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New Systems and Designs in the Construction of Professional and Amateur Astronomical Observatories (ProAm)

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ABSTRACT

A critical analysis of ten professional and amateur astronomical observatories, built between 2010 and 2015, has been carried out. In this analysis, different placement and engineering errors have been detected which have affected the operation of the facilities. As a result of this analysis, a set of practical solutions and applications to improve the performance of ProAm astronomical observatories has been presented. The study of climate conditions to ascertain the best placement for an observatory and new construction techniques have been taken into account for the construction of new astronomical observatories. Several of the solutions proposed have been applied and tested in six observatories built between 2013 and 2018, the results of which are presented in this work.

Key Points:
New designs for amateur and professional astronomical observatories
Analysis of the study of environmental conditions for the location of observatories
Efficient and innovative solutions in the construction of astronomical observatories

I. Introduction

Since Galileo Galilei used the telescope to observe celestial objects at the beginning of the 17th century, the protection and security of this optical instrument has been a constant worry for all astronomers (Hoskin, 2003). Over time, telescopes have evolved in size, precision and complexity, in such a way that the need to locate these instruments on suitable sites for optimum use is increasingly evident. The industrial revolution of the 18th century provided major advances which were applied to astronomy (Arcimis, 1878), but also, from this moment on, major elements which were harmful to astronomical observation began to appear in industrialised societies, such as environmental pollution and light pollution. (Comas, 1929).

From the 19th century, studies began on the ideal placement of observatories to minimize the elements which could harm the proper operation of telescopes as much as possible (Arcimis, 1879). Meteorological conditions and accessibility are also very important factors which are being increasingly considered (Galadí-Enriquez, 2001), which is why before deciding the placement of an observatory, it is essential to carry out a site-testing campaign (IAC, 2019). Technical advances and improvements in construction are of particular interest in the building of observatories, which start to stand out as very technically advanced engineering works. These are designed for each instrument and the location of observation.

Astronomical observatories have evolved together with human beings. Ancient civilisations mixed myths and religious beliefs with the observation of the stars (Sagan, 1980; Avilés & Hoskin, 2002), in such a way that astronomical observatories were also often religious temples. (Hoskin, 2003). From the Ziggurat of Ur (Babylon), until the present day, observatories have been developing along with the technical advances of each culture. We currently have astronomical observatories in space, giant observatories on land, and even autonomous robotic observatories (Castro-Tirado, 2010; Castro-Tirado et al. 2012) which can work independently or as a network as a whole. (Castro-Tirado et al. 2014).

Astronomical observatories are made up as a complex of facilities which provide support to astronomical research in different ranges of the electromagnetic spectrum (Moles et al. 2010), though currently, and with the help of new techniques and detectors, gravitational waves, cosmic rays, and even neutrinos can be studied. Until now, the buildings of astronomical observatories have been a set of facilities which allow a telescope and its accessories to be used efficiently (Espartero, 2013).

Whenever a team of astronomers has needed a new observatory, they have proceeded to seek the best location for its placement, taking into account the most beneficial elements and avoiding other circumstances that could cause observational problems. An observatory must be located in the best place so that the investment made, and its performance are optimal (Echevarría, 1998; Sánchez, 1985), taking into account the spectral range in which they plan to work. In this research and for the ProAm observatories, the visible spectrum region was mainly considered (3.800 Å a 7.800 Å) and the near infrared region was considered sporadically.

II. Methods

After a thorough bibliographical review (introduction), followed by an exhaustive analysis of the projects carried out in ten astronomical observatories, building and facilities faults and errors have been detected. The analysis of these errors has allowed the creation of different proposals for improvements to repair the observatories studied and improve future projects.

The consultations carried out by the experts responsible for the facilities studied, has established the need to understand the objective in advance and the main use of the Observatory to be as an essential aspect (it is common to join education and dissemination together with scientific objectives). From this point, the preliminary procedures which guarantee the suitability of the location where an observatory and its later construction are stated.

In a preliminary phase, it is necessary to study the location (site-testing) which determines sky quality and the best placement of an observatory. Secondly, a technical project of the building and facilities must be combined with a scientific project, which will justify the existence and use of the observatory itself. Finally, once the observatory is fully operational, it will be possible to draw new conclusions on the results obtained (feedback), which must promote technical improvements and new research projects on astronomy and astrophysics (Figure 1).

