DELFT UNIVERSITY OF TECHNOLOGY

The Typology of Astronomical Observatories

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Tout l'univers visible n'est qu'un magasin d'images et de signes auxquels l'imagination donnera une place et une valeur relative; c'est une espèce de pâture que l'imagination doit digérer et transformer

Charles Baudelaire, Le Salon de 1859

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Preface

This thesis is done at the Explore Lab studio of Delft University of Technology's Department of Architecture. The subject of the graduation project, that is divided into a thesis and a design part, is the typology of astronomical observatories. The thesis explores the role of typology in the development of the observatory and aims to clarify this architectural example of co-development in building type and science. The team of mentors consists of ir. Henk Engel (main mentor), dr. John Heintz (research mentor), and ir. Ype Cuperus (building technology mentor).

Bram Waumans, August 2013

Chapter 1

Introduction

Dat neemt niet weg dat ik enorme behoefte heb aan - zal ik het woord maar uitspreken - aan religie, dus ga ik 's nachts naar buiten om de sterren te schilderen.
Vincent van Gogh

"Human beings survive by means of cognitive systems. An essential part of a cognitive system is a 'map' of the world that helps us deal with reality"[1]. This map gives man his role and place in the universe and helps him understand life and his perceptions. Since antiquity, cosmology and God have been closely related[2]. At first people considered the sky itself to be godly, later it became the place where a God lived[3]; Only the last three centuries there has been a division between religion and cosmology.

Next to this religious and astrological meaning, astronomy served a practical purpose. "The increased productivity of [...] agricultural societies led to increased vulnerability. The growth in productivity led to an expansion of the population, which meant a greater dependence on agriculture, which in its turn led to greater vulnerability. [...] To cope with these threats a central role was played by a class of people who can be called priests. They possessed expertise in many areas and played a crucial role in the organization of society."[4]. Calendars gave reliable information for planting crops, helping to deal with increased vulnerability. Thirdly, the stars were vital for navigation on journeys.

Astronomy developed independently in ancient civilizations all over the world. The Chinese adopted the 365 day year as early as 3000BC and only a few years ago the

[1]Koetsier, T (ed.) and Bergmans, L (ed.) (2005). *Mathematics and the Divine: A Historical Study.* Amsterdam: Elsevier Science. p3.
[2]Wright, M.R. (1995). *Cosmology in Antiquity.* London: Routledge. p163.
[3]Ibid., p164.
[4]Koetsier, T (ed.) and Bergmans, L (ed.), op. cit., p10.

FIGURE 1.1: El Caracol at Chichen Itza

4100 year old Xiangfen observatory was discovered[1]. At that time in Mesopotamia and Egypt people explored the heavens and while the Chinese only named stars, comets, and eclipses, the Babylonians and Egyptians invented sundials to describe the movements of celestial bodies[2]. Important architectural structures such as Stonehenge, El Caracol at Chichen Itza[3], (Figure 1.1) and the Pyramids are all archaeoastronomical records.

The mathematical models that described celestial motions helped in predicting astronomical events and drawing up calenders, but these disappeared from Europe during the Middle Ages. Only in the late Middle Ages European interest in astronomy grew again, and in the early renaissance observatories started to sprout all over Europe. The Dutch astronomer Kaiser, first director of the new Leiden Observatory in the nineteenth century, understood this supporting role architecture could play. He stated that for an effective observatory there were three requirements: “good instruments, a proper building, and competent observers”[4].

1.1 Astronomical Observatories

Astronomy is a matter of scale: the incomprehensible immensity and distance of faraway galaxies can only confront the observer with the futility or wonder of his existence. The true charm of observatories lies in the sublime confrontation of man and universe, resulting in reflection, surrealism, and nihilism. At the same time the observatory has to solve this mismatch; how does one transfer the universe into a single room? The discovery that the universe is so immense that our solar system –let alone our planet, the human race, or a single person’s accomplishments– is rather insignificant and not in the main focus at all, cannot but lead to some relativism and modesty. It brings man to contemplate his existence.

Astronomy deals with the most fundamental cosmogonical questions. Unlike other exact sciences, astronomy is not exclusive to institutions with the highest technology, like physics or medicine. Surprisingly, it is a prime example of a citizen science, where amateurs have an influence and researchers sometimes depend on their contributions. This relation adds to the charm of astronomy. In a society where science is almost a religion and maybe even becoming too dogmatic and elitist, astronomy is the exception, bringing egalitarianism into the distant world of the sciences.

[1]Xinhua. (2005). *World’s oldest observatory found in China.* Available: http://www.chinadaily.com.cn/english/doc/2005-10/31/content_488952.htm. Last accessed 3rd Jan 2013.
[2]anonymous. (unknown). *History of the Sundial.* Available: http://www.sundial.net/sundial-history.html. Last accessed 3rd Jan 2013.
[3]Müller, P (1992). *Sternwarten in Bildern: Architektur und Geschichte der Sternwarten von den Anfängen bis ca. 1950.* Berlin: Springer-Verlag. p13.
[4]Enderman, E (2002). *De Sterrenwacht te Leiden.* [Bouwhistorische opgave] Nieuwkoop: -. p22.

The dome, so iconic for the observatory, depicts the dualistic aspect of the observatory; with the rich cosmic history[1] of the observatory, the dome represents the heavens, turning the observatory into a temple of the modern sciences. Additionally it is the logical result of encapsulating a telescope that rotates over two axes. It is important architecture facilitates both of these aspects in the design of the observatory.

1.2 Field of Study

This thesis is a typological study of observatories throughout history and the development of astronomy. While observatories can be considered a clearly defined building type, not much research has been done on their typology. Apart from the famous Observatoire de Paris by Perrault, there are only about a dozen books on the architecture of observatories. Observatories are the icons of astronomical institutions, and while there is research on the development of astronomy, there is hardly any research on the development of observatories themselves even though organizations and institutes are often very proud of their observatory. Nicolaus Pevsner briefly mentions observatories in his introduction of *A History of Building Types*, stating that "[...] [adding] observatories [...] would have been rewarding but would have swelled the book to unmanageable proportions"[2]. Typology plays a significant role in all building types, but typology has a stronger connection with observatories than most types. The next chapter discusses this connection in more depth. The goal is to provide an overview of the development and a thorough understanding of the observatory type. This is accompanied by an understanding of the role of type in the field of architectural theory and of the development of cosmology in Western culture.

The main research question:

> *What trends can be found in the development of the observatory type since 1579?*

It is important to define the term observatory in a more precise manner. Dr. Thornton Page of the Smithsonian Astrophysical Observatory defines an observatory as "a place where a group of scientists make regular observations"[3]. However, taking the developments in the scientific world of citizen astronomy into account, an observatory could better be defined as a place where regular observations can be made. For architectural purposes, this research treats the definition of the observatory as the enclosure of the space where observations are done. This excludes early outdoor installations such as the

[1]Lehmann, K. (1945). The Dome of Heaven. *The Art Bulletin.* 27, pp1-27.
[2]Pevsner, N (1976). *A History of Building Types.* Princeton, NJ: Princeton University Press. p9.
[3]Page, T (1966). *Observatories.* Cambridge, MA: Smithsonian Astrophysical Observatory. p1.

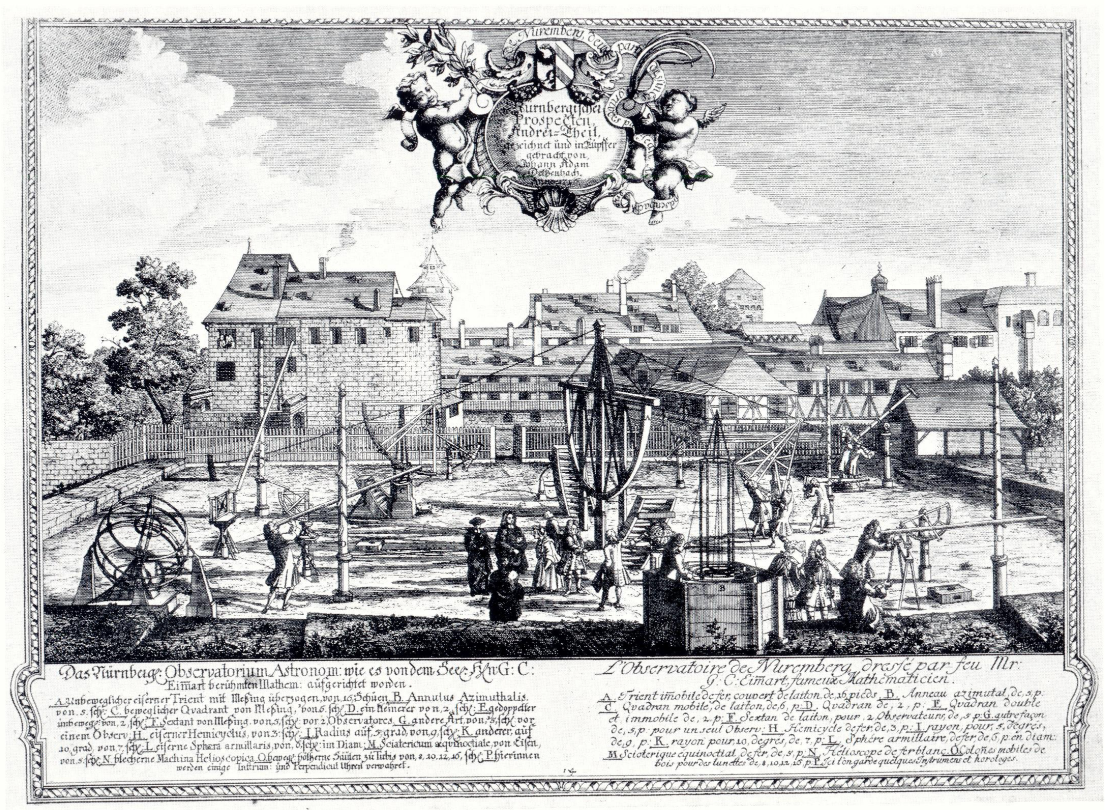

FIGURE 1.2: Nürnberg Observatory

ones in Jaipur, Beijing or Nürnberg (Figure 1.2). The study focuses on astronomical observatories located on earth, equipped with an optical telescope, that evolved from European astronomy since it was reintroduced around the fifteenth century.

One of the first Western, enclosed, astronomical observatories (of which sufficient documentation is available) is the Tower of the Winds in Vatican City (not to be confused with the Tower of the Winds on the Ancient Agora of Athens), one of the first tower observatories in Europe after the Middle Ages, built in 1579 and the starting point of this study.

Important subquestions:

> *What functions come and go through the ages, do these functions have special characteristics, and is there a development in their layout?*
> *What developments in astronomy caused changes in the type?*
> *Is there a type?*

1.3 Research Methodology

The classification of buildings will be strictly functional and the point of departure for such an approach must be Pevsner's *A History of Building Types*, where various types are formulated based on their different programs. Following Pevsner, building plans will not only be analyzed formally, but also developments in society, in this case astronomy (second subquestion), and developments of the functions themselves (third subquestion).

The research consists of five parts. The first part is a literature study to gain knowledge about astronomy, observatories, typology, cosmology, plan analysis, and research methodology. Also many building plans needed for the third part of the research can be found in literature. The second part consisted of visits to different observatories in California, Hawai'i, and Europe, given in Table 1.1. During these visits, astronomers explained the observatories' history, research, institution, equipment and users. Photographs were taken, blueprints were acquired and plans were drawn up if not

FIGURE 1.3: San Fernando Observatory, one of the observatories visited in the US.

Observatory	Location
Sonnenborgh Observatory	Utrecht, the Netherlands
Leiden Observatory	Leiden, the Netherlands
Royal Observatory, Edinburgh	Edinburgh, United Kingdom
Royal Observatory, Greenwich	Greenwich, United Kingdom
Galata Tower	Istanbul, Turkey
Robert Ferguson Observatory	Sonoma, California
Lick Observatory	Mt. Hamilton, California
C. Donald Shane Telescope	Mt. Hamilton, California
San Fernando Observatory	San Fernando, California
N.A. Richardson Observatory	San Bernardino, California
Murillo Family Observatory	San Bernardino, California
Ricard Observatory	Santa Clara, California
Oliver Observing Station	Carmel Valley, California
Krause Center for Innovation	Los Altos Hills, California
Griffith Observatory	Los Angeles, California
Mt. Wilson Observatories	Mt. Wilson, California
Gemini North Observatory	Mauna Kea summit, Hawai'i
Subaru Telescope	Mauna Kea summit, Hawai'i
W.M. Keck Observatory	Mauna Kea summit, Hawai'i

Table 1.1: Observatories visited

available.
Third, observatories were analyzed in three steps. The first step is a historical taxonomy consisting of 107 samples. These samples are clustered, investigating the formal development of the observatory and the development of functions housed in their observatories and their place in the plans. These clusters result in different matrices showing the type's development.

The second step consists of a selection of seventeen plans that together show the development of the observatory. Changes in layout and use are explained by these selected plans.

The last step is again a more careful look at plans with two case studies, the Leiden Observatory (first built in 1633 and a second building in 1861) and the Lick Observatory (1888), with attention to the design process and motivations behind design decisions. For the Leiden Observatory, conversations were held with Mr. Frans Dekker, director of real estate of Leiden University, and Mr. Gerard Smit, architect of the recent renovations of the Leiden Observatory. For the Lick Observatory, the observatory's archives were

1.3.1 Sample Selection

consulted at the University of California, Santa Cruz campus in California.
Since this research revolves around functional communality, it is understandable that samples were chosen on the availability of a building plan, since the building plan corresponds to the building's configuration, or utilitas. This is also affirmed by

001	1579	Tower of the Winds	Vatican	Vatican
002	1581	Uraniborg	Hven	Denmark
003	1633	Leiden Observatory	Leiden	The Netherlands
004	1642	Smeetoren	Utrecht	The Netherlands
005	1642	Rundetarn	Copenhagen	Denmark
006	1671	Observatoire de Paris	Paris	France
007	1676	Flamsteed House	Greenwich	UK
008	1704	Observatorium Tusculanum	Vridsløsemagle	Denmark
009	1723	Clementinum Observatory	Prague	Czech Republic
010	1725	Specola	Bologna	Italy
011	1733	University of Wroclaw Observatory	Wroclaw	Poland
012	1734	Kunstkamera Observatory	St. Petersburg	Russia
013	1758	Observatory of Kremsmünster	Kremsmünster	Austria
014	1771	Radcliffe Observatory	Oxford	UK
015	1774	Mannheim Observatory	Mannheim	Germany
016	1780	Copenhagen Observatory	Copenhagen	Denmark
017	1785	Zwehrenturm	Kassel	Germany
018	1785	Dunsink Observatory	Dublin	Ireland
019	1790	Gotha Observatory	Seeberg	Germany
020	1793	Old Observatory House	Edinburgh	UK
021	1810	Plan for a large observatory	–	–
022	1810	Tartu Observatory	Tartu	Estonia
023	1812	Osservatorio astronomico di Capodimonte	Naples	Italy
024	1816	Göttingen Observatory	Göttingen	Germany
025	1820	Royal Observatory, Cape of Good Hope	Cape Town	South Africa
026	1822	Parramatta Observatory	Sydney	Australia
027	1824	City Observatory	Edinburgh	UK
028	1825	Hamburg Observatory	Hamburg	Germany
029	1834	Helsinki University Observatory	Helsinki	Finland
030	1835	New Berlin Observatory	Berlin	Germany
031	1838	Loomis Observatory	Hudson, OH	USA
032	1838	Hopkins Observatory	Williamstown, MA	USA
033	1838	Observatoire de Toulouse	Toulouse	France
034	1839	Pulkovo Astronomical Observatory	St. Petersburg	Russia
035	1843	Old Naval Observatory	Washington, D.C.	USA
036	1845	Bonn Observatory	Bonn	Germany
037	1846	Georgetown University Observatory	Georgetown, D.C.	USA
038	1846	National Observatory of Athens	Athens	Greece
039	1850	Meridian Building	Greenwich	UK
040	1853	Sonnenborgh Observatory	Utrecht	The Netherlands
041	1857	Williamstown Observatory	Melbourne	Australia
042	1858	Sydney Observatory	Sydney	Australia
043	1861	Leiden Observatory	Leiden	The Netherlands
044	1861	Leipzig Observatory	Leipzig	Germany
045	1861	Copenhagen University Observatory	Copenhagen	Denmark
046	1864	Eidgenössische Sternwarte	Zürich	Switzerland
047	1865	Vassar College Observatory	Poughkeepsie, NY	USA
048	1871	Hurbanovo Observatory	Hurbanovo	Slovakia
049	1873	Astronomical Observatory at Ogden	Ogden, UT	USA
050	1874	Vienna University Observatory	Vienna	Austria
051	1874	Orwell Park Observatory	Ipswich	UK
052	1879	Astrophysical Observatory Potsdam	Potsdam	Germany
053	1882	Observatory of Strasbourg	Strasbourg	France
054	1886	Observatoire de Nice	Nice	France
055	1888	Lick Observatory	Mt. Hamilton, CA	USA
056	1889	Urania	Berlin	Germany
057	1889	Dearborn Observatory	Evanston, IL	USA
058	1889	Dr. Karl Remeis Observatory	Bamberg	Germany
059	1891	Royal Observatory of Belgium	Uccle	Belgium
060	1891	Ladd Observatory	Providence, RI	USA
061	1895	Theodor Jacobsen Observatory	Seattle, WA	USA
062	1895	Allegheny Observatory proposal	Pittsburgh, PA	USA
063	1896	University of Illinois Observatory	Champaign, IL	USA
064	1896	Royal Observatory, Edinburgh	Edinburgh	UK
065	1896	Old Perkins Astronomical Observatory	Middletown, CT	USA
066	1897	Yerkes Observatory	Williams Bay, WI	USA
067	1899	Thompson Building	Greenwich	UK
068	1900	Heidelberg-Königstuhl State Observatory	Heidelberg	Germany
069	1900	Whitin Observatory	Wellesley, MA	USA
070	1902	Dominion Observatory	Ottawa	Canada
071	1904	Fabra Observatory	Barcelona	Spain
072	1906	Physikalischer Verein Observatory	Frankfurt am Main	Germany
073	1908	Tacubaya Observatory	Mexico City	Mexico
074	1910	Palace Urania	Vienna	Austria
075	1912	Allegheny Observatory	Pittsburgh, PA	USA
076	1912	Hamburg-Bergedorf Observatory	Hamburg	Germany
077	1914	Van Vleck Observatory	Middletown, CT	USA
078	1915	Babelsberg Observatory	Potsdam	Germany
079	1917	Mt. Wilson Observatory	Mt. Wilson, CA	USA
080	1921	Einsteinturm	Potsdam	Germany
081	1923	Osservatorio Astronomico di Roma	Monte Porzio Catone	Italy
082	1923	Hale Solar Laboratory	Pasadena, CA	USA
083	1928	Ricard Observatory	Santa Clara, CA	USA
084	1930	N.A. Richardson Observatory	San Bernardino, CA	USA
085	1935	Griffith Observatory	Los Angeles, CA	USA
086	1948	Palomar Observatory	San Diego, CA	USA
087	1953	Holcomb Observatory	Indianapolis, IN	USA
088	1959	C. Donald Shane Telescope	Mt. Hamilton, CA	USA
089	1960	San Fernando Observatory	San Fernando, CA	USA
090	1965	Krause Center for Innovation	Los Altos Hills, CA	USA
091	1967	Stardome Observatory and Planetaruim	Auckland	New Zealand
092	1973	Nicholas U. Mayall Telescope	Kitt Peak, AZ	USA
093	1978	United Kingdom Infrared Telescope	Mauna Kea, HI	USA
094	1982	Oliver Observing Station	Carmel Valley, CA	USA
095	1987	James Clerk Maxwell Telescope	Mauna Kea, HI	USA
096	1996	W.M. Keck Observatory	Mauna Kea, HI	USA
097	1997	Ritchie Observatory	Bainbridge Island, WA	USA
098	1998	Subaru Telescope	Mauna Kea, HI	USA
099	1999	Robert Ferguson Observatory	Sonoma, CA	USA
100	2000	Gemini North Observatory	Mauna Kea, HI	USA
101	2004	Dekalb Observatory	Auburn, IN	USA
102	2004	Observatorio de Ballona	Riverside, CA	USA
103	2008	Kielder Observatory	Kielder	UK
104	2011	Murillo Family Observatory	San Bernardino, CA	USA
105	2012	Craigengillan Dark Sky Observatory	Galloway Forest Park	UK
106	2012	Stocker Astroscience Center	Miami, FL	USA
107	2012	Kansas State University Observatory proposal	Manhattan, KS	USA

