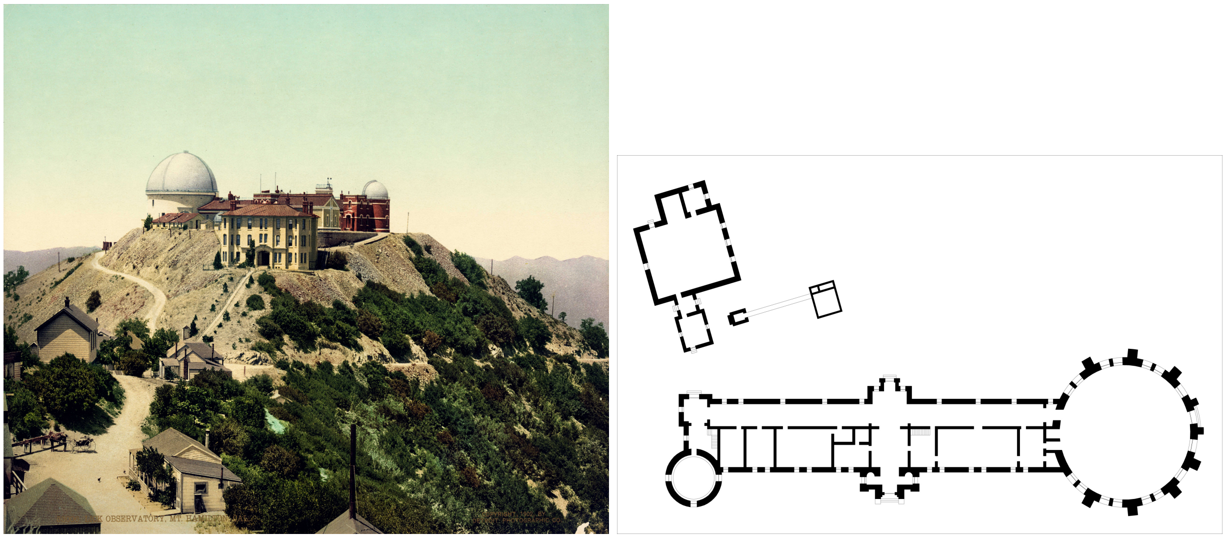

Fig. 1. *Left:* Lick Observatory perspective. *Right:* Lick Observatory plan. Adapted from Castro Tirado (2019).

Fig. 2. Tourism at the Pic du Midi Observatory.

in being intentionally and permanently conceived, designed and constructed as a set of independent buildings with a high level of specialisation. Although over the next few years, several astronomical institutions would emerge that fulfilled one of these two characteristics, it would be a quarter of a century before both were replicated simultaneously. This marks him out as a man ahead of his time who should be recognised as a benchmark. The aforementioned distance from urban centres will entail the disconnection of public installations from urban areas (electricity, water, etc.) so that, although there are solutions to this isolation (such as electricity generators or water tanks), the truth is that experience has shown in cases such as the Pic du Midi Observatory that connection to the supply networks is essential for the acceptable development of the research activity (Davoust 1998). On the other hand, the occupation of land that is isolated and disconnected from the population is evidence of the effects that such a facility can have on its surroundings. As the landowners who gave the land for the construction of the Mount Wilson Observatory have already warned, a large observatory becomes an important point of interest that gives its surroundings renown and prestige, attracting scientists and tourism, and catalysing the development of the industry directly and indirectly linked to this activity; in short, increasing the wealth of the place and its inhabitants. Shortly after 1900, the Mount Wilson and Hamburg observatories joined the trend set by the Nice observatory, which was to become consolidated throughout the 20th century: the formalisation of an independent building for each telescope, allowing an absolute level of specialisation by defining each of the characteristics that would condition the project on the basis of the functional requirements of its single instrument.

4. CONSEQUENCES OF UPSCALING

The inauguration of the Hamburg-Bergedorf Observatory preceded a period of instability from the First World War (1914-1918) to the Second World War (1939-1945), including the interwar years. During this period, both the possible funding and the thoughts of a large part of scientists, and of the population in general, will be focused on the war conflicts, their unforeseeable consequences or on the recovery