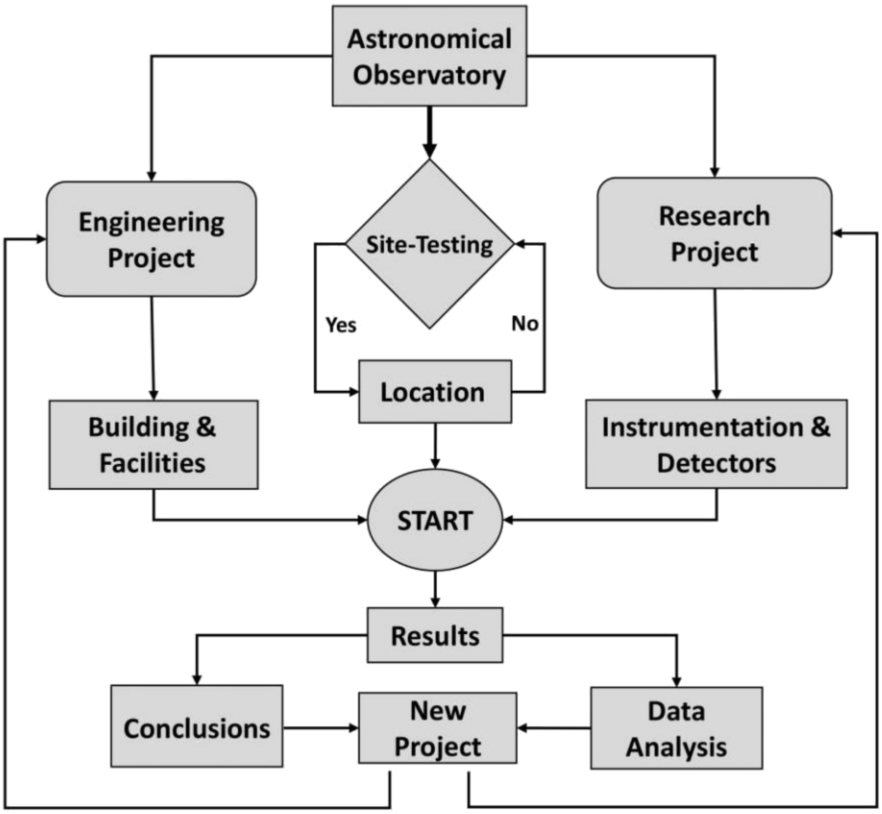

Figure 1 Framework to build an astronomical observatory: Engineering, research and location of the place.

2.1 Site-testing

According to the guidelines of the technical office of sky protection of the Instituto de Astrofísica de Canarias, the following must be considered as the main parameters to be considered for the selection of the location of a professional astronomical observatory: precipitable water vapour, photometric nights, infrared sky background, seeing, vertical turbulence, atmospheric extinction, meteorology, wind speed, inversion layer, night sky background, emission spectrum, sodium layer, seismicity, sky brightness, pollution light and environmental pollution. These elements must be evaluated during a campaign that could last several years and whose results will allow the sky quality of a specific location to be ascertained (McInnes and Walker, 1974; Murding P., 1985; Varela et al., 1999), from which, depending on the spectral range in which the instrumentation works, it will be possible to ascertain the suitability of the characteristics of the location (Moles et al. 2010; Castro-Tirado et al. 2012).. To these factors it is necessary to add the possibility of radio electrical pollution, the flight paths present at the location, and the unpredictable changing conditions caused by climate change, which seriously affect the previously mentioned meteorological and atmospheric parameters. (Giorgi & Francisco, 2000; Morice et al. 2012).

2.2 Location

The choice of a location for observation requires the placement of an observatory to be ascertained, its orientation, altitude and its position regarding the orography of the area, with respect to the ecliptic and the Pole Star, (essential reference point for the orientation of a telescope).