Table 1.2: Overview of samples

Giancarlo De Carlo, who states:

> *"One should identify the "type" with the horizontal section of the architectural space, that is the "plan", representing its distribution system in bidimensional terms."*[1]

In Table 1.2, all 107 samples included in the taxonomical research are stated. Plans of these samples are given in Appendix A. These plans were selected on some demands besides the availability of the plan. It was optimal to have a diverse set of samples, varying from the largest, most professional, and modern institutions (e.g. the W.M. Keck Observatory) to tiny citizen observatories (Dekalb Observatory) and old plans (Uraniborg). A consistent selection of observatories in Western civilization from 1579 to present time was the main goal, so that the development of the observatory through time could be as complete as possible.

For completeness one may review the extensive list of observatory codes by the Minor Planet Center, containing about 2000 observatories all over the world. When comparing the set of samples of this research with Minor Planet Center's list of observatory codes, there are three categories of observatories that need to be discussed: (1) observatories from the MPC list that may be considered important, but are not in this study's samples, (2) observatories that are included in this study but are not included in the MPC list, and (3) observatories that are not in this study but are also missing in the MPC list.

Observatories from the MPC list that had ideally been included in the study are for example of the observatory at Geneva, supposedly the first observatory with the observing room on the ground floor, preceding Copenhagen's second observatory from 1780. Secondly, the observatories of Uppsala and Stockholm play a role in the transition from tower observatory to a central building with wings in the same period. Moreover, influential observatories such as the Harvard College Observatory, the second Naval Observatory in Washington D.C. and the La Plata observatory in Argentina would ideally have been included, but plans were impossible to attain. Alpine observatories such as the Pic du Midi and Sphinx observatories (the latter not included in the MPC list either) would have been interesting variations of observatories and could have made the set even more diverse. This study's samples of modern institutions almost only consist of institutions on Hawai'i, because most of these plans were gathered when visiting the Mauna Kea summit. Large modern observatories such as the ones in Chile (Las Campanas, La Silla, Cerro Tololo), the island of La Palma, Russia (the observatory in the Caucasus and the Crimean astrophysical observatory), or Arizona (except for the Mayall Telescope) also have not been included.

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[1] De Carlo, G. (1985). Note sulla incontinente ascesa della tipologia. *Casabella.* 509-510, p47.

FIGURE 1.4: Naval Observatory in Washington, D.C.

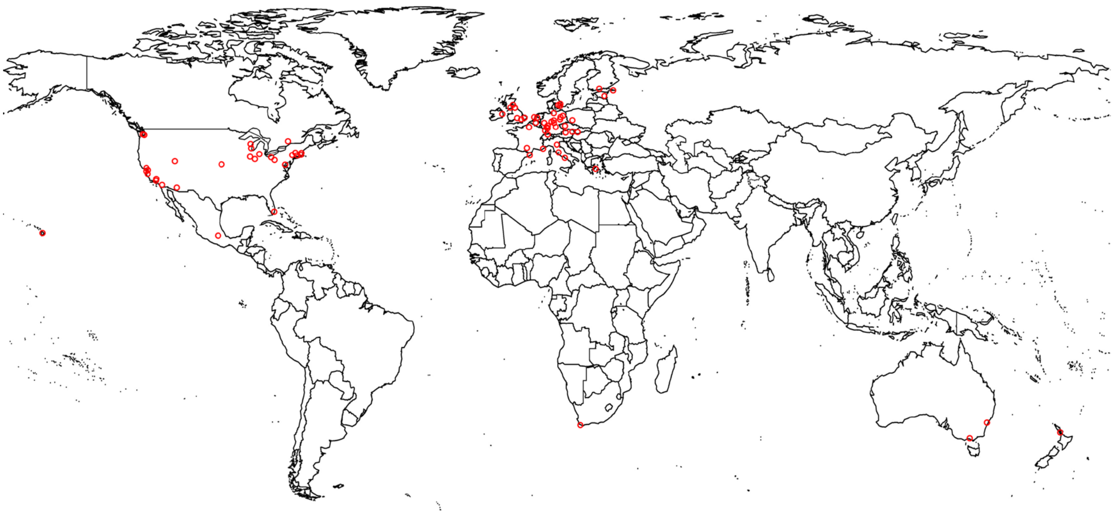


FIGURE 1.5: Samples on the world map

Regarding the observatories included in the samples but not mentioned in the MPC list, these samples can be roughly divided into four categories: citizen observatories, private observatories, university observatories, and old observatories that are not existent anymore or have been replaced.

Observatories that are not included in the samples, but are also missing in the MPC list of the Minor Planet Center. The Sphinx observatory on the Jungfraujoch was already mentioned. Other examples could possibly have been among the oldest observatories in post-medieval Europe, such as the 1613 observatory tower at the St. Anna Gymnasium in Augsburg, and the tower of Gießen University in 1611. Also the early observatories in Nürnberg (1471), Oradeao in Hungary (1471), and Kassel (1560) could not be included due to lack of documentation[1].

The selection of 107 samples proves to be a varied and complete enough selection of building plans possible to analyze. When consulting photographs of some of the observatories mentioned here that were not included in the research, one can put them in one of the formed clusters without too much trouble. E.g., the second Naval Observatory in Washington, D.C. (see Figure 1.4) perfectly fits in the Decentral domes cluster that is discussed later. The observatory plans that are not mentioned in the list by the Minor Planet Center are important for a wider coverage of the set and make the analysis more diverse, leading to better formulated clusters.

The samples are shown on the world map in Figure 1.5, indicating a prevalence in the Western world. The conclusion of the locations of these samples must not be interpreted as a realistic image of the global distribution of observatories, or astronomical research. However, many observatories built outside the Western world were either colonial observatories of Western countries, or are modern institutions built according to the same standards and demands.

For the representation of plans, issues arise in two situations. In some cases (notably observatories included in the Tower cluster) the section proved to be more informative than the plan. Therefore these plans are presented in this manner. Also, in many cases the building consists of more than one floor. It may be clear that it is not possible to record two floors in one plan, demanding the choice of a principle floor that bears the essence of the configuration of the building, causing ambiguity in some plans.

[1]Klamt, J-C. (1978). Bookreview of the books of M.C. Donnelly, A Short History of Observatories and P. Müller, Sternwarten: Architektur und Geschichte der Astronomischen Observatorien. *Zeitschrift für Kunstgeschichte.* 41, p173.

1.4 Thesis Structure

Overall this thesis begins with findings from the literature, continuing to the taxonomy, then zooming in on the 17 samples and concluding with the case studies. The second chapter goes into the relation between architecture, typology, astronomy and cosmology and how the cosmological image in Western Europe changed through time. Chapter three deals considers the role of typology in architectural theory, its development, different views, and roles that it can play in architecture. After that, in chapter four, the 107 samples of the taxonomy are studied. The development of functions housed in the observatories are considered and the samples are clustered and formed into matrices. These clusters describe the different configurations of the observatory type. In chapter five the development of the observatory in relation to its use and the development of astronomy is explained with the selection of 17 plans. The sixth chapter entails the two case studies that are first individually treated and afterwards compared. Finally, the seventh chapter concludes with a short discussion and recapitulates the results of the research, ending with a short look into the future.

Chapter 2

Cosmology

"I believe in Spinoza's God who reveals himself in the orderly harmony of what exists, not in a god who concerns himself with fates and actions of human beings."

Albert Einstein[1]

The earliest uses of the word cosmos "had primarily the sense of 'order', used, for example, of rowers at their place by the oars (Odyssey 13.77) or of soldiers sleeping with their equipment properly set out around them (Iliad 10.472)"[2]. According to Aristotle, it was Xenophanes who was the first that "looked up at the sky and had a theory of everything"[3]. As was mentioned in the introduction, cosmology helps mankind to deal with his role in the universe and consequently has a long tradition. This chapter describes the development of cosmology in the Western tradition.

2.1 The Greeks

Myth was used to explain the skies and natural phenomena, but later started to include philosophy, mathematics, and astronomy[4]. This tradition started with Pythagoras, who at the same time was the first to use the word cosmos as a description of "the sum of the whole [...] because of the order which it displayed"[5]. For Pythagoras and his followers, this use of mathematics was "a way to get in touch with the divine"[6]. Proportion was

[1]Koetsier, T (ed.) and Bergmans, L (ed.) (2005). *Mathematics and the Divine: A Historical Study.* Amsterdam: Elsevier Science. p41.
[2]Wright, M.R. (1995). *Cosmology in Antiquity.* London: Routledge. p3.
[3]Ibid., p3.
[4]Hetherington, N (1993). *Cosmology: Historical, Literary, Philosophical, Religious, and Scientific Perspectives.* New York: Garland. p70.
[5]Wright, M.R., op. cit., p3.
[6]Koetsier, T (ed.) and Bergmans, L (ed.), op. cit., p13.

FIGURE 2.1: Goethe's Altar of Good Fortune

of major importance in mathematics[1] since this mostly consisted of geometry, and both the three types of proportion[2] and musical proportions were developed. Later, Plato, who was heavily influenced by Pythagoras[3], set up a cosmological order in his dialogue the *Timaeus*[4], based on these laws of harmony[5]. In this way, the divine and arithmatic became closely connected, which has been enormously influential through the ages[6]. Platonism states that reality is not present in our visible world, but in the world of ideas[7]. This dualism was also present in geometric form. The universe was of a spherical shape[8], chosen for its perfection and "perfect, circular motion belongs to the superior incorruptible bodies of the heavens"[9]. In the terrestrial world, perfect circular motions were impossible, all motions on earth could be described as rectilinear[10]; the circle above the square symbolizes this dualism beautifully, also present in Goethe's Altar of Good Fortune in Weimar (Figure 2.1).

Aristotle applied this idea to motion and while Plato's description of our universe was mathematical, Aristotle's was physical[11]. He developed a complete[12], dynamic model, describing causes and descriptions of motions and the elements[13]. Because of this completeness people hesitated to question the system. Up to the Middle Ages, western cosmology became a combination of both Platonic and Aristotelian views[14]. The astronomer Ptolemy can be seen as the culmination of astronomy and cosmology in this period[15]. He developed a system of movable, concentric spheres describing the motions of the skies; and he included dualism with a sublunar, imperfect realm, and a perfect realm of the heavens[16]. Ptolemy's model is considered a descriptive model of aristotelianism and platonism, and was the generally accepted model for the next 1500 years, remaining quite unchanged until the Scientific Revolution.

2.2 The Middle Ages

At the start of Middle Ages, this combination of Platonism and Aristotelianism formed a

[1]Koetsier, T (ed.) and Bergmans, L (ed.), op. cit., p13.
[2]Wittkower, R (1971). *Architectural Principles in the Age of Humanism.* New York: W.W. Norton. p96.
[3]Koetsier, T (ed.) and Bergmans, L (ed.), op. cit., p14.
[4]Yourgrau, W, duPont Breck, A, Alfvén, H, et al. (1977). *Cosmology, History, and Theology.* New York: Plenum Press. p160.
[5]Gadol, J (1969). *Leon Battista Alberti: Universal Man of the Early Renaissance.* Chicago: University of Chicago Press. p111.
[6]Koetsier, T (ed.) and Bergmans, L (ed.), op. cit., p6.
[7]Hetherington, N, op. cit., p.71.
[8]Lilley, K (2009). *City and Cosmos: The Medieval World in Urban Form.* London: Reaktion Books. p28.
[9]Gadol, J, op. cit., p152.
[10]Ibid., p153.
[11]Hetherington, N, op. cit., p.95.
[12]Ibid., p98.
[13]Ibid., p73.
[14]Ibid., p73.
[15]Ibid., p74.
[16]Gadol, J, op. cit., p152.

complete world system: the four cardinal directions, the four seasons, the four elements, the four material properties[1]; a cosmological model that was also symbolically united. Astronomy was part of the 'mathematical sciences' just as much as astrology[4] because in the Middle Ages, the whole world was represented in symbolical forms[2]. Perfection existed in the spiritual world; there was not yet a division between science and mystical traditions[3].

An important aspect of medieval symbolism was the analogy between macrocosm, the cosmic 'body', and microcosm, the human body[5]. The medieval city played a role in between these two bodies, either as the macrocosm of the human body, or the microcosm of the cosmic body[6]. This way, the city mediated between two extreme scales, helping man to understand his position in the universe. Following the Timean concept of God as the 'great artificer'[7], God was given a role as "architect, who was minded to found the one great city"[8]. This idea of God as *artifex principalis*[9] had its consequences in medieval town planning, where the city "acquired its cosmological symbolism both through its spatial *forms* [...] and in its *functions* [...] all created to God's divine plan"[10].

2.3 The Ptolemaic Renaissance

The relation to the cosmos was in medieval times only symbolic, but this was to change in the *quattrocentos*. This is clearly visible in the *mappaemundi*, where for example the orientation with the east pointing up, religious, changed to the ptolemaic north-south axis[11]. Moreover, the early mappaemundi were drawn "proportionally untrue to their originals, [...] [and] commonly magnified interesting landmarks and regions much as medieval paintings magnified worthy or sacred personages. Significant objects and places cried out for depiction, not the spatial relations among them"[12]. With the rediscovery of Ptolemy's maps, in which he applied the same rules as in his celestial models[13], there was a change to the "relational ordering of space"[14]. The vital aspect of

[1]Lilley, K, op. cit., p34.
[2]Koetsier, T (ed.) and Bergmans, L (ed.), op. cit., p149.
[3]Borden, I and Rüedi, K (2006). *The Dissertation: an Architecture Student's Handbook.* Amsterdam: Architectural Press. p96.
[4]Koetsier, T (ed.) and Bergmans, L (ed.), op. cit., p349.
[5]Lilley, K, op. cit., p7.
[6]Ibid., p7.
[7]Ibid., p38.
[8]Ibid., p39.
[9]Ibid., p85.
[10]Ibid., p12.
[11]Gadol, J, op. cit., p164.
[12]Ibid., p162.
[13]Edgerton, S. (1974). Florentine Interest in Ptolemaic Cartography as Background for Renaissance Painting, Architecture, and the Discovery of America. *Journal of the Society of Architectural Historians.* 33 (4), p279.
[14]Gadol, J, op. cit., p157.

his maps is the grid that provides geometric continuity[1]. These maps were not meant for navigation, but, just like the earlier mappaemundi, were drawn for the intellectual elite of that time[2]. Interestingly, the result of the grid was that instead of trying to fit together the pieces of the world that were known, the proportions of the world and the grid were already known, and it became a mere task of filling in the unknown parts, inspiring the Age of Exploration[3].