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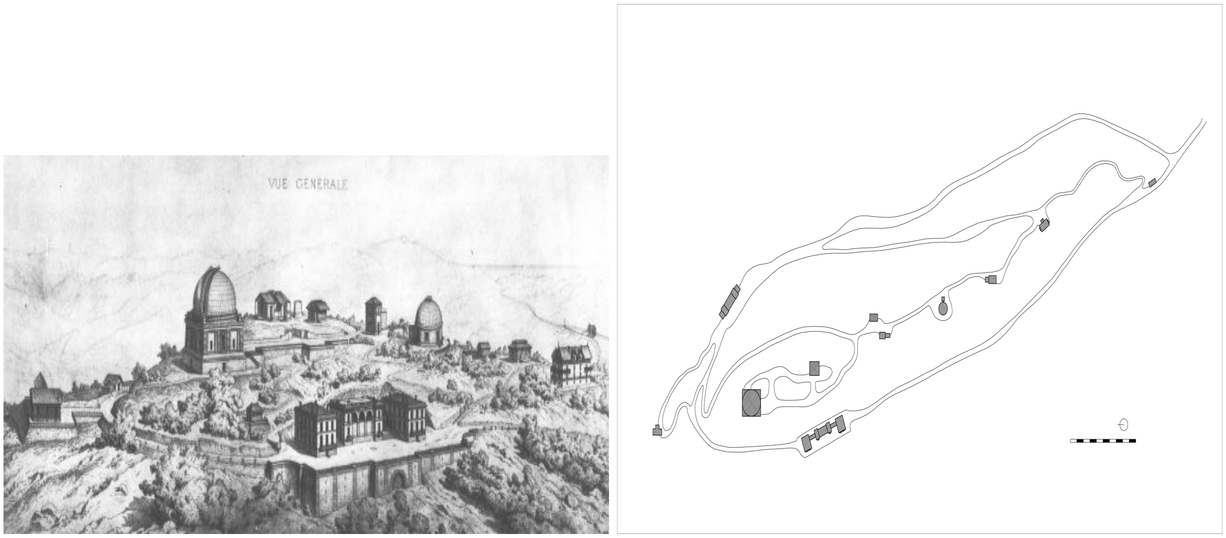

Fig. 3. *Left:* Nice Observatory perspective. *Right:* Nice Observatory ensemble plan. Adapted from Castro Tirado (2019).

from them. For all these reasons, no new astronomical observatory of any significance will be built until almost the middle of the 20th century. The only exception worth mentioning is the Griffith Observatory in Los Angeles, which was built between the two conflicts thanks to the tenacious efforts of a private investor (Krupp 2011). Prior to this parenthesis, during the 19th century there had been a race for the world's largest telescope which, perhaps, rather than scientific ambition, represented an ambition for fame, prestige or recognition. Thus, this competition was active from the installation of the large 76 cm diameter refractor telescope at Pulkovo Observatory (Russia) in 1839 until the 102 cm diameter refractor at Yerkes Observatory (US) in 1897, still holding the record of being the largest refracting telescope in the world. See also Castro Tirado (2021b). In addition to the technical difficulties that complicated this redundant growth of instruments, it would be a change in the prevailing telescope system that would eventually put an end to this competition. Although mirror-based telescopes had been installed in observatories for decades, their role had always been secondary to the importance of the large refractors. However, their relevancy was to increase thanks to the technological advances that would make it possible to manufacture the required mirrors in parallel with the development of astrophysics itself. Thus, with the installation of the large reflector at the Mount Wilson Observatory (152 cm) in 1908 and, above all, with the inauguration of the large Hooker reflector (254 cm) (see both in Figure 4) at the same complex in 1917, a new race began to build the largest reflecting telescope in the world. An aspiration that has been maintained to the present day.

Regardless of the type of instrument being referred to, the exponential growth achieved during these disputes reached such magnitudes of telescopes that it rivalled the very scale of the architecture that contained them. This would mean an increase in the size of the buildings housing the telescopes that would produce a large amount of contained space that could be taken up by other uses. Similarly, the large instruments would require larger structural supports. To such an extent that the scale they would acquire would generate interior voids or spaces that would even allow for the accommodation of some functions. In this way, the projects for these large telescopes would or could incorporate enough secondary functions (offices, workrooms, meeting rooms, laboratories, storerooms, workshops, rest rooms, toilets, etc.) to be able to contain almost the entire programme required for an entire observatory. Thus, each building planned for a particular instrument could have sufficient autonomy to constitute an entire astronomical observatory in its own right. At the same time, this independence allowed absolute freedom in the design of the project, which could be adjusted and specialised according to the specific observation needs of the instrument it would house, optimising its observation solution, adapting to its location and environment, and accommodating the rest of the secondary uses required to its architecture. From this point onwards, the most important observatories would be constituted as groups of independent structures which would usually include