The correct placement must make the necessary logistics and accessibility available to carry out the works and facilities of an observatory. It will be essential that the optical instruments and detectors which are to be incorporated are not harmed by the setting (proximity to mountains, trees, power lines, and buildings, among others), and its exterior conditions (artificial light, proximity to roads and highways, vehicle access, etc). Altitude will be a defining factor, in the case that infrared will be worked with, an altitude of over 1,500 mamsl is advisable (http://webs.ucm.es/info/Astrof/users/jgm/IA/IA_01.pdf) and a dry atmosphere (depending on the orography of the location) to minimise the presence of water vapour which hinders the ability to partially catch infrared radiation. The frequency of cloud banks or conditions of intense humidity will also be taken into account in areas whose orography has a propensity to retain or attract humidity, such as valleys, riverbanks and rivers and areas close to the coast. This information can be obtained by using geographical information systems (GIS) on different platforms such as http://signa.ign.es/signa/Pege.aspx?.

2.3 Construction

It is especially important that proper foundations, depending on the type of land of an observatory and the building of which it is a part. Correct design and formation of the pillars which support telescopes must be evaluated as well as proper insulation to avoid perturbations in the optics and detectors of the telescopes. The necessary and specific outer walls for the use of an observatory, the presence of aerators, (ventilation) which minimize thermal exchange between the interior and the exterior (which is very harmful for optics) are issues to be carefully taken into account. The problems which filtration and humidity can cause must also be carefully considered, as they increase the presence of water vapour, damaging the equipment, along with proper thermal isolation. The faults and errors in design, the motorization and control of the dome and automatic covers can frequently appear. The electrical and data installations must be of a good quality and must not produce unforeseen problems.

III. Field Data

During the period from 2010 to 2015, ten astronomical observatories on the Iberian Peninsula were visited and examined. In this analytical work, different problems have been detected which affect the proper operation of the observatories and the causes have been very diverse. Interviews with the technicians responsible for these observatories have been carried out in order to obtain real information on the state of these facilities and the different problems they suffer from.

The astronomical observatories studied are prestigious facilities and continue in operation. In order to maintain their anonymity, they have been named with letters from the Greek alphabet. This work intends to extract conclusions and proposals for improvement from the lessons learned using the utmost scientific rigour.

From a site-testing point of view, some deficiencies have been detected which have been able to be improved thanks to the data provided by the meteorological stations, and the sky quality detectors of the observatories. A slight increase in the relative humidity index (annual average) has been seen in two cases, and also in precipitation, when compared with the initial values. An increase in light pollution (six cases) and a slight decrease in the quality of sky brightness (seven cases) have also been detected. Clear days have decreased in three cases.

Regarding the placement of the observatories, general good judgement has been used. Only three cases have been found in which ecliptic visibility and access difficulties have been disregarded.

The largest number of the problems detected come from construction and facilities. All the observatories analysed have problems related to construction defects or defects in their facilities.

Some of these observatories were built without a project or optional technical management, others are the result of continuous extensions and some were the result of the renovation of disused old buildings. These circumstances make the appearance of anomalies predictable, as has been summarised in table1:

ISSUES	OBSERVATORIES ANALYSED									
	alfa	**beta**	**gamma**	**delta**	**epsilon**	**dseta**	**eta**	**theta**	**iota**	**kappa**
Relative humidity				x					x	
Annual precipitation				x					x	
Sky quality	x		x	x	x				x	
Light pollution	x	x	x	x		x			x	
Clear days				x	x				x	
Accessibility						x		x		
Location										x
Orientation										x
Foundations	x				x		x		x	
Outer walls	x		x		x	x		x		x
Ventilation	x	x		x			x	x	x	x
Leaks				x			x	x	x	
Insulation				x			x	x	x	
Dome / Vault		x					x			
Facilities	x	x		x	x		x		x	x

Table 1 Main issues detected in the ten observatories analysed.

In four cases, there is no evidence of the type of foundations that were used, nor a geotechnical study of the land (the composition of the pillar of the telescope is unknown). The outer walls have been designed mainly from brick or concrete blocks and do not meet the needs of the observatory (in six cases they are oversized). Only three observatories include aerators or ventilation systems. Leaks and a lack of insulation were detected in four cases. The domes have problems in two observatories, and all have had different types of faults at some point. Finally, in seven observatories, the facilities have evolved according to their needs. There was no prediction of future projects or extensions.

