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AFFIDAVIT

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This master thesis addresses the architecture of observatories, a typology characterized by hemispherical domes, observation platforms and the urge to get closer to the sky. Observatories are special; they offer the possibility of getting a glimpse of the stars and the universe and while observing, you may get the impression of entering a whole new world. A world with intriguing questions which may remain unanswered, like “Is there life somewhere else than on earth?” To find the answers, observatories are needed to offer astronomers a place to work, to conduct research and to ask questions.

This thesis focuses on the general theory about observatories, the typology of the building, the environmental conditions in which they are located, and the work done at observatories. Furthermore, the project P2036 Observatory, located in the High Atlas in Morocco, is part of the thesis and puts the theory into practice. Morocco is a country rich of culture, color and untouched nature. The latter is one of the reasons, why the High Atlas offers clear nights and a very low light pollution, which are ideal conditions for an observatory. The project P2036 Observatory, situated near Tizi n’Test, at 2500m altitude, is a combination of a university and research observatory, which should offer access to the stars for the Moroccan people. The project faces the typical problems of remote located areas and considers the high technical needs of a telescope for long-term observations, its separate foundation and the problem of a hotel/residence and working place near the telescope.

CONTENT

THEORY

CASE STUDIES

PROJECT

SOURCES

ANNEX

THEORY

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ss the heavens, composed of appr

most of which are too distant to be seen indi-

er Space: space beyond the atmosphere of the

nomer: an expert in astronomy; a scientific ob

e celestial bodies. Observatory: a place or bui

ped and used for making observations of astro

neteorological, or other natural phenomena, e

place equipped with a powerful telescope for

he planets and stars. Star: any of the large, se

heavenly bodies, as the sun, Polaris, etc. Ear

hird in order from the sun. Astrophysics: the

onomy that deals with the physical properties

bodies and with the interaction between ma

on in the interior of celestial bodies and in in

e. Telescope: an optical instrument for makin

ects appear larger and therefore nearer. Astron

ience that deals with the material universe be

th's atmosphere. Moon: the earth's natural sat

the earth. Observe: to see, watch, perceive,

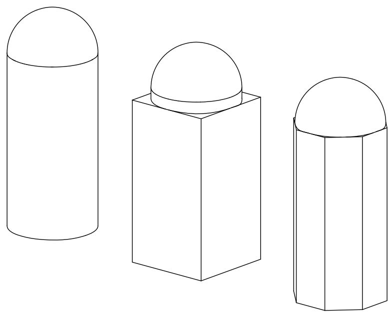
entific, official, or other speci

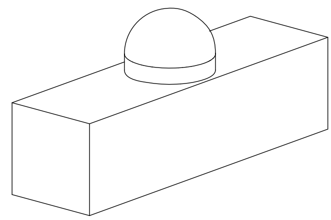
containing our

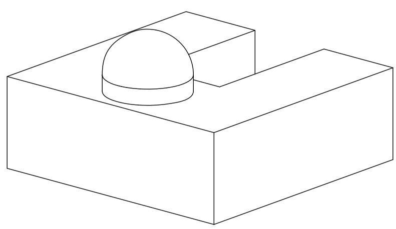
TERMINOLOGY

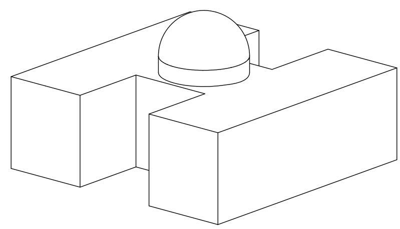
There are many different kinds of scientific observatories. Although they all share the name “observatory” and they are all meant for observing their aims vary depending on the scientific research done in/from this location. Most observatories include a building, but there are also some who are just a special site, place or structure which provides a good view. The range of research reaches from terrestrial to celestial events. Disciplines are for example: Astronomy, meteorology, geology, volcano-logy, oceanography, etc. An observatory can also be the institution that carries out the research and works on data gathered elsewhere.

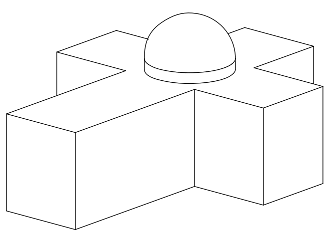
The word observatory originates from the Latin word “observo” (to observe). In German, there are two words with nearly the same meaning: “Observatorium” and “Sternwarte”. “Observatorium” is the translation for observatory and has the same wide range of possible disciplines that use it like in English. The word “Sternwarte” though includes the word “star”, which refers directly to the sky and to astronomy. It is only used for astronomical observatories and furthermore, it implies the use of the observatory for observational astronomy of the night sky.

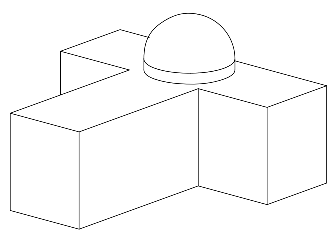


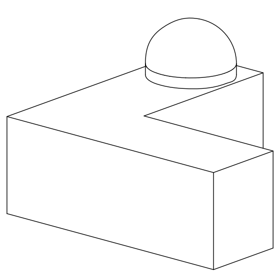


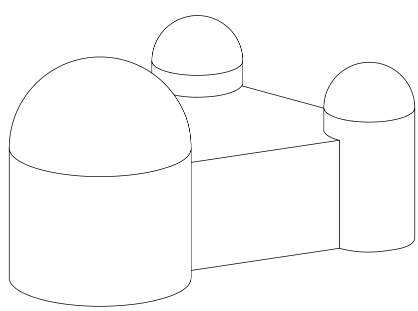












TYPOLOGY

There are many different types of astronomical observatories. To get an overview, it is necessary to differentiate between the fields of observation and their location. Furthermore, a closer look on ground-based observatories reveals more kinds of observatories defined by their architecture. While the typical dome seems to be playing a dominant role since its invention, the layout of the floor plan changed several times within history until the tendency to house the telescope separately from the working and living areas led to a so called “group form”. Finally, also the purpose of the observatory defines a kind of typology. Not only the size, but also the building form may be adapted according to the owner and his/her interests on how to use the observatory.

002 Typology by building geometry

TYPOLOGY I – FIELD OF OBSERVATION

Astronomy is traditionally divided into several subfields: Optical astronomy, infrared astronomy, radio astronomy, high-energy astronomy (gamma-ray, X-ray, extreme UV) and subfields outside the electromagnetic spectrum (neutrinos, gravitational waves, cosmic rays). Thus, ground-based observatories are classified by the wavelength range for electromagnetic radiation or by the particle they observe:

Night telescopes

The most famous type of telescope is the optical telescope in order to observe the night sky. These telescopes are used to observe stars, planets, moons, the Milky Way, galaxies etc. This type is well known for its typical domes, but also other enclosure forms are used nowadays, especially for big telescopes. Due to the sensitivity of the telescope to environmental influences, professional observatories separate housing and working areas from the telescope and its enclosure; therefore, the form of the building has changed. This is the type of observation this thesis mainly focuses on and is planned to be used for the project part of the thesis.

Example: W.M. Keck Observatory, Hawaii

Solar telescopes

In general, solar telescopes are quite similar to night telescopes but there are also some distinct differences. The main one is that observatories for solar observation require telescopes and instruments, which are able to dissipate the heat caused by the solar radiation. Therefore, special devices are required to achieve a better dissipation of the light and heat because otherwise, the image quality would degrade or the heat may even cause damage to the optical systems. Furthermore, also the building form is influenced by the heat. The tower form is typical for solar telescopes, as it offers the advantage of distance between the heated up surface around the observatory and the telescope and thereby helps to avoid a degradation of the image quality caused by turbulent layers near the ground.[1] Furthermore, laboratories can be installed directly underneath the telescope.

Example: Einstein Tower, Germany

[1] Cf. Instituto de Astrofisica de Canarias 2011, 33.

Infrared telescopes

Research about infrared light is often carried out by using the same telescopes like optical observatories and often only a detector sensitive to infrared wavelengths is added to the telescope. The best places for infrared observatories are dry locations in high altitudes, which correlate with other optical observatories.[2]

Example: Paranal Observatory, Chile

Radio telescopes

In terms of construction and design, radio telescopes are quite different to optical telescopes. The most obvious difference is that for radio telescopes no enclosure is needed. Furthermore, radio telescopes are able to peer through the clouds. Hence, they can be also located in lower regions between the mountains or in valleys. And actually, mountains are perfect to shield the telescopes from electromagnetic interference, caused by humans (e.g. radio or TV). The large parabolic antennas catching radio waves are often connected with each other through radio interferometry to improve the image quality. This is why they are often arranged in arrays. Moreover, big telescopes very far from each other can be connected nowadays.[3]

Examples: ALMA Observatory, Chile and FAST, China

Gamma-ray telescopes

Gamma-ray telescopes look similar to radio telescopes. This kind of telescope is often located at places, where there are optical telescopes. They are used at night time, when the moon is below the horizon, to observe the Cherenkov radiation given off by secondary particles. These secondary particles are generated when the gamma ray hits the atmosphere of the earth. Other detectors to find gamma observe gamma-rays and use water tanks to measure the interaction of secondary particles with the water.

Example: H.E.S.S. Telescopes, Namibia / Pierre Auger Observatory, Argentina

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[2] Cf. Infrared Processing and Analysis Center, Feb. 2016.
[3] Cf. Nyquist 2013, 17.

003 Ice Cube, Antarctica

004 ALMA, Chile

Neutrino telescopes

Neutrinos are elementary particles that are extremely numerous but have a really small mass. As they do not participate in the strong interaction and are electrically neutral, they mostly pass through normal matter undetected. Neutrino observatories usually use huge tanks filled with ultra-pure water to detect neutrinos. However, any naturally occurring large body of water can also be used as the medium. Hence there are some recent observatories at the bottom of the Mediterranean Sea or within the thick ice sheet of Antarctica.

Example: Ice Cube, Antarctica

Gravitational wave observatories

Gravitational wave observatories are extremely sensitive to any kind of vibration. Therefore, they are located in lonely areas, where no traffic affects the measurements.

Example: LIGO, USA

Finally, it has to be mentioned that even though the detection techniques of ground based observatories differ the main site requirements are quite similar. For this reason, and also for economic reasons, sites are often shared and a mixture of observation types may be seen very close to each other. Moreover, other institutions and researchers from similar fields of studies may even use the same building. In Graz, for example, the observatory also houses a satellite station, which is Austria’s fundamental station for cosmic and satellite geodesy.

TYPOLOGY II - LOCATION

There are 4 possible locations to place the observatory:

Space-based observatories / Satellite observatories

The important advantage of space based observatories is that in outer space the absorbing and distorting atmosphere of the earth doesn't influence the observation results. From outer space it is possible to observe objects in wavelengths of the electromagnetic spectrum that cannot penetrate the atmosphere of the earth like X-rays or ultraviolet radiation. Other observations are also possible at ground-based observatories, but as the atmosphere of the earth is partially opaque to them (e.g. infrared radiation) research is preferably done by the use of space-based telescopes. Also distorting and absorbing effects of the atmosphere, atmospheric turbulence and many other effects of the direct environment of ground-based observatory (e.g. light-pollution) are avoided and the telescope itself can be smaller. Therefore, it is possible to achieve a different perspective of the universe and also observe the planet earth more closely.[4]

Examples: Hubble Space Telescope

Airborne observatories

Airborne observatories in airplanes and balloons are using the benefit that height minimizes the effects of the atmosphere. As they are located above the part of the atmosphere containing water vapor, which absorbs infrared radiation, this type of observatory is interesting for observations concerning the infrared wavelengths. Furthermore, in stratospheric balloon experiments also UV and X-ray telescopes are flown. Airplanes are especially useful for the observation of fleeting events when the telescope needs to be on the right spot at a predetermined time to make certain observations possible. The targets of opportunity can be planetary occultation, eclipses, comets and supernovas.[5]

Example: SOFIA

[4] Cf. Nyquist 2013, 2-10.
[5] Cf. Nyquist 2013, 17.

Ground-based observatories

As the atmosphere of the earth is transparent to visible light, radio wavelengths and partially to infrared radiation, ground-based observatories can be used for optical, infrared, radio astronomy. Moreover, gamma rays, cosmic rays and gravitational waves can be observed. Compared to space-based observatories, ground-based observatories need larger apertures and collecting areas to achieve a high quality image.[6] Additionally, they need to be located very carefully due to the fact, that environmental conditions influence the observations enormously. Today, most newly built ground-based observatories are located at high mountain peaks, far from any civilization.

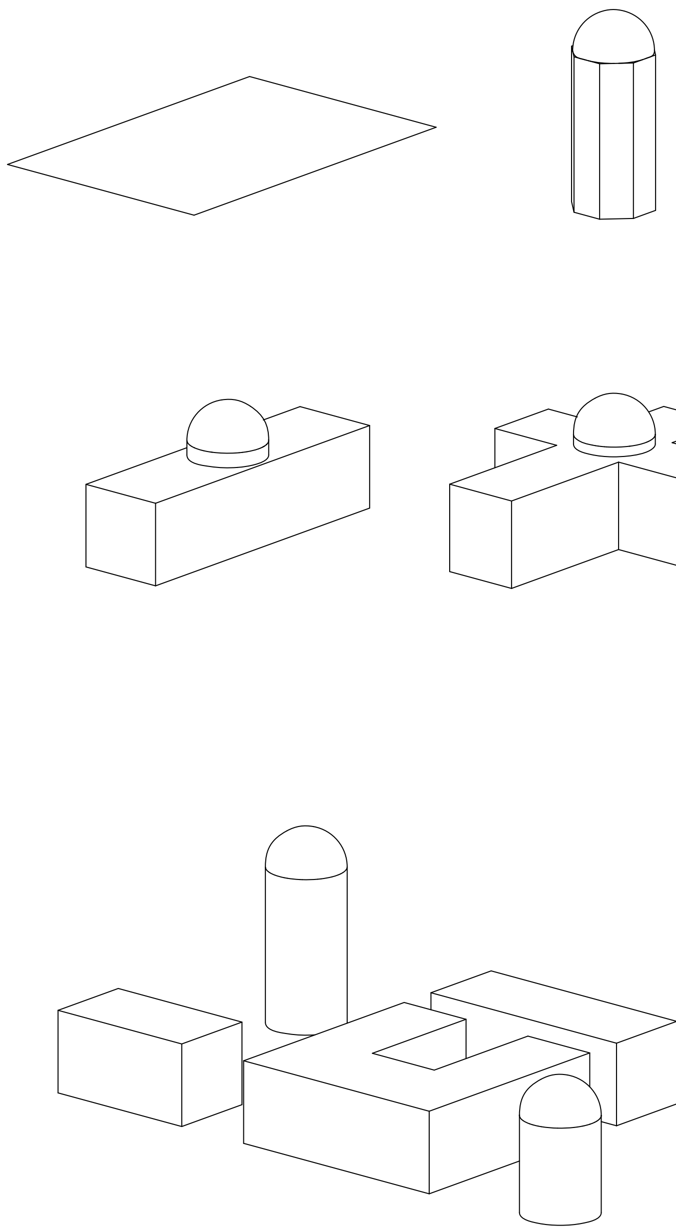
Example: Mauna Kea Observatory

Underground-based observatories

Although already in the 15th century in Samarkand a huge sextant was built to two thirds underground to observe the meridian, underground-based observatories didn´t play a big role in astronomy for a long time by reason of a lack of view with the telescope. But modern astrophysics asks for a low radioactive background environment for particle detectors to conduct research on gravitational waves, neutrinos, neutrons and cosmic-rays and in the 1960, the first deep underground observatories in huge tunnel systems evolved.[7]

Example: India-Based Neutrino Observatory

6 Cf. Nyquist 2013, 17.
7 Cf. Bettini 2014.



005 Platform, tower-form, rectiliniar-form, cross-form and group form

TYPOLOGY III – BUILDING GEOMETRY

Corresponding to the time they were built, the instruments and the environmental conditions of the location, observatories were and are built in different forms.

According to Peter Müller there are 5 main categories[8]:

Platform

Tower-form

Rectilinear-form

Cross-form

Group-form

Additionally, there are special shapes like U-forms, H-forms, T-forms, L-forms or triangle-forms, which are variations of the five main categories. Also, combinations outside these different types are possible. Group-form observatories, for example, consist of single observatory buildings combined with each other. Moreover, platforms can be found as a part of observatory buildings, but most of the time they are not a main part of the building shape anymore.[9]

All these forms existed predominantly at a certain period of time in the history of observatories: Platforms were the first observation spots used already by ancient cultures: During the baroque era it was the tower-form, in classicism the rectilinear-form, in historicism the cross-form and in modern times the group-form.

Nowadays, nearly all mountain observatories are built in the predominant group form. Separate buildings for residence, office and work, telescopes and other instruments cumulate at the top of a mountain peak, in certain distance to each other, so they don´t influence the instruments.

Examples for each form:

Platform: Paris (on top of the building)

Tower-form: Copenhagen Rundetaarn

Rectilinear-form: Greenwich Meridian Building

Cross-form: Copenhagen University Observatory, Potsdam

Group-form: Pic du Midi

U-form: Munich Bogenhausen

H-form: Cape Town

L-form: Zurich ETH Observatory

Triangle-form: Pittsburgh

T-form: Edinburgh

[8] Cf. Müller 1975, 263.
[9] Cf. Müller 1975, 263.

TYPOLOGY IV – USAGE AND USER

Astronomical observatories can be classified by the user/usage into four major categories - size, layout of the floor plan, location and instruments/ equipment. Thereof, the following types are distinguished:

Research observatories

Research observatories are mainly used by scientific personnel and professional astronomers. The main objective of such an observatory is to gather as much high quality data as possible. For this reason, these observatories need to fulfil all essential environmental and technical requirements. The ideal building form to achieve these requirements is the group-form, which is therefore also the most common form of modern observatories nowadays.

Educational observatories

The main focus of educational observatories is on the basic topics of astronomy and the possibility to learn something about astronomy. Therefore the location near the city and the accessibility is more important than a high quality image. Hence, tower-form and cross-form observatories are still very common among university and school observatories.[10] Nowadays, universities also tend to have a research observatory off campus, where the light pollution and seeing conditions are better than on the campus. In addition to that, they are closely connected to other research observatories worldwide.

Public observatories

The focus of public observatories is the accessibility of the observatory and the knowledge about astronomy to the public. The purpose and form of this type is therefore similar to educational observatories but their size is comparatively smaller. They are sometimes combined with planetariums, which can pave the way for understanding the universe before looking through the telescope on your own.

[10] Cf. Müller 1975, 273.

Private observatories

Many private observatories with highly professional telescopes can be found spread around the whole world. The form and size of these observatories depends on the owner, his / her purpose of observation and the money he / she is willing to invest. As the first observatories were all private - built by a king or very rich persons with a high interest in astronomy – private observatories have a long history and also nowadays amateur astronomers should not be underestimated because they often help to gain more information in the field of long-term observations. Some semi-professional observatories are often operated by astronomy clubs and similar organizations. Concerning the building form, often a platform, rectilinear forms or buildings with typical domes are used.

Kinds of founders of observatories[11]:

Private observatories, since 1471

(religious) Order observatories (Jesuit / Benedictine order), since 1579

University observatories, since 1633

Academy observatories, since 1667

Marine observatories, since 1675

School observatories, since 1748

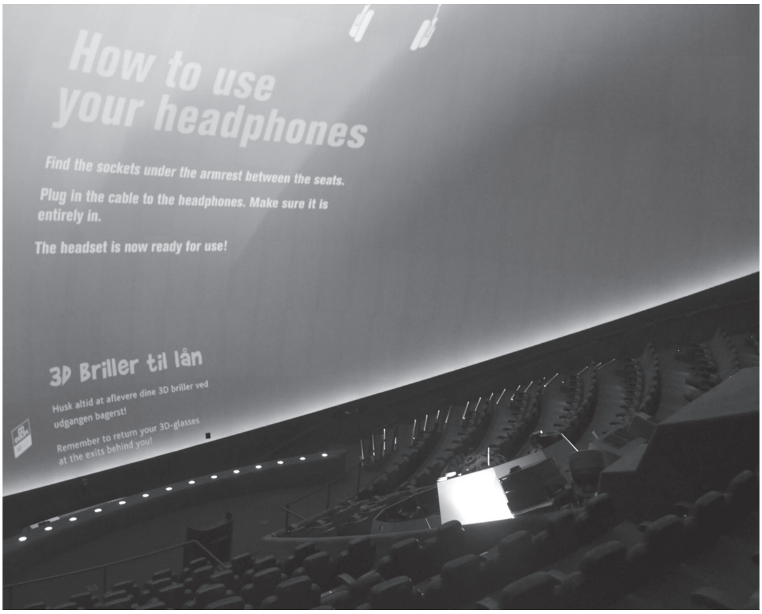
Newspaper observatories, since 1886

Public observatories, since 1888

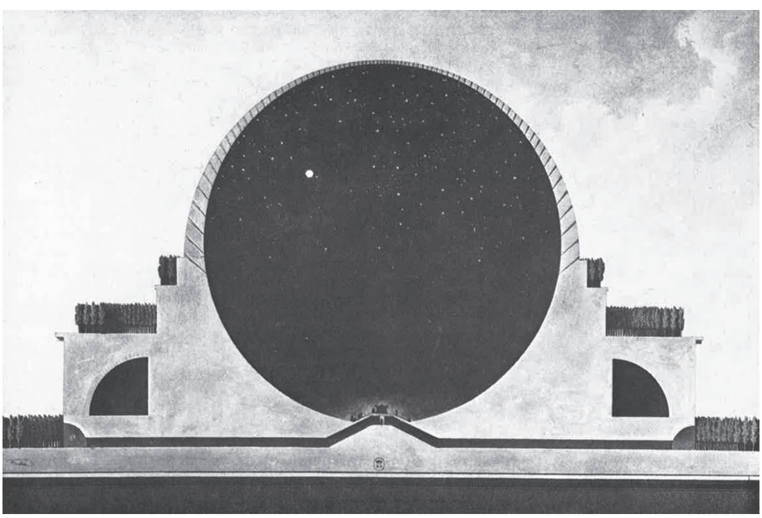
Factory observatories (e.g. Zeiss), since 1910

Museum observatories, since 1912

[11] Cf. Müller 1975, 270.



006 Tycho Brahe Planetarium Copenhagen



007 Section Cenotaph for Sir Isaac Newton

EXCURSUS PLANETARIUM

A planetarium can be defined as a special kind of theatre, showing videos about astronomy, planets, celestial bodies and the night sky. It should offer a realistic view over scenes of the sky from any point of the earth and at any time. “Star balls”, slide projectors, full dome projector systems and lasers can be used to project the sky onto dome-shaped screens. The room for the projection needs to be totally dark. Usually no openings except for the doors are facilitated. As the screen is often at the ceiling, the chairs need to be different to normal chairs offered in cinemas. Also, they need to be arranged around the projector. Another way of building a planetarium which can be seen for example at Tycho Brahe Planetarium in Copenhagen is to place the screen more like in a normal cinema in front of the auditory. This way, the seats are in an upright position and only part of the screen is still on the top of the ceiling.

In contradiction to an observatory, which has often a similar form from outside, it is a building for the public and it invites everybody to visit and experience the universe without scheduling an appointment. Most planetariums are used for educational videos, but may be also used for professional purpose, in particular because it allows the view to a cloudless sky at any time.[12]

One special kind of planetarium was the design of the French neoclassical architect Étienne-Louis Boullée. The cenotaph for Sir Isaac Newton should show the system of Newton; thus it can be also called “architecture parlante.” The 150m tall sphere gives an illusion of the night sky when the sun is shining through little holes into the interior of the sphere. Although the design is very famous, the building was never built.

EXCURSUS GARDEN OF STARS

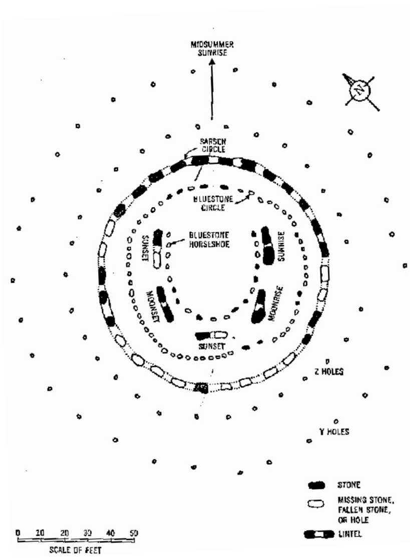
A garden of stars is a garden to watch the celestial bodies like in an open air planetarium. It offers certain sighting lines and instruments like sun dials, sun columns, step pyramids, etc. Most of the time it is a public garden, which may be visited during day- and nighttime

[12] Cf. Müller 1975, 250-252.

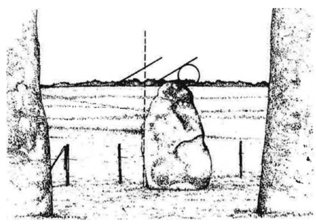
HISTORY OF OBSERVATORIES

For thousands of years mankind has tried to find clues about to the universe: Already early civilizations like the Mayas, Babylonians, Greeks, etc. tried to solve the mystery of the stars and their constellations in the sky. In the early development of astronomy religion and the determination of the time played a decisive role. As a consequence, this was also important for the very first observatories, which were mainly privately financed buildings. However, the study of the stars was not only useful to determinate the first calendars, but also to navigate at sea. From the 15th century on not only the understanding of the universe stars and planets, but also the determination of geographical positions was in focus of astronomers. The latitude could relatively easily be determined from the position of the sun or stars, but it was much harder to define east and west coordinates. Because there was no fixed point to start measuring from, early civilizations set up several 'zero points' to calculate the distance from (landmarks, cities, etc.). When more and more explorers started searching for new countries all over the world and sea trade with colonies increased, finding longitude became an international economic issue and many national observatories were established. Later on, the invention of larger telescopes and the increasing technical development changed not only the instruments, but also the requirements of the location and the building form. Today, the functions of an observatory are often split up into several independent buildings, which make the topic of observatories a very complex one.

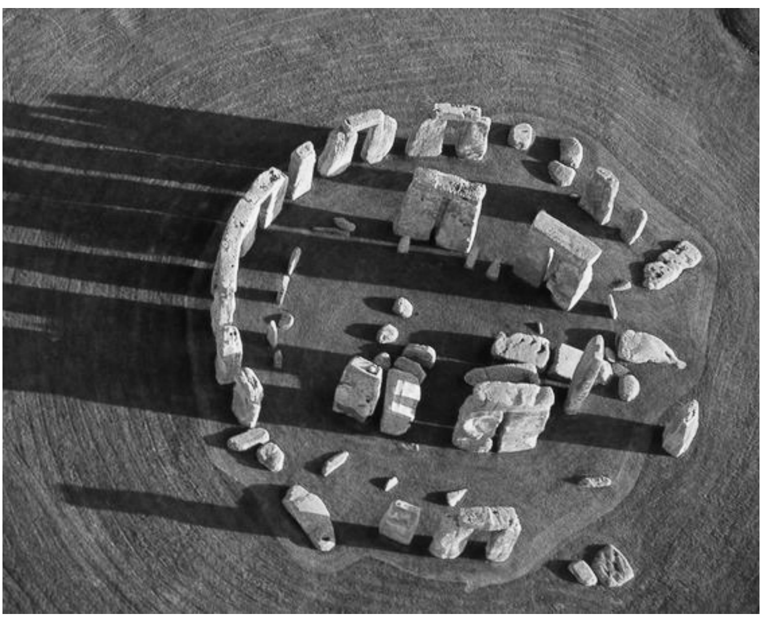
008 The sundial 'Samrat Yantra' is the most famous part of the observatory in Jaipur



009 Stonehenge plan



010 Reconstruction of the sunrise 3500 years ago (left line). Right line: nowadays



011 Stonehenge aerial view

CALENDAR BUILDINGS

Although astronomy is one of the oldest sciences within the natural sciences, it took a long time until buildings for the professional observation of the sky were built. The very first observations were conducted outside, under the open sky. The first astronomers observed the horizon with their eyes or with the help of sighting lines determined by stone settings or architectonic elements of buildings like windows, frames, walls, or even buildings. Typical observation spots were in higher lying parts of the landscape, like at the top of a mountain, at a hill, or also in and from buildings. These buildings were mainly early monuments, which were often religious buildings (temples, tombs, etc.) of highly developed ancient cultures and therefore in many cases no distinct differentiation between astronomy, astrology and religion existed. Because constellations in the sky can be seen at regular intervals, astronomic research also led to the invention of the first calendars. For this reason, the first buildings used for observing the sky are often called ‘calendar buildings’. They had - according to their culture, geography and the period of time - different forms:

Platforms on top of pyramids

The pyramids in Egypt were amongst the first known calendar buildings. Because of their orientation exactly towards the 4 cardinal points, they can be used as solar clocks and also the equinoxes can be defined. Furthermore the northern side of pyramids can show the season, since the sun reaches this side.

In Mesopotamia, the high priests observed the sky from the highest platform of the step pyramids, the ziggurats. As the movement of the sun, the moon and other visible celestial bodies in many cases could not be defined; they were often venerated as gods. As a result of the unity of astronomy, astrology and religion, the zodiac was invented by the ancient Babylonians.[13]

Observation platforms at mountains

A very famous observation platform can be found at the top of the Monte Alban in Mexico. The temple J is dating back to approximately 250 BC. Furthermore, in Peru, the Inca Empire built “Intihuatana” (sun observatories) to worship the sun-god; and on a platform of a holy mountain in Machu Picchu, you can still see a sculpture built around 1450 AD, which was used as a sundial.[14]

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[13] Cf. Müller 1992, 227.
[14] Cf. Müller 1992, 228-229.

Demarcated areas in higher regions

One example of a demarcated area is Stonehenge, a prehistoric monument in Wiltshire, England. Built thousands of years before Christi in the Neolithic period, it is the oldest calendar building in Europe used for praying, observation and experiments. Within a diameter of 105m certain stones mark the sunrise and sunset of solstice. The observer had to stand exactly in the center of the ring of standing stones, where the altar has been, to catch the sighting lines of the monument used to observe the moon and stars.[15]

Another example of a demarcated area can be found in India, where the tradition of Indian astronomy was closely related to the local Hindu religion and other religions. Here, 5 observatories were built by the Maharajah of Jaipur, Jai Singh II., in the 18th century. They are famous for their architectural astronomical instruments arranged in a kind of garden. On demand of Jai Singh II., no refracting telescopes were used, even though they were already invented.[16] The most famous one is the Jantar Mantar in Jaipur located next to the palace of the Maharajah.