This change from qualitative to quantitative representation, called *Prospettiva*, was the impetus behind the early Renaissance and manifested in all fields –art, geography, astronomy, and architecture alike– and strived to apply "the mathematically inspired outlook of proportionality"[4]. Three key figures of this development were Nicholas of Cusa, Toscanelli, and Alberti[5]. Cusa's fourth book says: "to take the measure of the empirical world, to weigh, to clock, to determine sizes, distances, weights, durations, and speeds"[6], Alberti said: "I believe much more in Reason than I do in any person"[7]. They yearned for a proportional picture of the world[8], "interested in the actual position of an object instead of its value"[9].

The objective for this approach was a new way of looking at and interpreting the world. In the Middle Ages, "visual space was usually additive, [...] it was governed by no single, controlling viewpoint"[10]. Brunelleschi composed a method of linear perspective for the first time since antiquity[11], that was included in Alberti's treatise *on painting*[12]. In contrast to the medieval visual space, linear perspective does use a single viewpoint, the eye. As Leonardo da Vinci put it:

> *"The eye is the master of astronomy, it makes geography, it advises and corrects all human arts [...] the eye carries men to different parts of the world, it is the prince of mathematics [...] it has created architecture, and perspective, and divine painting [...] it has discovered navigation."*[13]

Da Vinci sees the eye as the governing body of these disciplines and the interpretation of the world. Later, Copernicus employed the same method in his cosmological model: "To bring systematic order into the positions and movements of the planets, Copernicus had to replace the ontologically fixed center of the universe by a neutral

[1]Edgerton, S, op. cit., p287.
[2]Ibid., p286.
[3]Ibid., p275.
[4]Gadol, J, op. cit., p198.
[5]Ibid., p196.
[6]Ibid., p205.
[7]Ibid., p117.
[8]Ibid., p164.
[9]Ibid., p211.
[10]Edgerton, S, op. cit., p275.
[11]Ibid., p276.
[12]Gadol, J, op. cit., p2.
[13]Edgerton, S, op. cit., p292.

mathematical point. But this meant that no part of space was privileged any longer. Space was neutralized, as in a perspectival painting or a scientific map"[1]. Because of the introduction of a controlling viewpoint without fixed position, the world had to lose its ontological center, resulting in neutral space. This transition from a representation <u>without</u> single, controlling viewpoint, but <u>with</u> symbolic midpoint to a representation <u>with</u> controlling viewpoint, but <u>without</u> a fixed center, turned around the way man interpreted the world around him and the universe.

2.4 Objective Beauty

Alberti had contemporaries developed guidelines for architecture as part of the proportional image of the world. These rules "human reason discerned in individual examples, but in which it recognized a supreme cosmic law"[2]. These rules were applied to painting, sculpture, and architecture[3], and found in Pythagoras' musical ratios[4]. Alberti noticed these ratios when studying classical buildings[5], and stated: "[W]e shall therefore borrow all our rules for harmonic relations from the musicians to whom this sort of numbers is extremely well-known, and from those particular things wherein Nature shows herself most excellent and complete"[6]. The role of music in the arts differs from that of painting, sculpture or architecture, having applied mathematical ratios since antiquity. The mathematical character of music gave it a higher distinction than the other liberal arts. Mathematics was still considered to be closest to the ideal, which is why music was considered an example for the other, lesser, liberal arts[7].

In the Renaissance, scholars considered "this man-created harmony [to be] a visible echo of a celestial and universally valid harmony"[8]. Its mathematical truth was generally accepted[9] and beauty was considered to be nature's absolute *telos*[10]. Nature formed shapes after the musical ratios and these ratios found in nature, had to be used by man in order to attain beauty. This rational beauty was objective and universal, something that was bound to change later on.

[1]Gadol, J, op. cit., p199.
[2]Gadol, J, op. cit., pp116-7.
[3]Ibid., p143.
[4]Wittkower, R, op. cit., p29.
[5]Ibid., p40.
[6]Ibid., p97.
[7]Ibid., p103.
[8]Ibid., p7.
[9]Ibid., p95.
[10]Gadol, J, op. cit., p107.

2.5 Nature, God, and Beauty

Copernicus too believed in a "harmonious, mathematical cosmic order"[1]. Many consider that the scientific revolution to some extent replaced religious beliefs, but Copernicus, Newton, and Kepler were religious men, who were all convinced of a universal harmony[2]. God was believed to have used mathematics when he created the universe[3]. However, this notion changed during the seventeenth century: "[B]efore and during the scientific revolution nature HAD to be rational because god IS rational. after the scientific revolution the rationality of nature became for many authors an observable phenomenon[4]", as opposed to an act of the artifex principalis.

The change from objective beauty to an age of "nature and feeling"[5] can be traced back to Descartes[6]. He gave reason absolute authority[7] and supported a "mechanistic, non-theological view of the world"[8]. Even though Descartes presented this as a method to understand an object's behavior[9], this approach resulted in an *exclusively* mechanistic view on our world. Claude Perrault, architect of the famous Observatoire de Paris, "broke decisively with the conception that certain ratios were *a priori* beautiful and declared that proportions which follow 'the rules of architecture' were agreeable for no other reason than that we are used to them"[10]. In the field of architecture "the objective truth of the building" became the "subjective truth of the perceiving individual"[11]. In other words beauty became a matter of opinion and was no longer absolute[12]. As Christopher Alexander puts it in *The Nature of Order*: "[I]n the wake of the mechanistic world-picture, we have constructed a pluralist view of value"[13]. In particular cases, and especially in architecture, this leads to significant design problems, resulting in unattractive buildings. Science is factual, when it comes to opinion of beauty, we live in a time where there is no ground for an objective deliberation regarding something as more beautiful than something else.

[1]Gadol, J, op. cit., p155.
[2]Ibid.
[3]Koetsier, T (ed.) and Bergmans, L (ed.), op. cit., p29.
[4]Ibid., p31.
[5]Wittkower, R, op. cit., p139.
[6]Alexander, C (2002). *The Nature of Order: an Essay on the Art of Building and the Nature of the Universe. Book 1, The Phenomenon of Life.* Berkeley, CA: Center for Environmental Structure. p16.
[7]Koetsier, T (ed.) and Bergmans, L (ed.), op. cit., p29.
[8]Ibid., p29.
[9]Alexander, C, op. cit., p16.
[10]Wittkower, R, op. cit., p126.
[11]Ibid., p128.
[12]Alexander, C, op. cit. p20.
[13]Ibid., p18.

Chapter 3

Typology

Looking for building types is looking for a constant aspect in a pool of samples that is always changing. Alberti and his contemporaries understood that architecture is perceived by an infinite amount of views, depending on the position of the controlling viewpoint, the eye. Where painting was dominated by linear perspective (shortly before rediscovered by Brunelleschi), this way of recording objects was not suited for architecture since there is an unlimited number of views on a building. This asked for a different, objective way of documenting buildings, bringing about Alberti's introduction of the plan, section, and elevation. Using Vitruvius' three principles, the plan can clearly be linked to the building's configuration (utilitas), the section with its structural elements (firmitas), and the elevation with its decorative elements (venustas). These three different methods of two dimensional drawings could record three dimensional buildings in a way that they are reproducible. These methods of recording brought with them the possibility of comparing buildings on Vitruvius' aspects of utilitas, firmitas, and venustas, hence meaning it is possible to distinguish types. For the key figures of the quattrocentos, looking for this constant in the changing world was considered true knowledge.

Typology plays an important role in architectural theory, but the role of typology is disputed. Maldonado mentions that as long as classification techniques will not be capable to define all the problem's parameters, architects fall back on typology to arrive at a solution during the design process[1]. This part is to him equal to "a cancer in the body of the solution"[2]. He has to add that the mere intuition, that fills the part nowadays (replacing typology), is mostly based on the experience of earlier solutions for similar problems, and cannot be considered a solution either[3]. Monestiroli recognizes the undeniable importance of history by stating that nature and history

[1]Van Duin, L, et al (1996). *Architectuurfragmenten.* Delft: Publikatieburo Bouwkunde. p18.
[2]Vidler, A. (1977). The third typology. *Oppositions.* 7, pp1-4.
[3]Van Duin, et al., op. cit., p18.

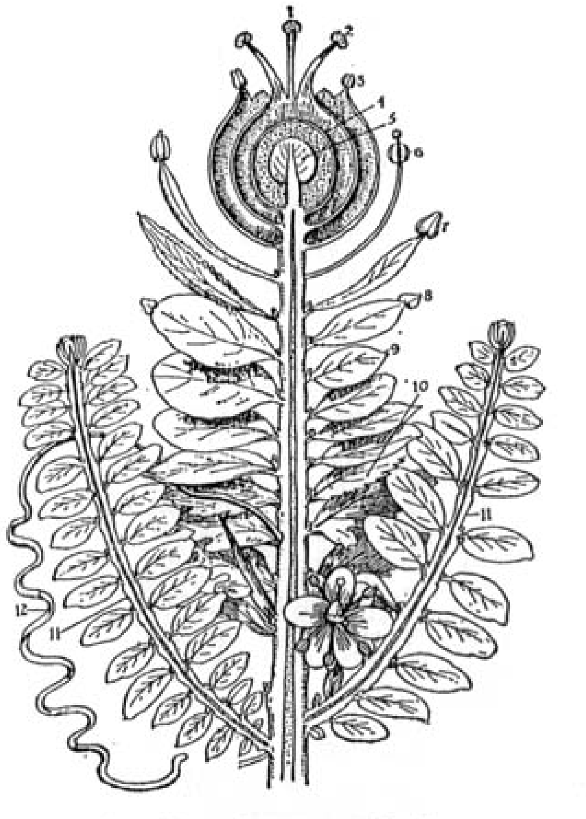


FIGURE 3.1: One of Goethe's morphological drawings

have functioned since the early days as constant references in the analogy with the formal world around us, that is used in the arts and architecture[1]. Arguably one may state that "[u]ltimately, the entire human structure of perception is based "a priori" on typologies"[2], therefore saying that in architecture such a phenomenon is absent can be considered shortsighted.

There are two other issues regarding typology: the understanding of the type and the representation of the type. Understandings of the type are quite ambiguous, there is no generally accepted clear definition of type[3], and sometimes definitions even contradict each other[4]. Overall, a dinstinction can be made between a Neoplatonic understanding of an eternal, constant type (as understood by Quatremère de Quincy), and a modern view of a evolving type (according to Durand and Argan)[5]. A second distinction must be made between a vague, more complex definition of type (as given by Quatremère de Quincy and Argan) and a shallower understanding relating more to a model or stereotype (Durand and the Modern Movement).

Because of these different interpretations, a clear view of the type's representation is also lacking. Ungers states that "[t]hinking in typologies is thinking in transformation and change, a constant creation of ever-changing, new, unknown levels of culture"[6] and that "[t]ypological thought refers to the whole"[7]. One can regard typology as "neither a spatial diagram not the average of a serial list ... it might even be said that type means the act of thinking in groups."[8]

For this research, Argan's definition of type will be used. Argan adopts Quatremère de Quincy's more complex definition of type, stating: "one might say that [according to Quatremère de Quincy,] the "type" arises at the moment at which the art of the past no longer appears to a working artist as a conditioning model[9]." At the same time, he frees the concept from its Neoplatonic notion, making it suitable for modern use.

[1]Engel, H, and Claessens, F (2005). *Wat is architectuur?*. Amsterdam: SUN. p165.
[2]Pfeifer, G, and Brauneck, P (2008). *Courtyard houses*. Boston: Birkhäuser. p10.
[3]Flemming, U, and Aygen, Z. (2001). A hybrid representation of architectural precedents. *Automation in construction*. 10 (6), p690.
[4]Reichlin, B. (1985). Tipo e tradizione del Moderno. *Casabella*. 509-510, p32.
[5]Vidler, A. (1977). The production of types. *Oppositions*. 8, p93.
[6]Ungers, O, et al.. (1985). Dieci opinioni sul tipo. *Casabella*. 509-510, p93.
[7]Ibid.
[8]Moneo, R. (1978). On typology. *Oppositions*. 13, p23.
[9]Argan, G. (1963). On the typology of architecture. *Architectural Design*. 33 (12), pp564-5.

FIGURE 3.2: Laugier's primitive hut

3.1 Different Understandings of Typology

3.1.1 Quatremère de Quincy and the Introduction in Architecture

The first one to introduce concept of type in the field of architecture was Quatremère de Quincy[1,2]. He defined the architectural type as follows: "The word "type" presents less the image of a thing to copy or imitate completely than the idea of an element which ought itself to serve as a rule for the model."[3] His focus lay on "the root and thereby the simple natural principle of architecture"[4]. In other disciplines, this search for the beginnings of civilization were common too, e.g. Locke in philosophy and Rousseau in anthropology.[5] Quatremère de Quincy was heavily influenced by Neoplatonism and understood type as eternal and constant, formed *a priori*. The primitive hut, described by Laugier (Figure 3.2), was "the true and scientific origin of shelter."[6,7] The architectural type was to be understood in a much broaderm more philosophical sense, explaining the reason behind architecture[8] and Quatremère de Quincy understood type in a metaphorical sense[9] as archetype, or origin[10].

Vital in Quatremère de Quincy's definition is the distinction between type and model. His type is thus not a definite form, but more like the outline of a form[11]. He adds:

> *"When a fragment, a sketch, the thought of a master, a more or less vague description has given birth to a work of art in the imagination of an artist, one will say that the type has been furnished for him by such and such an idea, motif, or intention. The model, as understood in the practical execution of the art, is an object that should be repeated as it is; the type, on the contrary, is an object after which each [artist] can conceive works of art that may have no resemblance. All is precise and given in the model; all is more or less vague in the type."* [12]

He was clearly aware of the danger of type simplifying to a prescriptive model.

[1]Pfeifer, G, and Brauneck, P, op. cit., p10.
[2]Lavin, S (1992). *Quatremere de Quincy and the Invention of a Modern Language of Architecture.* Cambridge, MA: MIT Press. p86.
[3]Quatremère de Quincy, A (1825). *Encyclopedie methodique d'architecture*, Paris.
[4]Vidler, A. (1977). The Idea of Type: The Transformation of the Academic Ideal, 1750-1830. *Oppositions.* 8, p94-115.
[5]Ibid.
[6]Stoppani, T (2008) *On type.* Lecture, University of Greenwich.
[7]Vidler, A. (1977). The Idea of Type: The Transformation of the Academic Ideal, 1750-1830. *Oppositions.* 8, pp94-115.
[8]Moneo, R, op. cit., p28.
[9]Vidler, A. (1977). The Idea of Type: The Transformation of the Academic Ideal, 1750-1830. *Oppositions.* 8, pp94-115.
[10]Markus, T (1993). *Buildings & power: freedom and control in the origin of modern building types.* London: Routledge. p33.
[11]Stoppani, T, op. cit.
[12]Quatremère de Quincy, A, op. cit.

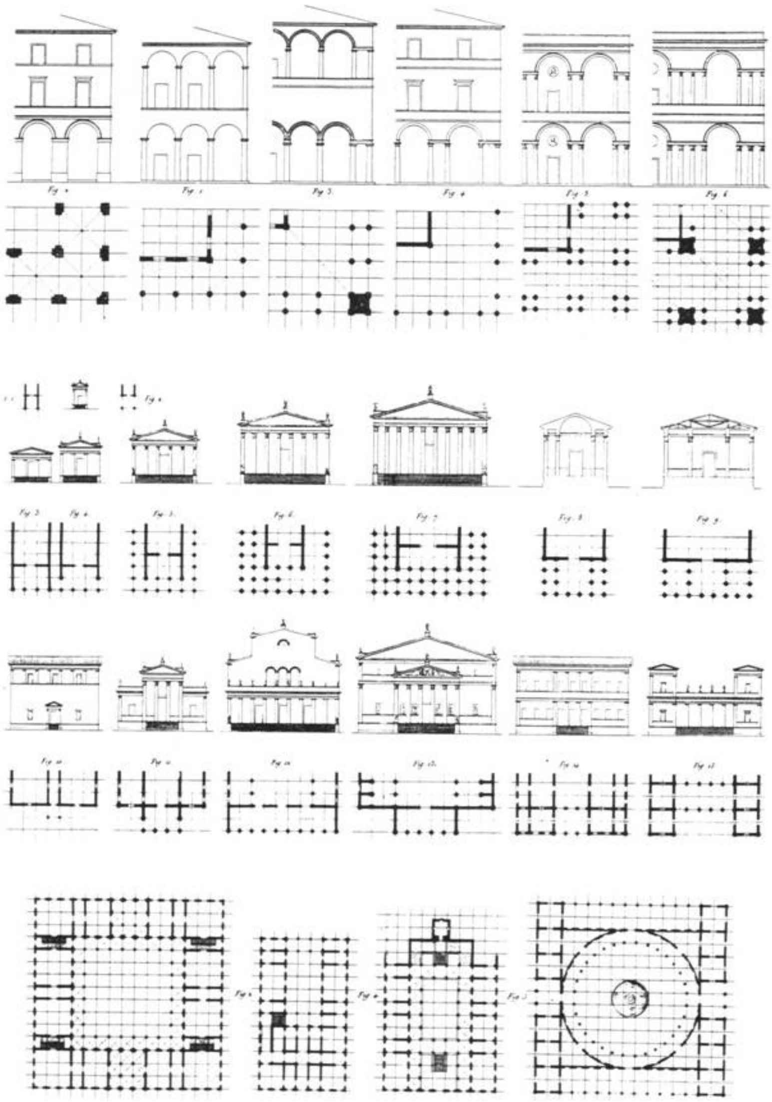


FIGURE 3.3: Example of Durand's schemes

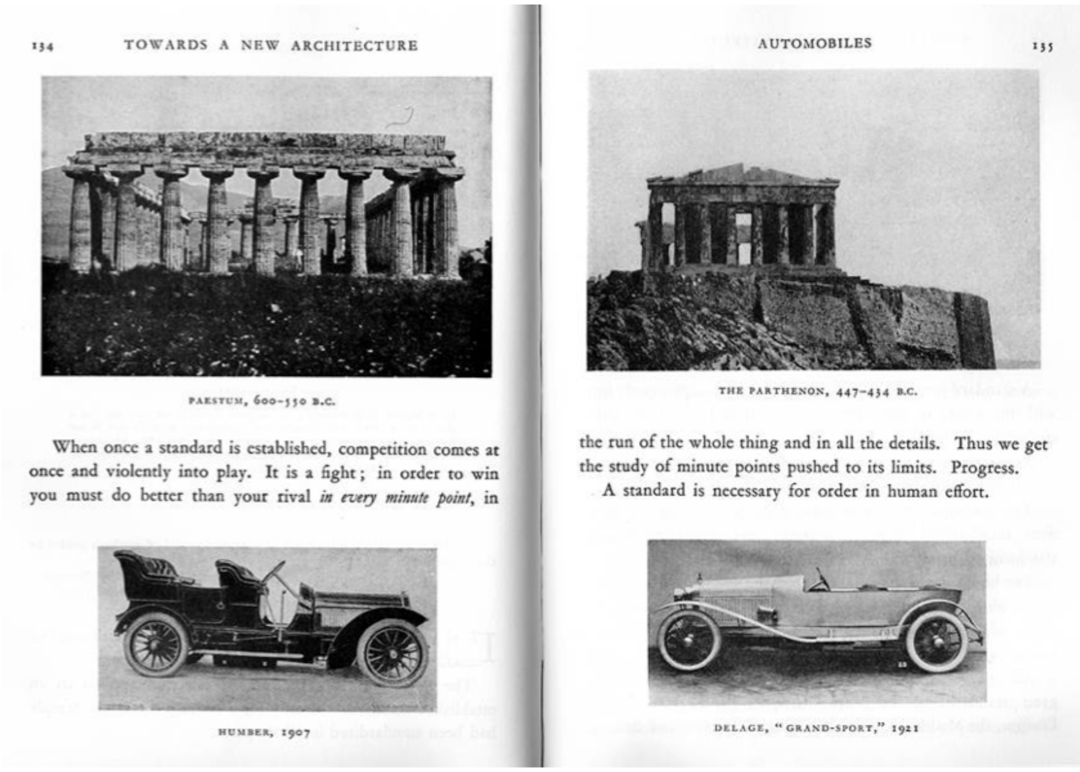
Typology is not merely about reduction[1,2], more than that it can be understood as “an intelligently developed construct in which the link is ensured between the systematic and the historical or conventional (and therefore always societally oriented) limitations of architecture in their reciprocal dependence.”[3]