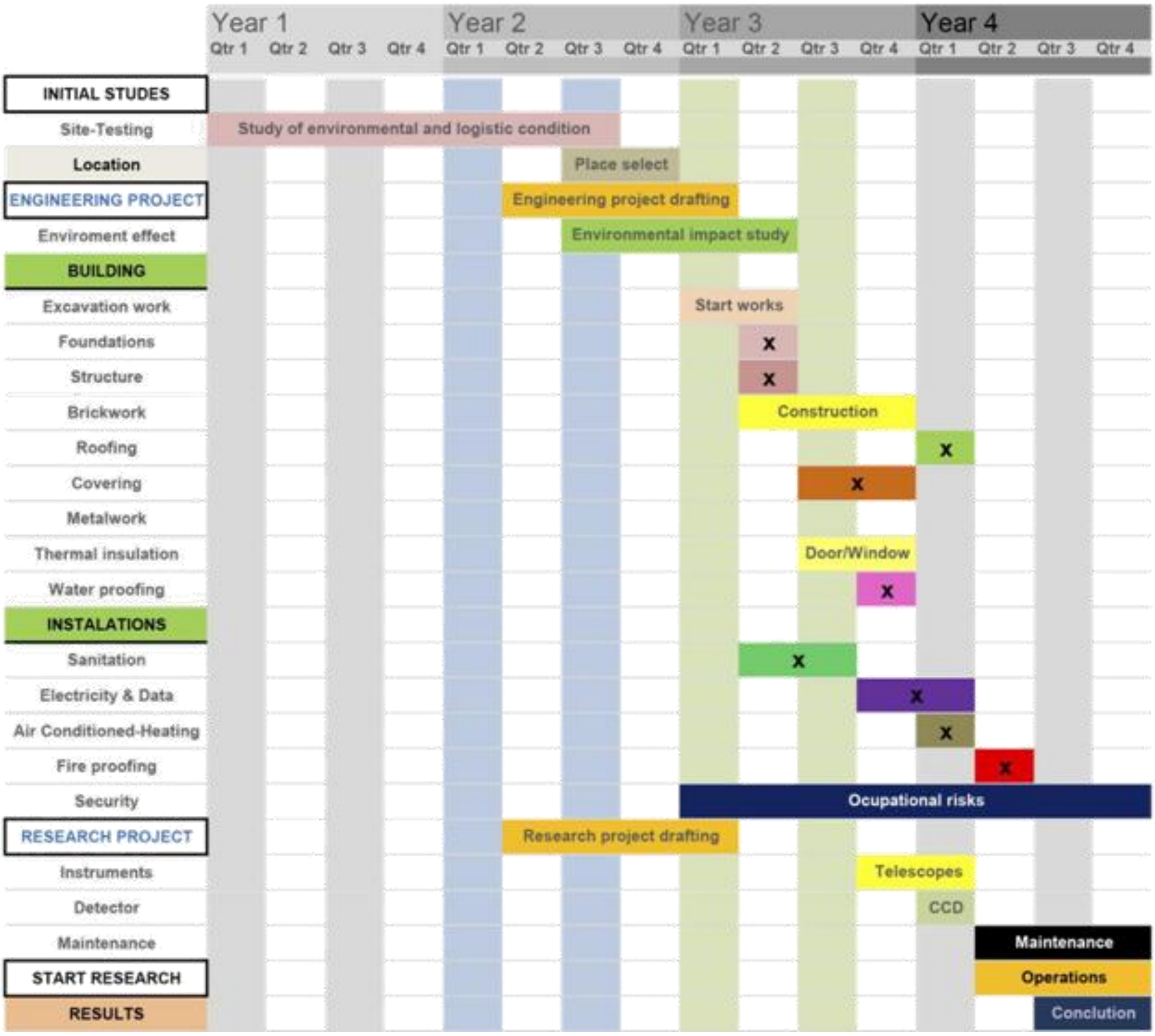

Table 2 Temporary distribution of actions to build and make an astronomical observatory operational.