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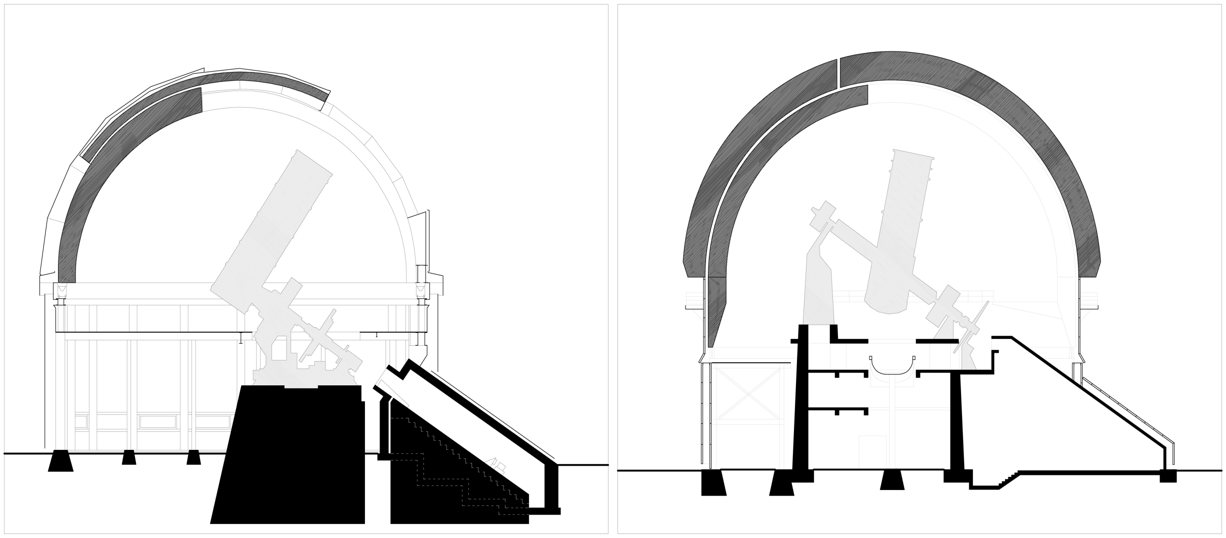

Fig. 4. *Left:* Mount Wilson Observatory section. Adapted from Castro Tirado (2019). *Right:* the Hooker Great Reflector section at Mount Wilson Observatory. Adapted from Castro Tirado (2019).

buildings containing some accessory uses (residences, coffee shops, exhibitions, rooms for visitors...), other constructions for astronomical instruments and the main buildings for the large telescopes together with the primary functions (meeting rooms, work rooms, laboratories, offices...), which would constitute the very essence of the observatory itself.

5. BUILDING-SIZE TELESCOPES

The war years would reduce investment in this science to a minimum, causing a standstill in the construction of new astronomical centres. This pause would lead, after its conclusion, to new projects for observatories with telescopes, and therefore larger and more ambitious buildings. Likewise, this parenthesis had allowed us to take a certain perspective on the latest advances in astronomical centres, discerning the values implemented by some observatories (it should be remembered that during the first half of the century both observatories typical of the previous period and others incorporating contemporary aspects were inaugurated). Thus, by the middle of the 20th century, the principles that would shape the characteristic features of the contemporary observatory had become apparent: location in the mountains, far from the population, and the configuration of the observatories as groups of autonomous buildings of high technical specificity destined for a particular instrument or function. In addition, the new century brought with it a paradigm shift in this science, from classical astronomy to contemporary astrophysics. This evolution brought the telescope back into the spotlight, which as a refractor seemed to be reaching insurmountable limits, but as a reflector had many possibilities for improvement and enlargement. The increase in the number of reflectors leads to a upscale in the building that contains them and in the structure that supports them. The size of the telescopes soon reaches dimensions that bring them into the range of buildings and their structural supports and foundations become so large that, since it would make no sense for them to be massive, the space they contain exceeds the architectural scale of man, so that they can be inhabited and occupied by all kinds of functions. Then some of the uses that had been broken up to make way for buildings exclusively for large telescopes are eventually reintroduced into their bases to take advantage of the space created by their increased scale. This leap in scale is first evident at the Hale Telescope (Figure 5), at the inauguration of which almost a thousand people were seated under the dome around the reflector mount supports in front of a stage.