Fortifications walls and first towers

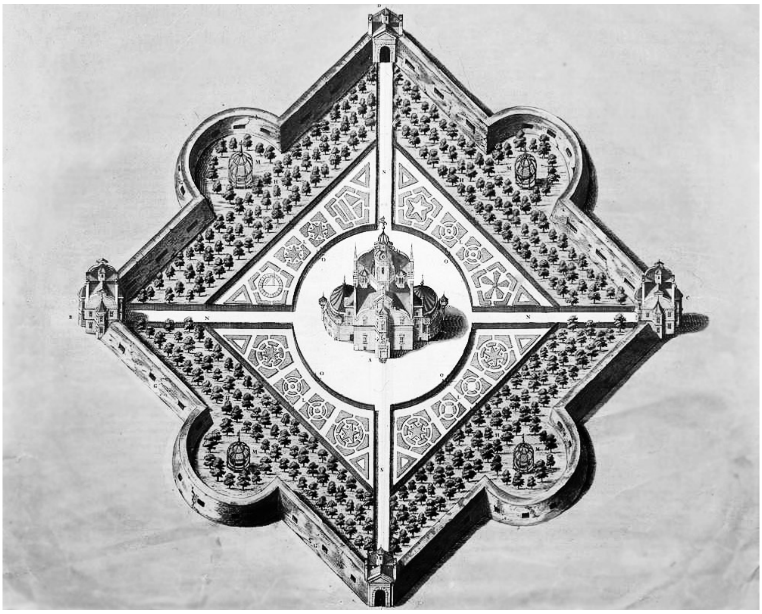
One of the oldest towers for astronomical observation is located in Asia. The ”Chomsong-dae” tower was built in South Korea only a few hundred years after Christ. Since many thousand years the tradition of observing the sky is part of the local culture in Korea and China and also in China observatories of similar age can be found. The first observatory of a Chinese Emperor was built approximately 1280 AD on the fortification wall of the Forbidden City in Beijing, which was later reorganized by the European Jesuit missionaries, who added a celestial sphere, a quadrant and an armillary sphere.[17]

It is assumed, that also in Greece towers/lighthouses were used for the first observations: The Pharos of Alexandria, built around 300 BC, and the “Specularium” in Capri, built approximately 30 AD. The ancient Greeks were the first ones to conduct serious scientific research concerning the earth and the sky.[18] Two of the main astronomers were Aristarchus of Samos, who already believed in the heliocentric system before Nicolaus Copernicus, and Eratosthenes of Cyrene, who was the first person to calculate the circumference of the Earth.

[15] Cf. Müller 1992, 227.
[16] Cf. Müller 1992, 230.
[17] Cf. Müller 1992, 229-230.
[18] Cf. Müller 1992, 228.

The Arabs passed on the knowledge about astronomy of the ancient Greeks and several provisional observatories were built in Bagdad, Cairo and Persia between 830 and 1260 AD. These calendar buildings that used to calculate the Islamic calendar were already equipped with instruments, but none has been preserved.[19]

[19] Cf. Müller 1992, 229.



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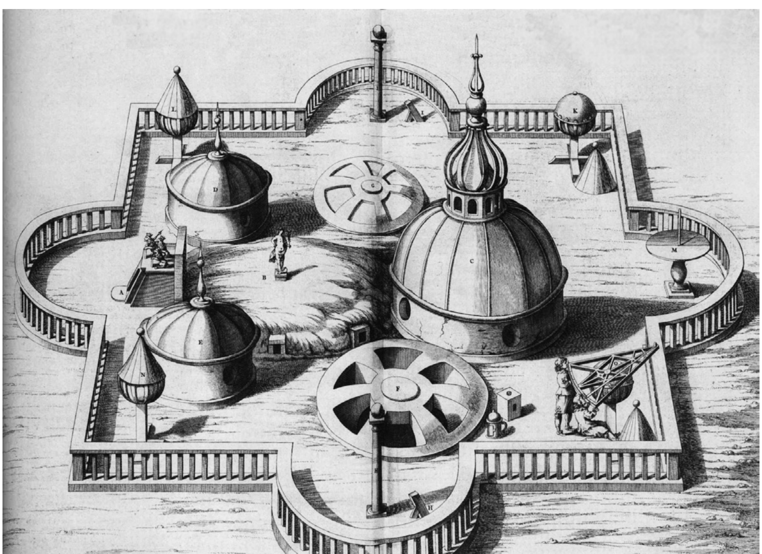

013 Stjerneborg

FIRST OBSERVATORY BUILDINGS

Concerning Europe, there are only assumptions about observatories before the early Renaissance. In the Middle Ages, the observations of the sky decreased, but astronomical knowledge from Antiquity was passed on by the Arabs.

Before 1500, in the early Renaissance, the first astronomers began to build observation places. The persons, who built an observatory, were mainly wealthy people or aristocrats, who were not only personally interested in the topic of astronomy, but also had the means to build one. Therefore, observatories were often dependent on the goodwill of wealthy people, and in many cases observations ended with the death of the sponsor. The observatories were mainly simple rooms with windows and terraces, equipped with instruments like quadrants, sextants, astrolabes and celestial spheres.[20] The first small observatory was built in 1472 in Nuremberg by the astronomer Regiomontanus and the wealthy citizen Bernhard Walther.[21]

In the 1570s Uraniborg, the very first custom-built observatory in Europe was established. It was the greatest observatory before the first telescope was invented. Tycho Brahe established and operated the observatory Uraniborg, built from 1576 to 1581, on Hven, an island located between Zealand and Scania, which was at that time a part of Denmark. Uraniborg was an observatory and residential building at the same time, surrounded by a park and a square defensive wall. The isolated location, the park, the cruciform ground plan oriented to the four cardinal points and the stone pillars to support the instruments[22] were quite advanced elements for this time, which may be found in observatories built much later too. Shortly afterward, in 1584, Tycho Brahe built a second, smaller observatory at Hven: Stjerneborg, the castle of the stars. It was entirely at ground level and each instrument was placed underground with its own circular pit and enclosure including opening shutters and a rotating dome. However, when Brahe fell out of favor of the Danish King, who was the sponsor of the observatory, he decided to leave the island and both, Uraniborg and Stjerneborg, were destroyed after Tycho Brahe's death. Stjerneborg was restored in the 1950s and the grounds of Uraniborg are being restored now.

After Uraniborg and Stjerneborg, the following observatories were built in various forms and differed from one another. Astonishingly, the invention of the telescope in 1608 by Hans Lipperhey didn't influence the architecture of observatories and it took some time until the telescopes got bigger in their size to influence the shape of the building effectively.

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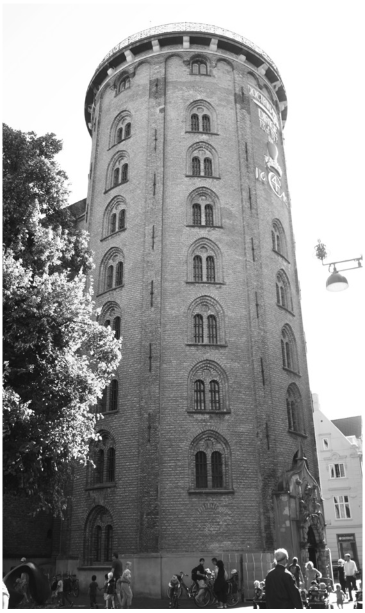
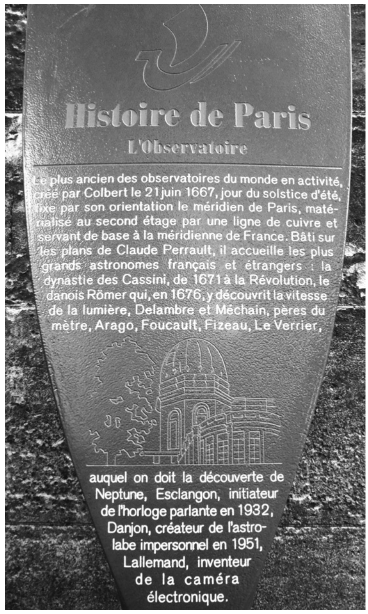
[20] Cf. Müller 1992, 231.
[21] Cf. Fladt/Seits 1957, 47.
[22] Cf. Müller 1992, 231.



014 Rundetaarn Copenhagen



015 Observatory Paris

016 Observatory Paris

Later on, tower observatories were the main form of observatories and actually, they could be found throughout the history of observatories, because the higher position compared to the other buildings in the city offered a better view to the sky. The Gregorian Tower, also known as Tower of Winds (Torre dei Venti) in Vatican City, built between 1578 and 1580, was the first institutional observatory built in tower form.[23]

Tower forms had often more than one function to fulfil. For example, the Round Tower (Rundetaarn) in Copenhagen is an observatory and church tower at the same time. From 1642 the Round Tower has been the main observatory of Denmark and it´s double function isn´t the only element which makes it special: The tower is famous for its spiral ramp to ride up to the tower on horses. The well in the middle of the ramp is also well known. This element was often built within observatories at that time; it was probably installed to observe the azimuth. By now it is possible to take a look in the other direction – from a glass surface to the bottom of the well.

The first university observatory emerged in 1633. A provisional platform at the top of a university building in Leiden, the Netherlands, is considered the first university observatory. Only a few years later, a famous observatory building was built by Ludwig XIV in Paris (1667-1672). Its connection to the Paris Observatory as a scientific institution to the French academy of Sciences was a role model for other, following observatories (e.g. Greenwich). Similar to the Round Tower in Copenhagen it has a well, but this one is also leading down to the catacombs of the city. The observation hall on the second floor features big windows to the south and a meridian line on the floor. The orientation towards the south was very common because the observation of the meridian line was an essential part of astronomy for a long time. Additionally, the flat roof at the top of the building was perfect to put up telescopes.[24]

Later, the first observatories in close connection to navigation schools were built. The Greenwich Observatory (1675-76) was one of these observatories, founded to find the longitude and to change the navigation on sea for the better. The solution to the longitude problem was finally found in the second half of the 18th century (John Harrison, H4 pocket watch); and in 1884, Greenwich Time, defined by the meridian at the observatory in Greenwich, became the standard world time.[25]

In the 18th century, during the time of baroque and early classicism, the main form for observatories was still the tower form. Most observatories were located within the city, thus only the tower form offered a clear view of the sky. Sometimes also existing towers were used, or parts of

[23] Cf. Müller, 232.
[24] Cf. Müller, 232-233.
[25] Cf. Lippincott 1991.

the city fortification. The still quite small instruments were usually stored safely inside the observatory and taken outside on balconies or terraces for observations only. Astronomers of the Jesuit order were famous for their tower observatories and their research on astronomy. Their missioners conveyed their knowledge about astronomy around the world and founded one of the oldest known observatories in the USA in 1841 (Washington Georgetown).[26]

The Benedictine order founded observatories as well: Kremsmünster and Ochsenhausen. In Kremsmünster, the "Mathematische Turm" is a combination of an observatory and a scientific collection with the aim to establish a universal museum, which was a concept also pursued by other observatories at that time (e.g. Kassel). The "Mathematische Turm" is part of the monastery. With a height of 50m it represented the biggest observatory tower during the baroque period.

In 1750 the achromatic lens was invented, which changed the design of refracting telescopes. The telescope got shorter, bigger, heavier and more sensible. This caused a change in the architecture of observatories, because the new telescopes required solid foundations, anchored deep in the ground. Therefore, the height was limited to one or two levels and high towers got superfluous. Moreover, the now typical dome as enclosure for the telescope was invented and elongated building forms, oriented from east to west with typical classicist symmetry (central dome), got common for observatories. The orientation from east to west was determined by the meridian-instruments, which were common at that time.

A large distance to the city, a big rotatable dome and a separate foundation for the telescope are main features of modern observatories. They were first realized at Dunsink Observatory in Dublin 1783-85 and later served as basic foundation for all newly built observatories. Sometimes also a vault was used instead of a support pillar for the telescope. The accommodations were located in the side wings of the building, where also rooms to observe the meridian were located.

At the end of the 18th century floor plans in L-, U-, H-, T- and cross shape had become typical. Furthermore, many classicist observatories have porticos, especially royal and imperial ones. The first observatory in cross form was built in Turku in Finland. This observatory and some of the following had a tendency to be more representative than functional: Sometimes the necessary vertical slits for the transit instruments were hidden; or the domes were only decorative ones. A good example of a representative and functional observatory in cross form can be found in Berlin. The observatory was planned by Karl F. Schinkel in the 19th century. This form of an observatory got necessary because of a new

[26] Cf. Müller 1992, 233.

transit-instrument from west to east; therefore it was the common form until the end of the 19th century. Also at the end of the 19th century, representative aspects, which included ornaments and a high demand on architecture, slowly lost their importance. Technical aspects and the needs of astronomers on the other hand started to become more important.

A turning point in the architecture of observatories was the construction of the observatory in Vienna. The heating of the accommodation beneath affected the view of the telescope. Therefore it is the last observatory built comprising accommodation for the director in the same building. From then on, the main buildings were split up in several buildings and got smaller in their sizes. Moreover, the orientation from north to south was no longer important as the meridian halls were no longer needed.[27] The following observatories had no more orientation.

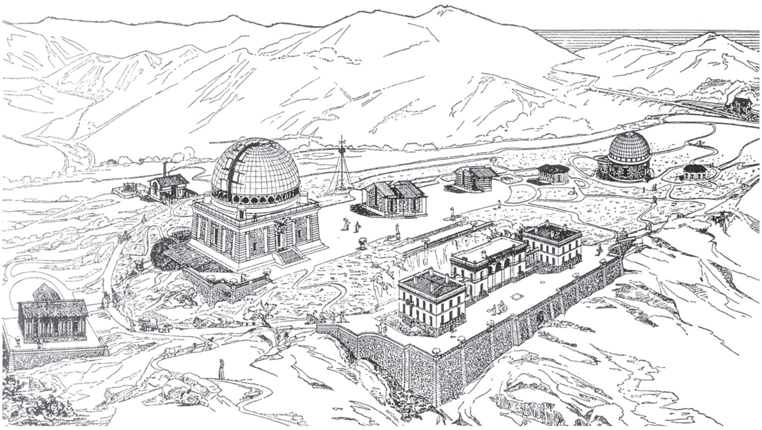
The Lick Observatory was the first observatory built in group-form like it is common practice today. Located in a dry climate, far from any city and on a mountain it comprises several buildings and each instrument had its separate building. This observatory became the archetype for modern observatories, especially for mountain observatories.

The first permanent observatory in the European mountains was founded in 1878 on the Pic du Midi in an altitude of 2865m. Shortly afterwards, the famous observatory in Nice (1879-1886) was built by Charles Garnier and Gustave Eiffel. Like the Lick Observatory it is built in a group-form, but as it is closer to the city the altitude isn´t that high. However, the tendency to warmer regions was clear.

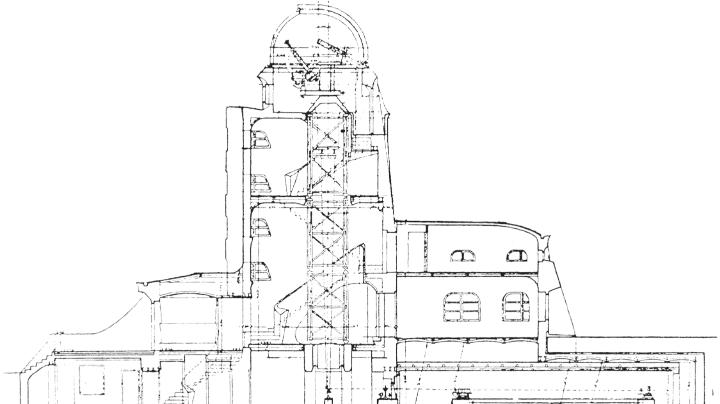
Also the site requirements changed after the Prime Meridian in Greenwich was determined in 1884. Before, the observatories in big capital cities defined their own zero points and time zones. The observation of the southern sky was very important in order to observe the meridian line; therefore they were mainly located in the south of the city. Not only that this was no longer relevant, but also the growing cities got closer to the observatory until the observatory was finally a part of it. Additionally, electrical lightning started to influence the observations. In consequence of these big changes, new observatories were built. But many of the big old observatories are still used for education, administration and as offices. University observatories started to build additional smaller observatories off-campus at better locations, which got more and more important as environmental influences increased constantly.

The tendency of research observatories at mountains in group form led to the fact, that they were merely accessible for scientists. This contributed to the founding of the first public observatories; because public

[27] Cf. Müller 1992, 237.



017 Observatory in Nice

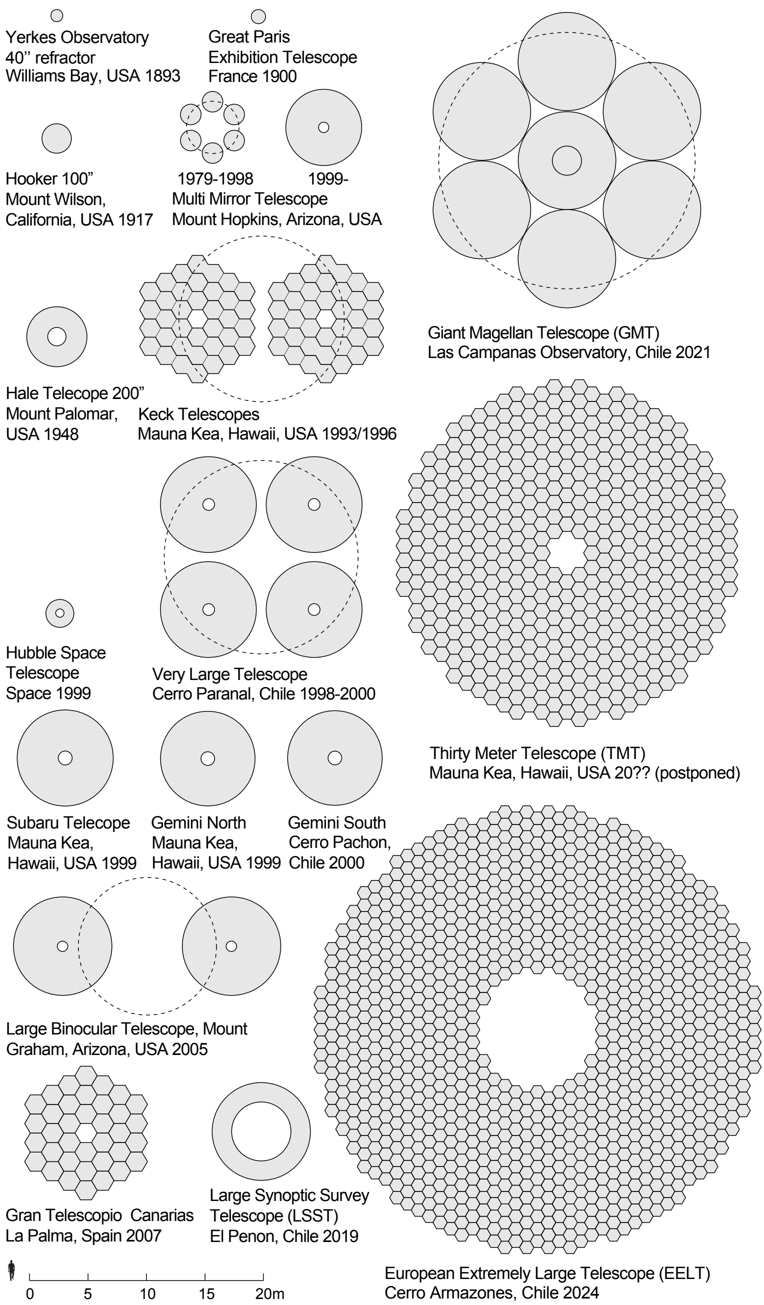


018 Einstein Tower section

accessibility was crucial they are mainly located in the city center. The form is often a tower-form, sometimes in combination with a building complex. Also universities started to build observatories in tower-form. Public observatories often include a planetarium (first invented in 1923 by Zeiss), a lecture hall and/or a library.[28]

An extraordinary example for an observatory is the Einstein Tower in Potsdam by Erich Mendelsohn. The famous sun-observatory was built from 1919 - 1922. Its expressionistic architecture combines organic forms and functionality.

[28] Cf. Müller 1992, 293.



019 Comparison of mirror sizes

DEVELOPMENT SINCE MID OF THE 20TH CENTURY

Over the years and the rapid technological development, the technical aspect of observatory buildings got prevalent and the architectonic aspect lost increasingly more of its importance. The typology characterized by its typical domes and observation platforms changed to high-tech enclosures, often shaped like a box, while the surrounding supporting facilities and housings are sometimes an accumulation of functional buildings of lightweight construction. This is partially justified by the fact that the big telescopes are getting more and more expensive. Therefore, astronomers try to save money by sharing their facilities and by using already existing site infrastructure. Additionally, international cooperations like the ESO (European Southern Observatory) were created (1962), who finance the big telescope projects together. However, as most new telescopes are unique fabrications, their enclosures vary according to their needs. Hence, sites like Mauna Kea, which is used by astronomers since the 1960s, show a big variation of enclosures and control buildings. Outstanding architecture at the nowadays very remote sites of telescopes are rare, but one shining example was set in 2002 by Auer+Weber at Paranal with the Residencia.

The tendency to remote control leads to telescopes that don´t feature a permanent office or residence nearby any more. This enhances the negligence of the importance of the architecture at astronomical sites, as the telescopes and their enclosures are far away from any civilization and therefore out of view for the public. Thus, especially small telescopes are often housed in standardized prefabricated domes. On the other hand, very large telescopes are prestigious projects, which attract rising attention. Hence also the design of the enclosure und its nearby buildings receive attention.

Another technical development is the possibility to join several single telescopes - even at different locations - into one big telescope. Some are already shared by countries and actually, arrays through e.g. interferometry are a common solution to avoid the difficult construction of one big mirror structure. Since the 1970s also remote controlled space telescopes are used to collect data. One of the first space telescopes for visible light was the Hubble Space Telescope (HST), launched in 1990.

Current projects are for example the TMT (Thirty Meter Telescope) at Mauna Kea in Hawaii (currently postponed), the GMT (Giant Magellan Telescope) in Chile (2021), the E-ELT (European Extremely Large Telescope) in Chile (2024), the EST (European large aperture Solar Telescope) on the Canary Islands, Spain, etc.

Eventually, the development of ground based research observatories can be summarized with one distinct phrase, “The bigger, the better.”

SITE REQUIREMENTS

An observatory with the best, newest and most expensive instruments can get worthless when the location isn´t good enough. Thus, the location is one of the most important aspects of an observatory and there are high demands considering the location of an observatory, especially in terms of the highly sensitive instruments nowadays. Hence, the ideal site for an observatory is hard to find and the main aim is to find a spot which offers a high transparency of the sky, a large number of useful observation hours, etc. To achieve this, many environmental factors such as the climate, the geography, the distance to the city, the accessibility, etc. need to be considered. Therefore, usually years of research and site testing are necessary to determine the site of the next telescope project. This chapter should give a short overview about the complex topic of site requirements and astroclimatology for optical observatories.

020 Light Pollution Map

HISTORICAL DEVELOPMENT OF SITE REQUIREMENTS

From the very beginning, the location of an observatory played an important role for astronomers. Most of the first observation spots were located in the Middle East and near the Mediterranean Sea, where the dry climate was ideal for observing, because of a high number of cloudless nights throughout the year. Also, they were situated in areas of higher altitude, on the top of mountains or hills (e.g. Monte Tiberio, Capri, Italy). In plain areas the observers took advantage of already existing high buildings like towers or lighthouses (e.g. Lighthouse of Alexandria, Egypt) to get a better view. Moreover, the feeling of being nearer to the sky played a role for the observers, next to the fact that they wanted to avoid any distraction during their observations. After the Middle Ages, many observatories in Europe were built on or along the town fortification. Walls and towers were preferred observation spots due to some obvious advantages: a higher position, a steady basement and a location aside of the busy city center. Additionally, the proximity to the city facilitated a certain level of living comfort to the observer. Later on, observatories were mainly located according to scientific reasons. Within a certain period, observatories were built in the south, outside of the city to get a better view of the meridian (e.g. Paris), but the orientation towards the south and a free view to the sky in this direction lost its importance in the 20th century when the meridian wasn´t observed any longer. However, the location outside of the city is still one of the main site requirements for professional observatories. And finally, all observatories close to the city center faced the same problem: The extending city surrounded the observatory sooner or later, and affected the observations in various ways. Smoke, all kinds of exhaust gases, fog, artificial lightning, vibrations caused by traffic, high buildings, etc. had become omnipresent disruptive factors. While the instruments got more sensitive, the surrounding factors got worse and observatories had to close. For new observatories, a green protective belt, consisting of trees and plants were planned. The park ensured a certain distance to the city, prevented reflections of the ground back to the sky and balanced differences in temperature. Therefore, botanical gardens, castle gardens and forests are often near observatories in or close to the city. Finally, observatories within the city became less and less attractive. Solely for educational purpose they were still usable. The astronomers started to move to locations in a distance of approximately 30-100km from the city[29], to stay in close contact with the “main” observatory in the city center. Later on, sites further away from the campus were established when sufficient long distance communication technology was developed. In Europe, the need to leave the local climate zones and to build observatories not only off-campus, but also at places with better climatic conditions wasn´t realized until after World War II, when

[29] Cf. Müller 1975, 261.

international relations improved and astronomers of northern countries started building observatories in areas of Mediterranean climate. This demonstrates that political stability and international cooperation are also relevant aspects for the site selection of new projects. But not only climate conditions led to the need to cross borders. Additionally, the tendency to build observatories on mountains increased. From the 19th century on observatories have been built in higher altitudes where the environment is less polluted and better atmospheric conditions prevail.[30] The tendency to sites in higher altitude and to the south also appeared in America and the quest for a perfect site in the mountains led them to regions in the southern Hemisphere. From the late 1950s on the Andes have been monitored and discovered. The dry desert climate in the Chilean Andes and in southern Peru turned out to be perfect for astronomical observations. But some of the possible sites were located very high and sometimes the conditions were too rough for humans and/or the transport route nearly impassable. The first European observatory in northern Chile was the La Silla Observatory in 1969 (ESO). Observatories at Cerro Tololo, Cerro Paranal, etc. followed. Other preferred regions for American astronomers were and are California and Hawaii. Until today, the tendency to warmer regions near the equator is unbroken and the same applies to the striving for height. Furthermore, places even more remote than the desert and the mountains, like for example Antarctica, are investigated by astronomers.

[30] Cf. Müller 1975, 259-261.

PARAMETERS OF ASTROCLIMATOLOGY

Astroclimatic parameters are used to measure the individual ideality of a site for an astronomical observatory. Measuring the sky quality is an indispensable part of the process of founding an observatory.

Weather

The weather highly influences the observations. Meteorological data showing the percentage of clear night time with no cloud cover, temperature variations, wind speed, water vapor content, etc. need to be taken into account when finding the right site.

Atmospheric extinction / transparency of the sky

Atmospheric extinction can be caused by clouds, aerosols and other masses of air, which absorb and disperse the light into the atmosphere of the earth. To classify the extinction, an extinction coefficient is used.[31]

Night-sky brightness

Airglow, scattering of starlight, indirect scattering of sunlight, artificial lightning, etc. influence the darkness of the night sky. While many of these light sources cannot be controlled, artificial lightning is caused by humankind. To improve the astronomical observation it is essential to avoid any kind of light pollution.

Astronomical seeing

To determine the image quality, the typical size of a point source in focus of an ideal telescope is measured, which is also called seeing. It is limited by the distortion caused by atmospheric turbulence.[32]

[31] Cf. Instituto de Astrofisica de Canarias 2011, 66.
[32] Cf. Instituto de Astrofisica de Canarias 2011, 66.

SITE SPECIFIC REQUIREMENTS

Astroclimatic parameters are influenced by several local conditions, which inevitably lead to a list of environmental requirements that need to be fulfilled.

The built environment

Telescopes need to be located far from buildings, trees, or other obstacles, which may affect the view. Isolated areas on mountain tops are therefore preferred.

Climate

The best sites for observatories have a large percentage of clear nights with no clouds above the observatory, an arid climate with low humidity and water vapor, as well as low temperature fluctuations. Low temperature and humidity fluctuation would be ideal to avoid the otherwise necessary air conditioning of the telescope enclosure to protect the mirrors and lenses of a telescope from deformation and condensation. Weather changes may influence not only the current quality of the pictures and research, but also the entire life cycle of the lenses, and thus of the telescope itself. Aside from that, climatic conditions like wind speed, snow/ice and aerosols in the atmosphere affect the useful time of a telescope.

Height

Placing the observatory above a certain height, in regions of high altitude minimizes the absorption and distortion caused by the atmosphere of the earth. Furthermore, clouds may impede on the view of the sky for optical telescopes and are one of the main reasons for few useful nights. A high altitude often correlates with a high possibility of being above the inversion layer, which is necessary to avoid the clouds. However, clouds beneath the observatory can be beneficial as they shield the telescope from light pollution coming from below. Furthermore, a location above the “sea of clouds” is important for research concerning the infrared light as water vapor absorbs some wavelengths of infrared light. Usually observatories are built above approximately 2000m over sea level. Here the atmosphere normally offers a clear view to the sky. The average height of observatories is around 2500m; the highest observatories are around 4000m.

021 Inversion layer at the left side of the mountains

022 Low visibility due to Smog

Geology / seismology

Although most of the best observation sites on earth are located near volcanos, seismic activity should be avoided. Furthermore, the risk factors of lava inundation, geological changes in the landscape and volcanic ash need to be evaluated in order to verify the most suitable site.[33]

Distance to cities and human-caused interferences

Mankind causes multiple interference factors for observatories. Therefore, astronomers are trying to avoid those by moving as far away from habited areas as possible. Good sites are characterized by low air pollution/atmospheric pollution, no thermal caused by heated up ground, no vibrations of any kind, low light pollution and dark skies, low radio electrical pollution, a lack of aviation routes and a good accessibility of the site.

In this context the problem of the distance between the telescope and the residence of the observers needs to be mentioned too: The site of the observatory should be as far from disturbance factors induced by humans as possible, but at the same time, astronomers themselves need to live and work close to the observatory. Therefore, they cause disturbance factors themselves. This contradiction can only be solved through architectonic solutions.

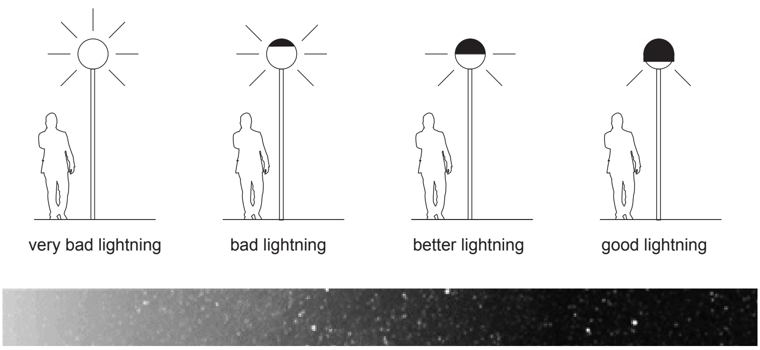
- Air pollution / atmospheric pollution

Gases released into the atmosphere can influence the quality of the atmosphere, which has a direct impact on astronomical observations. In general, any kind of air pollution deteriorates the astronomical view.[34]

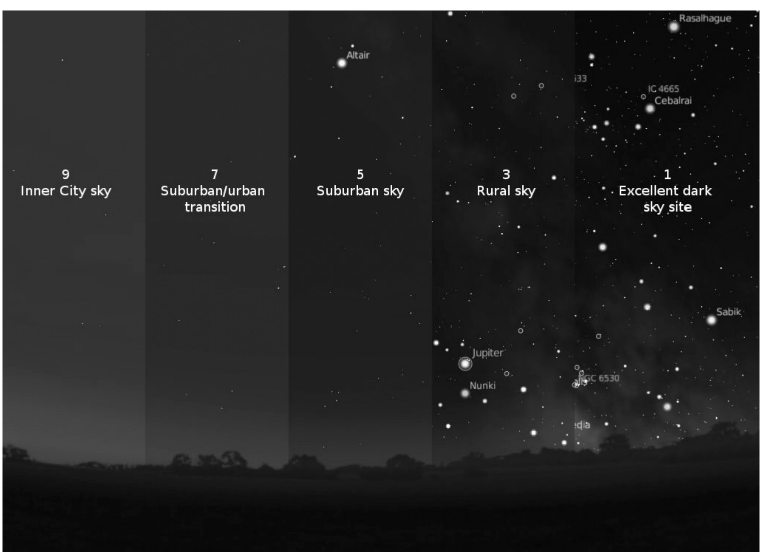
- Thermal / thermal column

In most cities the view of the horizon is not possible due to thermals. The sun warms the ground of urban areas and roadways more than its surrounding rural area and higher air layers, which causes convection and leads to the fact, that the first few degrees measured from the horizon have a very low visibility. On the countryside, however, the natural ground and plants or greenery don´t heat that much, therefore this effect is mainly seen in cities.