Plan of work which coordinates the technical actions of an engineering or construction project can be established with the scientific objective which is sought for an astronomical observatory. All of this starts from the establishment of an ideal place for its location. In Table 2, the initial works (site-testing) are developed for 2 years to correctly locate the placement of the observatory. Then, the development of the engineering project through the material execution of the works and its facilities. These actions must be coordinated with the installation of the telescopes and other detectors which allow the resources of the observatory to be efficiently used.

IV. Results

Below, the geographical location of the astronomical observatories that have been built or repaired between 2013 and 2018 are shown. In the six observatories mentioned in Table 3, the faults and errors detected in the observatories analysed have been taken into account (table 1). The design and construction procedures of a ProAm Observatory have been carried out according to the criteria in Table 2.

Nº	Station Code	Station name	Longitude (W)	Latitude (N)	Height (mamsl)
1	COU	Centre d`Observació de l`Univers Áger (Lérida)Observatorio	359º 15' 48"	42º 01' 29"	815,0
2	OAA	Observatorio Andaluz de Astronomía. Alcalá la Real (Jaén)	03º 57' 12"	37º 24' 53"	1.030,0
3	OAM	Obs. Astronómico del Monfragüe Torrejón El Rubio (Cáceres)	06º 00' 33"	39º 46' 24"	318,0
4	OSN	Observatorio de Sierra Nevada Dílar (Granada)	03º 23' 05"	37º 03´51"	2.896,0
5	OAZ	Obs. Astronómico de Zuheros Zuheros (Córdoba)	04º 18' 22"	37º 32' 23"	982,0
6	OMA	Kingsland Observatory Valdepeñas de Jaén (Jaén)	03º 46' 40"	37º 35' 09"	1.489,0

Table 3 Geographical coordinates of the observation stations.

Subsequently, the technical details of greatest relevance which have been carried out in the construction of these six astronomical observatories are presented.

In the Centre d`Observació de l`Univers (COU), an initial project, which the architect Joseph Rule oversaw, was followed. At this observatory, a very intense collaboration took place from the initial phase of the project, which allowed the prevention and improvement of essential aspects for the optimum development of this observatory, which was the first Observatory Education Room in Europe. In the final phase of the execution of the works, some improvements to lighten the weight of the roofing was carried out. Below, images of some of the highlighted aspects of this project are shown (Figure 2).