The enlargement of telescopes went hand in hand with the upsize of their mirrors, which became larger, heavier and more complex to manufacture, maintain and move. For this reason, it became increasingly essential to have facilities for the handling and maintenance of the large mirrors, and so they were eventually added to the telescope building itself. This incorporation of new functions will not be an isolated event, but on the contrary will become a recurrent feature as new developments are implemented as basic standards. In this way, various rooms for specific facilities or storage will be incorporated into the programme of essential uses of the observatories. Just

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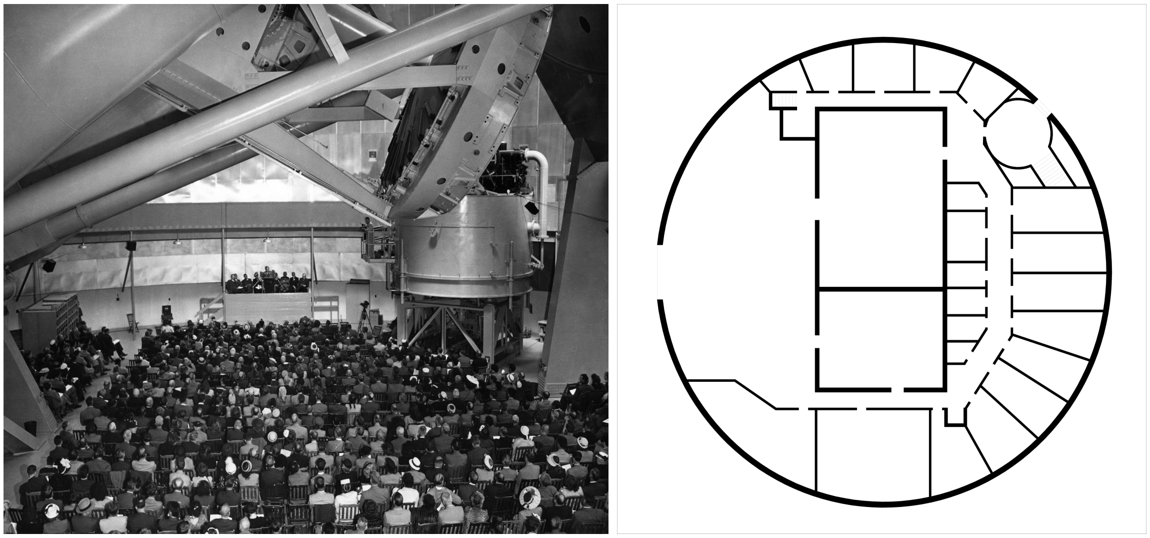

Fig. 5. *Left:* The Hale Telescope inauguration. *Right:* Hale Telescope plan. Adapted from Castro Tirado (2019).

as with the modern observatory there was a competition for the world's largest refractor, so the era of the large reflector saw the beginning of a similar competition, which has continued throughout the 20th century and into the present day. If around the turn of the century the orientation of science towards astrophysics would boost the weight of reflectors in research, then this type of telescope would remain modest until George Hale promoted the most powerful reflector of its time (1.52 m diameter), installed in 1908 at the Mount Wilson Observatory. However, his ambition led him to surpass his own milestone by promoting the Hooker (2.54 m diameter) at the same complex in 1917. This race continued with the inauguration of the Hale Telescope (5.08 m diameter) at Palomar Observatory (California) in 1948, followed by the BTA-6 (6 m diameter) at Zelenchuk (Russia) in 1975 and surpassed by the Keck I (9.8 m diameter) at Mauna Kea (Hawaii) in 1993. The current holder of the honour of being the largest reflector in the world is the Gran Telescopio Canarias (10.4 m diameter) in Spain since 2007. However, it is already known that this prerogative is about to expire as new observatories with reflectors larger than the GTC are already planned. For example, the Giant Magellan Telescope (24.5 m diameter) at Las Campanas Observatory (Chile) is under construction and is expected to start operations in 2030[2]. The Thirty Meter Telescope (30 m diameter) at the Mauna Kea Observatory is also in the pipeline, although it has been announced that work will begin in 2019 and it is expected to start operations in 2027[3]. And the Extremely Large Telescope (39 m diameter) at Cerro Armazones (Chile) is under construction too and is expected to be operational from 2027[4]. There were even plans for such a huge project as the Overwhelmingly Large Telescope (100 m diameter), which is, at least for now, cancelled[5]. Since the transition from monolithic mirrors to composite solutions, either of hexagonal or circular pieces, the weight of the reflector element has been reduced and its structure lightened, giving the possibility to continue with a growth, so far, without limit.