[33] Cf. Instituto de Astrofisica de Canarias 2011, 73.
[34] Cf. Instituto de Astrofisica de Canarias 2011, 71.



023 Lightning examples



024 Bortle scale

- Vibrations

Vibrations may be caused by various sources. One possible source is cars or heavy vehicles passing by the observatory. Also, if the foundation of the telescope mounting isn´t separate to the foundation of the enclosure, people walking in the building can cause visible interference.

- Light pollution

Light pollution has a huge impact on astronomy by forcing observatories to move as far as possible from any populated area, while there are barely any places left that offer dark skies. The main causes of light pollution are misdirected and excessive artificial lightning. Light used to illuminate streets, facades, landmarks and other objects get diffused by particles of gas and air, which causes a glow or glare into the night sky. Dust and air pollution enhance the diffusion even more by scattering the light in multiple directions. Hence the reflection and diffusion of light alternates the natural light level in the outdoor environment, which is visible mostly in and around big cities. It is also called “urban sky glow.” As observatories catch the light from stars and planets far away from our planet, observatories need to be placed somewhere, where no other light sources interfere. The multiple kinds of light pollution, such as glare, light trespass, sky glow, light clutter and over illumination, cause a massively increased sky background. Therefore, only sites with absolutely dark skies are acceptable for professional astronomical research and new telescope projects.

The problem of light pollution is actually closely connected to architecture. Especially big cities like Shanghai, Hong Kong, New York, etc. tend to illuminate the facades of famous high rises at night. Spotlights to illuminate the facades are often oriented to the sky, which is one of the main causes of lightning pollution; also street lights often shine in all kinds of directions, instead of focusing on the actual part of the street that is needed. Further on, designers and architects are often also responsible for the local lightning design of a city. And as the effects of the alternation of the natural light level at night doesn´t only affect astronomy, but also the animal kingdom, the vegetable kingdom and mankind itself, more attention should be paid to this topic. Especially because good lightning design can also help to save energy and money.

Although appropriate lightning design is part of the solution, also a change in people´s habits is necessary. International organizations like the International Dark-Sky Association are trying to raise the awareness of the problem of light pollution among the population worldwide. Furthermore, the UNESCO, the United Nations and the commission Internationale de l´Eclairage (CIE) are also concerned about this problem. The IAU (International Astronomical Union) Commission 50 is working on the preservation of the astronomical sky. Moreover, the Light Pollution Working Group of Commission 50 is trying to restrict light pollution through the encouragement of legislations and restrictions. In many countries laws, bills, ordinances, standard rules, etc. were introduced to limit the excessive waste of light. One example is the "Sky Law" (Law for the Protection of the Astronomical Quality of the IAC Observatories, Law31/1988) at the Canary Islands. It was passed on to protect the darkness of the sky, to limit radio frequency emissions and to control the light pollution as well as the aviation routes.[35] Any interference with equipment should be avoided in consideration of these increased standards.

"Any lighting installation within the area covered by the Sky Law must comply with some basic standards:

1. Outdoor lighting must not shine above the horizon and must use lamps that produce the least possible disruption to astronomical observations.

2. The spectral profile of the light emitted by outdoor lighting will be in such a way that the global radiance for all wavelengths under 440 nm will be lower than 15% of the total radiance.

3. Only sodium vapor lights may be used for road lighting. Color corrected mercury vapor and metallic halogen lights are prohibited.

4. Any type of lamp can be used for ornamental lighting on public buildings and at sports and recreation facilities, but they must be turned off after midnight.

5. Low pressure discharge lamps and incandescent lighting can only be used for advertising if they are turned off after midnight. Projectors and lasers may not be used for advertising, or recreational or cultural activities.

6. Finally, a total luminous flux limit is enforced in certain areas of the island La Palma."[36]

- Radio electrical pollution

Radio electrical pollution and electromagnetic radiation emissions, can cause possible interferences with the highly sensitive equipment. The

[35] Cf. Instituto de Astrofisica de Canarias 2011, 64.
[36] Instituto de Astrofisica de Canarias 2011, 70.

main sources are radio and television signals from broadcasting stations and electrical machinery. Near observatories flow density limits may be set.[37]

- Aviation routes

Condensation of airplane exhausts and combustion gases form clouds, which influence the sky transparency in a negative way. Therefore aviation routes should not be above the observatory.

Accessibility of the site

Although the necessity of an easy access way to the site is in contradiction to all other environmental requirements, there must be a safe and comfortable access route to reach the site. A guaranteed access to all facilities is not only important for the observers; it also ensures the steady supply of the observatory with their everyday sustenance at the residence/hotel.

Political stability and local economy

The political stability of the country, as well as the local infrastructure and economy are also major factors when it comes to site selection. The risk to place an expensive new telescope in a country, where it may be used one day is too high for international organizations. Therefore, some countries are not even taken into account for new projects.

[37] Cf. Instituto de Astrofisica de Canarias 2011, 70-71.

MISMATCH BETWEEN NORTHERN AND SOUTHERN HEMISPHERE AND CURRENT SELECTION OF THE HEMISPHERE

The number of astronomical observatories is still far higher in the northern Hemisphere than in the southern Hemisphere. This mismatch is not due to scientific reasons, but to historic and economic ones. Of course both Hemispheres are equally interesting, but the historical and economic development of the world has had a big influence on the development of observatories as most of the first observatories were built in Europe and later also in the US. This led to a high discrepancy in the allocation of observatories. However, the first observatory of the southern Hemisphere was founded by Abbé de la Caille in Cape Town in 1751. And in 1820, the Cape Town Observatory was officially established.[38]

Today, the giant observatories (e.g. in Chile) change the mismatch to the better. Some of the newest, best and most famous observatories of the world are located on the southern Hemisphere; and if only the bigger telescopes built after the 1950s are considered, the gap between the Hemispheres decreases significantly.[39] Currently astronomers are trying to place observatories in equal amounts on both Hemispheres in order to observe both. For example, the Giant Magellan Telescope will be located in the southern Hemisphere and the Thirty Meter Telescope will be erected in the northern Hemisphere. However, for big telescope projects the question of latitude is still very important and as locations near the equator access both hemispheres they are popular among astronomers.

[38] Cf. Müller 1975, 262.
[39] Cf. Marx/Pfau 1982, 24-26.

THE WORLD’S BEST PLACES FOR STARGAZING

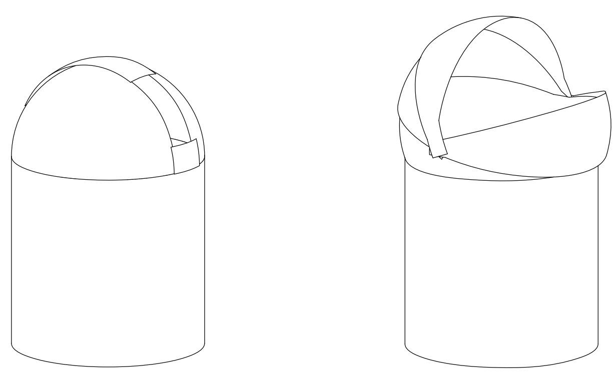
10 most famous places:
The area around the Mediterranean Sea (e.g.Sierra Nevada)
The Canary Islands (Tenerife, La Palma)
The south-western United States (e.g. New Mexico, Los Angeles)
Hawaii
The Andes (Chile, Peru)
South Africa (e.g. Kruger National Park)
Southern Australia
High mountains in Mexico (Sierra Negra)
The Himalaya (India)
The central part of eastern Antarctica

Further places:
Caucasus
High Atlas (Morocco)
The Yangtze River Valley in China
The Caribbean Sea
Sweden (Kiruna)
International Dark Sky reserves and parks all over the world

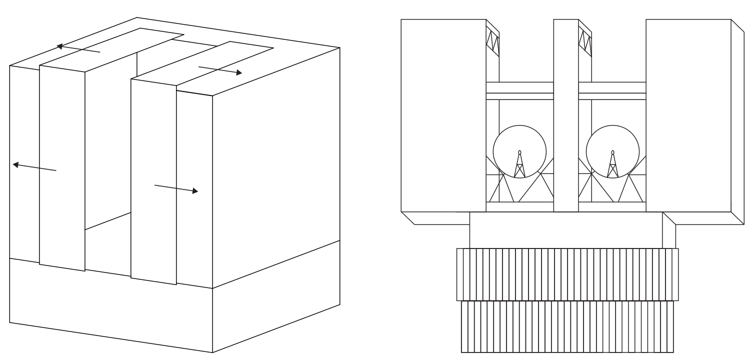
FACILITIES AND INFRASTRUCTURE

A telescope alone is not enough to conduct research in astronomy. The telescope needs an adequate enclosure, constant energy supply, a connection to the internet, etc. Additionally, scientists and astronomers need a place to work and live – a building, which needs to be close to the telescope building on the one hand, but not too close on the other hand as it may interfere with the observations. Moreover, further infrastructure, like streets or helicopter landing sites are necessary to ensure the access to the site(s) and the daily supply of the observatory.

025 Base camp, technical buildings and dormitories at Cerro Paranal, Chile



026 Typical enclosure with an observation slit and clamshell enclosure



027 Box enclosure and Large Binocular Telescope, Mount Graham, USA

FACILITIES AND BUILDINGS

Telescope enclosure / housing

The telescope enclosure is the main element to protect the sensitive equipment from exterior influences such as rain, snow, lightning, dust, etc. And also while the telescope is in use, it should still shelter from wind, dust and weather, while allowing a free view to the sky.

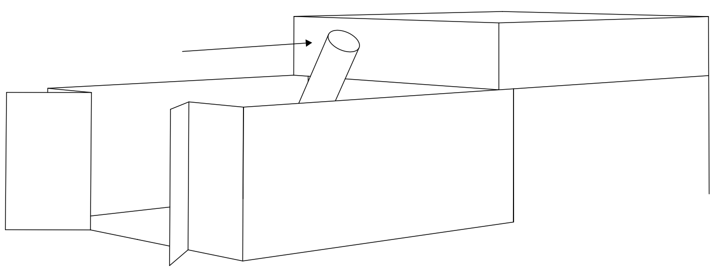
Due to the fact, that telescopes need to have the same temperature like the environment, materials with a high thermal mass should be avoided whenever possible. In order to achieve a good image quality, the thermic effect materials may have when it releases heat into the surrounding air of the telescope need to be minimized. Also, the enclosure needs to adjust fast to external temperatures to prevent condensation. At daytime, the temperature within the enclosure should not rise due to the direct radiation of the sun. The easiest way to avoid this is to paint the enclosure with a light-colored paint (white, silver) which reflects most of the infrared radiation. Other possible solutions to ensure thermal control are to build a double-skin façade, to use a thick layer of a material with a low thermal conductivity or to install air conditioning. Moreover, existing heat sources inside the telescope enclosure require active cooling.[40] The most commonly used materials for enclosures are aluminum and glassfibre-reinforced plastic. Wooden enclosures are also possible. They were often used in history and today, timber constructions are still popular for smaller telescopes. Especially amateur astronomers tend to use this material.

At night, ventilation doors or louvers /wind slits may be opened to allow a certain amount of ventilation. Windscreens allow controlling the air flow to improve the observing conditions. In general, enclosure design should also minimize the wind and turbulence over the telescope, which is especially of importance for big telescope.[41]

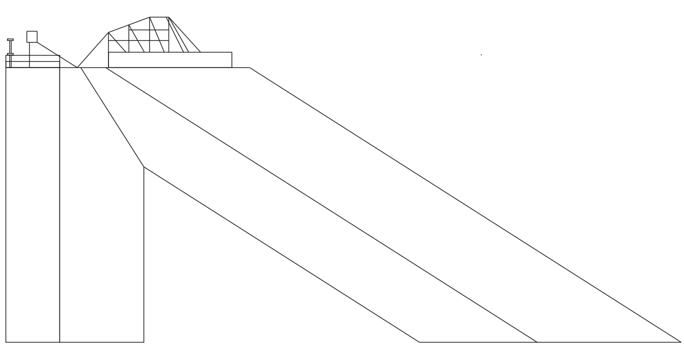
The inner structure of the telescope enclosure depends on the size of the telescope. There may be several platforms to access all necessary levels, a crane for lifting instruments, etc. inside. Furthermore, the access doors are usually wide enough for the telescope and its carriage.[42]

There are various forms to enclose telescopes. The typical and most famous one is the hemispherical dome which can be rotated manually or electronically to move the aperture to the right spot. Clamshell enclosures look similar to the typical dome, but they open up differently.

[40] Cf. Marx/Pfau 1982, 19.
[41] Cf. Guerra Ramon 2011, 59.
[42] Cf. ESO: The VLT White Book 1998, 38.



028 Roll-off roof observatory



029 Huge telescope shaft at Kitt Peak

Therefore they do not protect the telescope as good as a dome with an observation slit. Both round enclosure types, dome and clamshell enclosures, are usually prefabricated. Rectangular enclosures, formed like boxes, and cylindrical enclosures, which open up in the middle, are also used frequently. Especially big telescopes use this type of enclosure, which are able to turn with the telescope as well. Roll-off observatories (also called run-off roof observatories) are very popular with amateur observers, but sometimes they are also seen for professional use. In this case, the whole roof is sliding off the building until the telescope is directly under the clear sky. A disadvantage of this type of roof is that the telescope is exposed to wind loads, etc. during observation.

The form and features of the enclosure also depend on the type of telescope. For instance, for solar telescopes, domes that allow for a natural ventilation of the components are preferred as they reduce the heat. Domes, which can be withdrawn completely and leave the telescopes open during observations are best for this type.[43] Very few examples of observatories don´t have an enclosure at all; this is a benefit of the climate in which they are established. One example is the McMath–Pierce solar telescope at Kitt Peak in Arizona. The huge structure is merely a telescope shaft.[44]

Foundation

To avoid any kind of vibration the foundation of the telescope needs to be separated completely from the foundation of its enclosure. This means that at least two independent foundations need to be built: One for the telescope and one for the enclosure of the telescope. If there are multiple telescopes each telescope requires its own foundation.

Operating base / control room

The operating base is normally located near or close to the observatory. Inside the building, there are laboratories, workshops and storages as well as administrative, scientific and technical offices, common rooms and seminar rooms. Often also a tea kitchen is included to give the astronomers a possibility to cook a quick meal at night. For smaller observatories a control room is the absolute minimum.

[43] Cf. Instituto de Astrofisica de Canarias 2011, 23.
[44] Cf. Müller 1975, 275.

Residence / “Hotel”

As most telescopes are located in an isolated environment, an accommodation with all necessary facilities and services near the site needs to be provided. This accommodation, which may include recreation areas, sport facilities and a cafeteria, is often similar to a hotel, which leads to the fact, that they are also called “hotel”, even though they are not open to the public. At night the residence needs to be completely darkened to avoid light pollution near the telescope, and at daytime it needs to offer dimmed, quiet rooms to those, who are working night shifts. The travelling time between the telescope and the accommodation should not be too long; normally it is less than one hour.

Maintenance workshop

For maintenance and small repair works a workshop including the necessary tools needs to be provided in proximity to the telescope. In regard of the size of the telescope this could be a room, an annex or a separated building.

Garage

A garage might be necessary at big observatories to repair and maintain the vehicles. Even small gas stations might be part of the observatory facilities.

INFRASTRUCTURE

Water supply and sewerage

For the needs of the facilities, an adequate supply of drinking water and service water needs to be established. A well, a connection to the public water supply network or water tanks, which need to get refilled constantly, are possible solutions. Furthermore, a provision for the removal of waste water is necessary.

Wiring

Modern telescopes need a lot of wiring. Often the cable trays in older observatories don´t fit with the high amount of cables needed. Therefore, new cables need to be integrated into old structures or improvised wiring solutions take over. Thus, new observatories need to offer enough space for current wiring and possible further cables, especially because wireless systems may interfere with the technology used for observations.

Telecommunication and server

To assure the professional use of the telescope and its data worldwide high quality internet connectivity needs to be established. Moreover, it is required for the use of remote control and to facilitate the monitoring. Fiber optic cables are currently the best solution. Additionally, a server is necessary to save the data.

Energy supply

Similar to the internet connectivity, a guaranteed continuous power supply is essential for research. This can be achieved through diesel generator sets or battery backups. For isolated localities self-sustaining systems combined with a battery backup can be a good solution (e.g. photovoltaic panels, wind turbines, etc.). Diesel generators and multi-fuel turbines are common though, as they work regardless of current weather conditions. However, they not only harm the environment, but also give off heat. Therefore, the generators need to be placed separately in some distance to the telescope.

030 Computer room

031 Blasting for a new telescope

Liquid nitrogen tanks / plant

As detectors of modern instruments need to be cooled to -140°C or lower, a steady supply of liquid nitrogen is necessary. Due to the remote location it is sometimes easiest to generate the liquid nitrogen from the air on site.

Lightning conductor

The exposed position of most observatories increases the risk of getting struck by lightning. Therefore a lightning conductor must be installed to protect the expensive equipment as well as possible.

Site clearance

As the big telescopes need a lot of space and a stable underground, it is common to blast away the very top of the mountain. The new even top area becomes the base for further construction.

Roads and access ways

A guaranteed road accessibility of all sites (residence, operating base and telescope) at any time is essential. The road to the summit should not be too steep (e.g. for a Paranal Observatory max. 12%[45]) and sharp curves should be avoided.

Helicopter landing site

Some observatories feature a helicopter landing site. It allows reaching the observatory faster than by car and ensures a quick transport in case of emergency. Furthermore, it is convenient when the observatory is located on an island.

[45] Cf. Schilling/Lindberg Christensen 2012, 26.

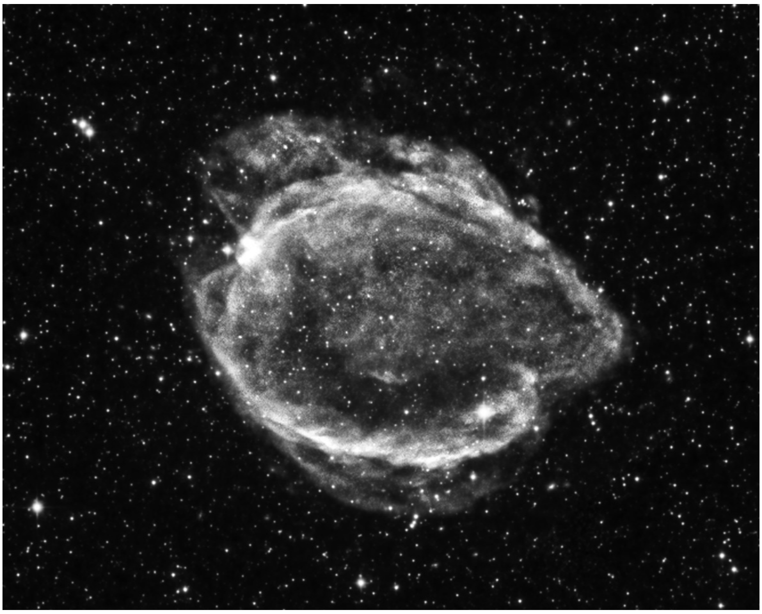
USER AND WORK

“Twinkle, twinkle, little star, how I wonder what you are.”[46]

For thousands of years mankind has wondered about the universe and the stars. How did it form and evolve? What exactly does it look like? And is there life on other, distant planets? Astronomers try to find answers to these age old questions by monitoring the day and night sky by use of X-ray, gamma, visible, microwave and UV frequencies. They try to find out more about the universe and solve its mysteries. And as the technology of telescopes improved, it also led to the fact, that astronomers are not the only ones that observe the night sky. To handle the large telescope structures, also engineers and technicians are often present when the telescopes are operating.

[46] Taylor: „The Star“ 1806.

032 Astronomer looking through the telescope



033 Supernova

034 Control Room during daytime

USER AND WORK FIELDS

The user

Nowadays, observatories are no longer a lonely, dark and cold place solely for astronomers. Especially larger observatories are full of life: Astronomers work and live together with engineers, computer scientists, university/PhD students, cooks (canteen), guards, physicians, paramedics, forwarding agents, administrative staff, and other general service personnel. The bigger the observatory, the more professions are actually needed to achieve a good living standard while conducting astronomical observations at the remote places observatories are built.

Work fields

Astronomers study the Universe, the solar system, galaxies, planets, stars, 'star stuff' (interstellar medium), clusters, quasars, etc. This study includes the observation of many different things, such as the moons, asteroids, dwarfs, supernovae, compact objects, etc. Furthermore, astronomers work together with other related work fields from physics, planetary science, geology, chemistry, etc.

While the newest technologies and telescopes are mainly used for short-term observations to use them as efficiently as possible, smaller and older optical telescopes often concentrate on long-term observations. They are mainly monitoring variable objects, comets and minor planet or searching for extragalactic supernovae, etc. But there are also further work fields, observatories with smaller or older optical telescopes specialize in, for example multi-object-spectroscopy, optic observations of gamma-ray bursts, recording the complete sky in various spectral ranges, finding extrasolar planets, or astrophotography.[47]

[47] Cf. Binnewies/Steinicke/Moser 2008, 10-11.

WORK AND LIFE AT THE OBSERVATORY

Work

The common picture that comes to one´s mind when thinking about an astronomer is a person looking through a telescope. This was the typical way to observe the sky for a very long time. This first changed with the invention of photography, but since the invention of computers the way to observe the sky has changed enormously. Visual observations, hand drawn maps of the sky and position measurement were replaced by astrophysics. Spectroscopy, astrophotography and photometry combined with computer-controlled telescopes are the new means of observation. Therefore, professional astronomers spend most of their time in front of computer screens, which allows the astronomer better working conditions, as the room can be heated and the data can be stored. By the use of remote control technology and the internet it is not even necessary to be near the telescope anymore and pictures taken by the telescope can be seen all over the world. Actually, nowadays the big telescopes are mainly controlled and navigated by engineers. Unlike the astronomers, who are often changing according to their project work, the engineers or assistants are working constantly at the observatory to guarantee a maximum use of the telescope without interruptions. The observation itself takes place inside the control room, whilst all shutters are closed in order to avoid light scattering. Eventually, the only way to see the stars during work is on the monitors. Furthermore, all neighboring buildings need to be completely darkened too and the ride up to the observatory may be a bit adventurous, as it is only allowed to drive on sidelights and sometimes no light is used at all.[48]

Frontline astronomy is mainly carried out in large research facilities and concerning the architectural part – mainly in offices. Computers are used to collect and analyze data and to calculate physical models of astronomical objects. And as the analysis of the data is the most work, astronomers spend a lot of time on reading and assimilating many forms of data. Writing proposals, research papers and presentations, teaching, providing support services, administrative work and managing projects are further duties of a typical astronomer. As office work is often the main part of the job and the opportunity to go to a big observatory for observations is seldom, it is possible that astronomers only spend one or two weeks per year on observing runs.[49] Regarding travelling to the observatory, the two different 'modes' to work as an astronomer need to be taken in account: 'visitor mode' and 'service mode'. 'Visitor mode' means the astronomer works at the observatory. It enables the

[48] Cf. Binnewies/Steinicke/Moser 2008, 8.
[49] Cf. Forbes 2008, 25.

astronomers to interact directly, which is really helpful when real-time decisions are needed. But it also has disadvantages. One can be, that the time at some observatories cannot be reassigned when the weather isn´t perfect for observations.[50]

As the telescopes are often far from any civilization and space at the observatory and residence is limited, lots of astronomers work in “service mode” from their local working space. They receive the data the telescope collects for them via internet and evaluate the results ‘at home’.

Life

Most modern observatories are located in the unwelcoming regions of the earth. Thus, after arriving at the observatory some time to acclimatize is necessary. Unpleasant weather conditions combined with the high altitude often cause headaches and a lack of concentration. General symptoms of sickness caused by the height are headaches, seeing “stars”, dizziness, breathing problems, ringing or blocking of ears, heart pains and acute muscular pains.[51] Additionally, the extreme weather at most of the sites often forces the researchers to stay inside. Wind, dryness, heat or extremely cold temperatures can make life outside the observatory rather uncomfortable. Therefore the residences / hotels usually offer a couple of opportunities to spend the time off work. Music rooms, small cinemas, interior gardens, fitness rooms, libraries, etc. make the stay more comfortable and welcoming. Moreover, the canteen is often considered a meeting point.

The life at an observatory is also characterized by the roster system, which influences the eating and sleeping habits. As the observations are mainly done at night, nightshifts are common among astronomers and therefore, residential buildings need to offer a quiet atmosphere and an efficient solution to darken the room against sunlight. In addition to the night shifts, also the distant workplace may cause personal problems, as the distance to the family also affects the private life of astronomers.

[50] Cf. ESO: FAQ, Jan. 2016.
[51] Cf. ESO: Travel to ESO Paranal, Jan. 2016.

HOW TO GET AN ASTRONOMER & FAMOUS ONES

How to become an astronomer

Unnecessary to mention, a strong interest in the astronomy is necessary to become an astronomer. Usually future astronomers already prepare for their career in high school with course work in physics, chemistry, math etc. In college astronomy, physics or astrophysics are possible majors to choose; sometimes also math or chemistry are taken. After college, graduate school follows; further four to six years are necessary to achieve a PhD. Postdoctoral, you normally have the opportunity to work on your own research.

Typical job opportunities for astronomers are research universities and teaching at the university/college, research facilities of the government or national observatories, planetariums, telescope support, etc. or they work in the private sector.

Famous astronomers and their achievements

Thales of Miletus (~624 BC - ~547 BC) - the earth as a circular disc, the sky is a hemisphere above

Pythagoras of Samos (~550 BC)

Plato (429-348 BC) - geocentric model (?)

Eudoxus of Cnidus (410-336 BC) - system of homocentric spheres

Aristarchus of Samos (270 BC) - heliocentric system

Hipparchus of Nicaea (~150 BC) - star catalog, classification of fixed stars, Earth's precession, measured the distance to the moon

Claudius Ptolemy (90-168 AD) - Planetary Hypotheses, book: Almagest

Regiomontanus (Johannes Müller von Königsberg, 1436-1476) - first observatory, planet boards

Nicolaus Copernicus (1473-1543) - book: De revolutionibus orbium coelestium 1543, Copernican heliocentrism/Copernican system

Galileo Galilei (1564-1642) – discovery of Jupiter´s moons, the Moon Landscape, the phases of Venus, the Rings of Saturn, sunspots, etc.

Tycho Brahe (1546-1601) - observation of Tycho´s supernova,

Johannes Kepler (1571-1630) - astronomical tables, 3 laws of planetary motion, discovered that the planets rotate in ovals around the sun

Isaac Newton (1643-1727) - Newton's law of universal gravitation, invention of the reflector telescope

Charles Messier (1730-1817) - catalogue of deep sky objects

William Herschel (1738-1822) - discovery of Uranus, infrared radiation, movement of the solar system, binary systems, deep sky objects (nebulae), etc.

Joseph von Fraunhofer (1787-1826) - achromatic objective lens, detailed wavelength measurements

Jean Joseph Leverrier (1811-1877) - discovery of Neptune

Albert Einstein (1879-1955) - general theory of relativity

Edwin Hubble (1889-1953) - observation and discovery of galaxies beyond the Milky Way, Hubble's law

Fritz Zwicky (1898-1974) - discovery of 'dark matter', introduction of the term 'super-nova'

George Gamow (1904-1968) - 'Big Bang Theory'

Clyde Tombaugh (1906-1997) - discovery of Pluto, stars, asteroids, etc.

Jocelyn Bell Burnell (1943-) - discovery of pulsars

Michael Brown (1965-) – discovery of dwarf planets and planetoids

Stephen Hawking (1942-) - proposed that the universe has a beginning and will end, combined 2 theories to prove that black holes emit radiation and evaporate

Alan Guth (1940-) – 'The Inflationary Universe' (theory)

CASE STUDIES


Kielder
Graz
Mauna Kea
Cerro Paranal

CASE STUDIES - OVERVIEW

The chosen case studies should give a short overview of different observatories. They are ordered according to their size, from the big research observatories at Mauna Kea (Hawaii) and Cerro Paranal (Chile) to the middle sized university observatory in Graz (Austria) and the small public observatory in Kielder (UK). Together, they show that although the size and the telescopes may differ, they are all built according to specific “rules of construction”, which apply for observatories. Furthermore, I chose this wide range of observatories to give examples for my project in Morocco, which should be a mix of research and university observatory with a middle sized telescope for long-term observation.

