New Designs and Procedures in the Construction of Robotic Astronomical Observatories

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Abstract

In this work, new models of robotic astronomical observatories are presented. These have been specifically designed for scientific research, using new working methods and a robust and reliable control system. These new observatories have been built with light materials and on a small scale, which has allowed costs to be reduced, building times to be cut and has enabled them to be located, quite easily, anywhere. In order to obtain up-to-date information, ten professional and amateur (ProAm) astronomical observatories were exhaustively analyzed between 2010 and 2015. Different placement and engineering errors were detected in these observatories. The analysis of this data has allowed very important information to be obtained on the development of the new ProAm robotic observatories. The conclusions drawn from this study have allowed the development of methodological improvements using new materials and facilities. New designs of astronomical observatories are also included. In this work, the applications of these improvements are shown in three new ProAm observatories which are currently in operation, and in which research projects are being developed.

Keywords *Astronomical Observatory, ProAm, Robotic Observatory.*

I. INTRODUCTION

Astronomical observatories have had transcendental importance for mankind throughout our history [34]. They were used as temples and sacred sites in ancient societies [3], while also serving as centres for meetings and political matters. As society has evolved over time, so have observatories [7].

Since the middle ages, and mainly since Galileo Galilei first used the telescope to observe celestial objects, astronomers have sought buildings designed for astronomical observation, where precise measuring instruments and, since the 17th century, even telescopes could be housed [22]. Telescopes have evolved in size, precision and complexity over time, in such a way that it has become increasingly necessary to have suitable sites for their proper use and safety [15].

The industrial revolution of the 18th century brought about major advances which were applied to astronomy [1]. However, 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.

In the 19th century, studies began on the ideal placement of observatories to minimise, as much as possible, the elements which could harm the proper operation of telescopes [1]. Meteorological conditions and accessibility are also very important factors which are being increasingly considered [17]. This is the reason why, before deciding on the placement of an observatory, it is essential to carry out a site-testing campaign to ensure the ideal place for an astronomical observatory. (https://www.iac.es/es/observatorios-de-canarias/calidad-del-cielo/parametros-de-calidad-del-cielo_). Technical advances and improvements in construction are of particular interest in the building of observatories, which are starting to stand out as very technically advanced engineering works. They are designed for each instrument and each observation location.

Currently, there are astronomical observatories in space, gigantic observatories on land and even autonomous robotic observatories [4, 5] which can work independently or together as a network [6].

Astronomical observatories are made up of a complex of facilities which provide support to astronomical research in different ranges of the electromagnetic spectrum [26], 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 which make up astronomical observatories have been a set of facilities which allow a telescope and its accessories to be used efficiently [10].

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 in the best place so that the investment made, and the performance of the observatory is optimal [9, 35], considering the spectral range in which they plan to work. In this research, and for the professional-amateur (ProAm) observatories, the visible spectrum region has mainly been considered (3.800 Å a 7.800 Å), and the near-infrared region has been considered sporadically.

II. ANALYSIS

After a thorough bibliographical review on the astronomical observatories which existed before the 20th century [1, 7, 34], and current astronomical observatories [2, 21, 23, 27, 29], detecting the main problems presented by ProAm observatories at this time was set as our objective, as well as simultaneously dating relevant improvements and advances in these observatories [10, 14, 19, 25, 32, 33]. In order to achieve this, ten astronomical observatories in continental Europe were visited and examined between 2010 and 2015. The procedure was based on visual observation of the facilities, followed by several interviews and consultations with the experts and scientists in charge of these observatories. As each observatory is different and practically unique (given their specific configurations for specific scientific objectives), the visits and interviews were standardized, considering specific technical issues. Therefore, information and data which provide clear, specific results could be obtained. This is how an objective vision of all of the facilities was obtained, with all their problems and benefits. This detailed analysis has allowed the identification of deficiencies which affect the proper operation of observatories, and deficiencies whose causes have a different origin (placement mistakes, incorrect maintenance and construction problems). Different relevant technical details, which provide significant improvements, have also been seen.

All the observatories studied can be classified as ProAm observatories because of their size and dimensions. The maximum diameter of the telescopes which these facilities house never exceeds 0.9m.

A. First phase

The astronomical observatories studied are prestigious facilities and continue to be operative. In order to maintain their anonymity, they have been named with letters from the Greek alphabet. This research work is based on detecting problems, studying their causes and establishing solutions for improvement, based on study and analysis, using the highest level of ethical and scientific rigour. The study and analysis of these observatories have been focused on three basic factors which are fundamental for their proper operation:

Environmental factors

Some deficiencies have been detected which have been improved on thanks to the data provided by the meteorological stations and the sky quality detectors at the observatories. A slight increase in the relative humidity index (annual average) has been seen in two cases, and 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.