3.1.2 Durand and the Loss of Style

Following others like Blondel, Durand applied taxonomy of the world’s flora and fauna of Linnaeus and Cuvier[4] to architecture, in an attempt to explore the natural order[5,6,7]. He matched the architectural type to the natural sciences’ species[8] and this way the type became a means to discover general principles in architecture from a collection of individual samples[9,10] (Figure 3.3). He was not the first attempting this, however, Palladio and Serlio had composed comparisons of specific building types earlier (influenced by Alberti’s developments in drawing methods), but Durand extended this to almost all types[11]. Much like Goethe tried in botany (Figure 3.1), Durand used the elements of a building as tools for the composition of new designs[12,13], creating a manual for his students[14]. For this typological comparison, objectivity was most important for Durand. He tried to accomplish this using a strict method[15], focusing mostly on composition and arrangement[16] and the “productive capacity of rules and elements according to programs inductively defined”.[17]

Durand focused only on economy and utility[18]. This had different consequences and led to a shallower (yet clearer) understanding of type[19]. First of all he abandoned Quatremère de Quincy’s Neoplatonic ideas. The type was no longer the essence, the archetype, but a system serving “convenance” and “économie”[20,21]. This “imperative of

[1]Oechslin, W. (1986). Premises for the resumption of the Discussion of Typology. *Assemblage*. 1, p51.
[2]Moneo, R, op. cit., p28.
[3]Oechslin, W, op. cit., p52.
[4]Vidler, A. (1977). The Idea of Type: The Transformation of the Academic Ideal, 1750-1830. *Oppositions*. 8, pp94-115.
[5]Ibid., p445.
[6]Ibid., p451.
[7]Madrazo, L. (1994). Durand and the science of architecture. *Journal of Architectural Education*. 48 (1), p12.
[8]Ibid., p13.
[9]Ibid.
[10]Ibid., p21.
[11]Villari, S (1990). *J.N.L. Durand: Art and Science of Architecture*. New York: Rizzoli. p54.
[12]Steadman, P, op. cit., p248.
[13]Lampugnani, V. (1985). Tipologia e tipizzazione. *Casabella*. 509-510, p85.
[14]Moneo, R, op. cit., p31.
[15]Madrazo, L, op. cit., p21.
[16]Pfeifer, G, and Brauneck, P, op. cit., p11.
[17]Stoppani, op. cit.
[18]Villari, S, op. cit., p67
[19]Oechslin, W, op. cit., p39.
[20]Durand, J-N-L (2000). *Précis of the Lectures on Architecture*. Los Angeles, CA: Getty Research Institute. p48.
[21]Ibid., p32.


134 TOWARDS A NEW ARCHITECTURE

PAESTUM, 600–550 B.C.

When once a standard is established, competition comes at once and violently into play. It is a fight; in order to win you must do better than your rival *in every minute point*, in

HUMBER, 1907

AUTOMOBILES 135

THE PARTHENON, 447–434 B.C.

the run of the whole thing and in all the details. Thus we get the study of minute points pushed to its limits. Progress.

A standard is necessary for order in human effort.

DELAGE, "GRAND-SPORT," 1921

FIGURE 3.4: Juxtaposition of architecture and technology

utility"[1] means that, when the needs and habits of architecture change over time, the type can also transform[2]. Utility and economy also replaced Vitruvius' three qualities[3], making a first step to modernist functionalism[4]. Even though venustas used to order and shape firmitas and utilitas, Durand lowered its status, stating that "the classical orders should be seen as mere decoration"[5]; the last layer of style can be filled in with anything.

3.1.3 Functionalism and the Demotion of Type

At the beginning of the twentieth century, the modernists followed Durand's ideas and his "cause effect relation between form and function [...] was taken to the extreme."[6] The interdependence of architecture and economics was developed further with the rise of mass production[7]. Typology in the Modern Movement is characterized by three aspects: functional determinism, the rejection of precedents in favor of pure forms, and the notion of prototype versus mass production[8] (Figure 3.4).

With functional determinism, anything related to history (and thus the type) was rejected, because functionality does not have a historical aspect[9,10]. The new concepts of cleanliness and higher living quality[11,12] brought for the first time a scientific ground for architecture. These aspects now were the only important characteristic of a building and anything else was rejected. The disappearance of tradition in the design process created a vacuum and eliminated the whole field of aesthetics[13]. Artists like van Doesburg were striving for a "formless architecture", with pure forms, free of any preconceived type"[14] and also Le Corbusier's plan libre negates the idea of type[15].

Where Le Corbusier and his contemporaries' interest lay, was the new possibilities of industrial production.[16] But mass production transformed the idea of type into a prototype[17,18] and "type became standardized,"[19] to be produced serially ad infinitum.

[1]Durand, J-N-L (2000). *Précis of the Lectures on Architecture.* Los Angeles, CA: Getty Research Institute. p18.
[2]Ibid.
[3]Vidler, A. (1977). The Idea of Type: The Transformation of the Academic Ideal, 1750-1830. *Oppositions.* 8, pp94-115.
[4]Kruft, H (1985). *Geschichte der Architekturtheorie.* München: C.H. Beck. p312.
[5]Moneo, R, op. cit., p28.
[6]Güney, Y. (2007). Type and typology in architectural discourse. *Baü fbe dergisi cilt.* 9, p9.
[7]Oechslin, W, op. cit., p39.
[8]Güney, Y, op. cit., p9.
[9]Pfeifer, G, and Brauneck, P, op. cit., p12.
[10]Moneo, R, op. cit., p33.
[11]Güney, op. cit., p8.
[12]Lampugnani, V., op. cit., p85.
[13]Colquhoun, A. (1969). Typology and design method. *Perspecta.* 12, pp71-74.
[14]Van Duin, L, et al., op. cit., p16.
[15]Secchi, B. (1985). L'eccezione e la regola. *Casabella.* 509-510, p31.
[16]Moneo, R, op. cit., p33.
[17]Vidler, A. (1977). The production of types. *Oppositions.* 8, p93.
[18]Moneo, R. (1976). Aldo Rossi: The Idea of Architecture and the Modena Cemetery. *Oppositions.* 5, pp1-30.
[19]Güney, Y, op. cit., p8.

Type lost significance and was downgraded to a model, as Quatremère had tried to prevent.[1]

3.1.4 The Renaissance of Typology Under the Neorationalists

Argan and contemporaries returned for their definition of type to Quatremère de Quincy. The type can be interpreted as the inner formal structure of a building (or series of buildings), "no type can be identified with a particular form, but all architectural forms can be referred to types"[2]. Influenced by Durand, the Neoplatonic understanding was lost[3]; where Quatremère de Quincy understands the type being formed a priori, Argan states that it is formed a posteriori[4,5] from a series of instances. So, if the type is formed from a set of building plans, this type is bound to change when a new building is added to the set[6]. Hence, type is not an timeless constant and ultimate truth as it was in Quatremère de Quincy's time, but a concept that can change, disappear and originate[7,8].

3.2 Three Different Uses of Typology

With type being a rather vague concept, the use of type in this study is divided into three parts. The first part is the use of type to analyze the development of the observatory, the second is a comparison of the building type with other building types, and the last part is the use of typology in the design of a new building.

The method developed by Durand of a juxtaposition of different plans, disregarding epoch, location, or style, suits the taxonomy[9] of observatories for the possible discovery of the type. After this taxonomy, it is important to evaluate if the found type(s) correspond to any other building types. This leads to a better understanding of the building type and its role in architectural history.

Next to these analytical methods, typology can also be used in a synthesis. Already in his early development of morphology in botany, Goethe was already interested in showing "how recombinations of the basic elements of plant form could create theoretical species

[1]Güney, Y, op. cit., p4.
[2]Rossi, A (1982). *Architecture of the city.* Cambridge, MA: MIT Press. p32.
[3]Moneo, R. (1978). On typology. *Oppositions.* 13, p35.
[4]Ibid., p36.
[5]Argan, G, op. cit., pp564-5.
[6]Van Duin, L, et al., op. cit., p13.
[7]Stoppani, T, op. cit.
[8]Moneo, R. (1978). On typology. *Oppositions.* 13, p24.
[9]Stoppani, T, op. cit.

unknown to nature"[1]. Analysing the different elements therefore could lead to insight in new combinations of these elements. In a similar way, Quatremère de Quincy writes that "the type is (...) something which can act as a basis for the conception of works which bear no resemblance to one another"[2] and also Durand deals with the generative aspect of his methods[3]. The clear bilateral analytical and synthetical character of type in the design process is recognized by Argan, who defines two moments that come together when designing: "(1) the typological moment, when the rules of design and building used in the past (and thus yielding types which have been called a posteriori) are identified and understood, and (2) the moment of invention, when the artist answers the historical and cultural questions through a critical approach (yielding so-called a priori types)"[4,5]. The research has to lead to thorough understanding of the type and its role compared to other building types, while the second moment will take place when designing a new observatory.

What is of utmost importance in synthesis is that the type does not become a model for formal imitation[6], as happened in Durand's generative method and in the understanding of the Modern Movement. "The 'type' is accepted but not "imitated" which means that the repetition of the 'type' excludes the operation of that kind of creative process which is known as mimesis"[7]. Involving typology in the design process only leads to more demanding conditions, rather than replacing the creativity with a strict guideline[8].

3.3 Conclusions

For this study, Argan's definition is used. This definition follows Quatremère de Quincy but does not acknowledge its Neoplatonic aspect. Durand's method of stripping building plans from all stylistic characteristics and comparing them, suits the historical taxonomy of the observatory. Because Durand's understanding of type is more shallow and arguably more related to the model, this method will only be used for analysis and not for synthesis. In this analysis it is important to avoid the "typification of the type, that is to say the tendency to discourage the emergence of new formal structures, implicitly accepting that already historically formulated types [...] could provide the answer to subsequent transformations of contents and production systems"[9].

It may be clear that especially in a time with a pluralist view of value typology can still

[1]Steadman, P, op. cit., p248.
[2]Reichlin, B., op. cit., p32.
[3]Moudon, A. V. (1994). Getting to know the built landscape: typomorphology. *Ordering space: types in architecture and design*, p308.
[4]Moudon, A, op. cit., p294.
[5]Engel, H, and Claessens, F, op. cit, p165.
[6]Scolari, M. (1985). L'impegno tipologico. *Casabella*. 509-510, p44.
[7]Argan, G, op. cit.
[8]Oechslin, W, op. cit., pp50-51.
[9]Ungers, O, et al., op. cit., p97.

fill the vacuum that individual intuition could not. When functioning as a model for mimesis and as long as the looseness of its character is recognized, the type can play an important role in the analysis of existing and the development of new buildings. Typology helps with understanding the old when designing the new. With a better view on the history of a certain building type comes more knowledge about previous decisions and paths already taken, leading to better design decisions.

Chapter 4

Taxonomy

After the revival of astronomy in Europe in the early Renaissance, it took three centuries before a clear type of the observatory emerged. In the early years of modern astronomy most observations were done from normal rooms, only approximately one per country was founded in Europe, by kings, Jesuit orders, universities or private fundings. Once the observatory had matured at the beginning of the nineteenth century, it gained popularity and appeared in almost every significant European city. Later in the nineteenth century, with the introduction of astrophysics (discussed later), universities, cities and even amateurs were in need of observatories (see chapter 5), which began to materialize in abundance. Telescopes grew in size making observatories more and more expensive and hence the number did not increase as fast. However the developing technology of telescopes made building observatories more expensive. The World Wars and economic depression of the interbellum also contributed to the stagnated flux of the observatory. After the second World War, due to the expense of astronomical institutions, most countries (with exception of the United States) began cooperating and institutions shared telescopes, reducing construction and maintenance costs. Additionally, amateurs started building small observatories for private or communal use. In Appendix B, an overview is given stating how many of the samples samples were constructed per decade. In this table, the observatories printed in blue are typical observatories that will come back later in the overview of the development of the observatory (chapter 5).

4.1 Functions in the Observatory

The functions housed in the samples –as far as they are known– are shown in the following diagram so that the development of functions accomodated by the observatory are pronounced with respect to time. Some functions are introduced, some abandoned, and some constant. Also innovative observatories that at once introduce many functions,

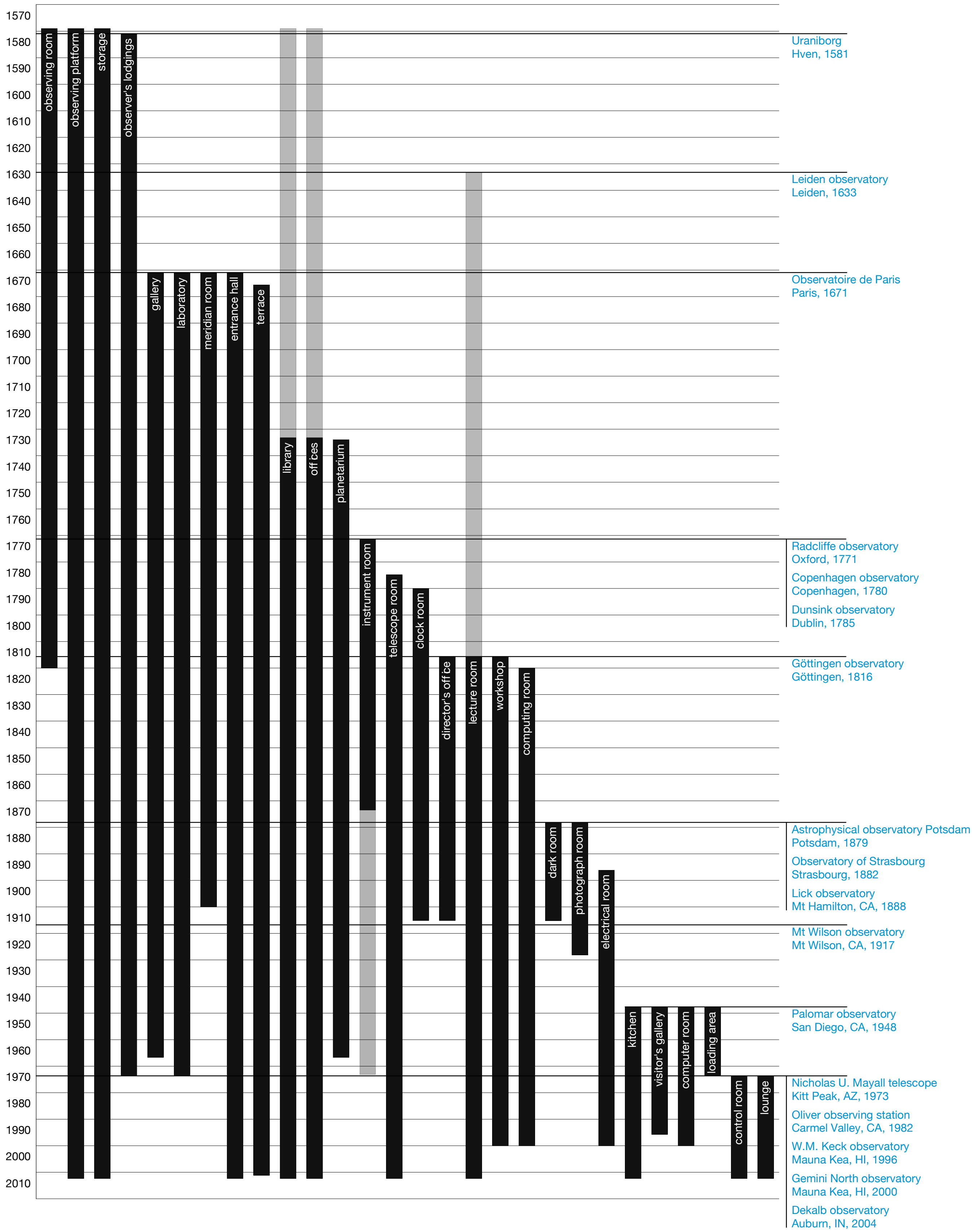


FIGURE 4.1: Functions in the observatory through time

such as the Observatoire de Paris or the Göttingen observatory become visible. It is reiterated that this diagram is the result of the available samples. Therefore, some functions seem to disappear (e.g. loading area), but most likely only lack evidence in these samples. This becomes clear when looking for example at the Nordic Optical Telescope on La Palma[1]. Functions that were already housed in different parts of a building, but not specifically in the observatory (e.g. library and office) are marked gray. Lastly, the instrument room, since it changes character (as discussed later, the instrument becomes dependent of the telescope and is no longer autonomous), is also marked gray.