035 Overview Case Studies

MAUNA KEA OBSERVATORIES
W.M.KECK OBSERVATORY

Optical, infrared, radio and submillimeter astronomical observatories
Operated by several independent astronomical research facilities

W.M. Keck: Visible light observatory, optical / infrared observatory with interferometry, first light in 1993 (Keck I) / 1996 (Keck II)
Operated by California Association for Research in Astronomy, partnership with University of California, the California Institute of Technology, and NASA[52]

Location

Near the summit of Mauna Kea, Big Island of Hawaii, USA
19° 49.6' N 155° 28.4' W
4123m altitude, highest point of the mountain: 4205m

Typology / building form

Mountain observatory / group form

Instruments and Telescopes at Mauna Kea

Optical and Infrared:

University of Hawaii at Hilo: UH 0.6m
UH Institute for Astronomy: UH 2.2m
IRTF (NASA Infrared Telescope Facility), 3.0m
CFHT (Canada-France-Hawaii Telescope), 3.6m
UKIRT (United Kingdom Infrared Telescope), 3.8m
Subaru Telescope, 8.3m
Gemini Northern Telescope, 8.1m
W.M. Keck: Keck I & II, 2 x 10m
Submillimeter:

JCMT (James Clerk Maxwell Telescope),15m
SMA (Submillimeter Array), 8 x 6m
Radio:
VLBA (Very Long Baseline Array), 25m[53]

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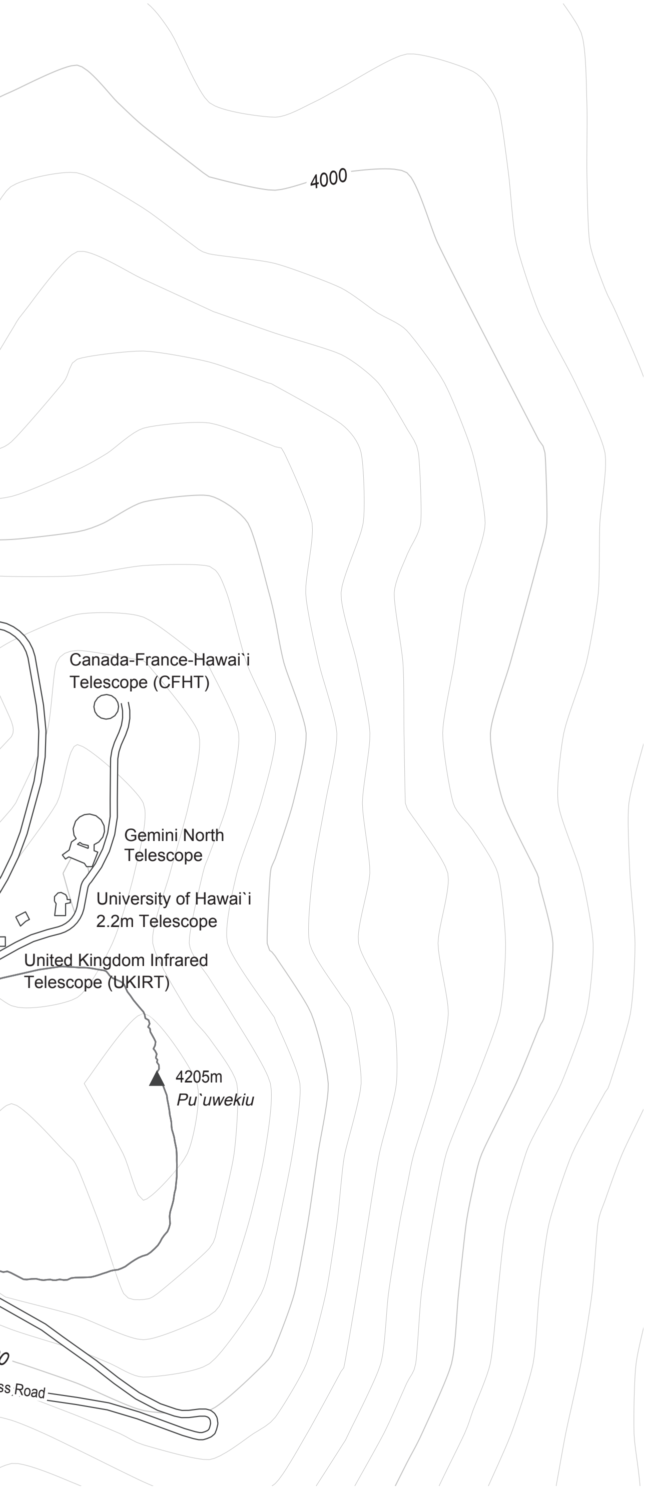
[52] Cf. Keck Telescope and Facility Instrument Guide 2002, 3.
[53] Cf. Institute for Astronomy Hawaii, Feb. 2016.

036 Mauna Kea Observatory

037 Mauna Kea Observatory summit map



Mount

W.M. Keck: Azimuthal mount

Enclosure

W.M. Keck: The two 31m high and 37m wide spherical enclosures with observation slits are insulated and air-conditioned against the heat during the day.

Facilities at Mauna Kea

Mid-Level Support Facilities
Mauna Kea Visitor Centre in Hale Pohaku

Costs

W.M. Keck: 174.5 M $ / 153 M €

Number of persons working in Hawaii

W.M. Keck: ~116 persons[54]

Climate conditions

Temperature: 0.3 - 4.5°C
Humidity: 30 - 41%, mean humidity: 36%
Rainfall: infrequent / snowfall[55]
>300 clear nights per year
Median seeing: ~0.5”

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[54] Cf. University of California W.M.Keck Observatory Program, Feb. 2016.
[55] Cf. da Silva, 11-12.

Work

The conditions in an altitude of over 4000m are challenging to the human body, but they are extremely good for astronomy. The dry air at this height is good for observations within infrared and millimeter range. And additionally to the island-wide lightning ordinance, the inversion layer below the observatories helps to avoid interference by light. However, to reach the summit, a stop at the mid-level facility in Hale Pohaku is a must for acclimatization. Facilities like the dormitory and the Mauna Kea Visitor Center are located here and offer shelter during the break, before moving on in a 4 WD vehicle to the summit. Due to this quite long way up and the harsh conditions at the Mauna Kea, remote control is very important to the astronomers. The W.M. Keck Observatory was the first observatory using remote control at Mauna Kea with assistants operating the telescopes at the Mauna Kea while astronomers gather the data from the headquarters in Waimea. Today, multiple communities are using the W.M. Keck Observatory: Caltech, the University of California, the NASA, the University of Hawaii, Yale University, the Subaru community, the National Optical Astronomy Observatory and the Gemini community. The telescopes are used in shifts and the time is allocated after a time allocation committee pre-approved the observing.[56]

For visitors of the mountain most of the telescope facilities are inaccessible. However, Keck I offers a visitor gallery to get a glimpse at the telescope during daytime. Furthermore, the headquarters of the W. M. Keck Observatory in Waimea include a visitor center open to the public and tries to reach out through a public outreach program in high-schools and with lecture series. Moreover, the Mauna Kea Visitor Center offers a daily stargazing program at night and the Imiloa Astronomy Center in Hilo tries to introduce the population of Hawaii to the work done at the observatories.

At the moment there are 12 active astronomical observatories within the conservation district of the summit. A 13th observatory, the Caltech Submillimeter Observatory (CSO), closed in September 2015. The next observatory is already planned to be built on the mountain but the construction of the Thirty Meter Telescope (TMT) is currently put on hold due to protests of indigenous Hawaiians, who consider the dormant volcano called “White Mountain” (=Mauna Kea) a sacred mountain. However, the University of Hawaii conducts observations at the Mauna Kea since 1964. And for a place at the mountain, only a symbolic 1$ and 10% of the observation time is charged.

[56] Cf. Keck Observatory Homepage, Feb. 2016.

Architecture

The architecture of the observatories, their headquarters and facilities vary. At the mountain cylindrical, spherical and classical dome enclosures for the telescopes can be seen. At the Science and Technology Park campus of the University of Hawaii at Hilo the mixture of different architectural languages is apparent. Modern buildings like the Imiloa Astronomy Center with conical shapes made out of titanium are right next to rather traditional building forms with a gabled roof. The Mauna Kea Visitor Center at Hale Pōhaku is built of stone.

Spatial distribution

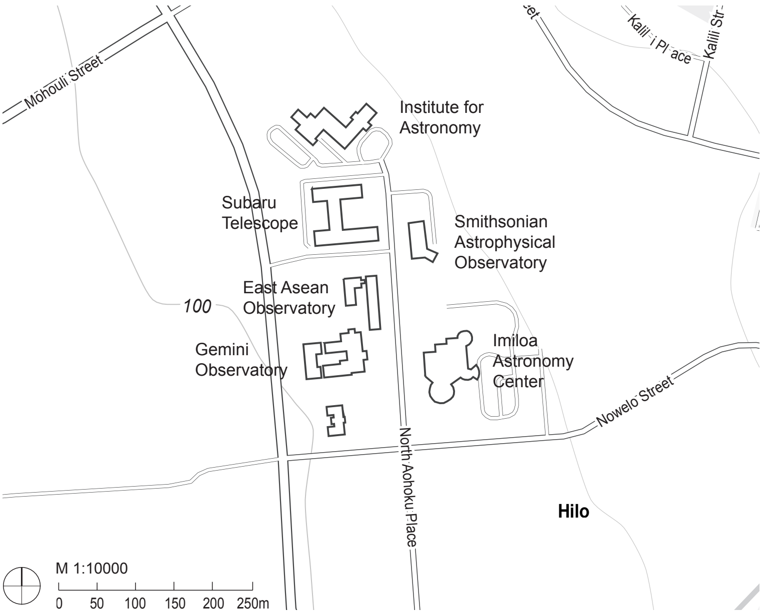
While the telescopes are located directly at Mauna Kea, most of the headquarters and operation bases of the observatories are at the Science and Technology Park campus at Hilo, next to the Institute of Astronomy (IfA). From here, it is approximately 67km to the summit, that´s a 1h 11min drive. Furthermore, the Mid-Level Facilities (Mauna Kea Visitor Center, dormitories, etc.) are located at Hale Pōhaku in a 2800m altitude. However, W.M. Keck Observatory Headquarters is located in Waimea, approximately 75km and 1h 20min from the W.M. Keck Observatory. Here, also residences for visiting astronomers and an own workshop for their 4WD vehicles can be found.

The spatial distribution of the control rooms, offices, laboratories etc. within the W.M. Keck Observatory building at the summit is quite unique: They are situated in between the two telescope enclosures. This middle part conjoins the two telescope housings into one big observatory.

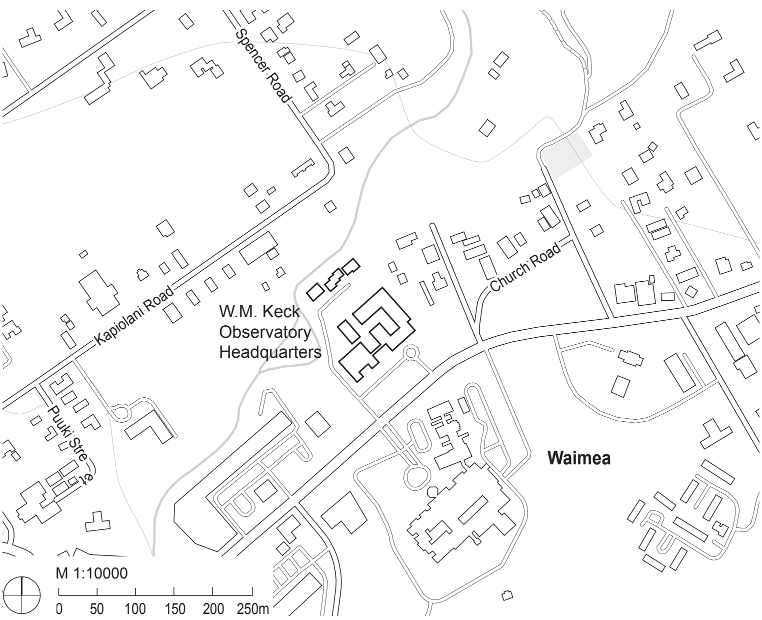
Infrastructure and construction

Electrical power is provided through a power line to the summit. In case of a blackout, power generators powered with diesel fuel or propane are used. Fiber optic cables are used for real-time communication and internet connection. Water supply is ensured by on-site tanks with potable water, which get filled weekly by trucks. The underground water storages and distribution systems are part of each major facility at Mauna Kea.[57]

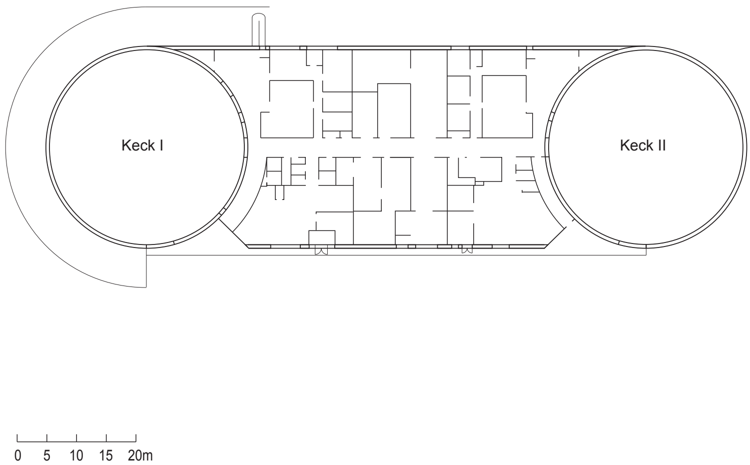
[57] Cf. NASA 2005, 4-110 – 4-112.



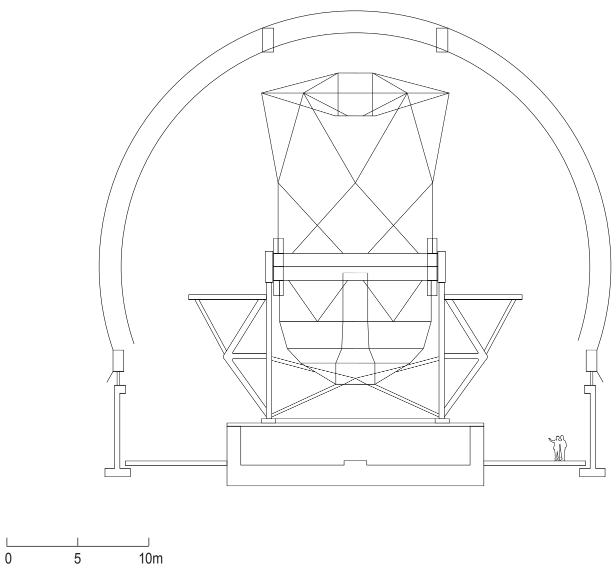
038 Science and Technology Park campus of the University of Hawaii at Hilo, Big Island of Hawaii, USA



039 Facilities in Waimea, Big Island of Hawaii, USA



040 W.M. Keck Observatory Floor plan



041 Schematic section of the W.M. Keck enclosure

CERRO PARANAL OBSERVATORY
VLT & RESIDENCIA

Visible light astronomical observatory, optical / infrared observatory with interferometry, first light in 2000

Operated by ESO (European Southern Observatory)

Location

Cerro Paranal (Mountain), Atacama Desert, Chile

120km south of Antofagasta, 12km from the Pacific Ocean

24°40' S, 70°25' W

2635m altitude

Typology / building form

Mountain observatory / group form

Instruments

VLT (Very Large Telescope): 4 separate 8.2 m reflectors

VLTI (Very Large Telescope Interferometer): all 4 telescopes combined & 4 auxiliary telescopes of 1.8m

VLT Survey Telescope: 2.6m

VISTA Survey Telescope: 4.0m

NGTS (Next-Generation Transit Survey): exoplanet-survey facility, 12 robotic telescopes a 0.2m

Covered spectral region: 300 nm (deep ultraviolet) - 24 µm (mid-infrared)

Mount

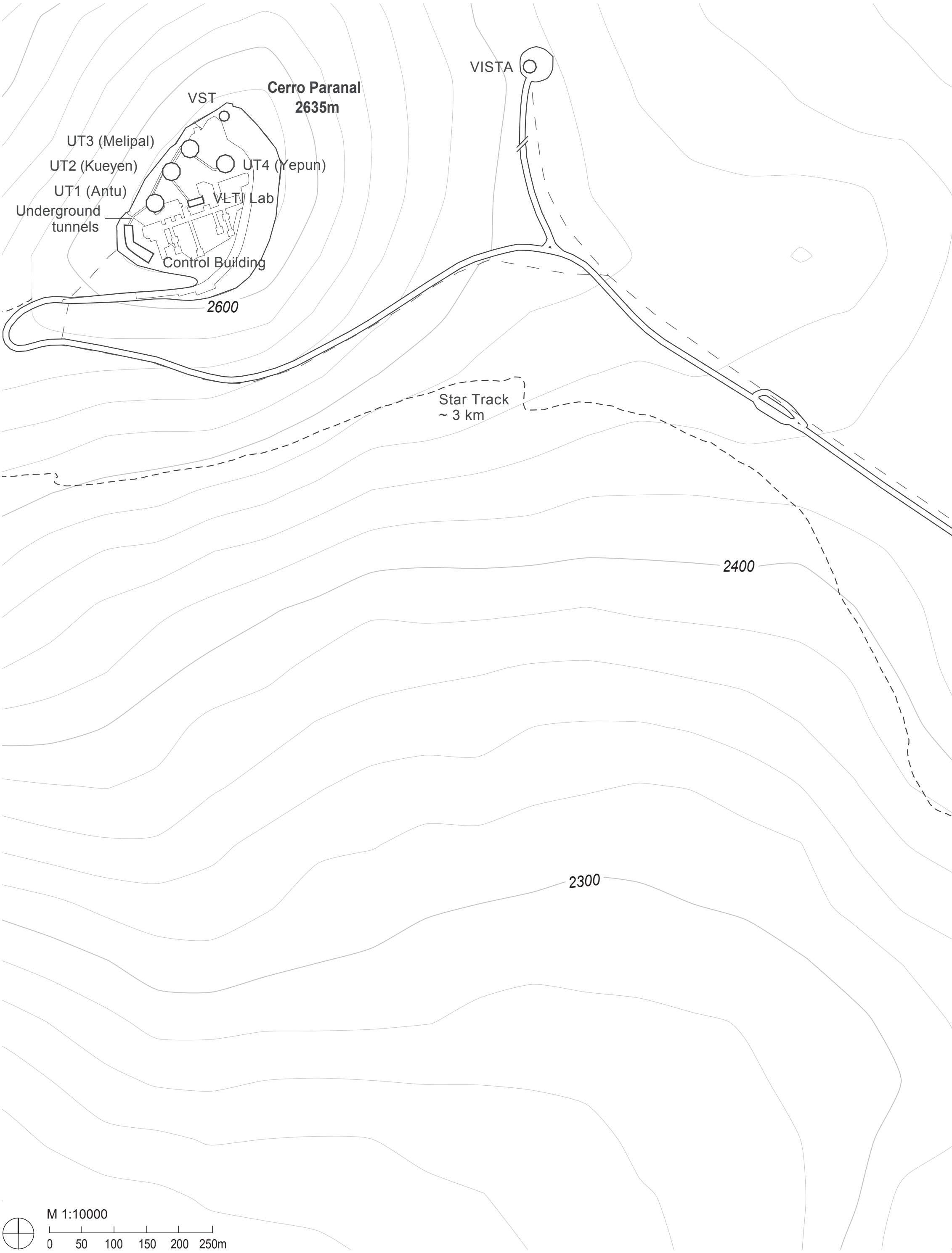
Alt-azimuth mount

Enclosure

The four cylindrical enclosures are thermally controlled buildings of 25m height, which rotate with the telescopes. The enclosure has a 9.50 m[58] wide observing slit and multiple wind slits.

[58] Cf. ESO: The VLT White Book 1998, 39.

042 Paranal Observatory



043 Paranal General Plan

Facilities

Base camp:
Parking area
Logistics area / warehouse and storage facilities
Maintenance facilities and workshops
Power, cooling liquid, compressed air and communications supply
Sports center
Medical station
ESO Hotel ‘La Residencia’

Telescope platform:
Telescopes
Control building / operating base

Costs

330 m €

Number of persons working at Paranal

174 FTEs (full time equivalents)

Climate conditions

Temperature: -8° - +25°C
Humidity: 5-20%
Rainfall: <10 mm / year[59]
~330 clear nights per year

[59] Cf. ESO: Paranal Site Information, Jan. 2016.

Work

The scientists stay for a rather short time at the Paranal Observatory, which is why they need to acclimatize quite quickly. Intense sunlight, high wind speeds, dryness, high temperature fluctuations and possible earthquakes make the life outside the building not very comfortable. However, the Residencia offers a save retreat for the scientists and therefore plays an important role to shorten this time of acclimatization and to improve the living quality at Cerro Paranal.[60] In order to ensure safety staff and visitors at the Cerro Paranal need to obey strict rules and safety regulations, which include that every visitor needs to register and log out when leaving, even if it is just for a quick walk outside. Furthermore, not everybody is allowed to work directly at Cerro Paranal; approximately 50%[61] of the researchers are doing their work in ‘service mode’ from somewhere else with the data of the telescopes and 60 - 70%[62] of the observation time at Cerro Paranal is done in ‘service mode’. Permanent employees provide this service and moreover, they guarantee the constant observation work and the living comfort at the mountain.

For safety reasons, nobody is allowed to be in the telescope building while observations are ongoing. Only when absolutely needed, authorized persons are allowed to this restricted area. They work remotely from a control room in a different building to avoid any light and heat contamination. Usually, the engineer starts the telescope and hands it over to the astronomer when it is ready for observations. The average number of astronomers of a shift is 10. This is less than 10% of the total number of persons living and working at Cerro Paranal. In fact, engineers and technicians on the site are four times more than astronomers. Their main work is to optimize the performance of the telescopes and machines to prevent time loss and technical problems.[63]

Work is done in shifts according to a roster system, as it is often seen at observatories. The canteen tries to find a compromise for this problem by offering breakfast from 07:00 to 10:30, lunch from 12:00 to 14:30 and dinner from 17:00 to 24:00. For night shifts, night meals can be ordered (e.g. sandwiches or meals available during the day), which get delivered directly to the dining room of the control building.[64]

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[60] Cf. Kiock 2003, 196.
[61] Cf. Binnewies/Steinicke/Moser 2008, 258-260.
[62] Cf. ESO: FAQ, Jan. 2016.
[63] Cf. ESO: FAQ, Jan. 2016.
[64] Cf. ESO: Safety and Logistics, Jan. 2016.

Architecture

Apart from the shining enclosures of the telescopes, only the residence is well-known for its architecture. Further facilities are either containers, halls for maintenance or sports or similar buildings in lightweight construction with a light color to reflect the heat. The Residencia by Auer+Weber sets a clear contrast to these buildings.

Spatial Distribution

There are two main areas, where facilities of the observatory are located. The first one is at the top of Cerro Paranal, where the telescopes and the control building are, the second one is the base camp, approximately 3km from the telescope. Part of the base camp are major buildings like the residence, the maintenance workshop and the power station.

Infrastructure and construction

The buildings need to be capable of withstanding earthquakes reaching up to a magnitude of 8 at the Richter scale. That's why the VLT includes an anti-seismic technology to protect the most important parts of the telescope. A special system anchoring the primary mirror to the cell safeguards the mirror from breaking or even falling.[65]

Paranal Observatory is off grid. Therefore, electricity is produced by two multi-fuel turbines working constantly and a third one that is on standby. Solar and wind power generators were considered, but the costs and the fact, that alternative power sources cannot be guaranteed at all time lead to the decision for the fuel turbines.[66]

The daily supply of the Paranal Observatory is brought in from the closest town, which is about 100km away. Everyday 60000 liters[67] of water are transported from Antofagasta.

The cell phone signal is weak or not available on the site of the observatory. For this reason phones are available in offices and rooms.

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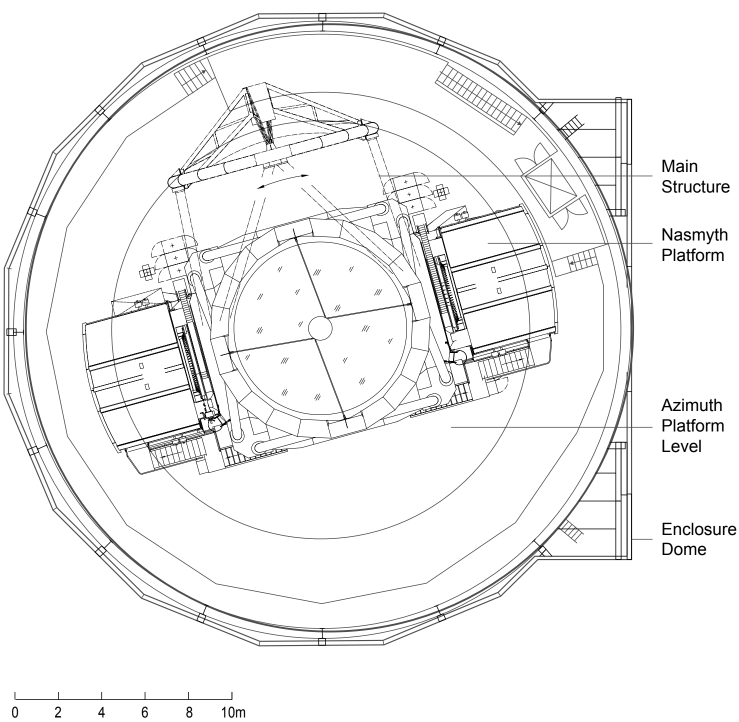
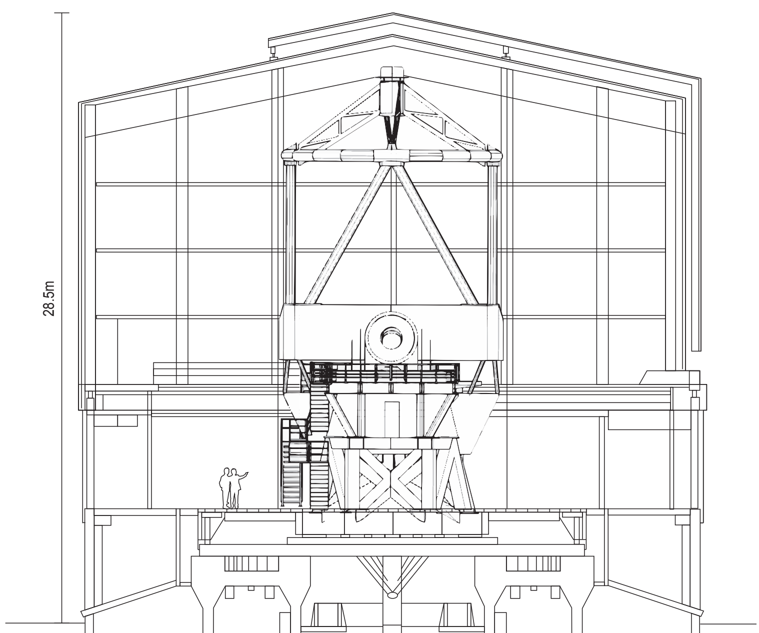
[65] Cf. European Southern Observatory: The VLT White Book 1998, 49.
[66] Cf. ESO: FAQ, Jan. 2016.
[67] Cf. ESO: FAQ, Jan. 2016.



044 Plan of the VLT



045 Section of the VLT

ESO HOTEL 'LA RESIDENCIA'

ESO Hotel 'La Residencia'
Auer+Weber, 2002
2400m altitude, 3km from the telescopes

Gross floor area: ~10 000m²
Measurements: 176m x 53m
4 levels
108 bedrooms (16m² each)
22 offices
Reception area / lounge
Canteen (capacity for 200 persons)
Cinema (capacity for 70 persons)
Social gaming room / meeting areas
Music room
Fitness center
Sauna
Library
Swimming pool
5 terraces / viewpoints
courtyards and interior gardens (1000 m²)

Architecture

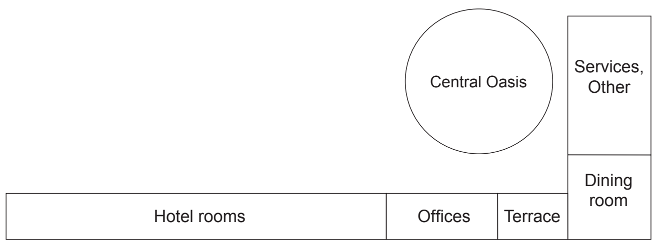
The L-shaped building blends perfectly into the existing natural depression: The chosen iron-oxide colored concrete for the partly subterranean construction matches perfectly with the surrounding desert and the straight lined profile of the building creates a contrast to the soft curved mountains. When you approach the building, only the dome rises above the horizon. Natural lightning is assured through this Ø35m glass dome, courtyards, skylights and the west façade. Gardens with tropical plants and a swimming pool under the dome improve the climate within the Residencia to create a good and more humid environment for working and recreation after work. The swimming pool, a fitness center, a sauna, a library, a cinema and even a music room offer lots of possibilities to the scientists to stay occupied whilst being inside nearly the whole day.[68]

[68] Cf. Radford/Morkoç/Srivastava 2014, 190-195.

Anchored concrete blocks with fiberglass mats to absorb movement stabilize the building in case of earthquakes. To reduce the impact, the building is not planned as one large structure, but as complex of building parts.[69]

Spatial distribution

The building can be divided into four main areas: The central oasis and public venue with a swimming pool, hotel rooms, offices/meeting rooms and a dining zone. Furthermore, the modular concept used has the potential for an extension to 200 bedrooms[70] in the future.



Hotel rooms

All hotel rooms are oriented towards the west with a direct view across the desert to the Pacific Ocean. The rooms are quite small, but offer everything an astronomer needs (bed, desk and bathroom). The small horizontal and vertical windows along the façade allow the sunlight to come in, while the closed part of the façade protects against overheating and light scattering at night. Additionally, the hotel rooms are facing away from the telescopes.[71]

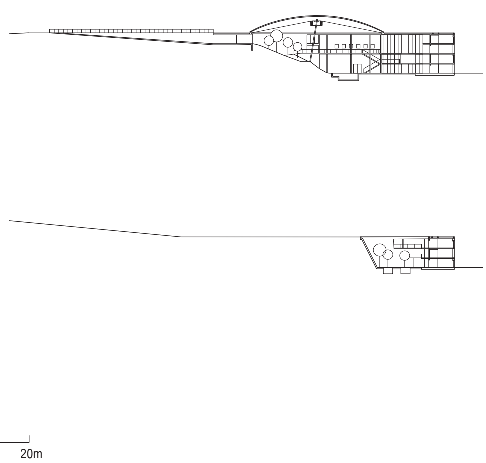
Blackout system

In the valley the dome is the main source of light interference. A special blackout system is installed to darken the dome with fabric covers at night to avoid light from escaping to the outside of the building. The blinds in the hotel rooms and offices need to be closed manually after sunset. After everything is closed, the building is completely light tight.

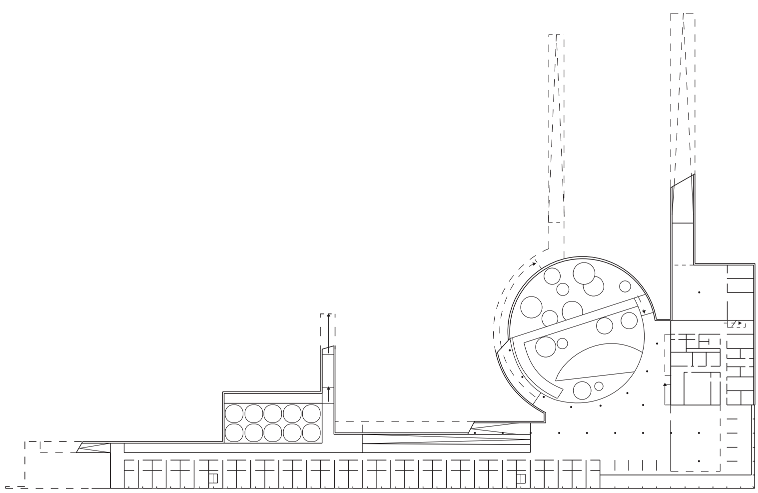
[69] Cf. Radford/Morkoç/Srivastava 2014, 194.
[70] Cf. ESO: Coming Home at Paranal, Jan. 2016.
[71] Cf. Radford/Morkoç/Srivastava 2014, 190-195.

046 ESO Hotel Cerro Paranal

047 View from the terrace to the ocean



048 Sections of the Residencia



049 Floor plan of the Residencia

LUSTBUEHEL OBSERVATORY GRAZ

Optical observatory, first light in 1976

University observatory operated by the Department for Geophysics, Astrophysics and Meteorology (IGAM), Institute of physics

Location

Lustbühelstraße 46, Waltendorf, Graz, Austria
47° 03.9’ N -15° 29.7’ O
484m altitude

Typology / building form

-

Instruments

0.3m BMK telescope
0.5m ASA telescope
Laser

Mount

German Mount (0.3 and 0.5m telescope)
Azimuthal mount (laser)

Enclosure

Classical dome enclosures (5.3m) with observation slits and automatic turning mechanism of the remote control system

050 Lustbühel Observatory

051 Lustbühel Observatory

Facilities

Telescope
Satellite Laser Ranging (SLR) Station
Radio telescope
Further antennas for variable ranges
Telescope tower
Atomic clock
Offices / meeting rooms / control rooms / laboratories
Workshop
Terrace

Number of persons working at Lustbühel

IWF:~6; IGAM:~2-4

Climate conditions

Temperature: -10° - +33°C
Relative humidity: 51-93%[72]
Rainfall: 30-142 mm/month, ~ 885 mm/year[73]

[72] Cf. Podesser/Wölfelmaier, 6.
[73] Cf. Statistik Steiermark, Aug.2016.