6. STAGNATION DESPITE TECHNICAL PROGRESS

Leaving aside improvements in optical systems or technological aspects, designers were so strongly influenced by the Hale Telescope design that almost all post-World War II astronomical centres were devoted to replicating the Hale Observatory pattern without a critical eye or study of other possible variations (Leverington 2017). In this sense, such transcendental advances for astronomy as the altazimuth mount or the incorporation of the computer control of the BTA-6 had little impact on its architectural definition (see for instance, Figure 6) beyond the not very significant displacement of the structural support of the telescope from a lateral position to the centre of the building's floor plan. In other words, although there have been some significant advances

[2] `https://www.gmto.org/`.

[3] `https://www.tmt.org/`.

[4] `https://www.eso.org/public/teles-instr/elt/`.

[5] `http://www.eso.org/sci/facilities/eelt/owl/index.html`.

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in this science after Hale, such as the altazimuthal configuration of the mount, computerised tracking, and even remote access to observations, the fact is that the architecture of the buildings has hardly had any representative evolution beyond some minor and specific variations that become the exception, such as the recovery of the dwellings in the construction of some observatories.

Just as the modern observatory paid attention to details such as structural independence or thermal stability as resources to reduce the constraints that reduced its resolution, the contemporary observatory, in addition to technical advances to improve the results of its observations (such as automated tracking or optical improvements through the controlled deformation of its mirrors), also pays attention to the impact of the complex itself on the nearby atmosphere. Experience has shown that the most unfavourable source of atmospheric turbulence for observation usually comes from the observatory itself, as the unattainable thermal inhomogeneity between parts of the building or even the telescope is detrimental to such precise instruments (Finn 1985). Therefore, some observatories already incorporate air-conditioning and/or ventilation to equalise temperatures and carefully control their own heat sources. While each new improvement in telescopes or in the tools for analysing their observations leaves their predecessors a little more outdated, the reality is that these reflectors that are not at the forefront of global research are still in high demand for use. After all, there are more lines of astronomical work than there are state-of-the-art observatories, and many projects do not depend on extremely high resolution observations[6]. Beyond all this, the importance of technological evolution in terms of computerisation and communication systems should be emphasised and reiterated. Although a priori it may seem a minor change with no particular impact on the observatories, both remote control and remote access to observations mark a decisive turning point for these complexes, since it seems to offer the possibility of abandoning all physical presence in the observatories, which would end up stripping them of their status as buildings.

7. CONCLUSIONS

Despite the many and far-reaching advances in the 20th century observatories, the changes from mid-century onwards have always been driven by technical issues, which has not meant a major transgression in their architecture, so that there has been no impediment for the projects of these buildings to adapt to this evolution in order to achieve designs that would incorporate these changes and, as far as possible, take advantage of them favourably. Even so, although during the beginnings of this period of contemporary development some design strategies for astronomical centres were occasionally manifested in terms of their spatial configuration or their arrangement on the ground, on many occasions these practices were limited to the replication of building envelopes with outdated architectural languages (neo-baroque in the Nice Observatory or art deco in the Hale Telescope) that had little or nothing to do with the activity for which they were intended, with the exception of their domes: those iconic features whose uniqueness was to make them a symbol of the astronomical function. However, although the hemispherical dome is the most common and popular, it is not the only existing solution for an observation building, and there are other less common alternatives such as the polyhedral or cylindrical dome, the vault, the folding or retractable roof, or even the completely movable covering (used in many autonomous and robotic observatories nowadays). The existing dissociation between container and content, between astronomy and architecture, which almost only the domes link in some way, has not been remedied in the development up to the present, but has increased. The ever-increasing budgets allocated to telescopes reduce to a minimum the funds allocated to the buildings in which they are installed, so that a hierarchical imbalance is created whereby architecture is completely eclipsed by science and the buildings lose all sense or meaning and become mere carcasses. Whereas the modern observatory achieved a perfect communion between astronomy and architecture, thanks to which observatory projects were developed in parallel to the construction of the instruments and the design of the buildings was based on generating the most propitious scenarios for observation on the basis of the equipment provided, the contemporary observatory perverts this relationship. The transition from a functionalist attitude, which demanded that every architectural decision should be based on the conditions of use, to a misunderstood utilitarianism, in which any design criterion must be justified solely and exclusively on the basis of its scientific convenience, ignoring users and surroundings, leaving architecture in a situation of absolute submission. Thus, the contemporary observatory is characterised by being governed almost exclusively by scientific-technological crite-

[6] "25 years of Calar Alto Observatory", Max Planck Institute for Astrophysics: `http://www.mpia.de`

Fig. 6. *Left:* Mount Wilson Observatory. *Right:* Calar Alto Observatory.

ria, reducing the architectural impact to the bare minimum and stripping architecture of its autonomy and leaving it subjugated to astronomy.

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