Figure 4.1 articulates the prominent traits in the progression of the observatory. First of all, the observing room, observing platform, storage, and lodgings together appear to be the functional core of the observatory since the beginning. The observing room and later the meridian and instrument rooms too slowly make way for the telescope room.

Astronomical instruments shortly explained

Meridian
Because of the earth's rotation, stars seem to pass across the skies. The moment a celestial body passes the meridian is referred to as transit. The meridian instrument times this and measures the angle with the nadir (the opposite of the zenith).

Transit
Similar to the meridian instrument and horizontally mounted. However, unlike the meridian, the transit instrument is not fixed in the east - west direction.

Zenith
A zenith telescope or sector is an optical telescope that measures the angle between star and zenith during transit.

Quadrant
An instrument measuring the vertical angle between a celestial body and the instrument. Quadrants come in many different sizes and variants, from portable instruments to large mural quadrants built on or into walls. The quadrant is recognized by its quarter circle shape.

Sextant
A more advanced version of the quadrant but in the shape of a sixth of a circle. Unlike most quadrants, the sextant could measure the angle between a celestial body and the horizon, improving accuracy. In navigation sextants were used to define the ship's latitude.

There are not many added functions that were not already indirectly present in earlier building samples. For example the lounge was introduced only in 1973 as a separate area for the staff of the Nicholas U. Mayall Telescope to be able to relax in between shifts. This does not imply that observatory staff could not relax inside of the observatory before the addition of the lounge, but only in 1973 the observatory got a special area for this activity. This trend was also administered to the gallery, entrance

[1]Karttunen, H. (1992). *NOT 2.5 m telescope manual.*

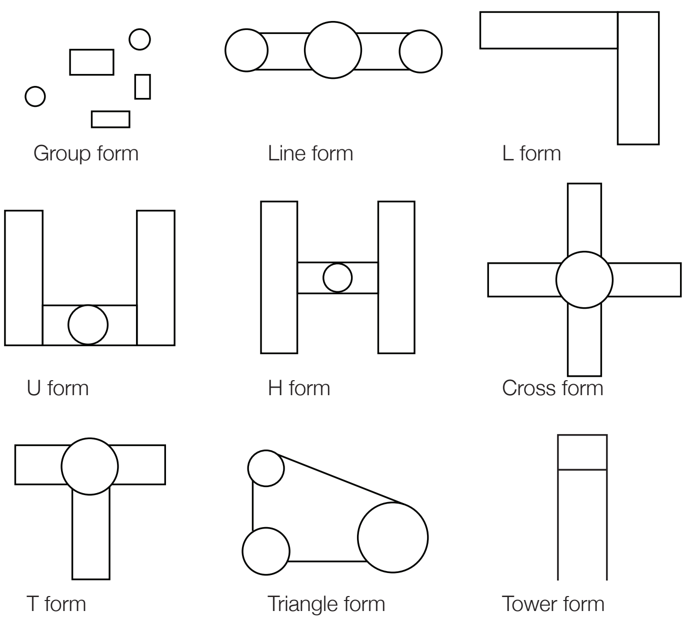


FIGURE 4.2: Clusters as proposed by Müller

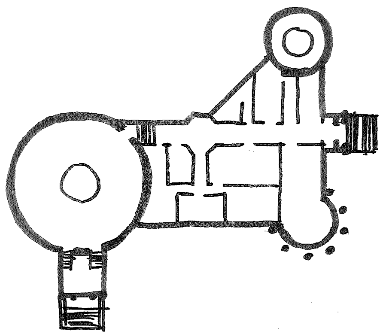


FIGURE 4.3: The Allegheny Observatory plan

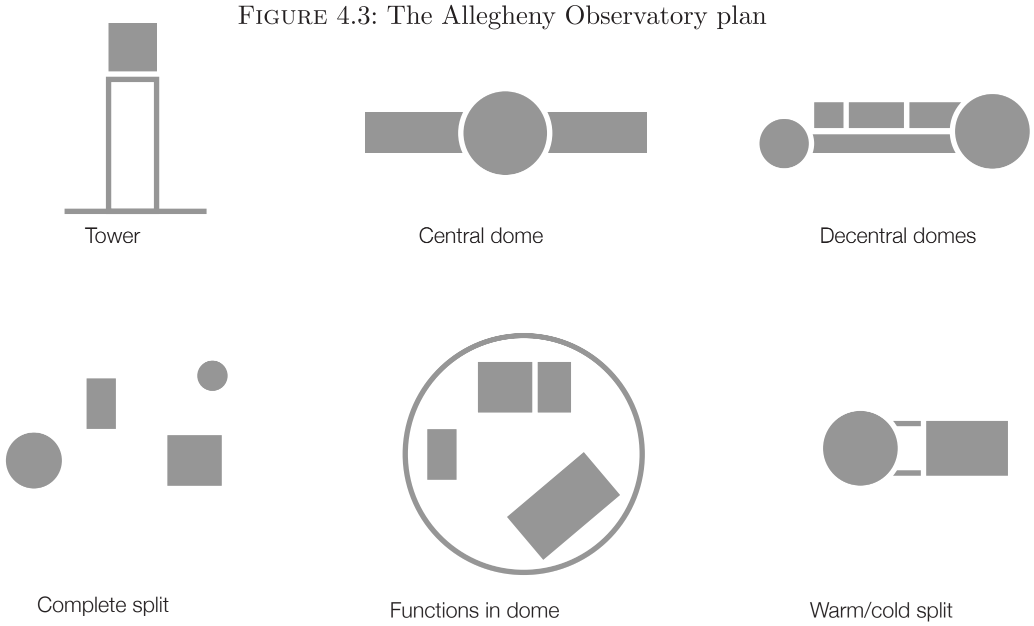


FIGURE 4.4: Graphical representations of the different subtypes

hall, offices, director's office, workshop, computing room (the room where humans handled calculations themselves), kitchen, and visitor's gallery. All of these functions were in once implicit in earlier observatories, but attained a separate functional space in later plans. These suppelementary functions are not requirements for astronomical observation, but rather operate as support for the institute and also appeared in other building types, such as laboratories.

Some functions are no common in the observatory and were introduced as the observatory evolved. This has mostly to do with the development of the observing room, which slowly evolved to specific instrument, meridian, and telescope rooms. In their turn, the meridian and instrument rooms disappeared around the fin de siècle. The clock room was also of utmost importance to an observatory and moreover, the planetarium –used primarily for demonstrations rather than research– was introduced at the Kunstkamera in St. Petersburg. With the introduction of photography in the second half of the nineteenth century, photograph and dark room became necessary for the development of photographic plates taken by telescopes. The introduction of the control room brought with it rigorous changes in observatory use and planning.

4.2 Clusters

The matrix that follows distinguishes seven clusters. Some clusters coincide with ones found in the literature, others are original. Müller[1] is the only author to clearly recognize clusters (Figure 4.2). These are:

1) Group form	*2) Line form*	*3) L form*
4) U form	*5) H form*	*6) Cross form*
7) T form	*8) Triangle form*	*9) Tower form*

The central form with wings is divided into six of the nine groups (T, H, Cross, L, Line, and U form). However, the U and H form might be considered the same, as Müller himself states that an H is nothing more than a double U and that the T and L forms are merely incomplete Crosses. The place of the telescope, which changes the functionality and characteristics of the plan is not specified in his clusters. In the T form cluster, for example, the telescope may be at the crossing of the three wings, but it might just as well be at the end of each wing. Of Müller's samples, only one observatory (Allegheny Observatory, Figure 4.3) corresponds to the Triangle form, but under close inspection and consideration it might actually fall into the "Decentral dome" cluster mentioned

[1]Müller, P (1992). *Sternwarten in Bildern: Architektur und Geschichte der Sternwarten von den Anfängen bis ca. 1950.* Berlin: Springer-Verlag. pp252-7.

Cluster name	Years	Typical observatory	Characteristics
Tower	1579–2012	Leiden observatory	> observation room with portable instruments > unicellular > addition to existing structure or building > high on building or tower
Central dome	1771-1953	Göttingen observatory	> spacial differentiation of the program > additional functions added to program (library, lecture room, offices, etc.) > central building parts with wings > telescope (pier) moves to ground floor
Decentral domes	1671-2012	Yerkes observatory	> same characteristics of central telescope model are kept > chosen for if there are two telescopes/observing rooms > chosen for if telescope is too big for central position
Complete split	1886-1965	Mt Wilson observatory	> internal conflict: offices/dwelling/etc. versus instruments > instruments are housed each in a separate building
Functions in dome	1948-1987	Palomar observatory	> astronomer's comfort is neglected with total split > (partial) reunion of program > telescope room is so big that additional functions are shoved in extra space
Warm/cold split	1882-2000	Oliver observing station	> because of the introduction of control room comfort not neglected with split > instruments housed in one part of building, all hampering functions in different part
Exceptions	1581-2004	–	> observatory is too small > observatory does not have a decentralized layout > other

Table 4.1: Observatory clusters

below. The Group form contains every observatory that is split up (the observatory is divided over several buildings), from the Lick observatory to the Nice and Palomar observatories. However, there is a clear distinction between the Nice observatory, where a building only contains a telescope, and the Palomar observatory, where the building contains a whole set of functions next to this telescope.

Müller ends up with wrongly divided clusters not only because of this. Of course, the warm/cold split, for example (to be discussed later), is not present in any of Müller's samples, but Müller's clusters are mostly concerned with the formal appearance of the plan and not enough on its functionality. The result is that some clusters are too specific (e.g. U form), and some are too broad with samples differing too much from each other (Group form). Therefore, a new set of clusters (Table 4.1) is proposed here that applies to the morphological development of the observatory, their typical representation given in Figure 4.4.In Appendix C a matrix is given showing the clusters in relation to each other. In Appendices D and E a chronological matrix of the clusters is given.

4.3 Conclusions

Forming functional clusters of observatories rather than superficial categories provides a foundation on which to establish the typological features of the observatory. It becomes clear that none of the clusters are specific for the observatory type. Each of the clusters is a more general formal scheme that is used in different building types too. The decentrality that is present in all (except for the "functions in dome" cluster) can have other causes, such as entry of daylight or expandability. However, the prominent role that is assigned to the telescope can be considered unique. From table 4.1 it becomes clear that apart from the central dome, not any of the clusters has ceased to exist. There is no clear line of development in which newly introduced clusters replace existing ones; the new clusters are additions to the assortment of subtypes.

Chapter 5

The Development of the Observatory

5.1 Developments in Astronomy

When astronomy was reintroduced in Europe around the middle of the fifteenth century, only small portable instruments were used for observation. Only much later, in the second half of the eighteenth century, it was understood that better measurements can be done when instruments are fixed to diminish vibrations and irregularities. Onward, observational instruments were mounted on piers that were constructionally isolated from the rest of the building to prevent vibrations from users. The requirements for solid mounting lead to separate instrument rooms, causing differentiation of the program. The telescope became the prominent astronomical instrument in the nineteenth century because of the rise of astrophysics and their capability for more accuracy. The instruments such as the transit, zenith, and meridian instruments were all associated with traditional astronomy (focused on the position of celestial bodies). These instruments all disappeared by the beginning of the twentieth century, because positions can also be measured with the telescope.

The rise of astrophysics, however, also demanded more precise instruments and this lead to more isolation from disturbances. The internal conflict that was the result of this is discussed later. With the observatory torn apart because of this conflict, it was only really resolved with the introduction of the control room, making it possible that the observer did not have to be next to the telescope in order to operate it, but could be in a different room or building and thanks to the internet later even in a different country or continent. Even though scientists are able to operate observatories from far away, this luxury is mostly reduced to enthusiasts of citizen astronomy. Increasingly, observatories are constructed and telescopes are timeshared among amateurs, sharing

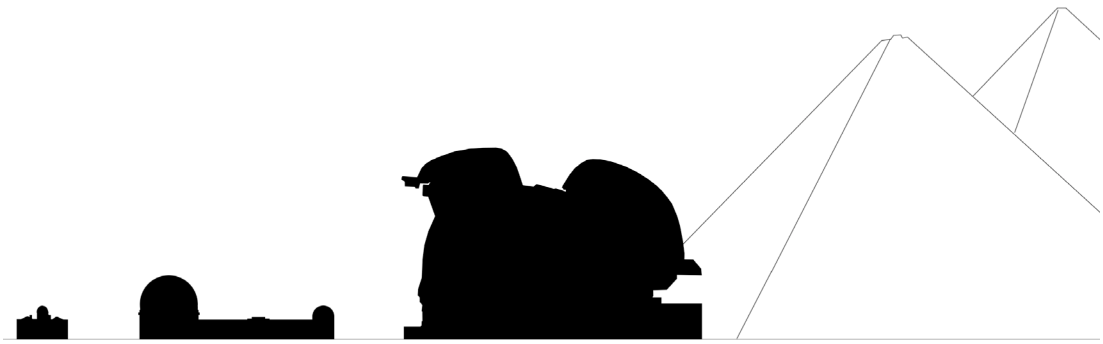


Figure 5.1: Growth of the telescope through the ages: the silhouets of the Dunsink, Yerkes and E-ELT observatories next to the pyramids of Gizeh

costs of more expensive technology.

With the development of optical technology since the start of the twentieth century, the size of telescopes grew excessively. This created a disbalance between space housing the instrument and the rest of the building, which is expected to increase in the future. Figure 5.1 clearly shows the increase of scale with the comparison between the Dunsink Observatory (1785), the Yerkes Observatory (1897), the biggest telescope at the end of the nineteenth century, and the European Extremely Large Telescope, currently under development[1]. It may be clear that observatories are rapidly evolving to be among the biggest buildings in the world.

5.2 Different Kinds of Observatories

A unique characteristic of astronomy is that it is a citizen science, and has been for centuries. William Herschel, discoverer of the planet Uranus and amongst other things built the largest telescope of that time (Figure 5.2), but nothing more than an enthusiastic citizen astronomer and mathematician[2]. At the end of the nineteenth century, amateurs started to organize themselves into astronomical societies and gathered in citizen observatories, the first being Urania in Berlin in 1889. From that time on citizen astronomy (or amateur astronomy) started to be more organized and was no longer exclusive to wealthy individuals. Next to professional observatories, amateur societies have built their own amateur or citizen observatories. In a time where professionals were looking for better and better observing conditions, citizen observatories were situated close to the city and resemble the tower observing rooms of the fifteenth to eighteenth century. Now that telescopes are more readily available, many amateurs have started to build their own observatories in their backyards for the last decades, leading to a flux in citizen astronomy. These individual enthusiasts now contribute more precise data that through organizations such as the AAVSO in the United States is used for scientific research.

Due to variations in size and technology, there are three subspecies of the observatory: citizen observatories, professional institutes, and educational observatories. In the early days, professional observatories were the same as educational observatories (consider the many observing rooms built on towers and university buildings, i.e. the first Leiden Observatory). However, with the search for better observing conditions that lead professionals to more remote locations, educational observatories became

[1] anonymous. (2013). *The European Extremely Large Telescope ("E-ELT") Project.* Available: http://www.eso.org/sci/facilities/eelt/. Last accessed 16th March, 2013.

[2] Moore, P (1972). The story of astronomy. London: Macdonald and Co. p49.