Work

The Lustbühel Observatory was founded for the purpose of educational astronomy in Graz. Before, the observatory tower at the campus of the University of Graz was used. Then, like in most cities, the environmental conditions within the city center worsened for the astronomers. But the astronomical observatory is only one part of the observatory. Initially, four institutions of the observatory: the Institute for Astronomy, the Institute for Meteorology and Geophysics (today: IGAM), the Institute for Geodesy and the Institute for Communications Engineering and Wave Propagation.[74] Since 1982 the observatory has been shared with the SLR Station of the Space Research Institute (IWF) of the Austrian Academy of Sciences. The Satellite Laser Ranging Station is a fundamental station measuring the distance to satellites orbiting the earth. Officially, the building is part of the Graz University of Technology, which is represented by the Institute of Communication Networks and Satellite Communications at the Lustbühel. The University of Graz and the Space Research Institute are subtenants.

Today, after receiving a new 0.5m telescope, the observatory is used again for scientific observations and for educational purposes. Also the telescope tower at the campus is still used: The 6” Steinheil refractor[75] is used as a solar telescope for education. Furthermore, the Lustbühel Observatory offers an insight into astronomy hosting public events like the Lustbühelfest or the “Lange Nacht der Forschung” (Long Night of Research).

Architecture

Gross floor area: ~1000m²
Measurements: ~40m x 20m

The Lustbühel Observatory is located at the Lustbühel, a hill in Graz Waltendorf where the city is less dense than in the city center. Trees surrounding the building help to shield the observatory from light and additionally, the lights leading to the building are designed to direct the light mainly to the ground.

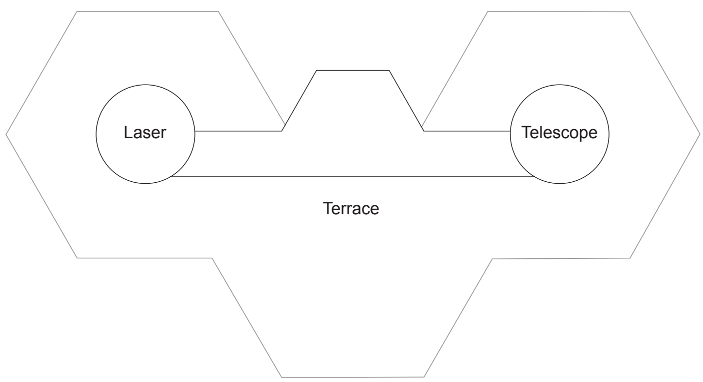
The architecture of the Lustbühel Observatory is extraordinary compared to other observatories. The floor plan of the building is formed of three hexagons joined together in the second floor, whereby the middle hexagon is adjusted to house the staircase connecting the three levels of the concrete building. On the first level, the hexagons of the first level are offset inwards whereof the hexagons on the first level overhang. This underlines the edges of the hexagons from the outside even more.

[74] Cf. Haupt 1976.
[75] Cf. Sternwarten in Österreich, May 2016.

The third level of the observatory consists mainly of observation rooms formed round to match the typical domes as enclosures, and a big observation terrace. From here large parts of the city can be seen.

Spatial distribution

The Lustbühel Observatory is shared by three different institutions, which are working independently from each other. According to this, the observatory can be divided into three areas defined by the hexagons they are in: The western hexagon accommodates the laser and offices of the Institute of Space Science of the Austrian Academy of Sciences, the eastern hexagon accommodates the telescope and offices of the institute of physics. The hexagon in the middle conjoins them with a common staircase and hallway and contains the offices of the Institute of Communication Networks and Satellite Communications of the Technical University of Graz. Additionally, the rooftop is shared and some rooms on the first floor are shared.



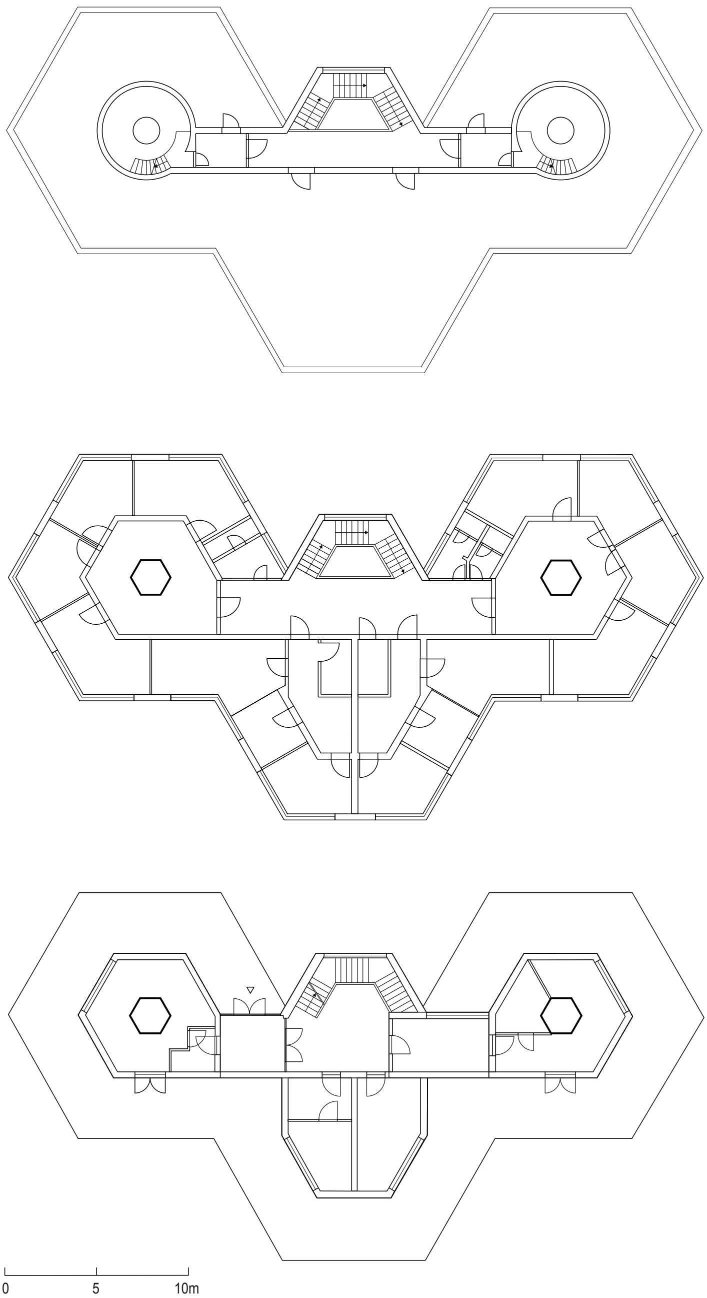
Infrastructure and construction

As the observatory is located within the city of Graz, the observatory is connected to the electricity grid and to the public water network. Nevertheless, it has an emergency diesel generator to ensure the power supply in case of a blackout.

The building was planned to have separate foundations for the telescopes, which are placed in the middle of the eastern and western hexagon. However, during the construction process something went wrong and now the pillars for the mount of the telescopes are connected to the building itself. This causes problems as every step in the hallway around the telescope causes vibrations and interference with the image.

052 View to the Telescope Tower and the Building of the Physics Insitute

053 Telescope at the Lustbühel Observatory



054 Telescope at the Lustbühel Observatory

KIELDER OBSERVATORY

Optical observatory, first light in 2008

Public observatory operated by the Kielder Observatory Astronomical Society (KOAS), founder and director: Gary Fildes

Location

Black Fell, Northumberland, North East England, UK

Kielder Water and Forest Park, protected Dark Sky reserve, 2km from Kielder Village

55°13′55″N 2°36′58.5″W

370m altitude

Typology / building form

Rectilinear form

Instruments

20” (0.5m) Newtonian reflector, manually operated

16” (0.4m) Meade LX200 reflector telescope, computer controlled

60mm Hydrogen Alpha Solar telescope[76]

Mount

20”: Split ring equatorial mount

16”: German equatorial mount[77]

Enclosure

The enclosures are 2 rotating turrets with a rack and pinion drive turning mechanism, each weighs six tons. They are constructed of steel octagons.[78]

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[76] Cf. Northumbrian water, Jan. 2016.
[77] Cf. Kielder Observatory Homepage, Jan. 2016.
[78] Cf. Galvanizers, Jan. 2016.

055 Observatory in Northumberland

056 Kielder Observatory

Facilities

Telescopes
Warm room / office
Observation deck / terraces

Costs

£ 450 000 / 557 600 €

Number of persons working at the observatory

-

KOAS volunteers

Climate conditions

Temperature: 0° - +18°C
Relative humidity: 77-85%
Rainfall: 56-98 mm/month, ~ 897 mm/year[79]
Best seeing conditions in England

[79] Cf. Met Office, Jan. 2016.

Work

The 20” Newtonian reflector is operated manually. It is mainly used to observe nebulae and distant galaxies. The second, smaller telescope is computer controlled. Via remote-control it can be operated from within the warm-room. The small solar telescope is used to observe the basic features of the sun (surface, solar flares, sun spots, etc.).[80]

Kielder observatory is a public astronomical observatory, which offers the possibility to observe the night sky for amateur astronomers as well as for school groups, researchers and specialists. The observatory regularly hosts events to bring astronomy closer to people of all ages. Additionally, Star Camps are organized in autumn and spring.

Architecture

Gross floor area: 246m²

Measurements: 41m x 6m

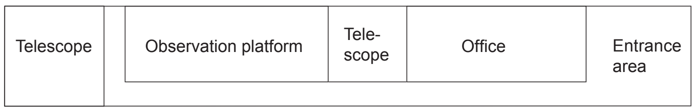
The elongated building by Charles Barclay Architects (2008) is functional and aesthetic at once. Located at the edge of a forest in Kielder Water & Forest park, the timber construction made of Douglas fir and larch cladding fits perfectly into the scene. Diagonal bracing is achieved through additional steel tie rods. Only on the side of the entrance it touches the ground. The elevated building takes advantage of the slope by using the height difference to put the turrets behind each other. Thereby both telescopes have an obstacle free view to the southern night sky. Skylights offer a view to the sky at night and natural light by day in the warm-room. From outside it doesn’t look like a typical observatory. Therefore, it is possible that until the square-turrets open up their aluminum shutters and rotate at night, the building will not be recognized as an observatory at first glance. The pier-like design of the observatory invites you to come and visit not only during stargazing events, but also during the day, when it acts as a viewpoint. The observatory´s orientation is in direction of the Kielder Sky Space by James Turrell only 1km away, which is considered its sister project.[81]

Spatial distribution

The relative small building features a very efficient sequence of allocated functions. The large covered entrance area offers a bench to sit down and a direct access to the warm-room / office area. This is also the

[80] Cf. Northumbrian Water Limited, Jan. 2016.
[81] Cf. Galvanizing, Jan. 2016.

room, where short presentations about the universe may be shown. The higher turret tower for the smaller, computer-controlled telescope can be entered from this room. After the first telescope turret, an observation deck (50m^2) offers space for amateur astronomers to set up their own telescopes and to see the stars. In the end of the sequence, there is the second telescope tower, which is lower than the first one.



Infrastructure and construction

The telescope mounts have separate foundations to disconnect the telescopes from the vibrations of the building caused by wind loads, people walking, etc. The telescopes are mounted to concrete-filled steel columns.

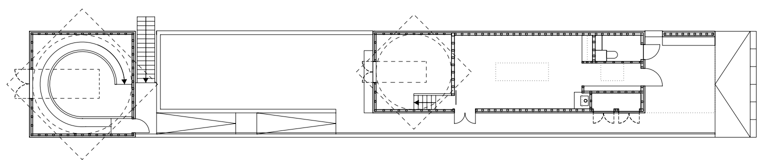
The self-sustainable building is completely off-grid. Electricity is produced by a 2.5-kW wind turbine and to be prepared for windless days, it is backed up by photovoltaic panels on the roof. A wood-fired stove heats up the warm room in cold nights.[82] And a composting toilet is the solution to a completely water-free structure.

It is planned to be a temporary structure with a life-span of 25 years.

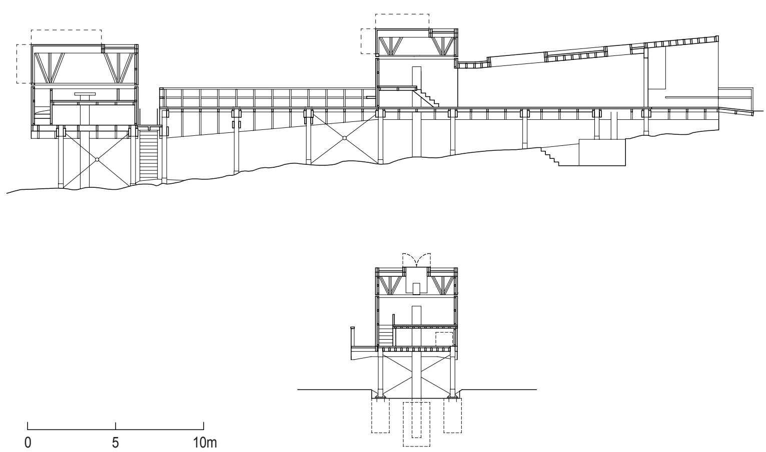
[82] Cf. Detail 2008/12, 1440.

057 Observatory in Northumberland

058 Enclosure and Telescope



059 Kielder Observatory floor plan



060 Kielder Observatory sections

PROJECT

INITIAL IDEA

The idea to build an observatory was initiated by an architecture competition of reTH!INKING called ”Astronomy Center Redsand”. The idea of building a research observatory somewhere at a remote place was fascinating. Nevertheless, the place suggested in the competition (London) didn´t fit for an observatory. Therefore, a new location had to be defined. Research about the perfect environmental requirements for the observatory showed that appropriate sites are rare and new sites hard to discover. However, eventually, I found a travel report online, which mentioned a good site in the High Atlas, where actual site testing was done. According to the travel report, the testing results were really good and the local astronomer hoped an observatory and a hotel were to be built at the site to bring astronomy closer to the people.

Thus, my project, the P2036 Observatory, is located on a mountain near Tizi n’Test, at approximately 2500m altitude. The observatory is planned to be equipped with a 40-50” telescope (azimuthal mount) for long term observations and all the facilities need to operate the telescope. Furthermore, the observatory should not be a mere research observatory, but a combination of research and university observatory. The P2036 should offer researchers and students an adequate environment to study and conduct research and in addition be open to the public. Hence, the room program also includes not only accommodation and offices for approximately 50 persons, but also a small planetarium, an exhibition and a place to observe the sky with small portable telescopes to catch a glance of the stars yourself. The project should contribute to strengthen the interest in astronomy, physics and education in general. Moreover, it should enhance international relations.

061 Stargazing at night


Spain
Atlantic Ocean
Rabat
Morocco
Tizi n´Test
Algeria
Western
Sahara
Mauritania

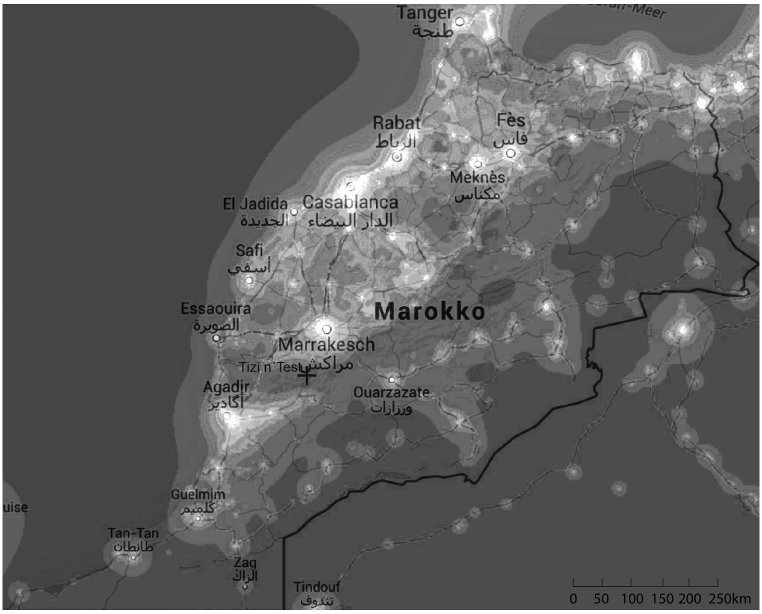
MOROCCO

The Kingdom of Morocco is a former French colony that reached independence in 1956. Today it is ruled by King Mohammed VI. The country has coastlines to the Atlantic Ocean, as well as to the Mediterranean Sea. Neighbouring countries are Spain, Algeria, Western Sahara and Mauritania. Its capital city is Rabat, which is located on the coast of the Atlantic Ocean. The total population is 33,850,000 inhabitants[83], with a main ethnic group of Arab-Berber and only 1% Jewish or other.[84] The main religion in Morocco is Muslim, only very few people are Christian or Jewish. Spoken languages are mainly Arabic and Berber dialects, but also French is common.

Topographically Morocco varies a lot and the country has many facets: To the west and north, there is the Atlantic Ocean and the Mediterranean Sea, to the south there is the Saharan desert and in between, there are mountains. The highest mountains are located in the High Atlas, which is the counterpart to the European Alps.

[83] Cf. Architecture d'Aujourd'hui 408, 48.
[84] Cf. Marokko-Info, Sept. 2016.

062 Map of Morocco



063 Light pollution map of Morocco

064 Astronomical observatories in Morocco

Astronomy in Morocco

There are at least four observatories in Morocco. One of them, the Oukaimeden observatory (J43) is located in the High Atlas. It is close to Mount Toubkal, only 50km from Marrakesh. The 0,5m telescope is operated by Cadi Ayyad University in Marrakesh. Further observatories can be found in Rabat and Marrakesh. The observatory in Rabat is also combined with a planetarium and the observatory in Marrakesh is a “Centre Culturel Atlas Golf Marrakech”. Additionally, a privately owned observatory exists in Merzouga. The “SaharaSky” observatory is located at the top of the Kasbah Hotel SaharaSky. Furthermore, also astronomer clubs exist.

Concerning astronomical education four universities offer programs: Casablanca, Rabat, Oujda and Marrakesh. There are ambitions to raise the interest of high school students in astronomy, but this isn´t an easy task within a developing country with high unemployment and illiteracy rates. Research concentrates on astroclimatology, astroparticles, cosmic radiation, near earth objects, search for supernovae, and helioseismology. Moreover, site testing for the E-ELT was done as Moroccan mountains were taken into account as potential sites.[85]

[85] Cf. Darhmaoui / Loudiyi 2007, 104.

065 Courtyard inside Bahia Palace

066 Kasbah

Architecture in Morocco

Today’s architecture in Morocco varies. Throughout history several influences have shaped the way of building, which is most obvious in urban planning. Big cities like e.g. Marrakesh consist of different parts: The historic city center, which is defined by its Souqs and alleys, is often called the Islamic part of the city, while the newer part of the city is called the “ville nouvelle” or “catholic part”. This part of the city was planned after a master plan during the time of colonialization, whereas the historic city center is naturally grown. Sometimes, also a small Jewish part is distinguished.

The traditional Moroccan architecture is famous for its Riads, Kasbahs and Ksars. The rooms of traditional housing typologies are usually arranged around a patio or garden, with openings towards the courtyard and rather closed facades in direction of the street to ensure privacy. The central patio acts like a chimney and pulls up the warm air, enhancing the cross ventilation of the building. Especially windows towards the street side are normally mainly from the 2nd floor upwards, small and shielded by musharabia, a form of wooden or metal grating. The rooms arranged around the courtyard often don´t have an assigned utilization and can be used flexible depending on the current situation. Vernacular architecture can be found at historic buildings in the city center, as well as in the mountains, where rammed soil in combination with straw was the main material to build traditional Berber houses and villages. The Kasbas (large fortified houses) and Agadirs (foritified castles for storage) in the mountains were not only used for housing, but also for the storage of anything of commercial interest: salt, sugar, gold, etc. Therefore, the 4-6 level high buildings also have corner towers.

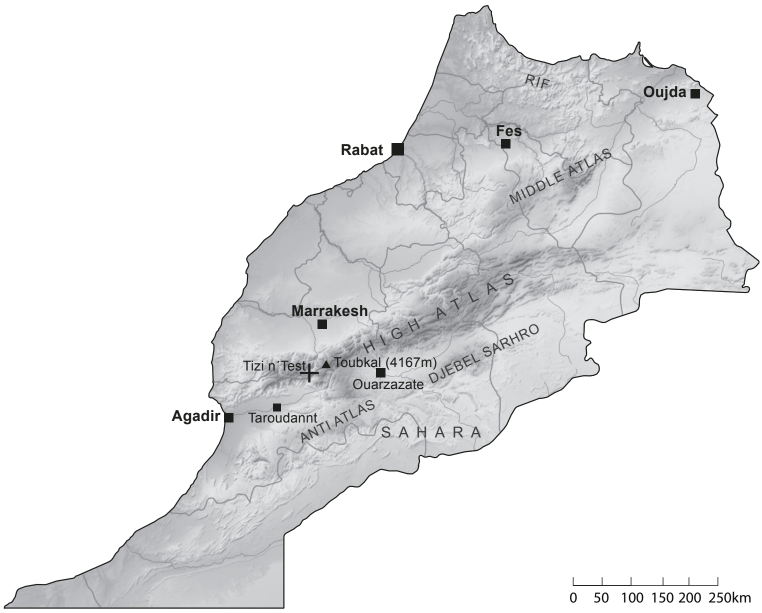
The traditional way of building with local materials like earth and stone can still be seen in the mountains, but people lost trust in this construction method because urban planning regulations prohibited the use of rammed soil for some time. Thus, nowadays most buildings are built out of concrete and brick. Now ambitions to a new approach towards local materials like earth, timber and stone raise, but concrete is still the main material used.

Modern architecture can be found primarily in cities; examples are the airport in Marrakesh, the Rabat Theatre, the Volubilis Museum in Meknes, etc.

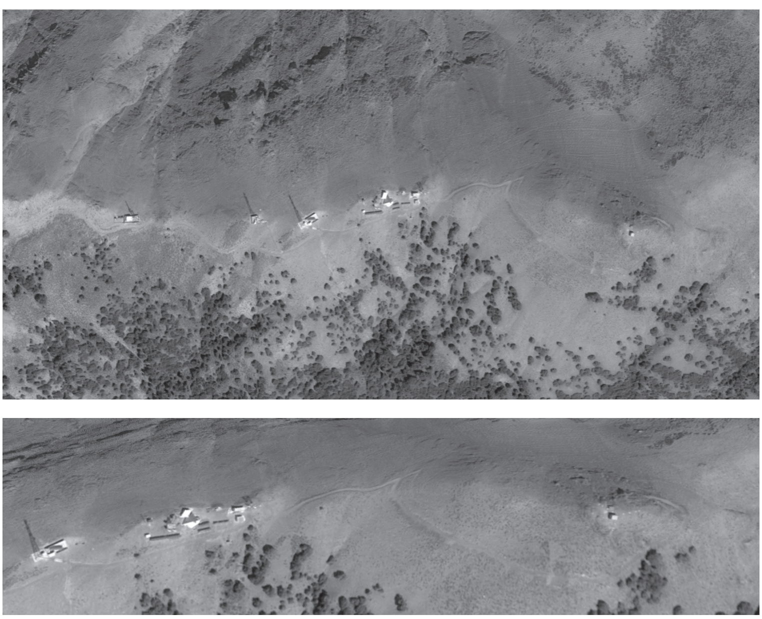
THE SITE

Near Tizi N'Test, Morocco
High Altlas, between Marrakesh and Taroudannt
30°52'36.0"N 8°23'34.5"W
2510 m altitude

067 The mountain



068 Topography in Morocco



069 Aerial view of the mountain

Topography and vegetation

The mountain is located west of Djebel Toubkal, between Marrakesh and Taroudannt. To the north, west and east, further mountains and valleys of the High Atlas can be seen, while in the south the Souss valley is visible and beyond, also the Anti-Atlas.

The environment is characterized by red clay hills, which stands in contrast to the partially green mountains. Also the mountain of the P2036 site is partially green due to shrubs. The greenery is mostly located on the south side and beneath 2400m. There is barely any vegetation on the top 100m of the mountain. This particular mountain ridge also seems to be the dividing line between a green area in the south and a rather vegetation free area in the north.

Climate

Data of Tizi n'Test, 400m below the site:

Temperature: -1° - +37°C

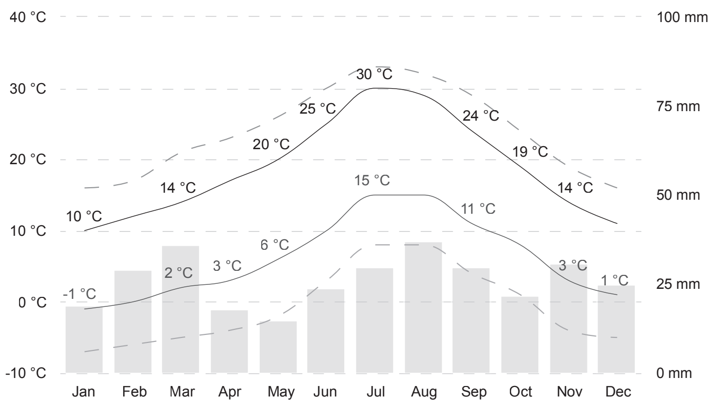
Relative humidity: 14-75%

Rainfall: 15-37 mm/month, ~ 320 mm/year[86]

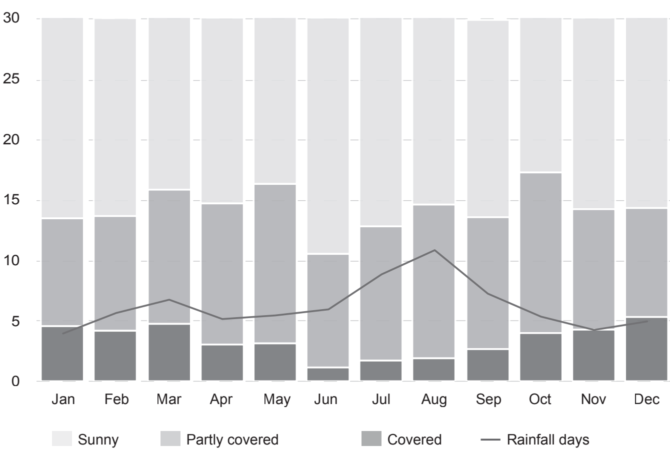
The climate at Tizi n´Test is a typical mountain climate with the possibility of snow in winter. Compared to the warm climate in Morocco, the mountain climate is definitely a bit colder. The site is located in 2500m altitude, which is above the average inversion layer of 2000m. Therefore less rain is expected to fall. The sea is quite far from the site, but it can be assumed, that the big valley reaching the sea to the mountains allows the favorable air layers of the sea to reach the mountains.

A rough comparison of the climates at the site through general climate data of the site and sites of major optical observatories shows, that the climate is quite suitable for observatories. Unfortunately, rain data and cloud coverage are often an average value of several 100m height at mountain sites. Hence, they cannot be taken into account completely, especially because the site data is of Tizi n´Test, which is 400m beneath the actual site of the project. In comparison to European sites, the site at

[86] Cf. Meteoblue, April 2016.



070 Temperature and precipitation Tizi n´Test, Morocco



071 Cloudiness Tizi n´Test, Morocco

Tizi n'Test shows clear benefits.

„Auf diesem einen Berg zwischen Marrakesh und Agadir hatte er eine besondere Atmosphäre entdeckt, die nachts so kippt, dass eine außerordentliche Klarheit auf dem Gipfel entsteht, die alle Astronomen mit den Ohren schlackern lässt. Gemeinsam mit einem Astronomieprofessor führt er dort Messungen durch und hat die wilde Idee, auf dem Gipfel ein Hotel für astronomieinteressierte Touristen zu bauen. Vom Laien, der einfach mal die Milchstraße von Nahem sehen will bis zum Experten, der dort seiner Forschung nachgehen kann. Noch steht aber nichts, bis auf den Astronomieprofessor und sein Teleskop."

„Das Panorama war unglaublich. Die Wolken waren unter den Gipfel gesunken, sodass sie aussahen wie das Meer."

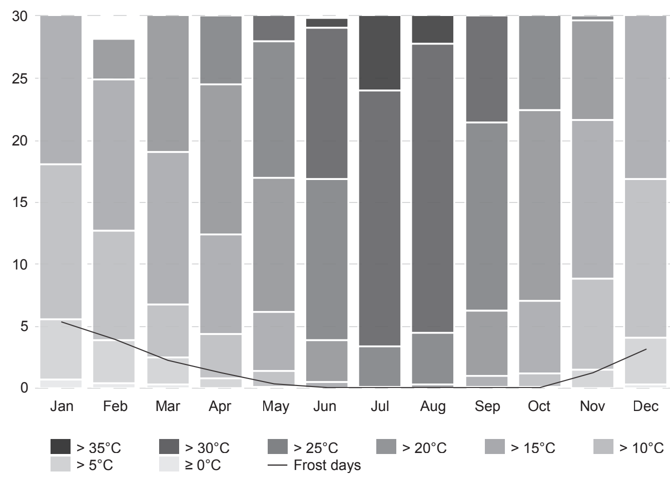
„Nachts hörten wir immer Sabylls Jubelrufe ‚+0,0372!' Er brach ständig Weltrekorde im Genauigkeitsmessen von Sternen."

"On this mountain between Marrakesh and Agadir he discovered a special atmosphere which tilts at night, so that every astronomer flabbergasts about the extraordinary clarity on the summit. Together with an astronomy professor he performs measurements and he has the wild idea to build a hotel for astronomy interested tourists on the summit. From the layman who simply wants to see the Milky Way up close to experts who can pursue research there. But yet there is nothing, except for the astronomy professor and his telescope. "

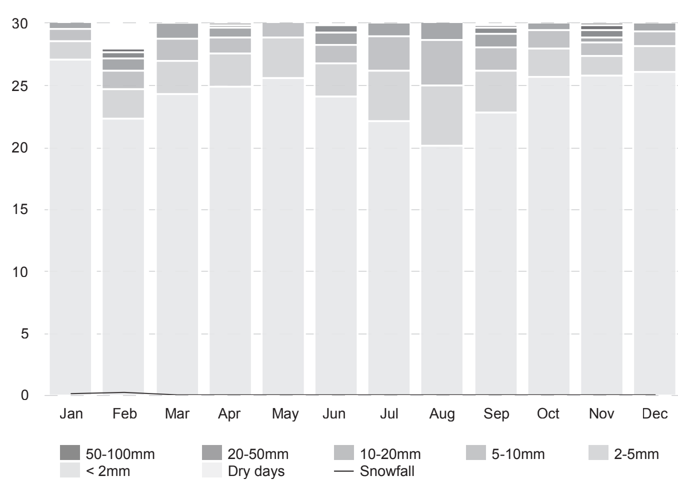
"The panorama was incredible. The clouds had fallen below the summit, so that they looked like the sea."