Location

Good judgement has generally been used. There have only been three cases in which the visibility of the ecliptic and difficult access to the observatory has been ignored.

Construction and facilities

The majority of the problems detected come from the construction and facilities of the buildings. Even though these constructions were built following the architectural and engineering guidelines which are typical for a unique building, the special location and the climatology of the area have caused unexpected adverse effects. Table 1 shows a summary of the main problems and deficiencies detected.

In four cases, the foundations were laid without considering the optical equipment to be installed (the formation of the telescope pillar and its internal structure was not considered). In six observatories, the exterior walls of the building which house the telescope do not meet ventilation needs (to minimize the thermal temperature exchange between the detection equipment and the exterior). Insulation and waterproofing (very important for avoiding humidity problems) needs are also not met. Only three observatories have good insulation and a system of aerators which enable ventilation and reduce the interior/exterior thermal exchange.

There are problems with the domes in two observatories and, at some point, all of the domes have had different types of defects due to the low resistance of the materials used, such as polyester, fibreglass and aluminium. In seven observatories, the basic domes (Polyester/Aluminum) have been substituted for new models manufactured in steel and with a more robust and efficient control system. The lateral opening systems have also been changed for overlapping gates, in order to increase visibility at the zenith.

B. Second phase

After this stage, the experts in charge of the observatories studied were interviewed. They were asked questions such as, what defects can be seen in your facilities? What would you have incorporated into the observatory? What could be improved? The majority agree that it is essential to have advance knowledge of the objective and main use of the observatory (it is common to combine education and outreach with scientific objectives).

Table 1 Main problems detected in the ten observatories analysed (blue, environmental factors, green, location and logistics, in beige, construction and facilities).

ISSUES	OBSERVATORIES ANALYSED									
	alfa	**beta**	**gamma**	**delta**	**épsilon**	**dseta**	**eta**	**theta**	**iota**	**kappa**
Annual precipitation				x					x	
Relative humidity				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	
Exterior 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	
Roof		x					x			
Facilities	x	x		x	x		x		x	x

This advance knowledge is highly valued. This knowledge helps to establish prior procedures which guarantee the suitability of the area where the observatory is to be located and its later construction.

III. METHODS

By analysing the questionnaires used in our consultations, a clear and decisive conclusion can be reached to establish a new procedure to be followed in the development of an astronomical observatory. A sequence of organised actions can minimise errors and optimise the resources needed to construct an observatory. The vertical and horizontal distribution of the actions allows feed-back on the project using precise information and improves the execution of the works and the facilities.

The diagram in Figure 1 sets out our procedure for developing the Astronomical Observatory project. The sequence starts from the main idea of Astronomical Observatory (upper box) that will have to follow three procedures (Engineering project, Site-Testing and

Research project) that determine the best location of the observatory (Location), which is (Building & Facilities) with the necessary requirements for the proper functioning of your equipment (Instrumentation & Detector).

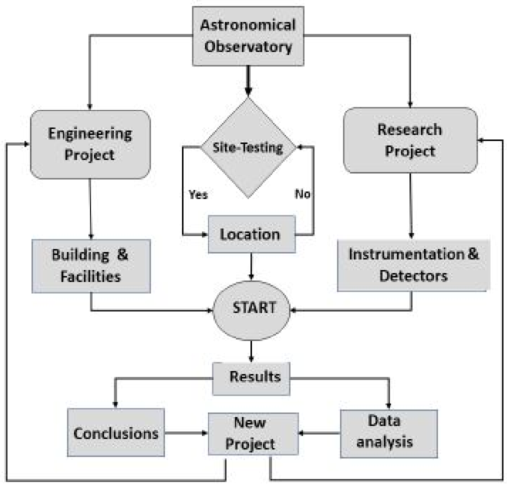
These coordinated actions will allow the start of operations (Start) at the observatory and the obtaining of its first work (Results). The information obtained (Data analysis + Conclusions), will allow to draw new conclusions (New projects) and generate a feed-back will allow promoting technical improvements (Engineering project) and new research work (Research Project).

Firstly, a wide site-testing study will have to be carried out, which will determine the use of the observatory. This last premise will determine the construction of the observatory and the facilities needed.