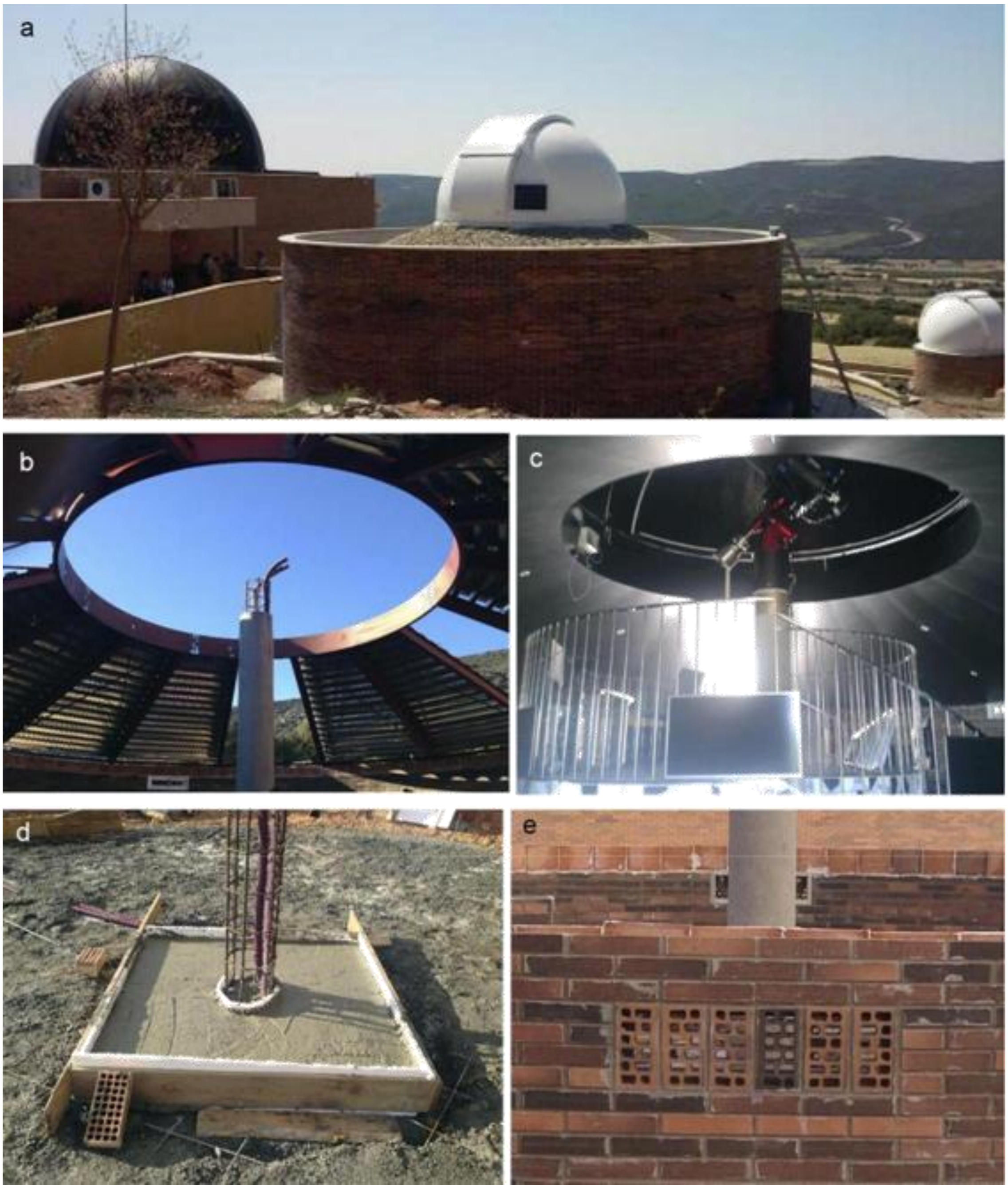

Figure 2. Details of the improvements incorporated into the Observatory Education Room. a) Education Room COU finished, b) Lightweight metal roof that replaces concrete roof, c) Insulated interior with fireproof plasterboard and topped with black satin paint, d) detail of insulated pad for telescope pillar, e) integration of wall aerators.

In the Observatorio Andaluz de Astronomía (OAA) and the Observatorio Astronómico del Monfragüe (OAM), the outer walls were constructed with clay blocks (load-bearing walls and insulation) achieving a diaphanous insulated interior. The floor was created using a slab of reinforced concrete and insulation with BBC. A water-repellent was incorporated into the mortar to avoid humidity, and hollow PLIEXPAN bricks in the base. The dome with a diameter of 4 metres was installed on the second floor of the buildings to minimise humidity, increase ventilation and improve visibility of the horizon. This can be seen in detail in Figure 3.

Figure 3. a) Observatorio Andaluz de Astronomía finished, b) Detail of the floor and pillar of the telescope, c) Observatorio Astronómico de Mongragüe finished.

The Observatorio Astronómico de Zuheros (OAZ) and the Observatorio Astronómico de Sierra Nevada (OSN), as with the Observatorio Astronómico de Monfragüe, required an environmental impact study and compliance with the legal legislation in vigour regarding Reserves and National parks. In the OSN, the actions were to improve the existing facilities, electricity, data and mechanics) and adapt it to health and safety regulations. In the OAZ, the project was a new one, and was carried out paying special attention to astronomical tourism. (Figure 4).

Kingsland Observatory is a complex of observatories which is being constructed and developed in the Ánimas mountain (OMA). This complex of observatories aims to be the second largest in continental Europe, after the Calar Alto Observatory (Almería). It will have five observatories with a total of six operative telescopes. Only one observatory has currently been built, whose design is totally new. It consists of a dome divided into two parts which can operate together or independently. The observatory has two robotic telescopes which can function manually or by remote control. The structure has been designed in steel and the outer walls with sandwich panels with polyurethane, which makes it very light and economic (Figure 4). All the systems work with renewable energy.