"At night we always heard Sabyll's shouts of joy ' +0.0372! '. He was constantly beating world records in precision when measuring stars."[87]

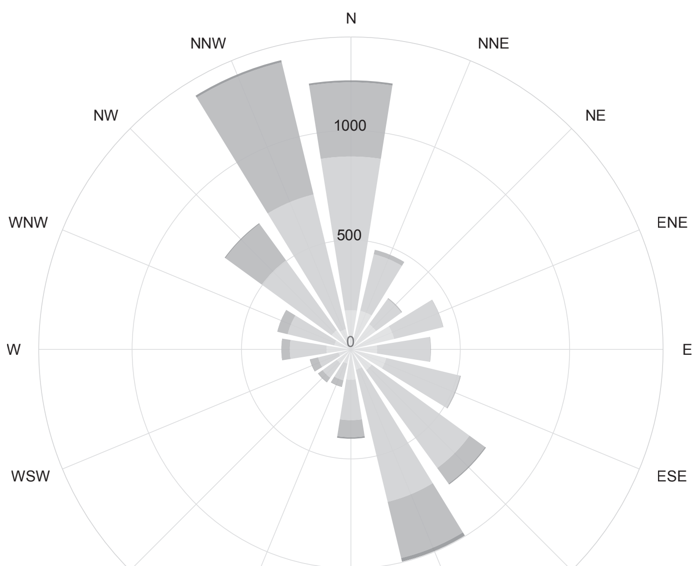
[87] Kuhlmann, Reisedepeschen, Feb. 2016.



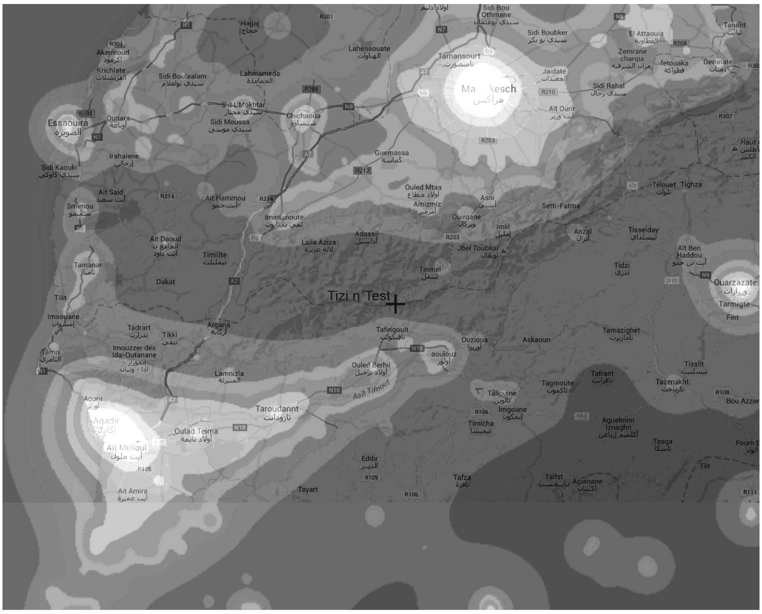
072 Maximum Temperature Tizi n´Test, Morocco



073 Precipitation Tizi n´Test, Morocco



074 Wind rose Tizi n´Test, Morocco



075 Light pollution map of the area around Tizi n´Test

076 Road map of Morocco

Surrounding environment and light pollution

The mountain is a rather remote place, only very few houses are located close to the site and Berbers are the main inhabitants of the little mountain villages in the High Atlas. The Berbers are locals with a rather traditional and simple lifestyle, who are not to be expected to be a source of interference for the observations. The next small village is located in approximately 3km linear distance in a valley between the mountains. In general, the light pollution level at the High Atlas is extremely low and big cities are far enough away. Additionally, the clouds beneath the summit would protect the observatory additionally if necessary. The only possible source of interference may be the Tizi n'Test pass, but the route isn't very often used and especially at night time the number of cars to be expected is negligibly. Furthermore, the route is roughly 2km linear distance and 400m height distance away. However, according to light pollution maps the location of the P2036 Observatory offers a perfectly dark sky.

Accessibility of the site

Tizi n'Test is far in the mountains and can only be reached through the Tizi n'Test pass reaching from Marrakesh to Taroudannt. These two cities are closest to the site. Both offer an airport, which paves the way for international visits at the observatory. The distance from Tizi n´Test to Marrakesh is approximately 137km, which is a drive of nearly three hours. Taroudannt is 90km away; it takes approximately one hour and 45 minutes to reach the city.[88]

At the moment, warnings can be found that the road may be closed for a few hours or days in the rare case of snowfall. These warnings are familiar to astronomers, as this is often the case at the remote observation sites. The eventuality of closed roads needs to be taken into account when it comes to supply deliveries or unexpected overnight stays at the residence/hotel of the observatory. However, most astronomers are acquainted with the necessity of 4WD vehicles to reach the mountain top. And following the construction of the observatory, improvements of the road conditions may be anticipated. Currently, access to the site is possible through the dirt road leading up the mountain.

[88] Cf. Google Maps, Sept. 2016.

Planetarium

Water supply

Meeting Point

Power Supply

Visitor Center

Technical Facilities

Exhibition

Cafeteria

Server Room

Reception

Maintenance Workshop

Hotel / Residence

Hotel rooms

Lightning Conductor

Telescope

Blackout System

Library

Wiring and Fibre Optic Cable

Lecture Hall

Telescope Enclosure

Control Room

Office / Insitute

Turning Mechanismn

Observations Slit / Shutters

Seminar Rooms

Bureaus

Tea Kitchen

Telescope Foundation

Common Room

Places of encounter

Outside Stargazing Area

Recreation Area

Parking space

Common spaces

ROOM AND FUNCTIONAL PROGRAM

The program is calculated for approximately 25-50 persons staying regularly overnight. To get a first impression of astronomy and the work done by astronomers, there should be a visitor's center for the public. The main focus of the visitor center should be on students, amateur astronomers and people with a general interest in astronomy. Furthermore, locals are expected to be working at the hotel, cafeteria, exhibition area, etc.

077 Cloud of functions

Visitor's center	250m² (+50m²)
Exhibition space	75m²
Planetarium	50m² (x2)
Sanitary rooms	25m²
Reception area	25m²
Back office	40m²
Storage for telescopes	15m²
Storage exhibition	20m²

Residential area	1210m²
Hotel rooms x51	1020m² (~20m² / room)
Fitness room + showers	80m²
Music room	25m²
Common room / TV room	60m²
Sanitary rooms	25m²

Office area	757m²
Offices and Labs	500m²
Seminar rooms x2	80m²
Library & study room	40m²
Common room	30m²
Tea kitchen	12m²
Sanitary rooms	25m²
Server room	30m²
Archive	40m²

Conference area	80m² (+80m²)
Auditory / Lecture Hall	80m² (x2)
(Seminar rooms)	(80m²)
(Sanitary rooms)	(45m²)

Cafeteria	160m²
Storage	20m²
Kitchen	40m²
Dining hall	100m²

Facility services	145m²
Staff room	20m²
Laundry room	40m²
Storage x3	60m²
Changing room + shower 25m²	

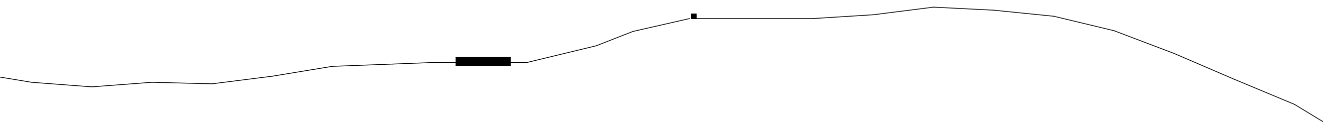
Workshop	60m² (+40m²)
Maintenance Space	40m² (x2)
Storage Workshop	20m²

First-aid room	20m²
Technical facilities	350m²
Telescope building	40m²

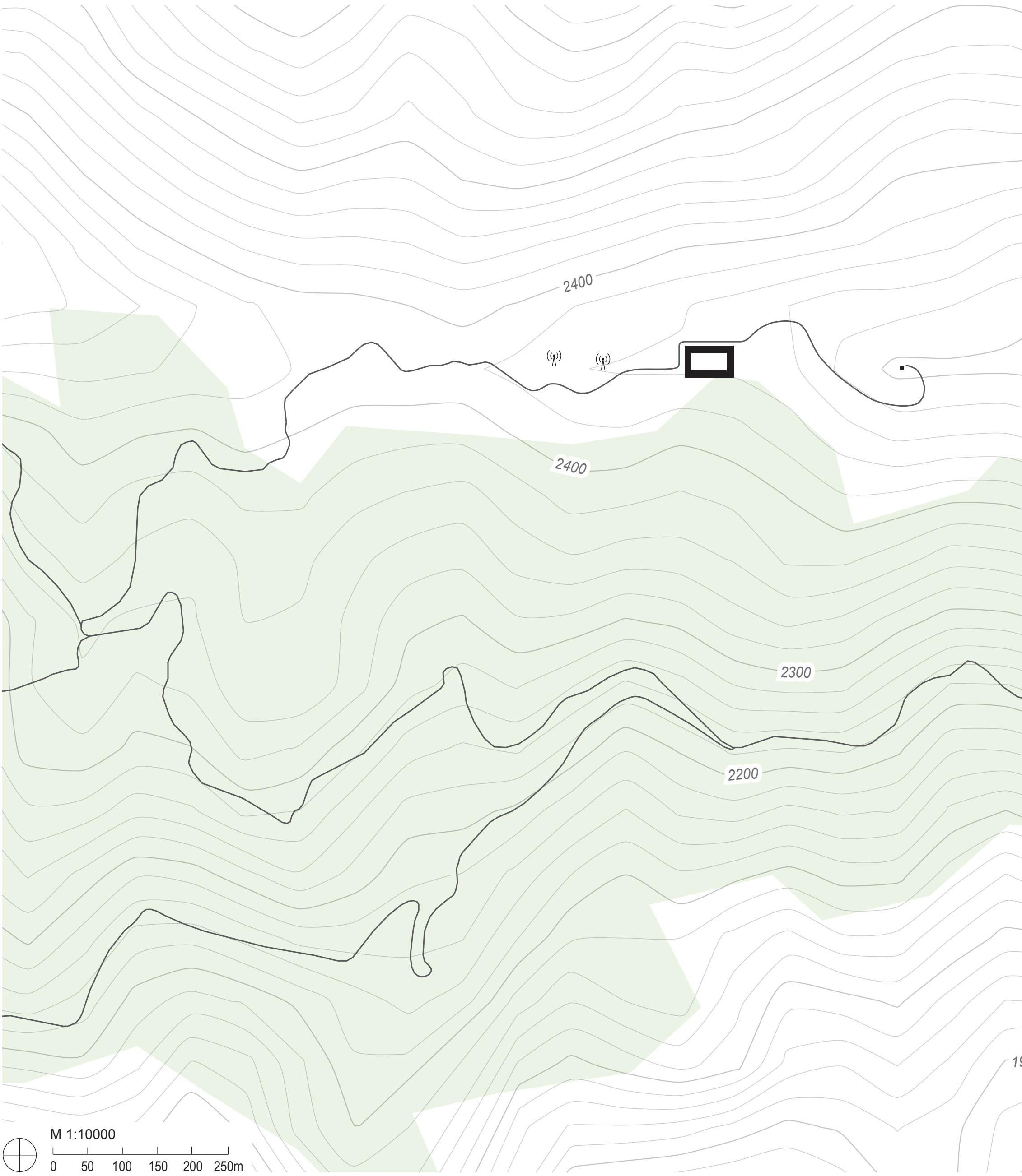
Outside space for stargazing

Parking space

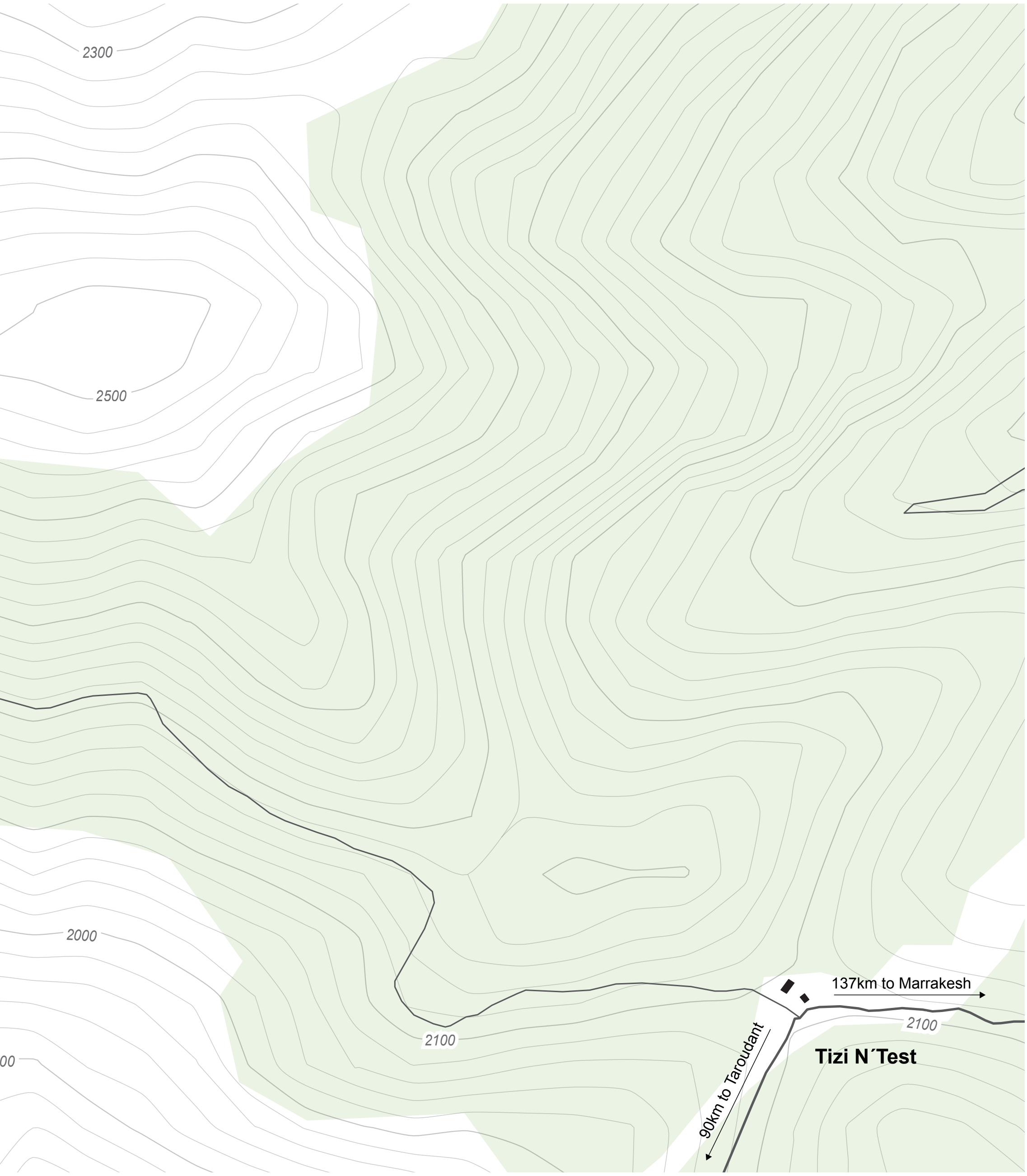
TOTAL	3072m² (+ 170m²)

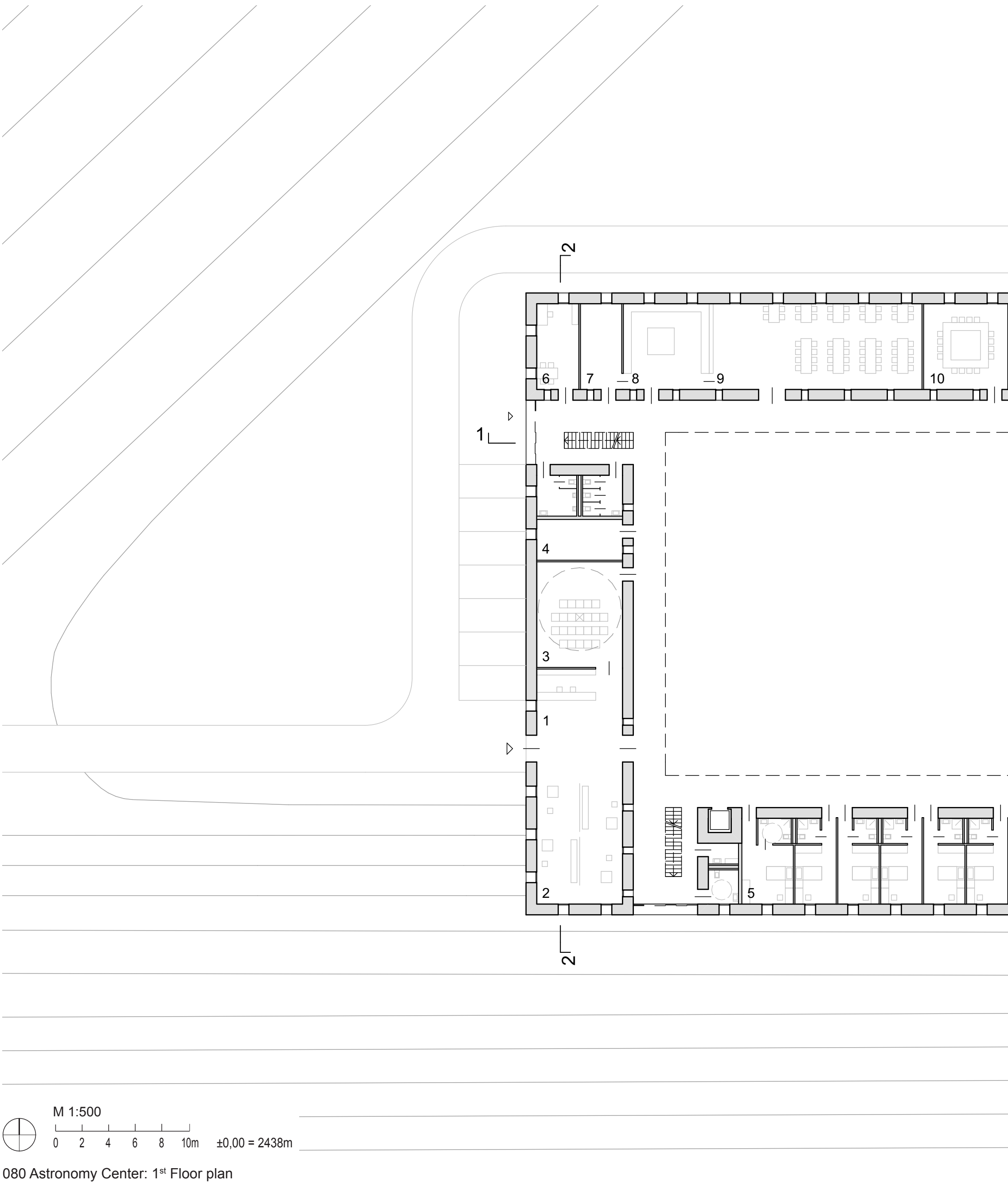


DESIGN

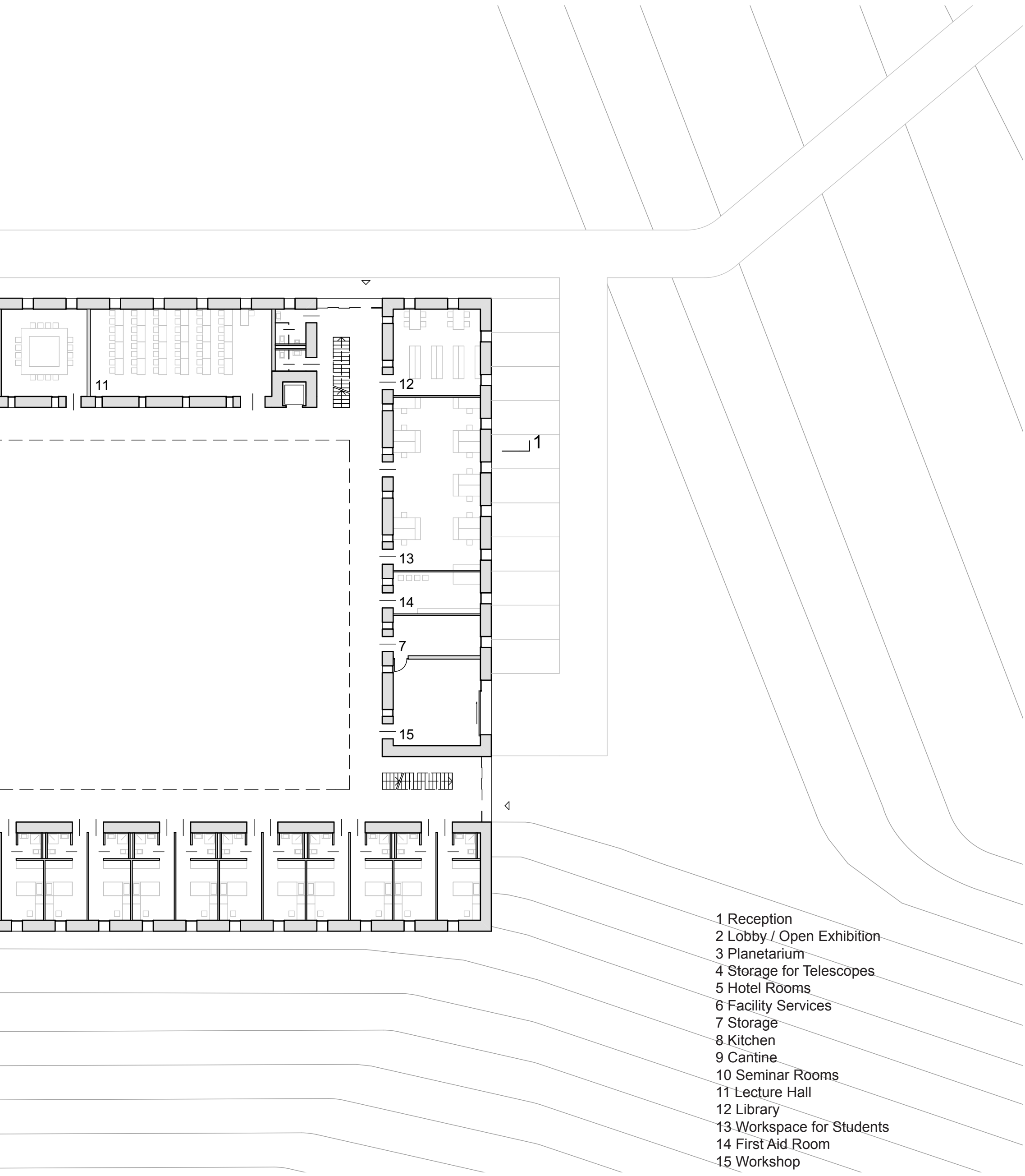


079 Site plan

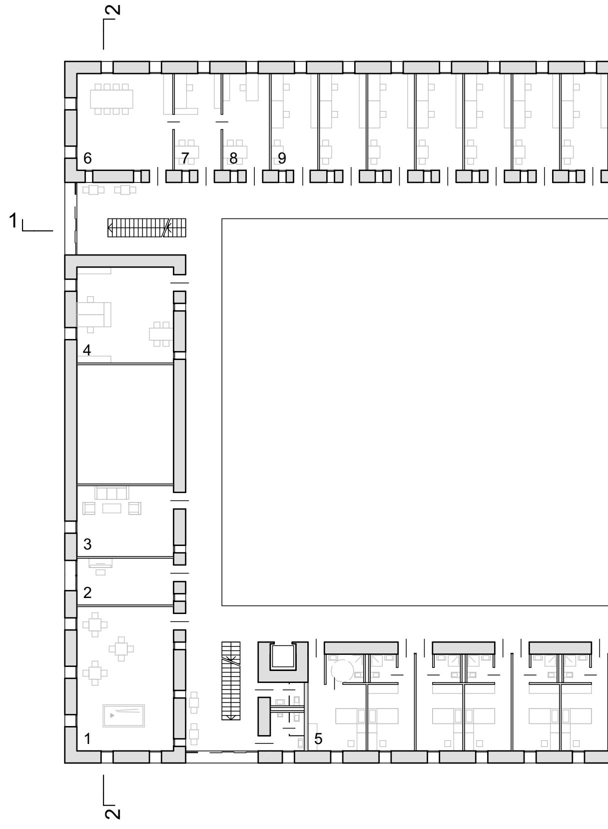

2300
2500
2000
2100
137km to Marrakesh
2100
Tizi N´Test
90km to Taroudant



080 Astronomy Center: 1st Floor plan



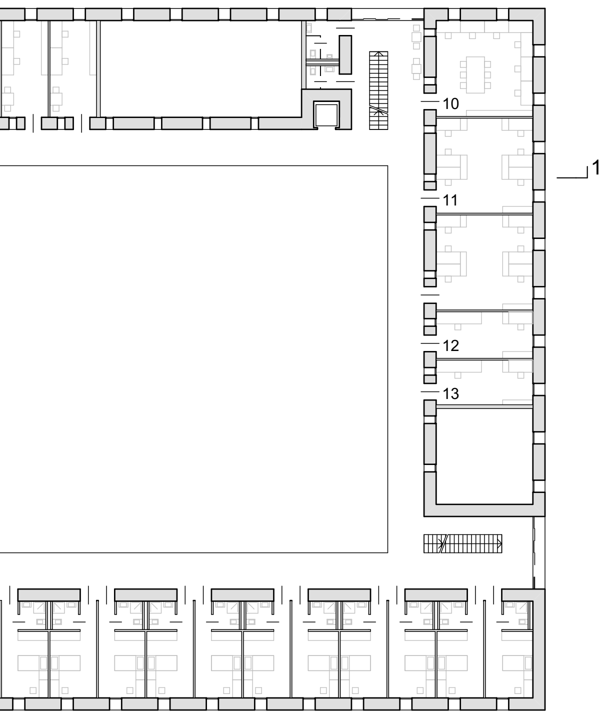
1 Reception
2 Lobby / Open Exhibition
3 Planetarium
4 Storage for Telescopes
5 Hotel Rooms
6 Facility Services
7 Storage
8 Kitchen
9 Cantine
10 Seminar Rooms
11 Lecture Hall
12 Library
13 Workspace for Students
14 First Aid Room
15 Workshop



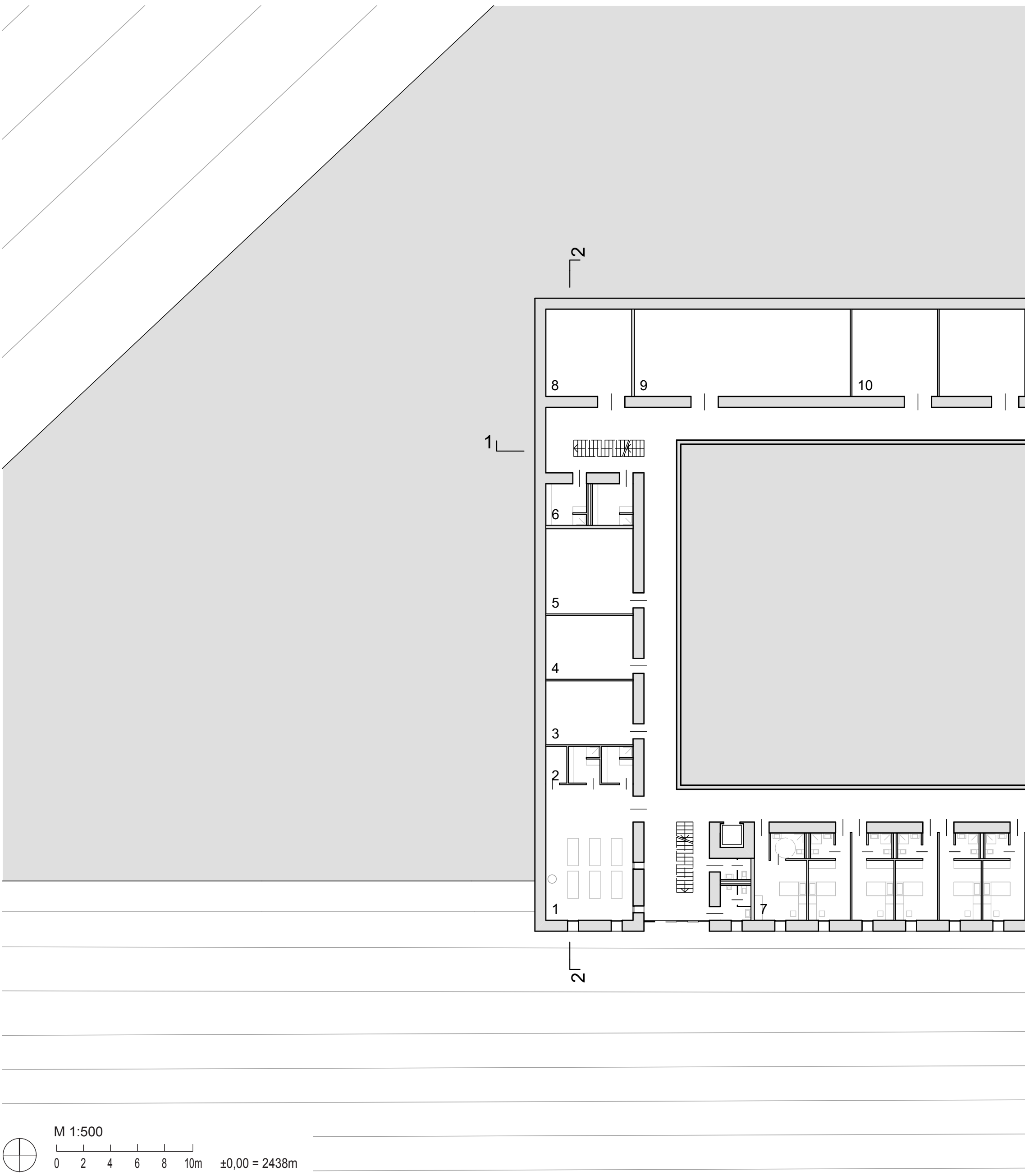
M 1:500

0 2 4 6 8 10m ±0,00 = 2438m

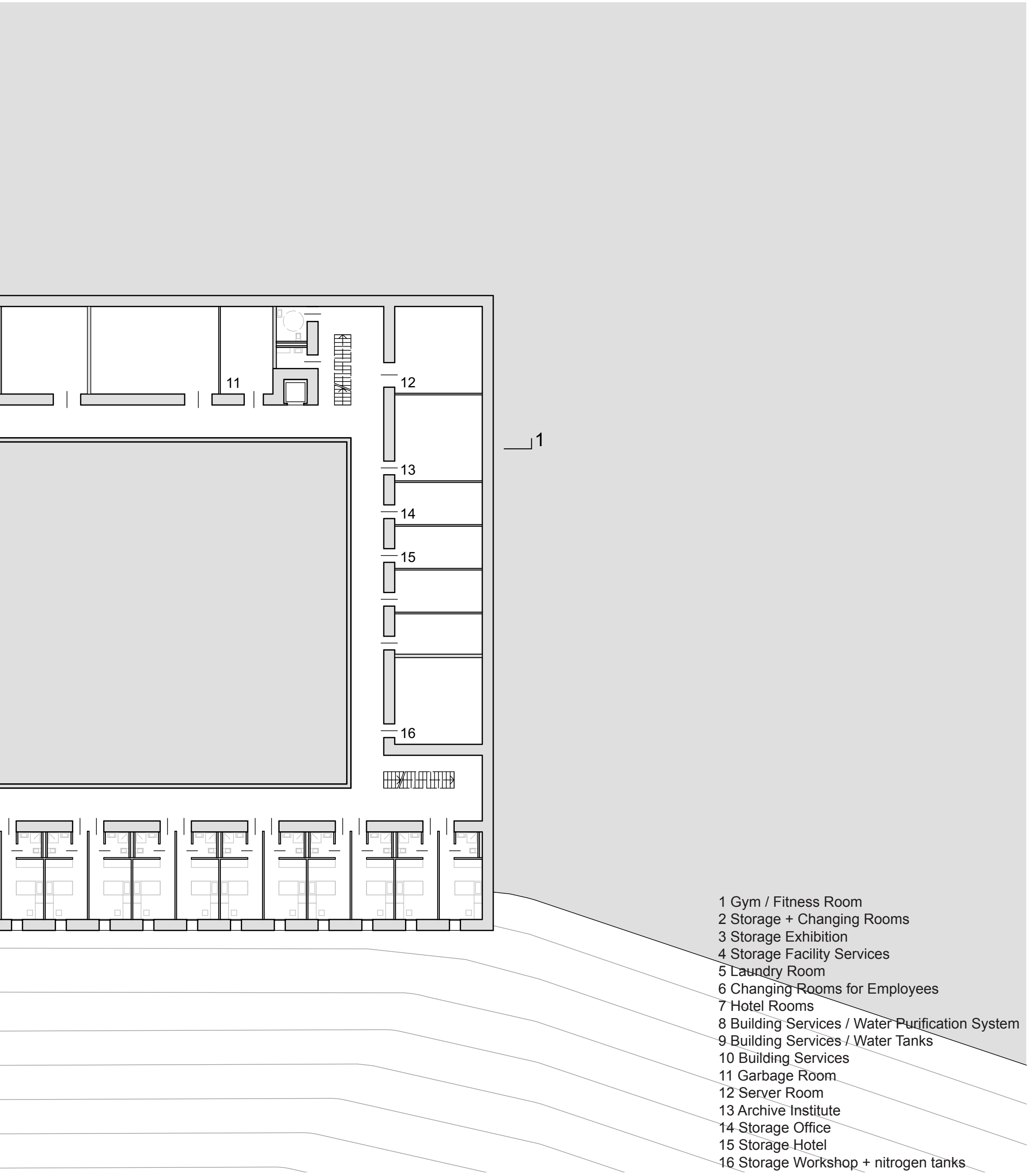
081 Astronomy Center: 2nd Floor plan



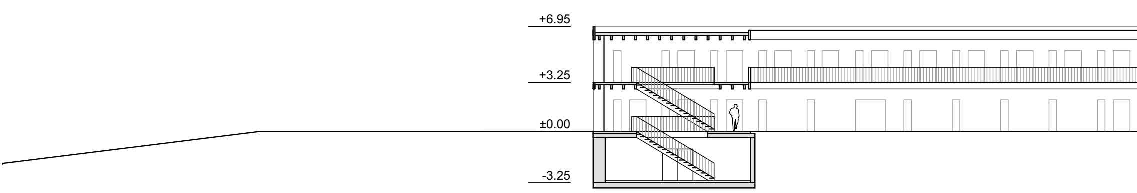
1 Common Room
2 Music Room
3 TV-Room
4 Office Hotel
5 Hotel Rooms
6 Common Room
+ Tea Kitchen Institute
7 Secretariat
8 Office Director
9 Offices Institute
10 Control Room
11 Offices
12 Electrical Lab
13 Optical Lab