A. Site-Testing

According to the guidelines of the technical office of sky protection at the Instituto de Astrofísica de Canarias, the following elements must be considered as the main parameters 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 [26, 31]. From these results, depending on the spectral range in which the instrumentation works, it is possible to ascertain the suitability of the characteristics of the location [5, 28]. It is necessary to add the possibility of radio- electrical pollution to these factors, as well as the flight paths present at the location, and the unpredictable changing conditions caused by climate change [20], which seriously affect the previously mentioned meteorological and atmospheric parameters [18, 30].

Figure 1 Basic scheme to build an astronomical observatory: Engineering, research and location for the placement.



B. Location

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

The correct placement must allow the necessary logistics and accessibility to be made available to carry out the works and facilities of the observatory. It is 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 the exterior conditions (artificial light, proximity to roads and highways, vehicle access, etc.). Altitude is a defining factor, in the case that infrared is to 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 https://www.gistandards.eu/gis-standards/

C. Construction

Proper foundations are especially important, depending on the type of land of the observatory and the building of which it is a part. Therefore, a geotechnical study of the land must be carried out, which will determine the type of foundations and the proper technical calculation [15]. The presence of fibreglass sheet (Pefoplast) in the foundations and the incorporation of waterproofing compounds, as the MasterCast 644 (BASF), into the concrete will allow for proper insulation against humidity and condensation. They will also stop leakage caused by capillary action.

The base of the foundations and the formation of the pillars, which must support the telescopes must be carefully designed [36]. Proper insulation, using expanded polystyrene or polyurethane sheets, will stop interference with the optics and detectors of the telescopes [8]. This will be essential for proper operation at a later date.

The necessary, specific exterior walls can be made of light materials such as resin 40 mm thick sandwich panels (polyurethane and polyisocyanurate insulation) and double outer sheet of lacquered steel. These materials have a light, resistant design which makes them easy to assembly and provides good insulation. The presence of aerators (ventilation) which minimize the thermal exchange between the interior and the exterior (very damaging for the optic) matter and will also have to be incorporated so as to enable air circulation in the interior.

The new covers with 0.8 mm thick lacquered steel sheet and DC01 quality represent a significant improvement over the traditional dome. The operation of classic domes is limited to only one telescope, and the field of view is limited to a very restricted area. These restrictions have always meant that only one telescope has been installed in each observatory, and its movements have been restricted, only made possible by the movement of the dome itself (rotation and opening of the observation gate). With the new roof designs, such as vaults, roll-off roofs and even retractable sloping roofs, it is possible for an observatory to operate with more than one telescope and even with other additional devices simultaneously. The field of observation can also be widened greatly. It is now possible to work simultaneously with spectrographs, video cameras, imaging systems and more than one telescope with their own guiding and data capture systems.

With these new technical and design-based applications, the cost of the project is reduced, and a modern, smooth, versatile and multifunctional observatory can be designed, in line with the needs of the scientific project to be carried out.

IV.RESULTS

Three new observatory models are presented, in which major improvements have been implemented as a consequence of the study of the ten observatories analyzed. The conclusions obtained have allowed new techniques and materials to be applied in the construction of ProAm´s. In each of these observatories, the resulting improvements have been based on the location and the scientific objectives of each site.

A. Domo Observatory

The Domo observatory was built on Monte de las Ánimas (1.492 mamsl) in Valdepeñas de Jaén (Spain) in February 2019. The observatory has two telescopes and operates manually or by remote control. The structure has been built with a profile of laminated steel with a cross-section of 40x20mm and sandwich panel walls with polyurethane insulation of 40mm.

The roof was expressly designed as a roll-off vault comprised of two matching semi-vaults so that it can operate with one semi-vault (for one telescope) or with both semi-vaults (for two telescopes). With this type of cover, more than one telescope can be housed in the same observatory, and space and facilities can be made the most of (figure 2).

The cover is made of laminated 0.8mm steel plating, lacquered white on the outside and black gloss on the inside (to minimise the effects of reflection and stray light). All the systems run on renewable energy. The new methods and procedures explained in chapter 3 of this work have been considered in the construction, design and project phases [13]. This observatory is already in service and is being operated remotely by Space Explored Ltd., headquartered in Ireland

http://www.spaceexplorationltd.com/home.html

Figure 2. Detail of the vault in Kinsland Observatory closed (above) and opened (below).