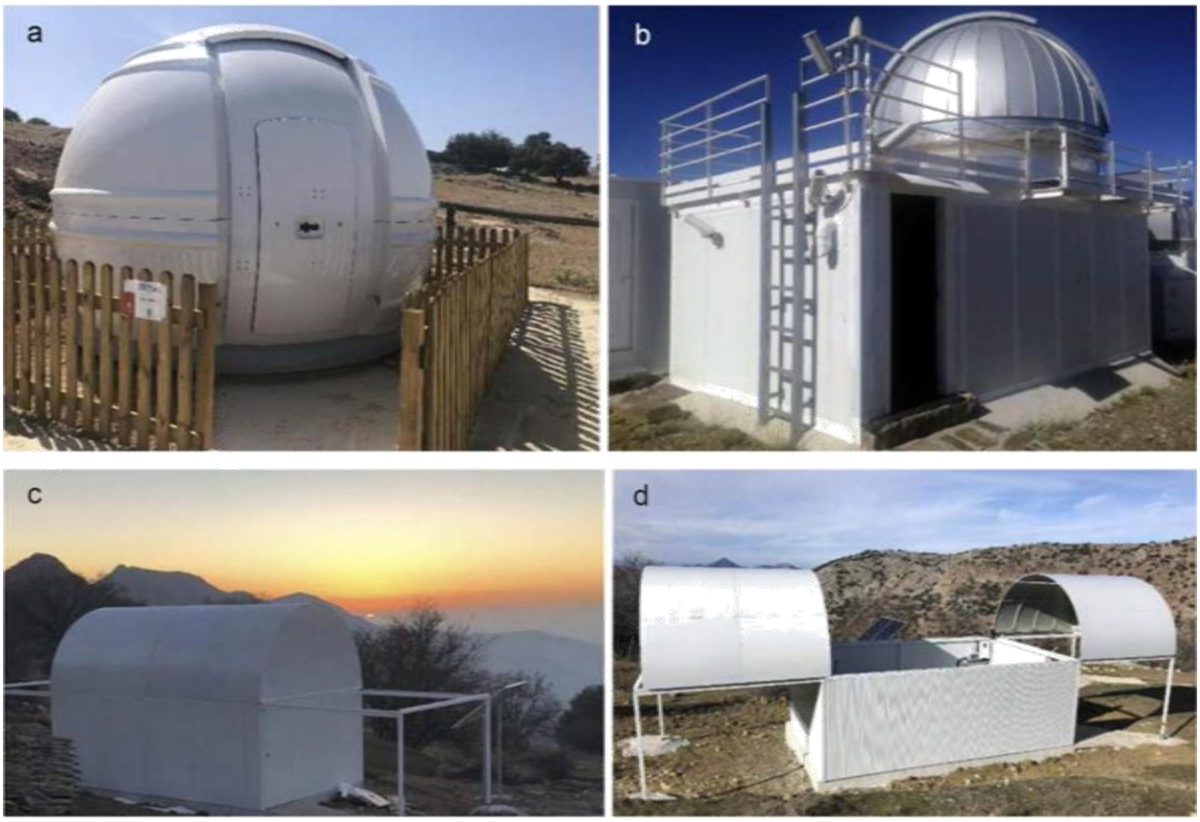

Figure 4. Detail of the OAZ, OSN and OMA. a) Observatorio Astronómico de Zuheros finished, b) Detail of the Observatory in Sierra Nevada, adapted for external work, c) Kingsland Observatory closed, d) Kingsland Observatory open (renewable energy).

V. Conclusions

The construction of a ProAm observatory is a multidisciplinary project. It must be developed between the research team who promote the project and the engineers/architects responsible for its construction and facilities. The coordination of the project by a project manager with training in astrophysics and engineering is very important

A plan and work manual must be established, with the technical and scientific objectives of the observatory project.

For the outer walls and structures for observatories, light materials of a sandwich panel type or something similar are recommended because of their technical quality, price, and easy installation. This building system provides stability to the telescopes and minimises possible vibrations.

It is recommended that the pillars for telescopes are constructed using reinforced concrete and insulated pads for the rest of the foundations, which will also preferably be of reinforced concrete.

It is necessary to embed and bury the facilities of the observatory. This will increase cleanliness, comfort and the safety of personnel.

VI. Acknowledgments

We would like to thank the company Espartero Building & Services S.L., for providing information and images of the works and projects which have been carried out in the observatories which have been included in this work.

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