082 Astronomy Center: -1st Floor plan



1 Gym / Fitness Room
2 Storage + Changing Rooms
3 Storage Exhibition
4 Storage Facility Services
5 Laundry Room
6 Changing Rooms for Employees
7 Hotel Rooms
8 Building Services / Water Purification System
9 Building Services / Water Tanks
10 Building Services
11 Garbage Room
12 Server Room
13 Archive Institute
14 Storage Office
15 Storage Hotel
16 Storage Workshop + nitrogen tanks

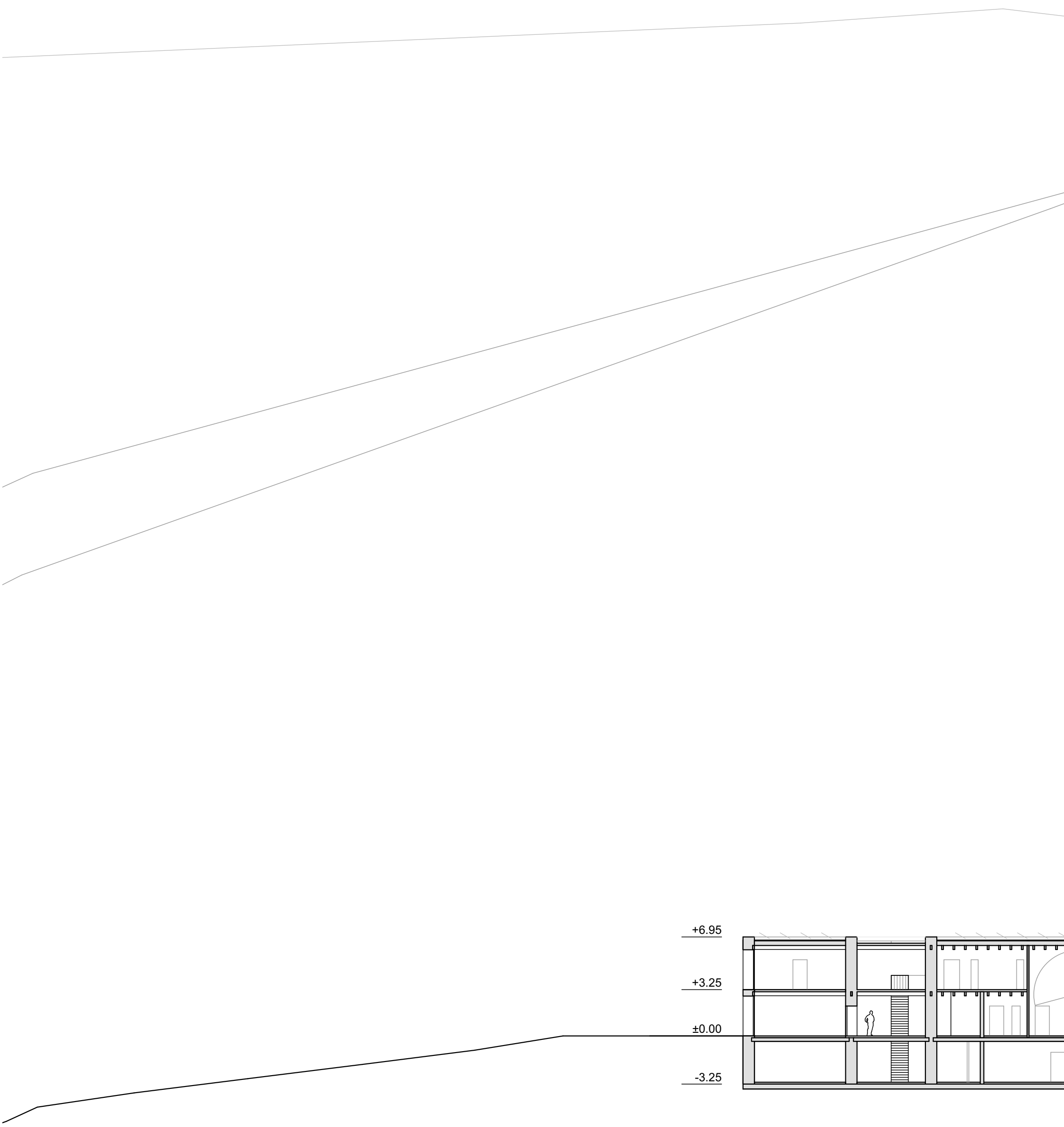


M 1:500

0 2 4 6 8 10m

083 Astronomy Center: Section 1-1

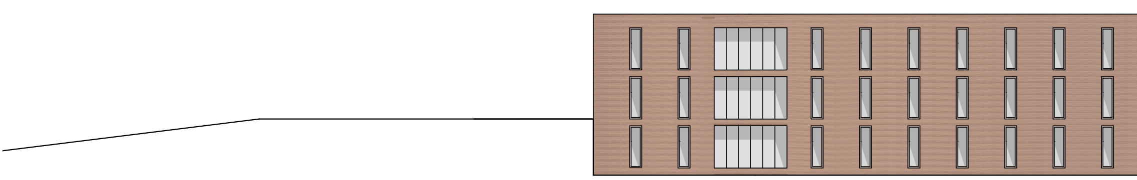
+6.95
+3.25
±0.00
-3.25



M 1:500

0 2 4 6 8 10m

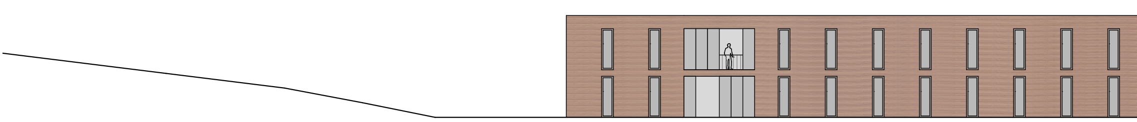
084 Astronomy Center: Section 2-2



M 1:500

0 2 4 6 8 10m

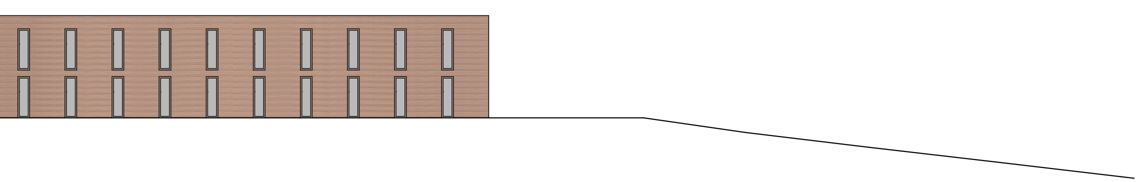
085 Astronomy Center: Elevation south

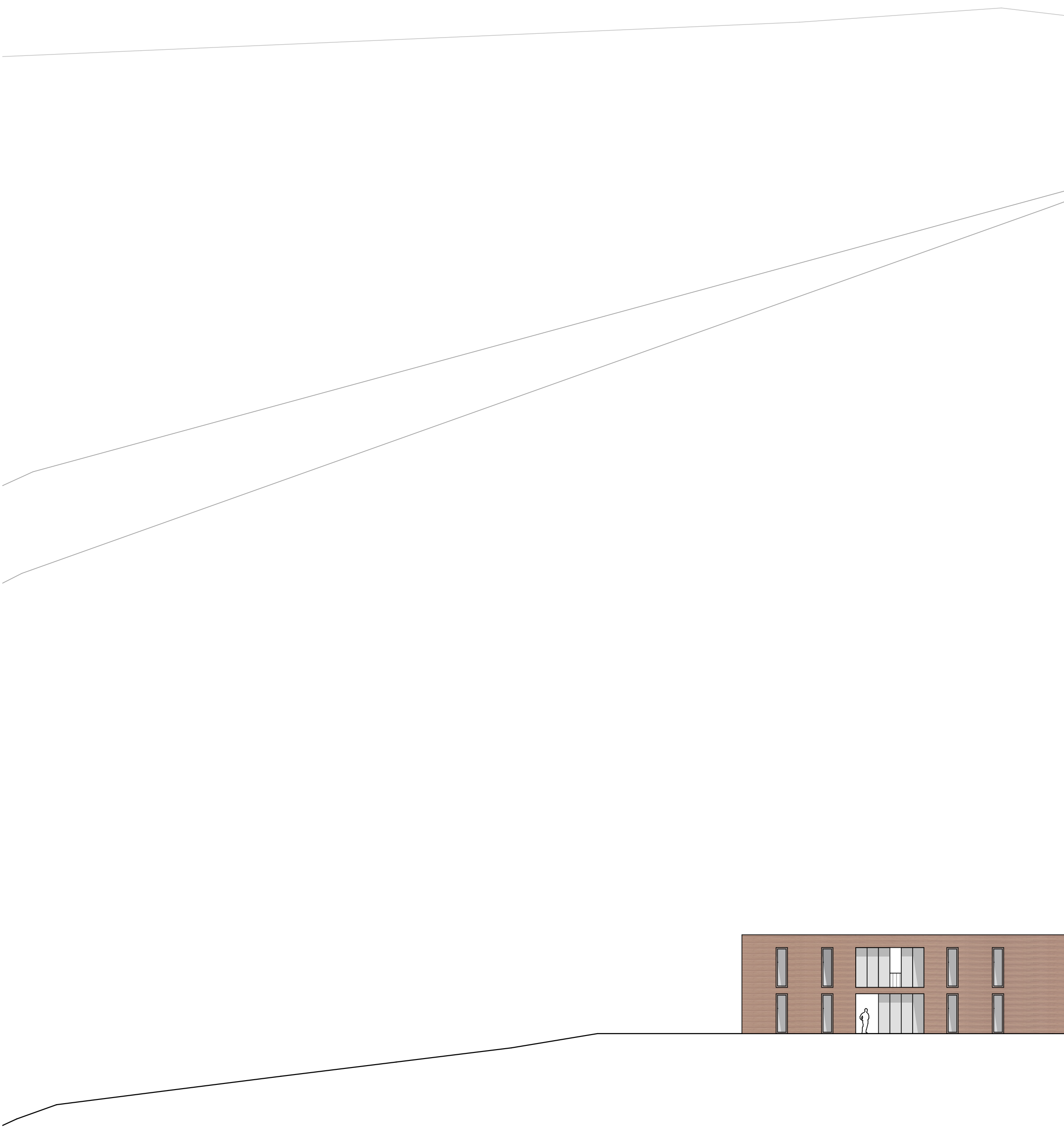


M 1:500

0 2 4 6 8 10m

086 Astronomy Center: Elevation north

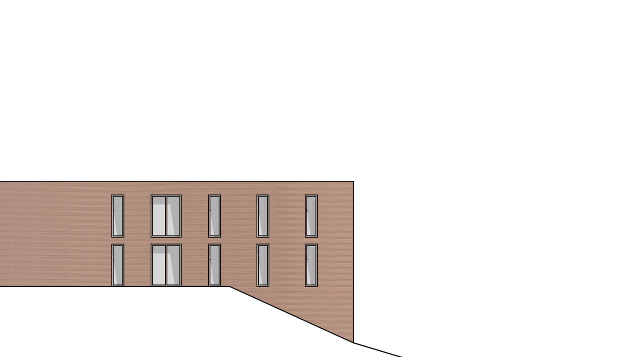


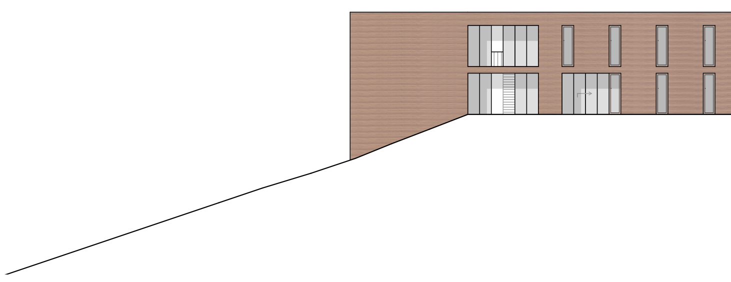


M 1:500

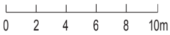
0 2 4 6 8 10m

087 Astronomy Center: Elevation west





M 1:500

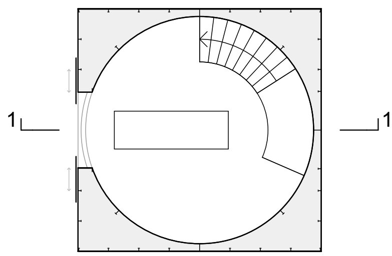


088 Astronomy Center: Elevation east

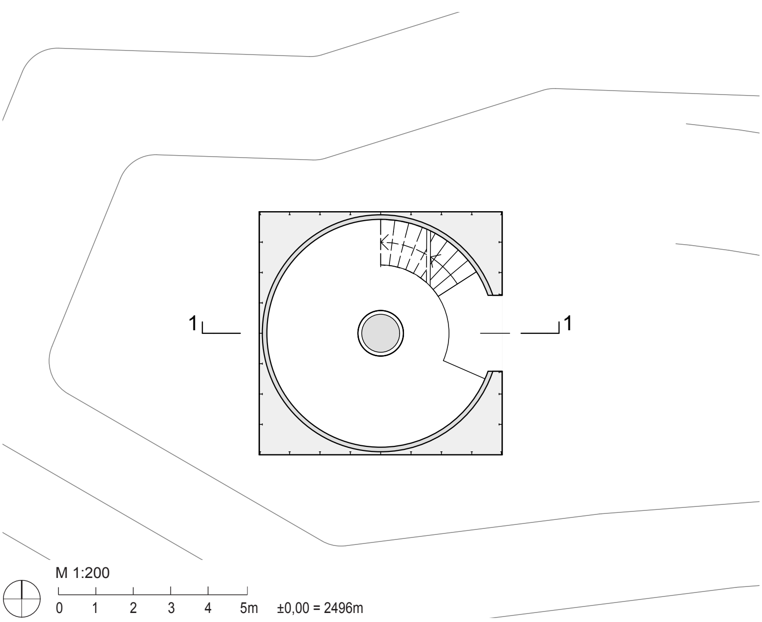
M 1:2000

0 10 20 30 40 50m

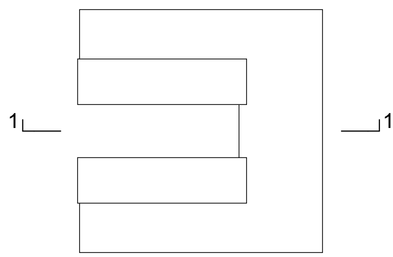
089 Elevation Astronomy Center and Telescope



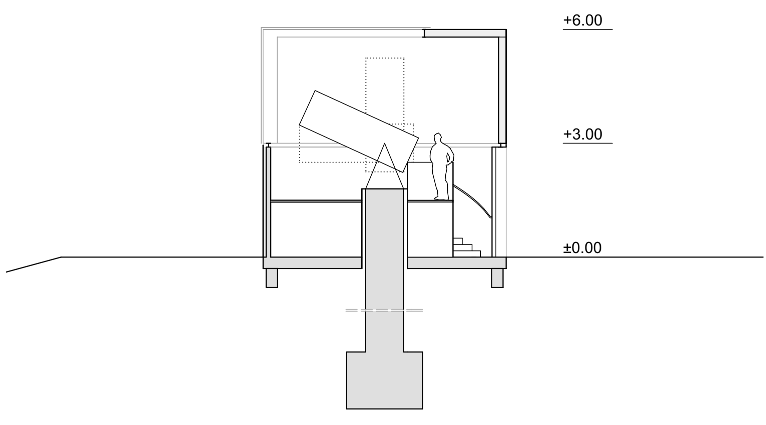
090 Telescope: Floor plan, upper part



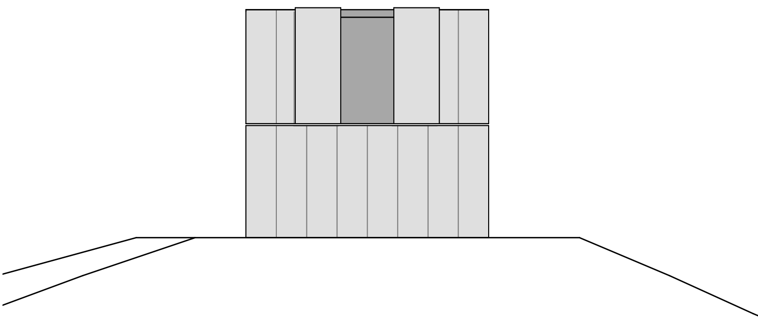
091 Telescope: Floor plan, lower part



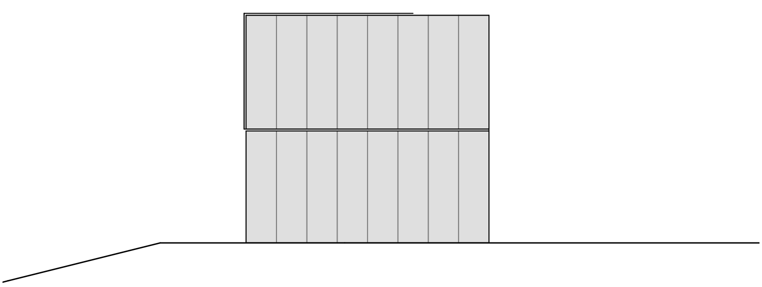
092 Telescope: Top view



093 Telescope: Section 1-1

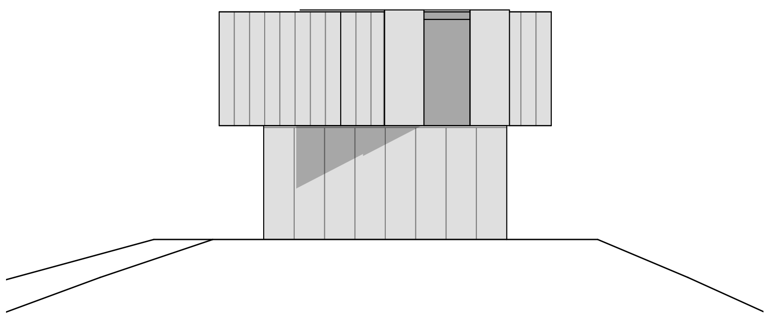


094 Telescope: Elevation west

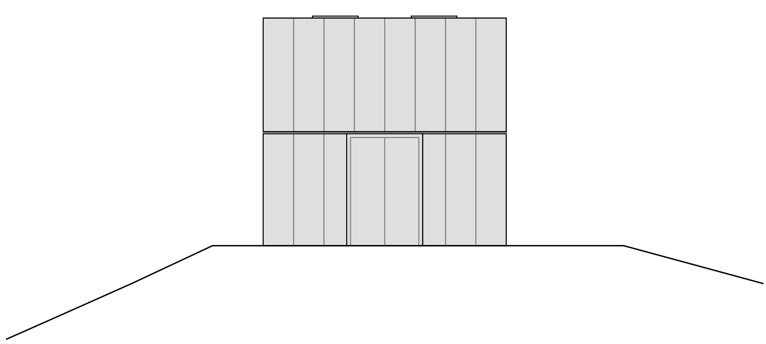


M 1:200
0 1 2 3 4 5m

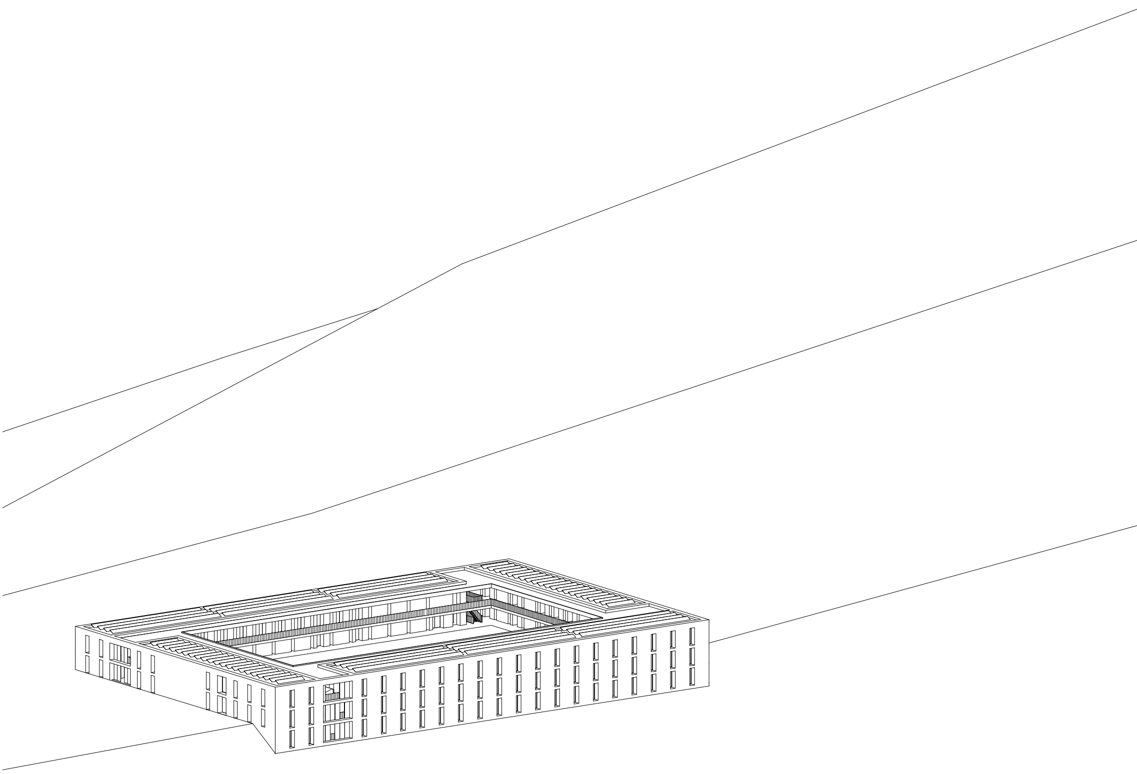
095 Telescope: Elevation south



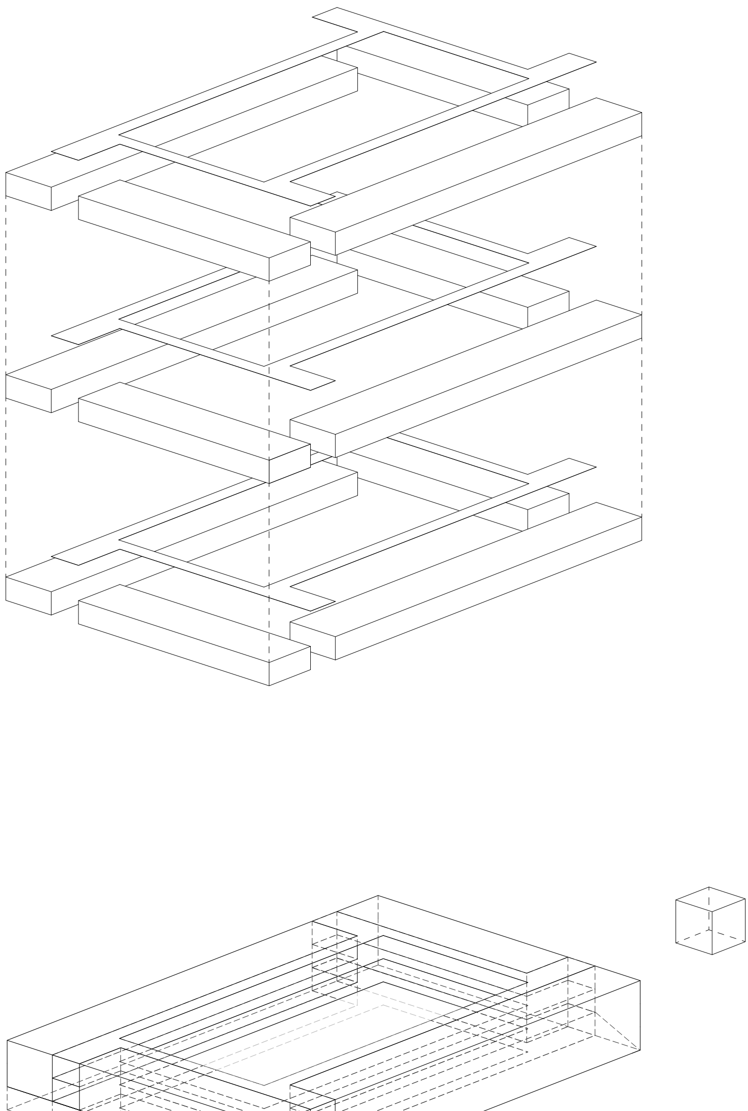
096 Telescope: Elevation west, rotated upper part



097 Telescope: Elevation east



098 Axonometry



099 Axonometry

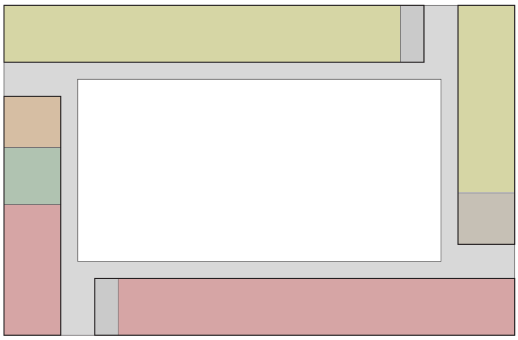
Form and location

The location on the mountain was chosen according to the natural formation of the mountain. The steep mountain offers very few places to build the observatory without major excavation work. Hence, the chosen site is a small natural plateau approximately 550m linear distance and 60m height distance of the highest point of the mountain top. The site of the telescope building will be close to the top of the mountain, approximately 250m from the observatory. A second site at the very top of the mountain is also suitable for the telescope, but the direct visual contact from the control room to the observatory is only possible at the chosen site. The decision to place the telescope separately was made due to the needs of a professional telescope, which otherwise would be influenced by the heat, light, etc. of the Astronomy Center.

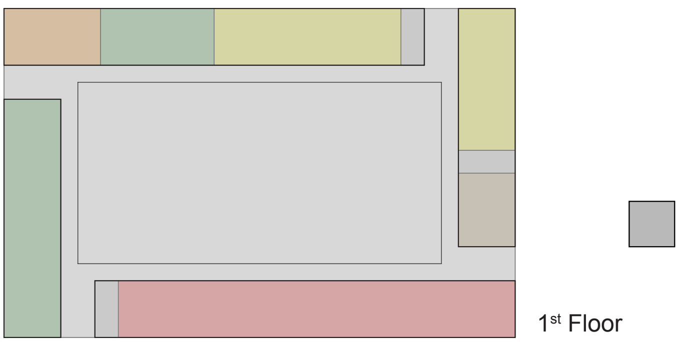
The design of the P2036 observatory tries not to interfere too much with nature and the natural formation of the mountain. In contrast, the elongated shape of the south and north façade should underline the natural plateau of the mountain ridge. The functions of the building are arranged around a courtyard, separated by open staircases and passage ways. This open passage way forces the people of the observatory to live with nature and to experience the current weather conditions, which also have an influence on the observation conditions. This direct link should raise the awareness of students and visitors about the importance of the environment to the observations.

The big courtyard in the middle offers a safe space for stargazing nights, far from steep mountain edges. Inside the courtyard, the view of the stars and to the telescope is in focus; the beautiful view down to the valley can be enjoyed from the hotel rooms, the common room, the fitness room, the exhibition space and small terraces. Additionally, the north side of the building offers a nice view to the continuing mountain region of the High Atlas.