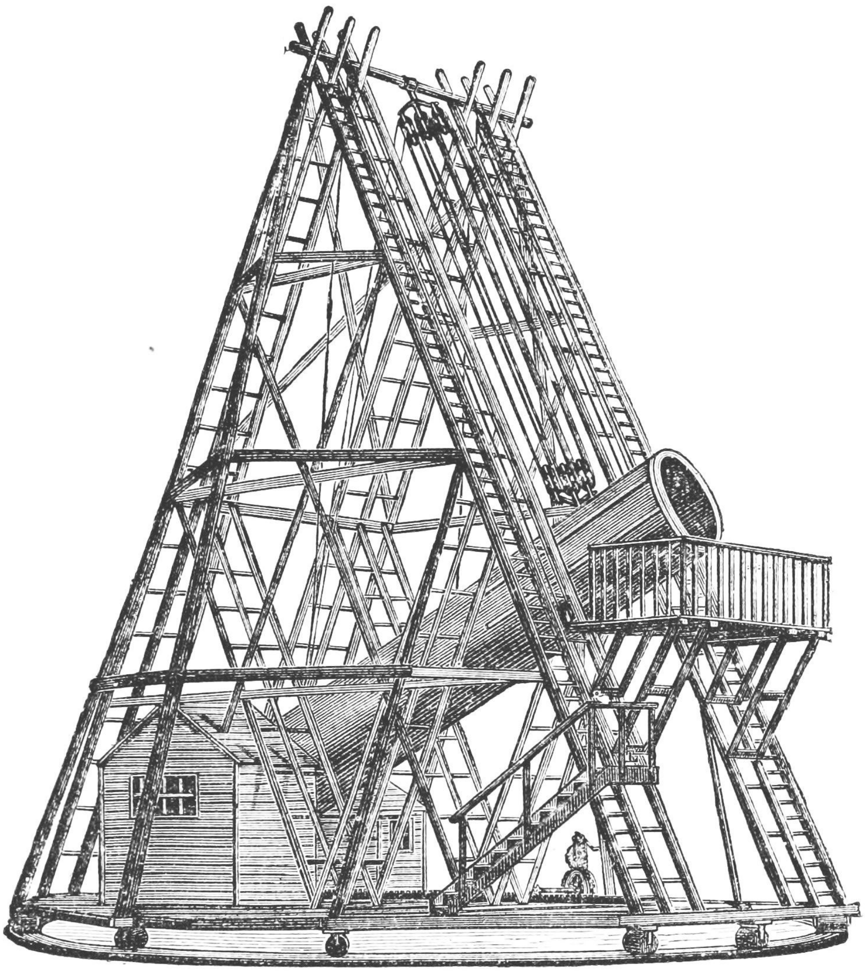


FIGURE 5.2: Herschel's Great Forty-Foot Telescope

another subspecies that are primarily used to educate new scientists. Many professional observatories are related to universities as well, but are not characterized by this educational aspect. Educational observatories are generally in between professional and citizen buildings regarding size and house different functions, such as a lecture room.

5.3 Location

Location is pertinent to observatories because readings are sensitive to environmental factors. Because vegetation diminishes changes in temperature between the observatory and the surrounding grounds and air, observatories have made use of their natural surroudings, serving as a buffer for disturbances. Generally speaking, the private observatories of the late Middle Ages and early Renaissance (such as Uraniborg, discussed later) were mostly located in parks. The first public observatories, often Tower types, were located closer to people, on the outskirts of the city, explaining their verticality. University observatories (such as the ones in Strasbourg and Leiden) have mostly been combined with botanical gardens. At the end of the eighteenth century, observatories were often placed outside the city in a park or on the edge of a forest.

Starting in the second half of the nineteenth century and around the turn of the century site analysis determined the best locations. In the second half of the twentieth century the choice for location became even more critical, because large institutions wanted to build on the best sites on earth. These locations are characterized by dark skies, many clear nights per year, dry air and, as suggested by Newton (to be discussed later in this chapter and chapter 6), at high elevations, such as mountain tops. Regions in the world that have these characteristics are the Southwest of the US, Hawai'i, the Canary Islands, the southern Andes, the mountains in Mexico, South Africa, the south of Australia and the Mediterranean.[1,2] A first American observatory was founded in Chile as early as 1849, but most of these locations were only fully utilized about a century later, with the founding of both the European Southern Observatory in Chile in the 1960s, the Kitt Peak Observatory in the 1960s, the Mauna Kea observatories on the island of Hawai'i in the 1970s and the observatory on La Palma in the 1980s. Astronomical institutions began collaborating to build observatories, supported by a long tradition of international cooperation in the astronomical professional world. Astronomers from all over the world travel to these remote observatories. This ended the constant struggle between remoteness for observations and proximity for astronomers with remoteness as the winner. However, at the same time more citizen observatories are built in the backyards of individuals, to be used as often as possible. Of course, with

[1] Chaisson, E and McMillan, S (2002). *Astronomy Today.* 4th ed. Upper Saddle River, NJ: Prentice Hall. pp116-9.

[2] Müller, P (1978). *Sternwarten: Architektur und Geschichte der Astronomischen Observatorien.* 2nd ed. Frankfurt am Main: Peter Lang GmbH. p261.

FIGURE 5.3: Brahe's observatory palace Uraniborg

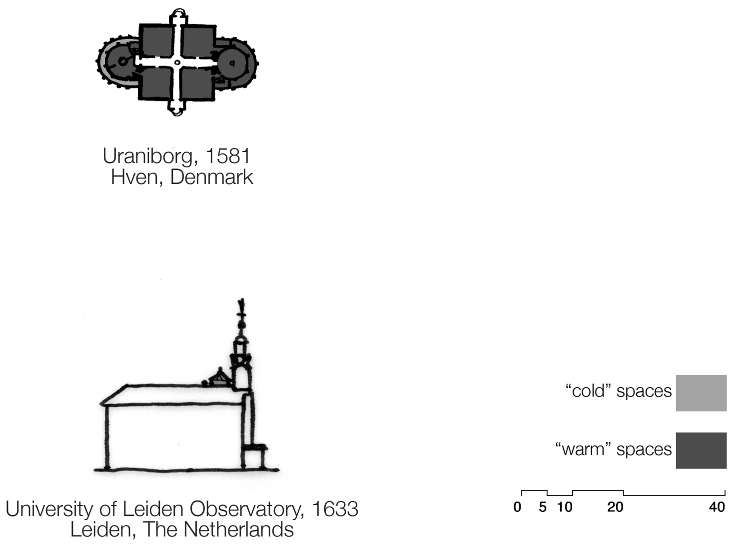


FIGURE 5.4: Uraniborg and Leiden schemes

the introduction of orbital observatories such as the Hubble telescope, a new dilemma is again present, but the enormous expenses that come with these operations have prevented explosive popularity of such observatories.

5.4 Reintroduction in Europe

After a long period of absence in Europe, astronomy came back from the East around the 15th century because of the rediscovery of Ptolemy's writings. Astrology had because of the Middle Ages' mysticism a strong influence on politics and society. It is for this reason that the Danish king and the Holy Roman emperor gave Brahe an observatory to perform his observations, and also his famous successor Kepler was officially an astrologist. As mentioned before, since the beginning of days, astrology and astronomy had been closely together and only from the second half of the 17th century this relation started to disappear.

During the Scientific Revolution of Copernicus, Kepler, Galileo and Newton, the skies were mostly observed from private rooms or balconies and the observatory slowly stabilized as a building function. This first period in the observatories development, roughly lasting until the first half of the 18th century is characterized by small observing rooms appearing on the outskirts of different European cities.

5.4.1 Uraniborg, 1581: The Last Private Palace

Uraniborg (Figure 5.3, 5.4) resembles a palace more than an observatory, and it is a good last example of the medieval private observatories. Since Uraniborg was Brahe's private mansion, the observatory can be seen more as an addition to this than the other way around, which was very typical for the earlier private observatories. Operating in the pre-telescope era, Brahe used different instruments like quadrants and sextants on platforms to determine the movements of the stars and planets. Uraniborg had a library, a study for Brahe, and an entrance hall. However, these functions were more closely connected to the mansion, than to the observatory.

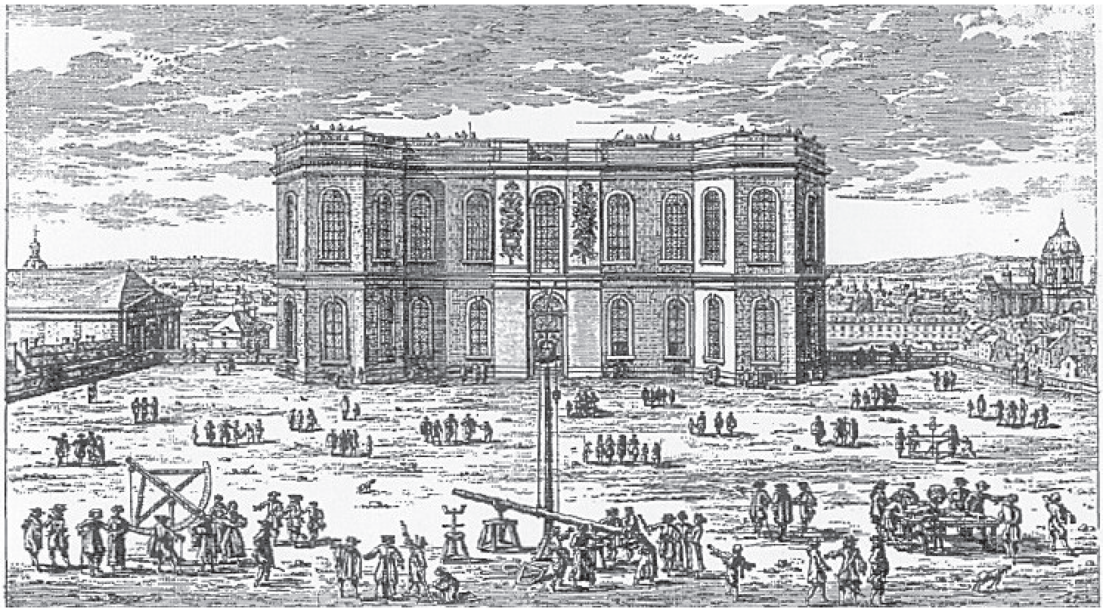


Figure 5.5: The Paris Observatory

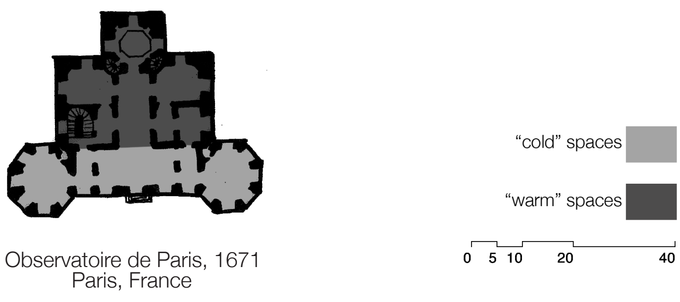


Figure 5.6: Paris scheme

5.4.2 University of Leiden Observatory, 1633: The Early Observing Room

The small observatory of the University of Leiden (Figure 5.4) was added to the university's building in 1633 and was the first public observatory in Europe after the Middle Ages. This observatory is a typical example of early observatories; added on top of an existing structure (often a tower no longer in use) for unobstructed views and consisted of not much more than an observing platform and a small observing room. This model clearly defines the first cluster of observatories, whereas Uraniborg and the Observatoire de Paris should be seen more as exceptions for this period.

The observing room, only one space, almost always had an octagonal shape for views in all directions and was used for both storing and observing with the small portable instruments. Despite the invention of the telescope in 1608 and favored by Galileo since that time, ancient observational instruments (e.g. quadrants, sextants, zenith, and meridian instruments) remained the primary technology until the 18th century and the Leiden observatory did initially only use a quadrant and sextant.

The observatory was in every way an addition to the existing university building. The library and lecture room were built for the main university building and therefore must be considered as functions of this main building rather than of the observatory.

5.4.3 Observatoire de Paris, 1671: Astronomy as Status Symbol

The Observatoire de Paris (Figure 5.5, 5.6) is, together with the Royal Observatory in Greenwich, atypical compared to other seventeenth century observatories. As the world's first national observatory, it was not just a building for observing the skies, it was a meeting place for the scientific community. The building seems to be more of a monument added to the crown of Louis XIV. This was not without reason, as discussed by Johann-Christian Klamt:

> *"Das [...] Pariser Observatoire als [galt] als ein Werkzeug des Sonnenkönigs, ohne Waffengewalt die Erde zu erobern: Er erinnerte sich jener Jesuiten französischer Abkunft, die durch ihre imponierende astronomische Kenntnis sich Eingang und Einfluß in China verschafft hatten."* [1]

The king understood these powers of astronomy and without doubt did this also have a role in the foundation of the Royal Obsevatory in the United Kingdom around the same time.

[1]Klamt, J-C. (1977). Die Frühen Sternwarten im Dienst von Religion und Kolonialismus. *Kunstchronik.* 30, p91.

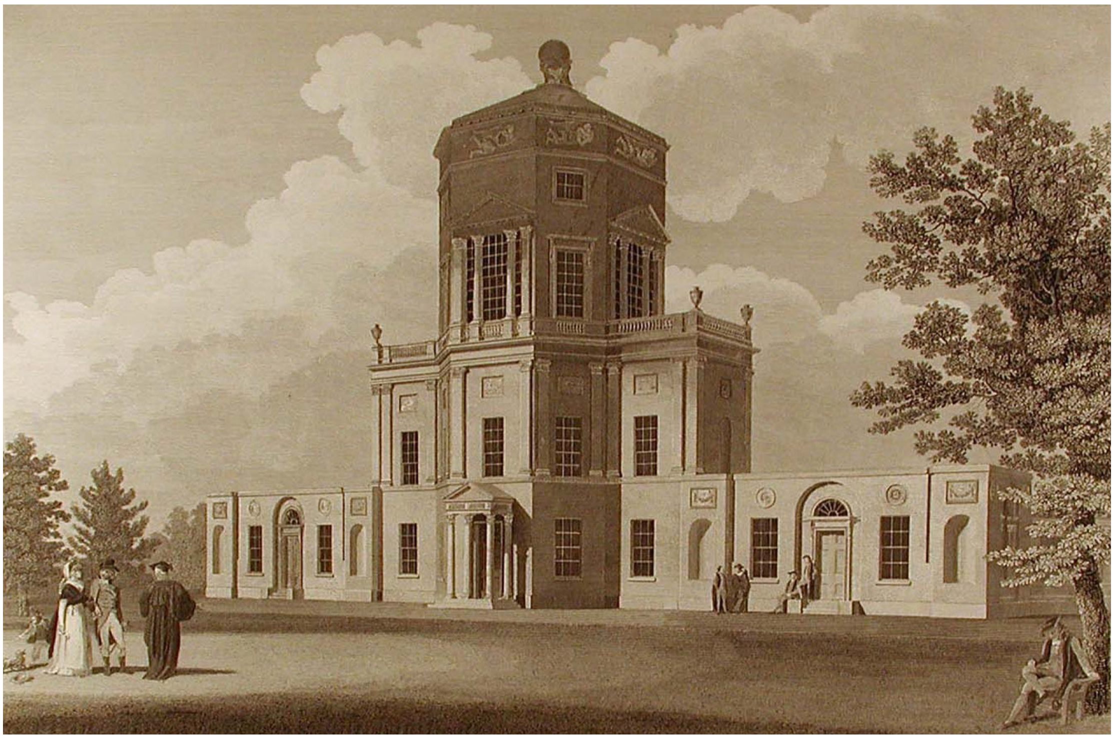


FIGURE 5.7: Radcliffe Observatory in Oxford

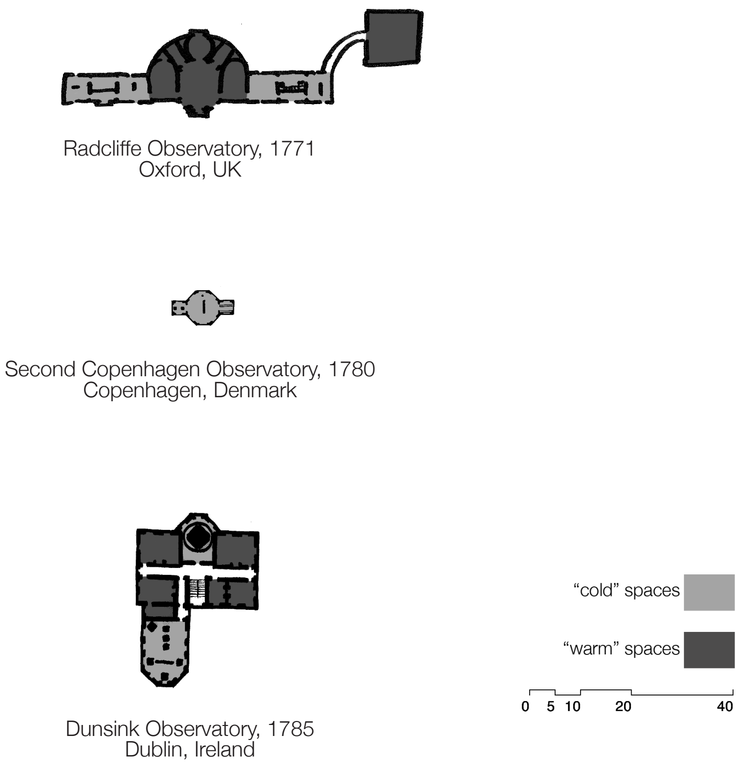


FIGURE 5.8: Oxford, Copenhagen, and Dublin schemes

Much like Tycho Brahe's mansion, the observatory is an grand gesture, with exceptionally large halls for observing instruments for its time. However, the observatory's first principal observer, the Italian Cassini, seemed dissatisfied with its usability. It proved that astronomy had to have an influence in the design of an observatory. Several additional functions are housed in an observatory for the first time; a gallery for curiosities, a laboratory, and a meridian room are introduced.

5.5 Maturation of the Institution: From Observing Room to Telescope

By the end of the 18th century Newton had provided a scientific mechanical base for Copernicus' statements, and astronomy flourished. Also, John Dollond introduced the achromatic lens making the telescope preferable over ancient instruments as the main observing instrument. The telescope allowed people to take a closer look at the stars, not only because of the magnification, but also because by looking through the eyepiece, one isolates himself from his surroundings. The technological development made observatories and astronomy popular among European communities. The growth in observatories also lead to the founding of observatories overseas in the first half of the nineteenth century.

5.5.1 Radcliffe Observatory, 1771: Introduction of Instrument Rooms and Differentiation of the Plan

Up to the Radcliffe Observatory (Figure 5.7, 5.8) in Oxford, observatories were mostly unicellular observing rooms added to existing buildings or structures. The Radcliffe Observatory shows a central building part, with wings on both sides for its instruments. Instead of one observing room filled with different portable instruments, each instrument had its own room in the wings, an important feature of later observatories. However, next to these instrument rooms, the Radcliffe Observatory also had a central observing room with portable instruments. This observing room is not an addition to an existing building but still has the same characteristics as the traditional observing room, for which some consider the observatory a tower observatory. With the observing room of the old tower observatories and the newly introduced wings, the Radcliffe observatory may be seen as an excellent example of a bridge between two phases.