B. ProAm Observatory

There are different astronomical research projects which require the use of various observatories with at different locations around the world. The BOOTES [4] and GLORIA [6], projects and the new systems for the detection of space debris require several observatories to carry out their work. This new demand is also reflected in the increasing number of amateur astronomers who participate and collaborate with professional astronomists by contributing their research work. These astronomers need to protect and provide security for their equipment and telescopes with robust, economical observatories.

The ProAm observatory has an ergonomic design which is both simple and efficient. It is based on the movement of a roll-off roof which works with a guided sliding system. The materials used in its construction are similar to those used in the construction of the Domo observatory (sandwich panel, 0.8 mm steel sheet and 40 x 40 mm steel internal structure). The result has been a product which can be easily installed and mounted anywhere. (Figure 3). The ProAm2 model, with a floor area of 2 x 2 m, can only house one telescope, but the ProAm3 (3 x 3m floor area) has space to house two telescopes and other devices which can be operated simultaneously [11]. These observatories have also been designed to work remotely (robotically) through control software and devices. Currently, these observatories are being marketed by the company Espartero Building & Services SL https://www.esparterocs.com/proam.

Figure 3. Detail of ProAm Observatory open (above) and Hardware Talon6 for ProAm Observatory (below).

C. *Automatic Enclosure System*

In its first phase, this observatory was developed as a prototype for the spectrograph of meteorites and is currently operating at the Andalusian Astronomy Observatory. It was built using a galvanized steel box, with a gable roof which allows automatic movement, allowing images of the whole sky to be taken using different capture devices [12].

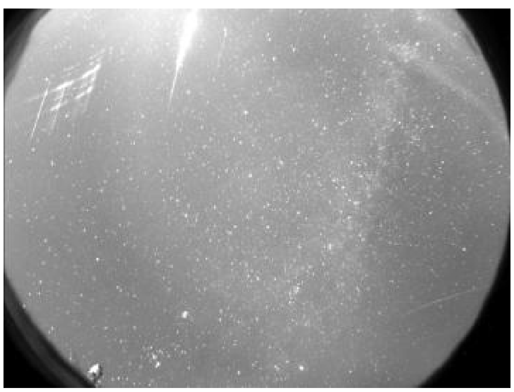
This observatory has recently incorporated Talon6 software to improve its robotic operation [13] as well as including new improvements at the meteorological station which help to control the detection devices, new materials such as extruded polypropylene (to help proper insulation) have been incorporated. More reliable and robust mechanisms have been installed, which open and close the observatory roof (chain and cog system) more quickly and safely. The field of view of the detectors (170º) has been improved and widened in this model. The roof opens in such a way that it almost reaches the same field of view as an all-sky camera. This is a very interesting new milestone as there are no astronomical observatories on land which have obtained such a wide opening range. (Figure 4).

Figure 4. Detail of Automatic Enclosure System (above) and open (below).

The applications of the Automatic Enclosure system are very wide, as its large opening (the whole sky) and speed (Talon6 can be configured to open completely in 4 seconds) make it the ideal observatory for numerous research projects in which it is necessary to rapidly direct the telescope at specific objects. This type of observatory is the best candidate for research projects such as the early detection of GRBs, supernovas and the lesser objects of our solar system. It can hold two or three optical detectors (video cameras, photographic cameras and spectrographs).

The results obtained in the field of meteorite spectrometry support the reliability of this observatory. More than 50 captures of fireballs and meteorites were taken with two spectrographs installed inside, obtaining images of meteorites and their spectra. (Figure 5). These images were analysed, and it was possible to identify the physical-chemical composition of the meteorites [12].

Figure 5. Images of the M20151106_231637 (above) M20151118_220605 (below) meteorites with their spectral lines, taken by the spectroscopes of the Automatic Enclosure System.



V. CONCLUSIONS

A standard system for the design and construction of ProAm astronomical observatories has been established. Site testing, suitable placement, technical construction considerations and the use of new materials adapted to the new projects and their needs are all essential tools to achieve a quality astronomical observatory. Three models of robotic astronomical observatories have been presented. They are all based on very similar construction materials, with designs adapted to new projects and a new robotic control system which has been tested and proved to be reliable and versatile. The new designs of roll-off roofs with vaults and retractable gable systems provide a very wide field of view, with significantly optimize these facilities. The results show that it was possible to construct new observatories which have better materials and can be specifically adapted for any research project. The models presented in this work not only show notable improvements in methods and materials but also present a new concept of more versatile, economical and efficient observatories. The three observatories are currently operative and Performing the functions which they were designed for at 100%.

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