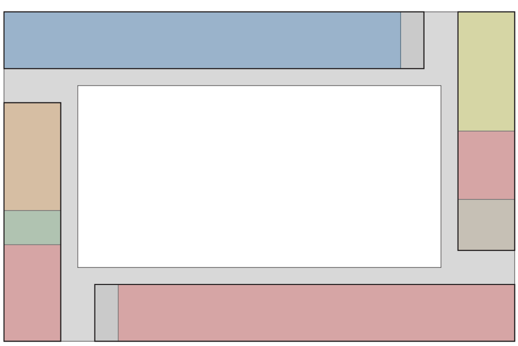
The telescope building at the top of the mountain is a rectangular, almost cubic structure, whose upper part opens up and rotates at night. The telescope and its enclosure can be controlled through remote control from the control room at the Astronomy Center. In contrast to the Astronomy Center it is situated close to the top of the mountain and is therefore located at a quite prominent place. This is necessary due to achieve a better view to the sky and as the telescope is the most important part of an observatory, the prominent location is legitimate.



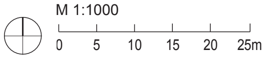
2nd Floor



1st Floor



-1st Floor

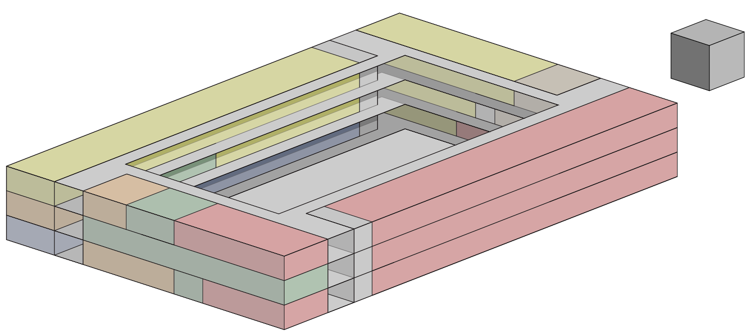


100 Program

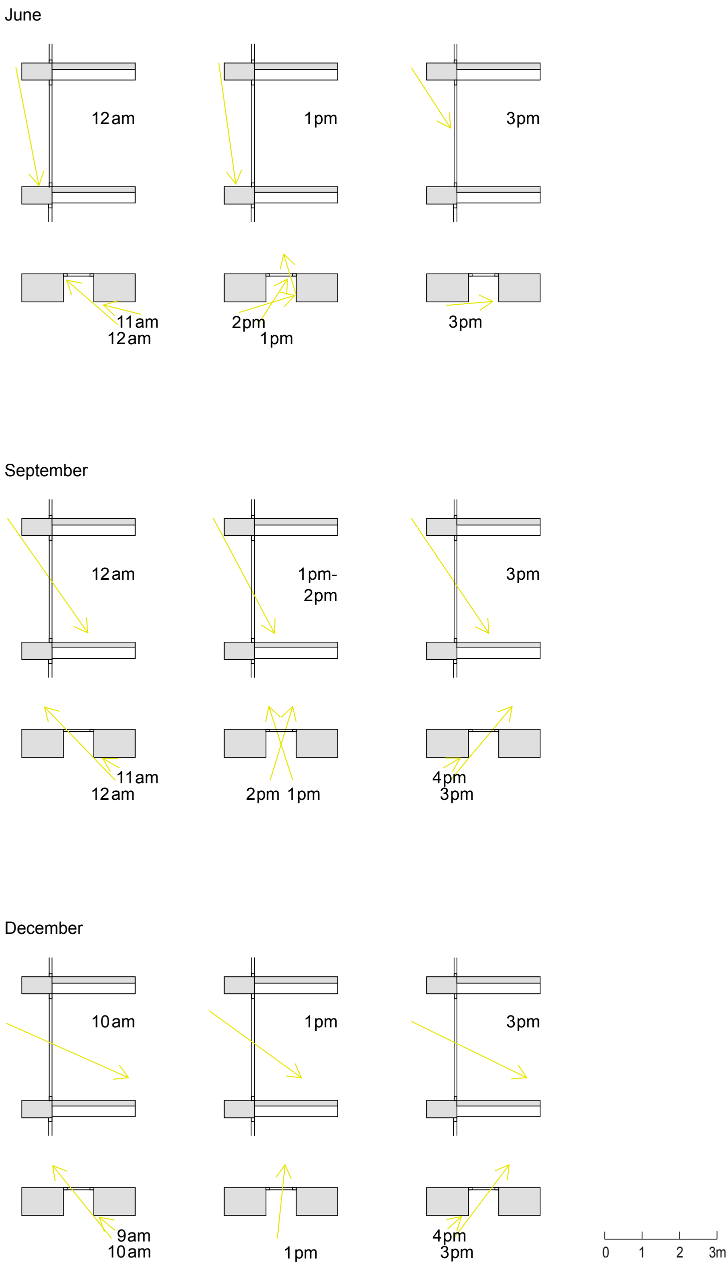
Program

The P2036 Observatory unifies all its necessary functions in one building, except for the telescope, which needs to be placed separately. The functions are distributed in different parts of the buildings, which are arranged around a central courtyard. Public functions like the planetarium, the exhibition, cafeteria, seminar rooms, etc. are in the first floor, while more private functions, are placed in the second floor. Multiple passage ways with sliding doors connect the courtyard of the building to the outside and offer access to the observatory from 3 sides. An additional "official" entrance for visitors and persons, who wish to check in to the hotel, is on the west side of the building.

- Hotel: 51 Rooms & Common Areas
- Public: Exhibition, Planetarium, Cafeteria
- Institute / Offices
- Hotel-Staff
- Workshop
- Technical Equipment
- Circulation / General Spaces
- Telescope



101 Program 3D



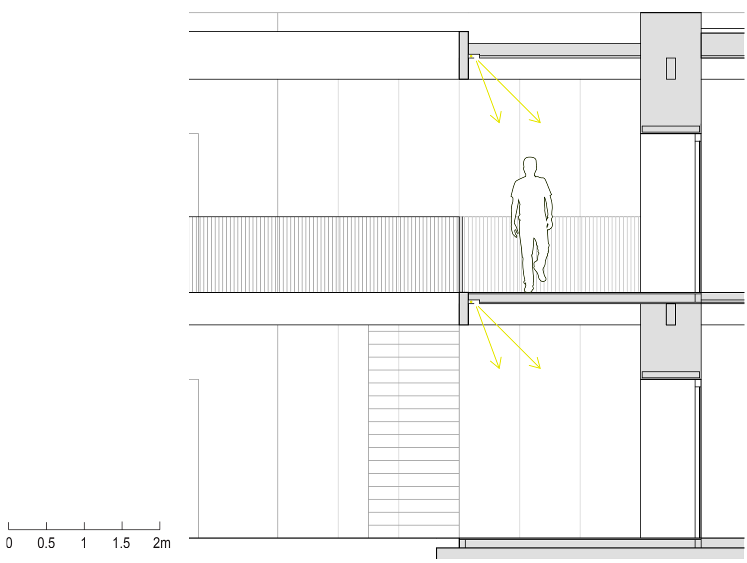
102 Sun study of the hotel rooms

Sun light and artificial lightning

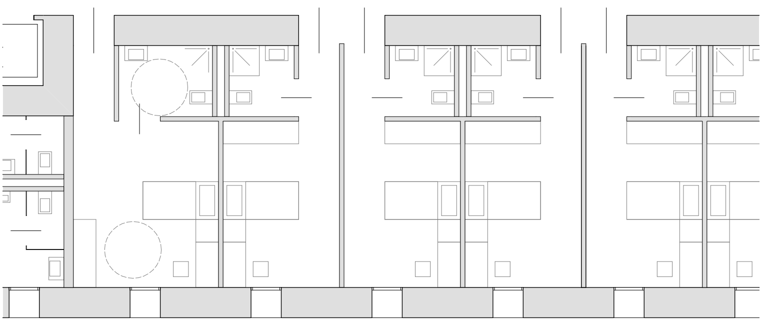
The lightning concept of the observatory is in this case a darkening and shading concept. During daytime, there is the problem of possible overheating in summer, while at night, light scattering needs to be avoided. Therefore, the hotel rooms are not oriented towards the telescope and an interior darkening system will be installed at every window. The same blackout blinds can be used during the day to darken the room to sleep.

The orientation of the hotel rooms towards the south helps to save energy during winter, when the sun is lower at the sky and reaches the glass surface of the windows. During summer, the massive wall construction provides shade and avoids overheating.

As light pollution also needs to be avoided at the outside passageways, only punctual light sources with low luminosity will be installed and the light will be directed only towards the floor of the passageway. To avoid light scattering at the staircases, the sliding panels need to be closed at night.



103 Artificial lightning



104 Standard single rooms

105 Possible 2-bed rooms for couples or in case of unexpected overnight stays

Hotel rooms

The hotel rooms are rather simple rooms, equipped with a bed, a wardrobe, a bedside table, a small desk and a chair. Each room has its own bathroom. If necessary, a second bed can be added to the room, but standard rooms are single rooms.

Water supply

An average person needs approximately 124 liters per day[89]. For seven days and 55 persons (51 hotel rooms + local personal) a minimum of 47740 liters of water is needed. This amount of water can be stored in 3-4 standard 18000 liters tanks of 2.5 x 2.5 x 4.8m. 4 water tanks would guarantee the water supply for 10 days, but this number of days should only be important in case of maintenance work at the otherwise operating water purification / sewage treatment system. A separate grey water and black water cycle will be installed. Rain water will refill the lost water of the black water system to create a constant cycle and to keep the necessary refills at a minimum (depending on the rainfall). Hot water will be generated by solar thermal panels on the roof.

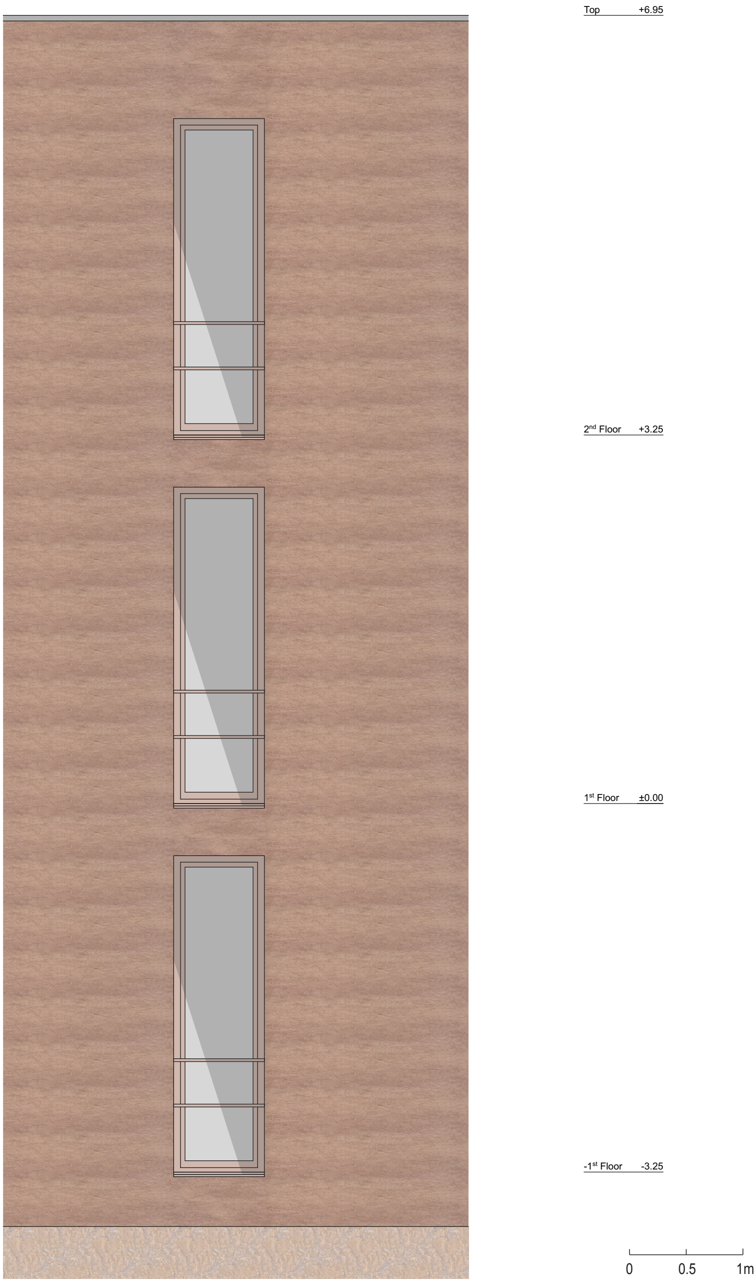
Power supply and internet connection

Electricity is expected to be already at the mountain, as there are already some small buildings existing close to the site. In addition to the power line a fiber optic cable will be needed for the telescope. Furthermore, the P2036 will be equipped with photovoltaic panels to ensure the power supply in case of a power failure. An additional battery-backup system will guarantee the use of the telescope at any time.

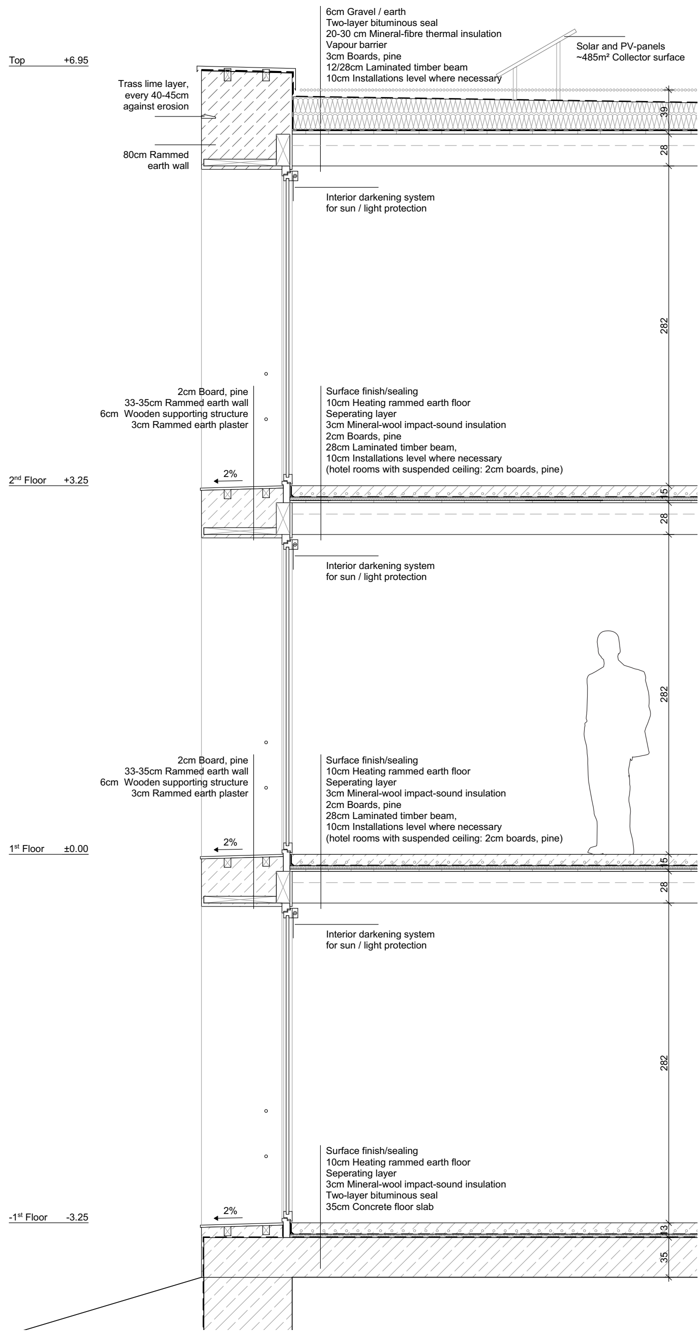
Foundation

The telescope will be mounted at a massive concrete pillar, which reaches down into the earth until hard enough underground for a stable foundation is reached.

[89] Cf. WWF, Sept. 2016.

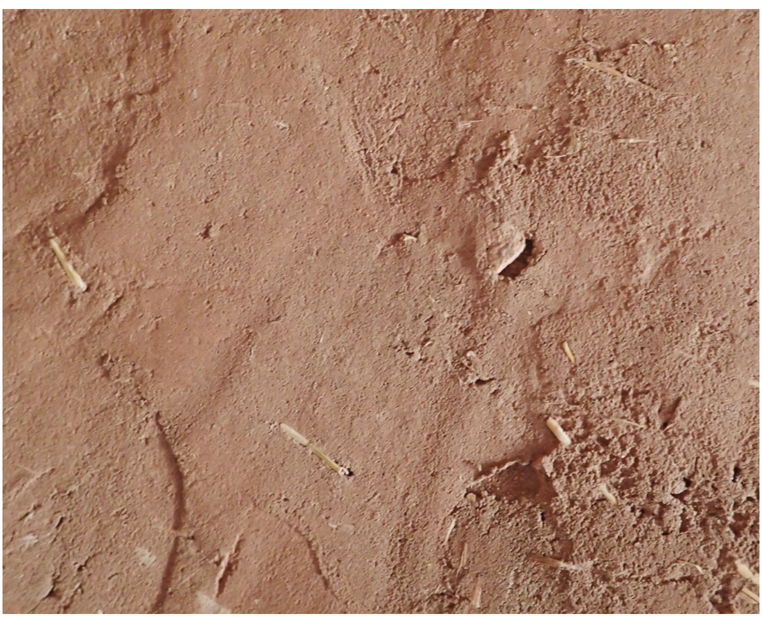


106 Details - Section through the hotel rooms



Top +6.95
6cm Gravel / earth
Two-layer bituminous seal
20-30 cm Mineral-fibre thermal insulation
Vapour barrier
3cm Boards, pine
12/28cm Laminated timber beam
10cm Installations level where necessary
Solar and PV-panels
~485m² Collector surface
Trass lime layer, every 40-45cm against erosion
80cm Rammed earth wall
39
28
Interior darkening system for sun / light protection
282
2cm Board, pine
33-35cm Rammed earth wall
6cm Wooden supporting structure
3cm Rammed earth plaster
Surface finish/sealing
10cm Heating rammed earth floor
Seperating layer
3cm Mineral-wool impact-sound insulation
2cm Boards, pine
28cm Laminated timber beam,
10cm Installations level where necessary
(hotel rooms with suspended ceiling: 2cm boards, pine)
2%
2nd Floor +3.25
15
28
Interior darkening system for sun / light protection
282
2cm Board, pine
33-35cm Rammed earth wall
6cm Wooden supporting structure
3cm Rammed earth plaster
Surface finish/sealing
10cm Heating rammed earth floor
Seperating layer
3cm Mineral-wool impact-sound insulation
2cm Boards, pine
28cm Laminated timber beam,
10cm Installations level where necessary
(hotel rooms with suspended ceiling: 2cm boards, pine)
2%
1st Floor ±0.00
15
28
Interior darkening system for sun / light protection
282
Surface finish/sealing
10cm Heating rammed earth floor
Seperating layer
3cm Mineral-wool impact-sound insulation
Two-layer bituminous seal
35cm Concrete floor slab
2%
-1st Floor -3.25
13
35

107 Materials



108 Rammed earth with straw

Materiality

In general, the observatory is planned to be built of local resources and materials. Therefore, the chosen material for the observatory is rammed soil, built out of a mixture of clay (ideally 12%[90]), straw, sand, gravel, earth, water and animal dung/urine. The reason the material was chosen for the observatory is, that the material is a local one, which is more ecological and sustainable than concrete in combination with insulation material. As Morocco's climate is in general quite warm, insulation isn´t very common in Morocco. The k-value of a rammed soil wall varies between 0.64 and 0.93 W/m^{2}K[91], depending on the materials used. Calculated with a k-value of 0.64 W/m^{2}K, an 80cm rammed earth wall has a 0.7 W/m^{2}K U-value. The added straw will improve the U-value, but probably a value of <0.35 W/m^{2}K, which is required in European countries like Austria, won´t be reached. For Morocco, no required U-levels were found, even though minimum energy requirements are discussed since a few years to reduce the energy consumption.[92] The advantage of rammed soil is its good thermal mass capacity. Thus, it is capable of keeping the temperature for a long time, which improves the thermal comfort inside buildings at locations, where the summer can get really hot. Further advantages of rammed soil are its good hygroscopicity for passive humidity control and its low embodied energy and carbon.

The walls inside the observatory will be either a timber frame construction with earth plaster or clay bricks, also plastered. The brick walls will be mainly used for the walls separating the hotel rooms, while the light timber walls divide the areas of the offices allowing adaptions of the office sizes in the future.

The ceilings are a timber construction. Laminated timber beams carry the weight of the ceiling. They are projecting 2.4m to carry the outside passageway. The surface of the passage way is wood; inside the building, there is a rammed earth floor, matching the walls. Doors and window frames will be also made out of wood. The sliding panels are partially wood and partially aluminum. Pine wood was chosen for all wooden parts as this tree can be found in forests in the Atlas Mountains next to oak, evergreen, cedar, etc.

Foundations and basement walls will be made of concrete with local gravel.

The telescope is made of different materials due to its high requirements on the materials. It is an insulated aluminum/steel structure with concrete foundation.

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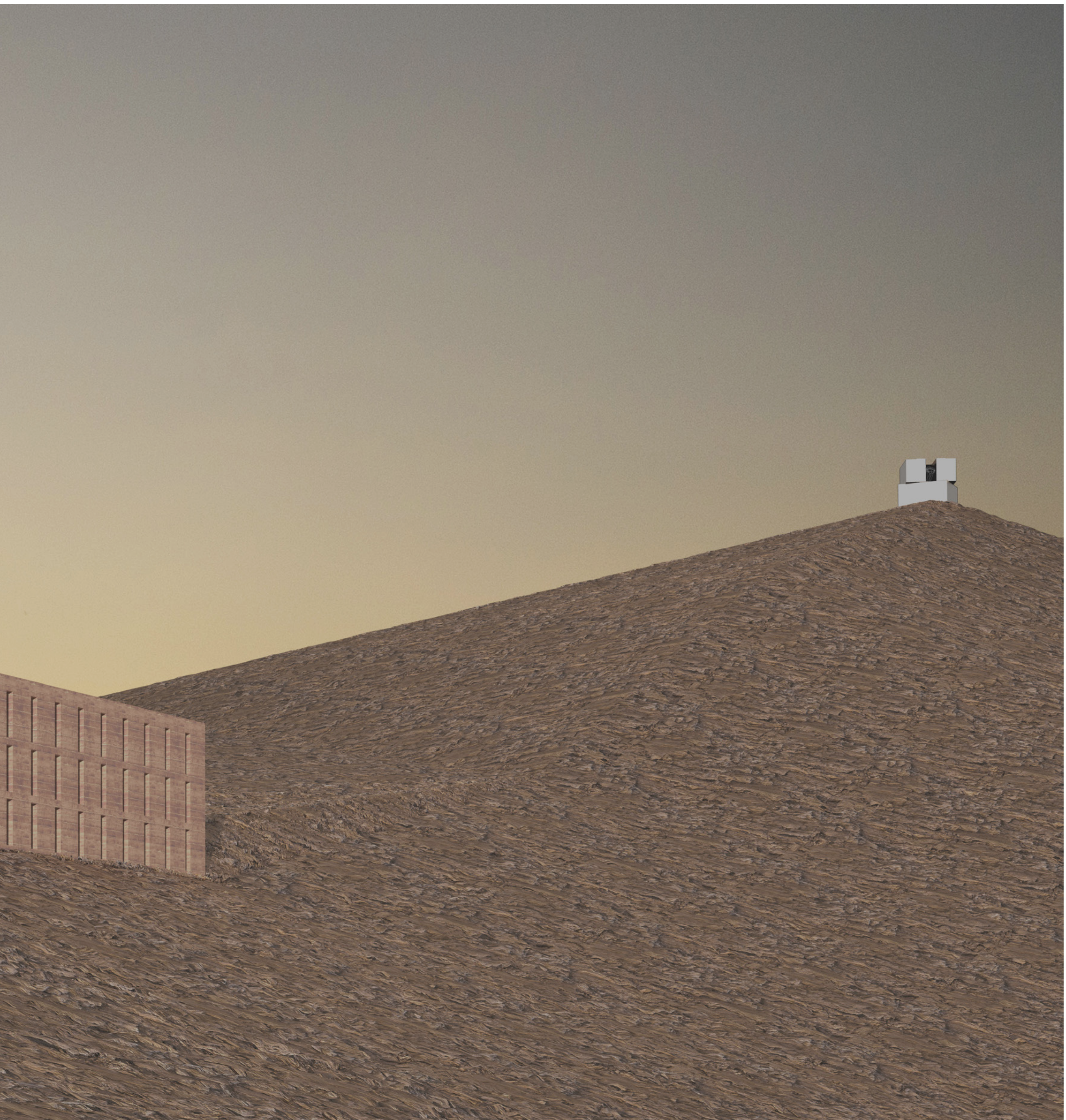
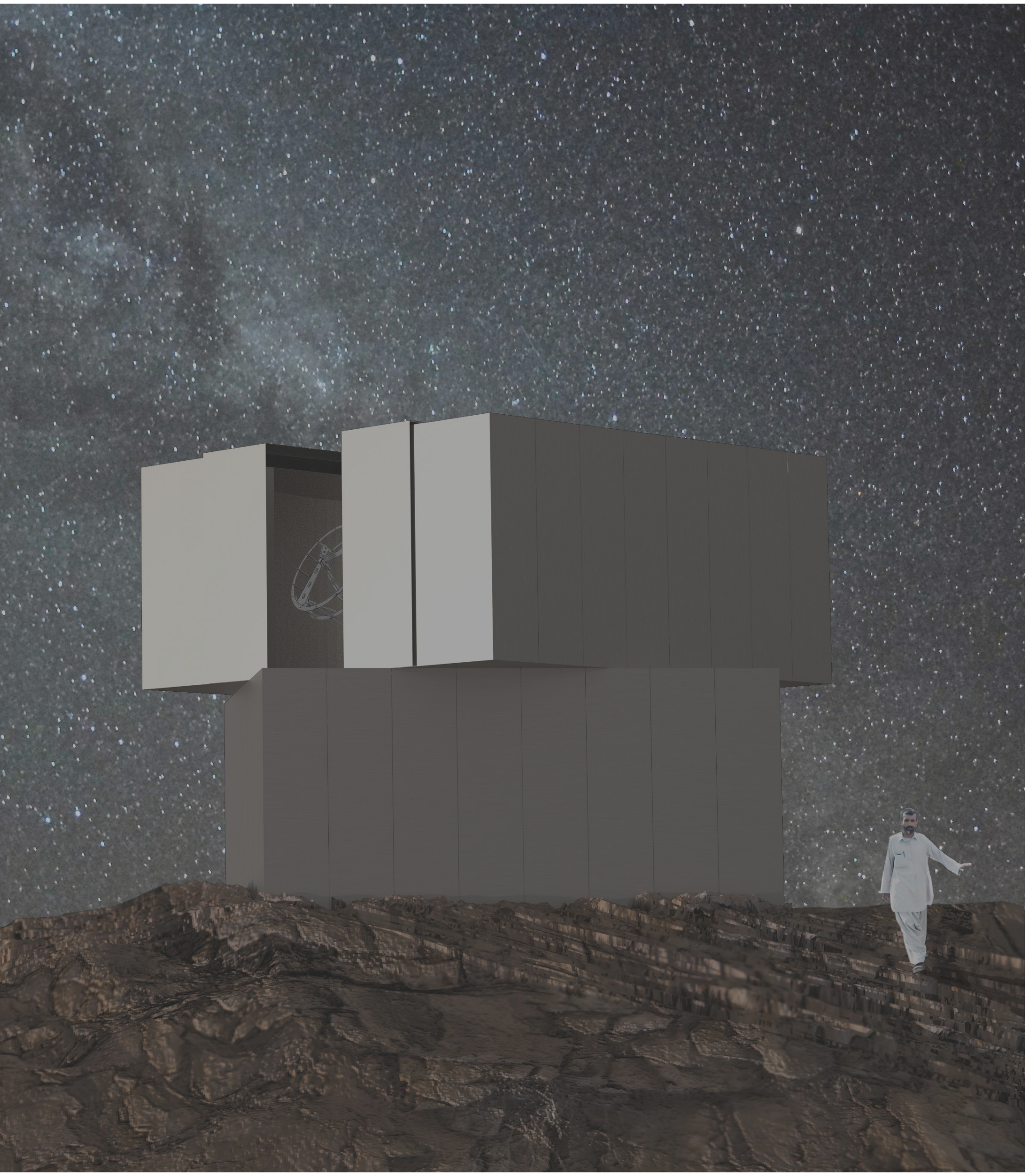
[90] Cf. Pelsmakers 2015, 224.
[91] Cf. Rauch 2015, 125.
[92] Cf. Oxford Business Group, Oct. 2016.

109 Rendering: View from the way up to the observatory



110 Rendering: Telescope



111 Rendering: Courtyard

112 Rendering: Elevation west

113 Rendering: View from the observatory to the valley

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076 Marianne Hufnagl / Free Vektor Maps.com / Eric Gaba: Morocco relief location map

079 Marianne Hufnagl, based on data of Open Street Maps

110 Background picture: Matthias Lorentz

111 Background picture: MindBlowingPicture.com

113 Background picture: Lena Kuhlmann

ANNEX
IMPRESSIONS OF MOROCCO

Marrakesh

Marrakesh

Marrakesh

Airport in Marrakesh

Marrakesh

Marrakesh

Picture of a wall in Marrakesh

Ali ben Youssef Medersa (former Islamic college in Marrakesh)

Ali ben Youssef Medersa

Ali ben Youssef Medersa

Entrance to the Saadian Tombs

Bahia Palace

Saadian Tombs

Marrakesh

Badi Palace

Badi Palace

Ourika Valley, High Atlas

High Atlas

High Atlas

Serpentines in the High Atlas

High Atlas

Ourika Valley, High Atlas

Ourika Valley, High Atlas

Berber Home, High Atlas

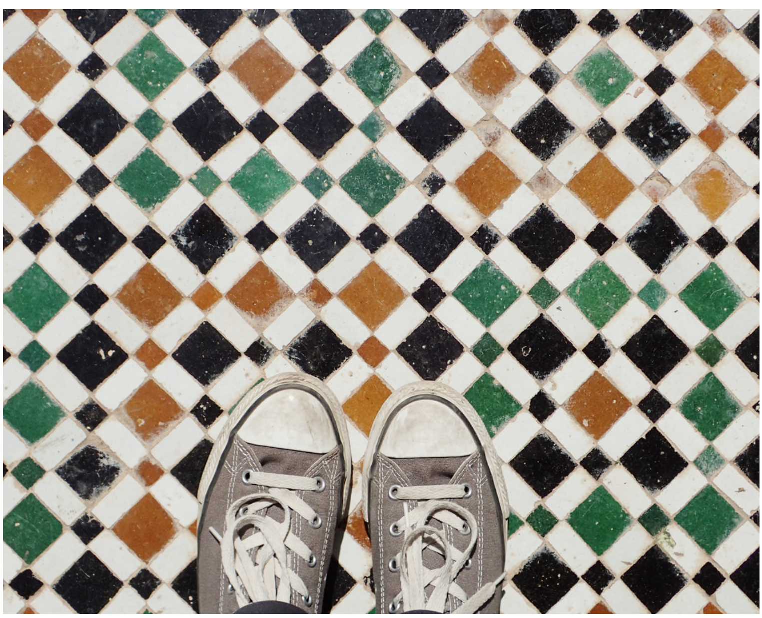
Berber Home, High Atlas

Berber Home, High Atlas

Traditional carving

Stucco and window

Modern forms of art in Marrakesh



Example of an typical colorful tiled floor pattern in Morocco

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