FIGURE 5.9: Göttingen Observatory

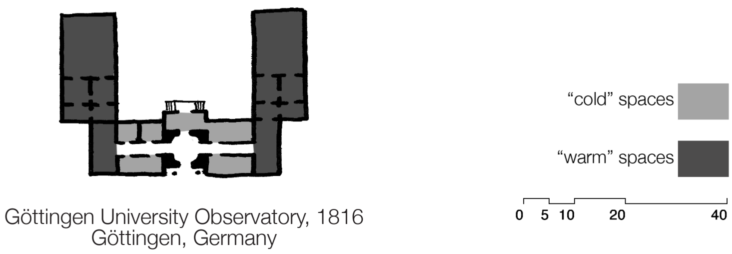


FIGURE 5.10: Göttingen scheme

5.5.2 Second Copenhagen Observatory, 1780: Mounting on Piers

The second Observatory in Copenhagen (Figure 5.8) was one of the first observatories with an observing room on the ground floor. Earlier observing rooms on top of existing constructions were prone to vibration. To deter interference with measurement, instruments needed to be mounted on solid piers. The second Observatory in Copenhagen resembles the Radcliffe Observatory scheme with a central observing room and instrument wings on both sides. The important difference, however, is that most of these instruments are no longer portable. The layout of the plan shows the smallest form of the scheme with wings as introduced by the Radcliffe Observatory, with one instrument room on each side of the central observing room.

5.5.3 Dunsink Observatory, 1785: Telescope as Focus

The Dunsink Observatory (Figure 5.8) demonstrates some of the most significant developments in the evolution of the observatory, the advocation of the telescope as the primary instrument for observation. The telescope was mounted on a pier for solid foundation and this was completely isolated from the rest of the building. The Radcliffe Observatory's central room under the observing room could still be used as a central hall, but the massive pier under the telescope at the Dunsink Observatory prevented such use here. For the first time the telescope, or in fact any instrument, can be seen as the focus of the observatory. From this point on, the instrument itself would form a prominent aspect of the plan.

5.5.4 Göttingen University Observatory, 1816: Completion of the First Transitional Period

The Radcliffe, Copenhagen, and Dunsink observatories show the stabilization of the observatory as a building type. The Göttingen University Observatory (Figure 5.9, 5.10) marks the full transition to a new generation of observatories characterized by a central building part with a telescope replacing the observing room. The wings house other functions that are introduced here for the first time, such as a lecture room, offices, workshops, instrument rooms, a library, and two wings with residences for the astronomers. The nineteenth century witnessed a momentous propulsion of the sciences and research facilities such as laboratories, where the building housed many general functions (such as a library, offices, a residence and lecture room) in addition to the main function.

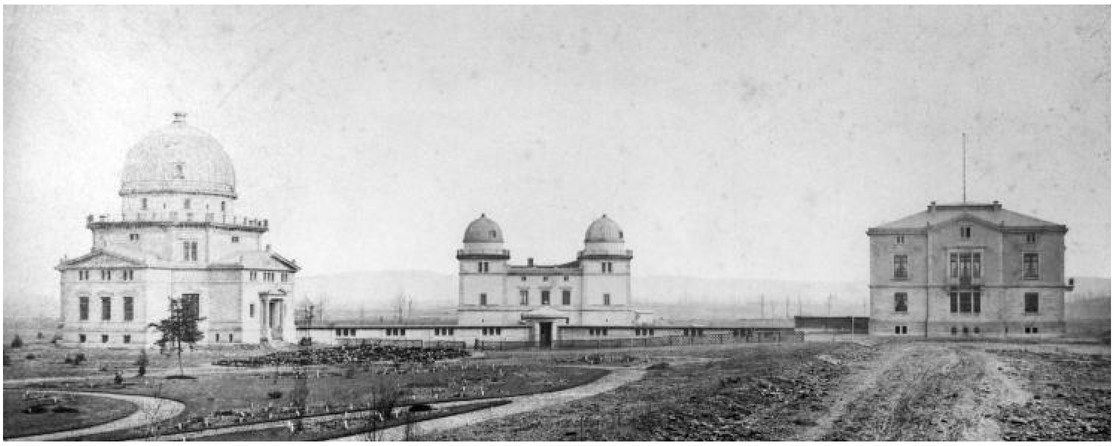
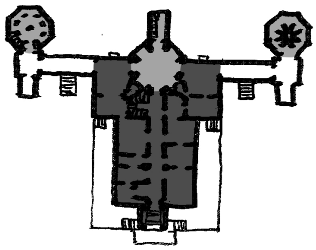
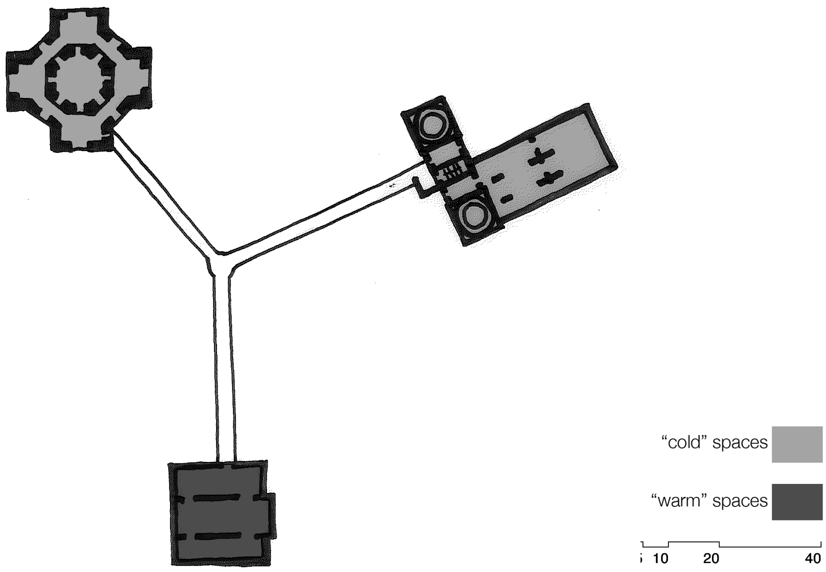


FIGURE 5.11: Strasbourg's three building parts with the corridors in between



Astrophysical Observatory Potsdam, 1879
Potsdam, Germany



Astronomical Observatory of Strasbourg, 1882
Strasbourg, France

FIGURE 5.12: Potsdam and Strasbourg schemes

5.6 Internal Interferences

The nineteenth century introduced new technology to astronomy. Photography enabled astronomers to make objective recordings of the skeis, which were previously drawn by hand. Photography was able to capture objects not visible to the human eye. The breakthrough of spectroscopy and consequential inception of astrophysics meant that man could not only map outer space, they could now analyze the chemical composition of celestial bodies. The spectroscope, invented by Joseph von Fraunhofer in 1819, and further developed by Gustav Robert Kirchhoff and Robert Bunsen in 1859 endowed scientists with the ability to record the wavelengths of light emitted by stars. These new instruments were much more sensitive and it became clear that they were not only susceptible to outside disturbances but also internal ones. The internal interferences led to the disjunction of the observatory building: Functions that should be close together for practical reasons, must be distanced from each other. When presented the plan of the Vienna University Observatory, dr. Warren de la Rue reacted:

> *"Although the personal comfort of the astronomers will be greatly promoted by residence within the walls of the Observatory, it would have been, in my opinion, preferable for the dwellings to have been detached, as the heated air emanating from them will be liable to disturb the definition of the instruments."* [1]

After the long conflict between city and observatory, there now was a conflict on a different scale, that is one between working and living. Later, this conflict would move to an even smaller scale, the split between warm and cold spaces.

5.6.1 Astrophysical Observatory Potsdam, 1879: Start of the Split

The observatory in Potsdam (Figure 5.12) is one of the earliest astrophysical observatories, and exhibits an early phase in the partition of the observatory. The Potsdam Observatory introduced the photography room and accompanying dark room for the development of film. There is a central dome with wings. The two wings connecting the main building with the auxiliary domes are merely non functioning covered galleries, but visually the observatory is still one united building.

5.6.2 Astronomical Observatory of Strasbourg, 1882: Disappearance of Visual Unity

The Astronomical Observatory of Strasbourg (Figure 5.11, 5.12), completed shortly

[1] De la Rue, W., (1875). The New Observatory at Vienna. *Monthly Notices of the Royal Astronomical Society.* 36. (1), p7.

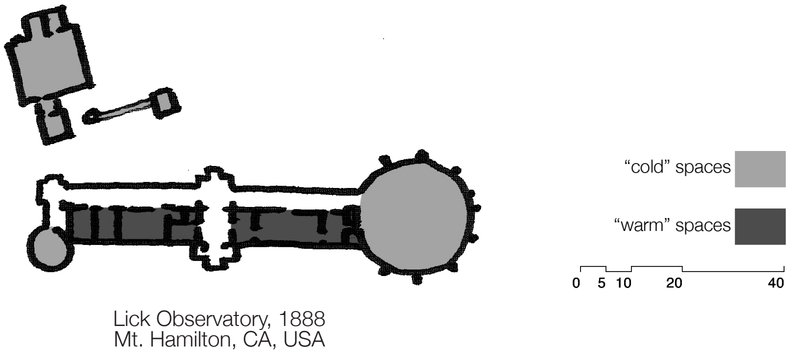


FIGURE 5.13: Mt. Hamilton scheme

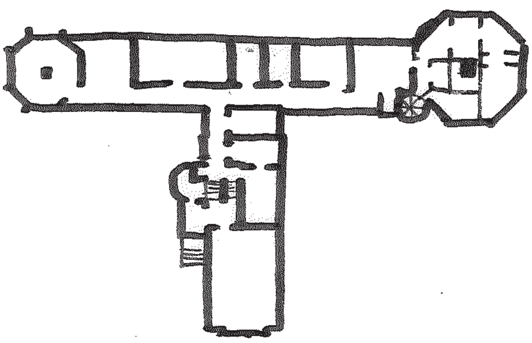


FIGURE 5.14: Royal Observatory, Edinburgh

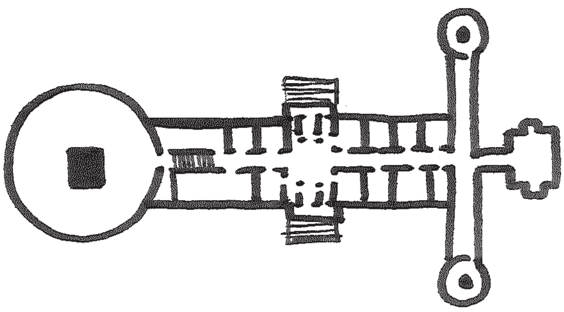


FIGURE 5.15: Yerkes Observatory

after the Potsdam Astrophysical Observatory, conisists of three very different building parts connected by covered corridors that are significantly considerably lower. Unlike the Potsdam Observatory, there is no visual unity. For the first time, there is a division between instrument (cold) spaces and residential and work spaces (warm). This warm/ cold split would disappear, but reappear a century later.

5.6.3 Lick Observatory, 1888: Physical Split and Search for Better Observing Conditions

The design of the Lick Observatory in California (Figure 5.13) was innovative in several respects. It was the first observatory to emanate a physical separation, though subltly pronounced; the main building still accomodated several functions beside the two telescopes. The Lick had the largest telescope at the time (a 37 inch refractor), meaning that the dome housing this telescope was so big that aesthetically it was no longer possible to place it in the building's center. This decentral placing is for the first time visibile in the 1858 plan of the observatory in Sydney and once more in Leipzig in 1861. Because of this decentralization, the Lick was the first to utlize long corridors that lead toward the main dome. The Royal Observatory, Edinburgh (Figure 5.14) and the Yerkes Observatory (Figure 5.15) followed this example, despite deviating from the general trend toward physical disjunction.

In 1704, Newton wrote in his second book, *Opticks*:

> *"If the Theory of making Telescopes could at length be fully brought into Practice, yet there would be certain Bounds beyond which Telescopes could not perform. For the Air through which we look upon the Stars, is in a perpetual Tremor; as may be seen by the tremulous Motion of Shadows cast from high Towers, and by the twinkling of the fix'd Stars. But these Stars do not twinkle when viewed through Telescopes which have large apertures. [...] Telescopes [...] cannot be so formed as to take away that confusion of the Rays which arises from the Tremors of the Atmosphere. The only Remedy is a most serene and quiet Air, such as may perhaps be found on the tops of the highest Mountains above the grosser Clouds."* [1]

Nothing was done with this remark until in 1856 Piazzi Smyth set up a telescope on the Teide volcano in Tenerife and continued Newton's assertion. Subsequently, under the initiation of Edward Holden the Lick became the first permanent observatory located on a mountain top. Although the observatory could be seen from its patron James Lick's backyard, the search for ideal observing locations had begun.

[1] Newton, I (1730). *Opticks.* 2nd ed. London: W. and J. Innys. pp98-9.

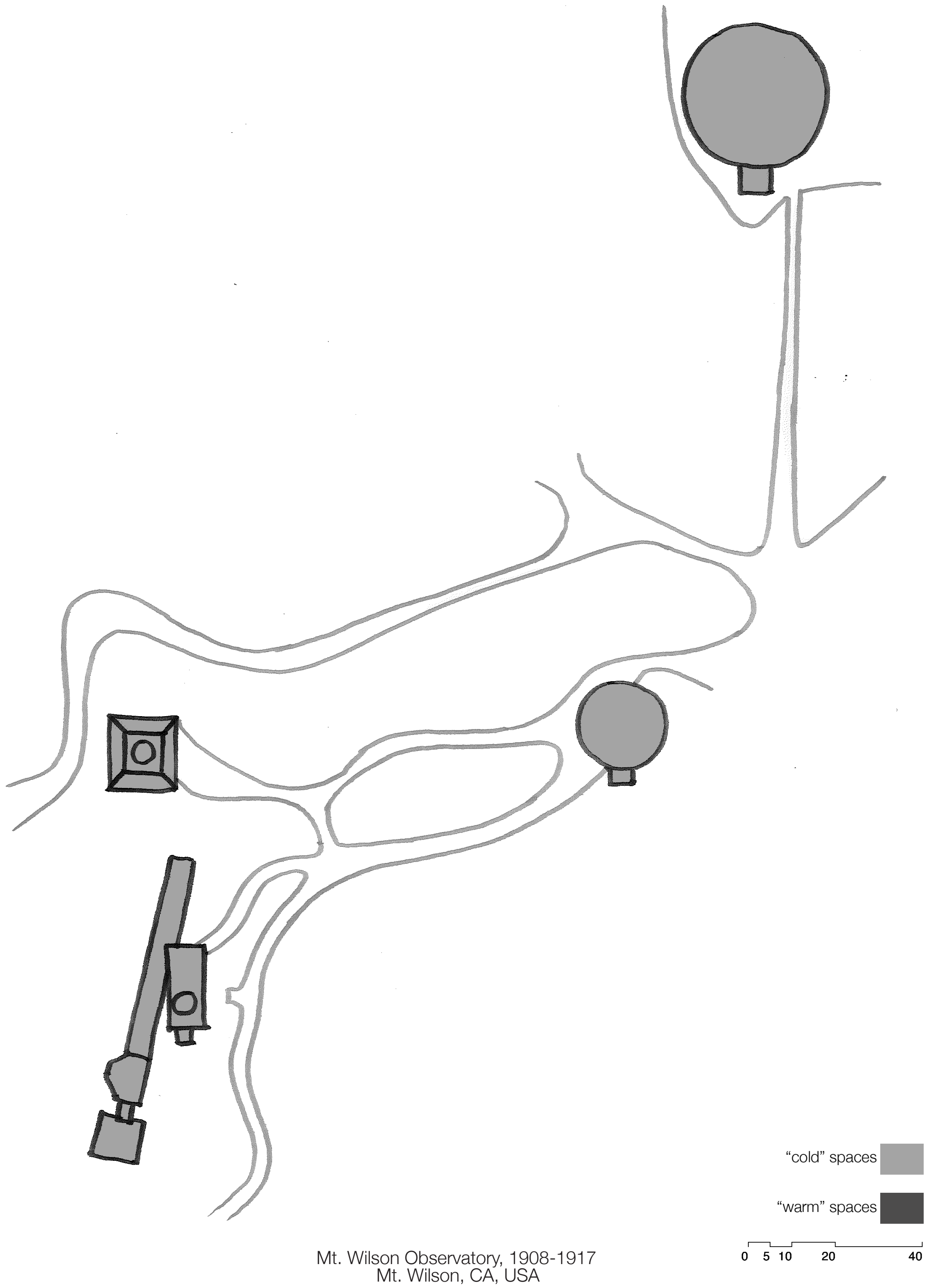


FIGURE 5.16: Mt. Wilson scheme

5.6.4 Mt. Wilson Observatory, 1908-1917: Culmination of the Split

The choice to build on Mount Wilson was the result of an objective study for the best conditions within the confines of the West coast of the United States. The split, initiated by the Potsdam plan, culminates in the plan of the Mt. Wilson Observatory (Figure 5.16), in which at first only the telescope was housed in a dome on a mountain, and all other functions such as workshops, library, and offices, located in Pasadena, which remains a 1.5 hour drive today.

In earlier examples such as the Nice and Bordeaux observatories, both designed in between the Lick and Mt. Wilson, the telescope was also housed in a separate dome, but in these plans offices, residences and other structures stand elsewhere onsight.

5.7 Growth, Variance and Extremes

The meridian, transit, and zenith instruments became obsolete and inoperate in the twentieth century, which is dominated by the telescope. New discoveries and theories ranging from supernovae to the Big Bang theory stoke a widespread infatuation with outer space, physics, cosmology, and cosmogony. New fields in astronomy were developed, such as radio astronomy, resulting in the radio telescope, with enormous dimensions and very different than the optical instrument. At the same time, optical telescopes grew excessively and newly developed instruments are not independent, but always support the telescope, that plays the leading part in modern astronomy.

Fascination with the stars and sky, not exclusive to professionals, was driven amateur enthusiasts to pursue their own discoveries through citizen observatories.

5.7.1 Palomar Observatory, 1948: Convergence in the Plan

For half a century the 200 inch telescope of Palomar Observatory (Figure 5.17, 5.18) dominated the field of astronomy, following the motion toward the supermassive. The dome needed for this telescope was so large, that whereas on Mt. Wilson the structure only housed the telescope, in the Palomar scheme, many different additional functions, even ones such as the library, are moved back into the building. Where the telescope room of the Lick Observatory was too large to be placed in a central position, the telescope room of the Palomar Observatory is so enormous that it has encapsulated all the other functions (Figure 5.17).

FIGURE 5.17: Palomar Observatory, everything is covered by the dome

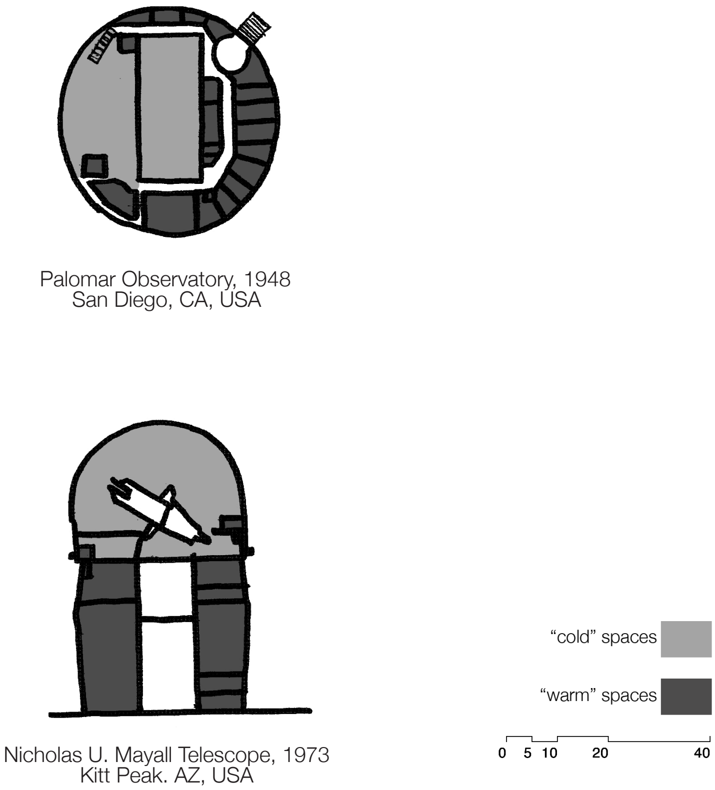


FIGURE 5.18: San Diego and Kitt Peak schemes

5.7.2 Nicholas U. Mayall Telescope, 1973 (professional): Introduction of the Control Room

The Nicholas U. Mayall Telescope (Figure 5.18) embodies the return of the tower cluster[1]. The tower subtype, which once served to rise above the town, was used in the Mayall Telescope plan to escape the unstable, faster vibrating air just above ground level. This telescope was also the first to be remotely operated from a control room, which signifies a critical change in the use of the observatory. The observer no longer needed to be in the telescope room during observations, minimizing interference such as temperature change and vibration for more precise imaging. Steve Hardash, GN Head of Engineering Operations and Mechanical Systems Group Manager at the Gemini North Observatory on Hawai'i, defines the control room as the true heart of the building[2].

5.7.3 Oliver Observing Station 1982 (citizen): Reintroduction of the Warm/Cold Split

The introduction of the control room reintroduced the split between cold observing spaces and warm spaces for operating and working. As was explained by dr. Babcock when visiting the Oliver Observing Station (Figure 5.19), nobody is present in the cold (or non-vibrating) part of the building during observations. This part consists of storage, the telescope room, and a space nowadays used as lecture room (there are no lectures when observing). The control room, installations, and residence make up the warm part of the building, the two components forming one united building mass.

5.7.4 W.M. Keck Observatory, 1996 (professional): The Split on a Large Scale

The W.M. Keck Observatory (Figure 5.19) shows the possibilities of combining the warm/cold split cluster with the decentral dome cluster. its two domes, each housing a 10 meter telescope, do not encapsulate other building functions like the Palomar scheme. Instead there is a division between warm and cold spaces. All warm functions are located in between the two observing domes, while insulation replaces the need for a physical split. A corridor connects the two telescopes and runs past all other rooms, referring back to the scheme that originated in the plan of the Lick Observatory.

[1]Tower observatories were already reintroduced for solar observatories such as at Mt. Wilson or the Einsteinturm in Potsdam from 1921 (see Appendix A), but this was only because of their enormously long focal length.
[2]Hardash, S, 2012. *Using the Gemini North Observatory.* [convseration] (Personal communication, 7 August 2012).

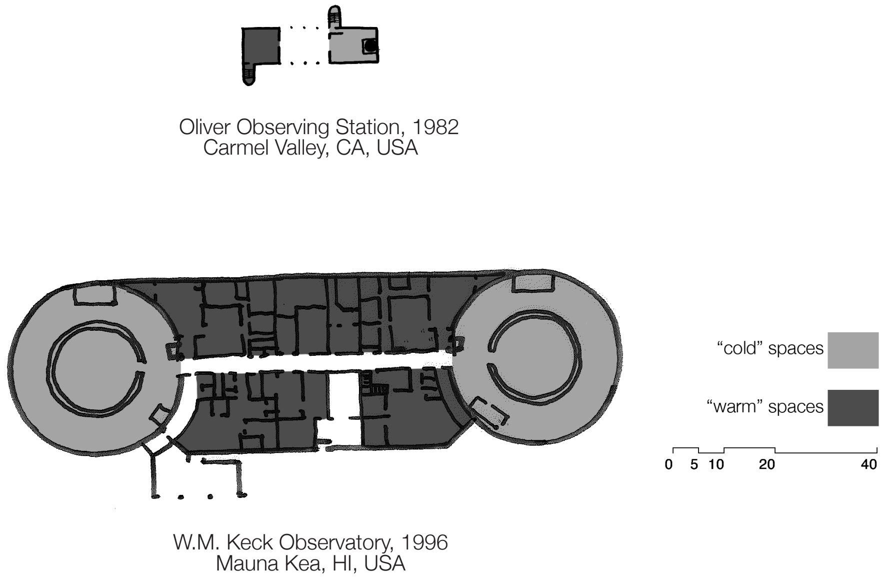


Figure 5.19: Carmel Valley and Mauna Kea schemes

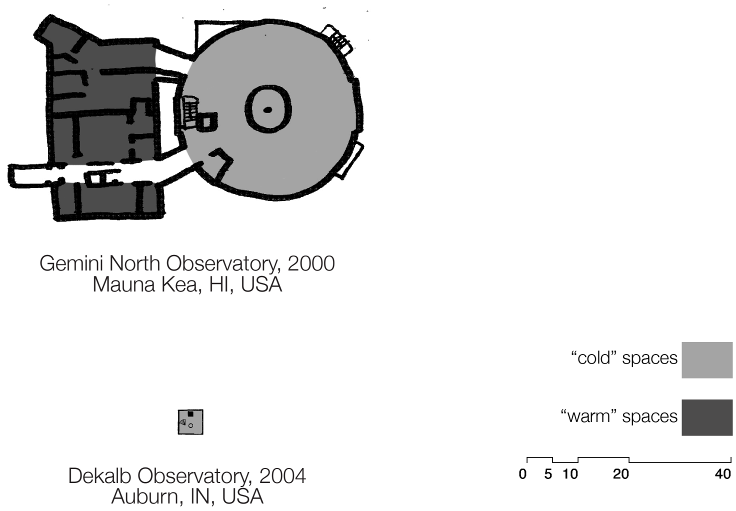


Figure 5.20: Mauna Kea and Auburn schemes

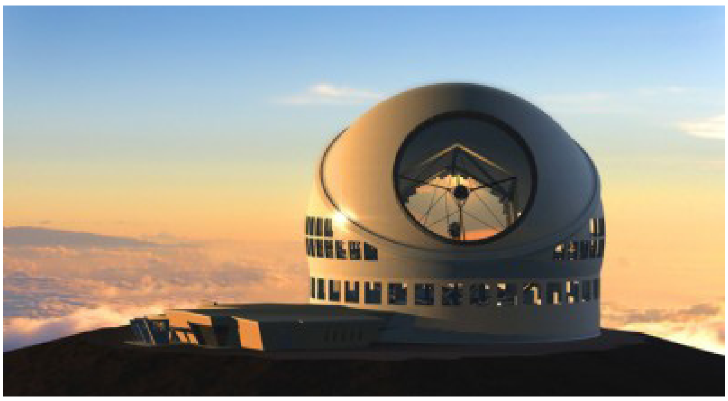


Figure 5.21: The Thirty Meter Telescope

5.7.5 Gemini North Observatory, 2000 (professional): Disproportion in the Plan

The warm/cold split characterizes the plan of the Gemini North Observatory (Figure 5.20). The control room thus changed both large and small scale plans. The enormous telescope space does not entail other functions; these are all clustered in the adjacent building that is connected to the telescope space by two corridors. Gemini's limited program of offices, control room, etc. cannot match the enormous size of the telescope. This disproportion between the increasing size of the telescope room and the building part containing the other functions is a growing problem in the plans of modern large institutions that has not been solved yet (Figure 5.21).

5.7.6 Dekalb Observatory, 2004 (citizen): The Backyard Observatory

The Dekalb Observatory (Figure 5.20) is similar in size to the early observing room, but this modern observatory does not house portable instruments. Just like the structures around the professional telescopes, the backyard observatories are a skin around the telescope protecting it from wind and rain. The rise of these small private observatories indicates the possibility for amateurs to have more precise and delicate equipment, increasing amateurs' influence in astronomy

5.8 Conclusions

In the sixteenth century most observatories were unicellular and consisted of observing rooms housing portable instruments. When instruments were mounted on piers, the plan differentiated and took form after the Palladian scheme. When the internal split arose around 1880, it took almost a century before this issue appeared to be solved with the introduction of the control room.

The control room made it possible to operate the telescope from a distance, not causing any disturbances and resulting in better observations. There has always been a conflict around the observatory between the instruments and people. In the beginning this struggle was between the observatory and the populous city, in the nineteenth century it evolved into a split between working and living, and towards the end of the last century the distinction between warm and cold divided the observatory between observing and working.

It is debatable if plans from the "functions in dome" cluster (e.g. the Palomar Observatory) proved to be as proper of a solution for the disjunction within the

observatory as the warm/cold split that followed the introduction of the control room. However, observatories making use of the warm/cold split face new issues with the growing size of the telescope. This resulted in disproportion between the two building parts, an issue not present in the “functions in dome” cluster.

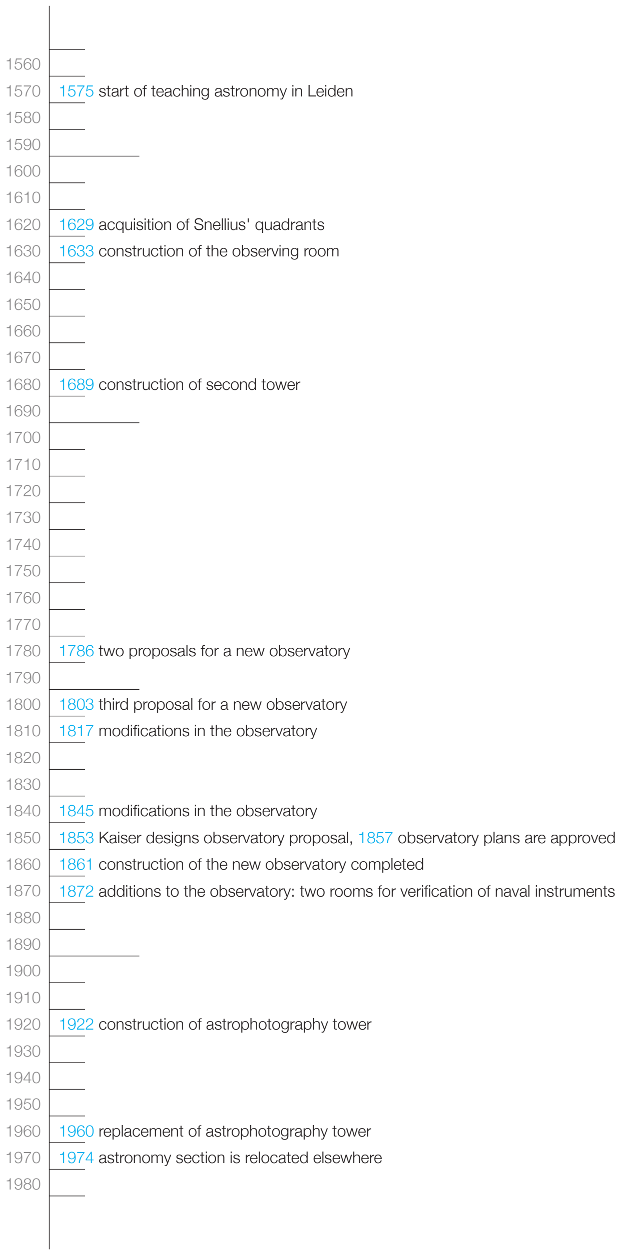


FIGURE 6.1: The history of the Leiden Observatory

Chapter 6

Case Studies

The Leiden Observatory is the oldest university observatory still in use[1]. Since the beginning of the twentieth century, a few decades after the construction of the second Leiden Observatory, it has been among the best research centers in astronomy in the world. The second observatory building from 1861 is an example of a central dome type, typical for nineteenth century observatories. Leiden was chosen as a case study for practical reasons too. Information and involved people were close by, making it possible to consult these within the timeframe. The Lick Observatory, the second case study, is the first observatory with a physical split, the first permanent observatory on a mountain top[2], and one of the first observatories where the dome is not centrally placed. Since its construction in 1888 it has contributed tremendously to astronomy and is part of the University of California.

Mostly the functional design of the observatory was done by the astronomer; often the architect was only involved with the outer appearance and construction of the building[3]. Both observatories were designed by their first directors; Frederik Kaiser designed the Leiden Observatory and Edward Singleton Holden the Lick. Astronomers have always been heavily involved in the design of observatories. A noteworthy exception is the Observatoire de Paris, where the architect Charles Perrault designed both in and outside, with consequences mentioned in chapter 5.

When an astronomer was tasked with designing an observatory, he would travel with

[1]anonymous. (unknown). *Geschiedenis van de Leidse Sterrewacht.* Available: http://www.oudesterrewacht.nl/Geschiedenis.php?node=5. Last accessed 6th Jan 2013.
[2]Müller, P (1978). *Sternwarten: Architektur und Geschichte der Astronomischen Observatorien.* 2nd ed. Frankfurt am Main: Peter Lang GmbH. p220.
[3]Ibid., p273.

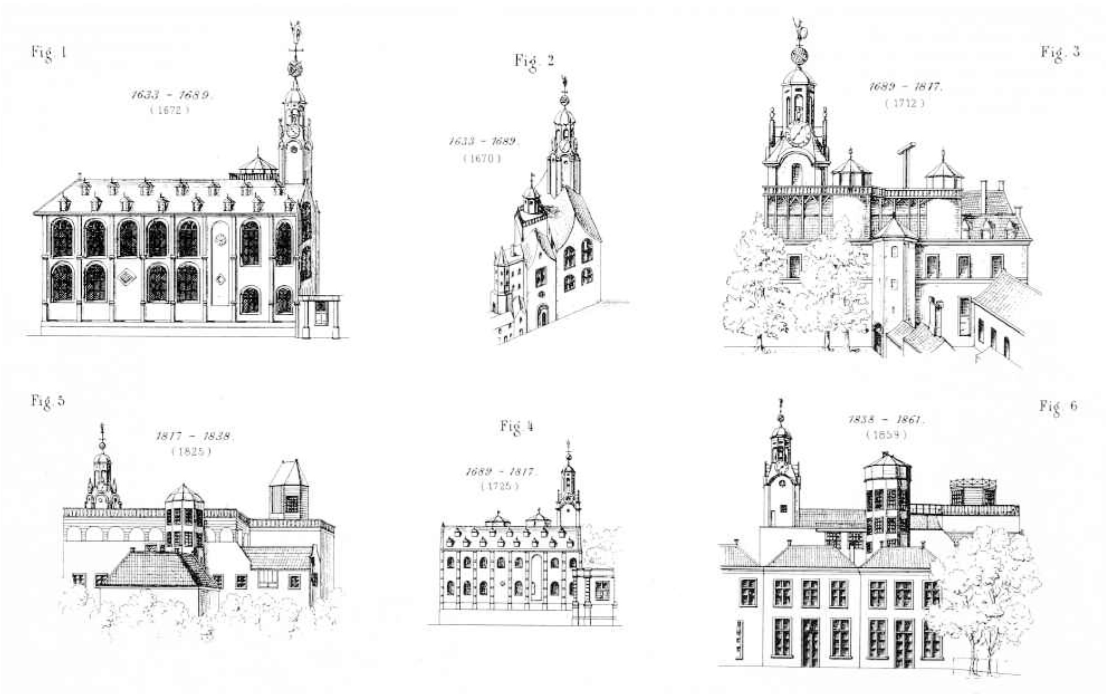


FIGURE 6.2: The Leiden Observatory until 1861

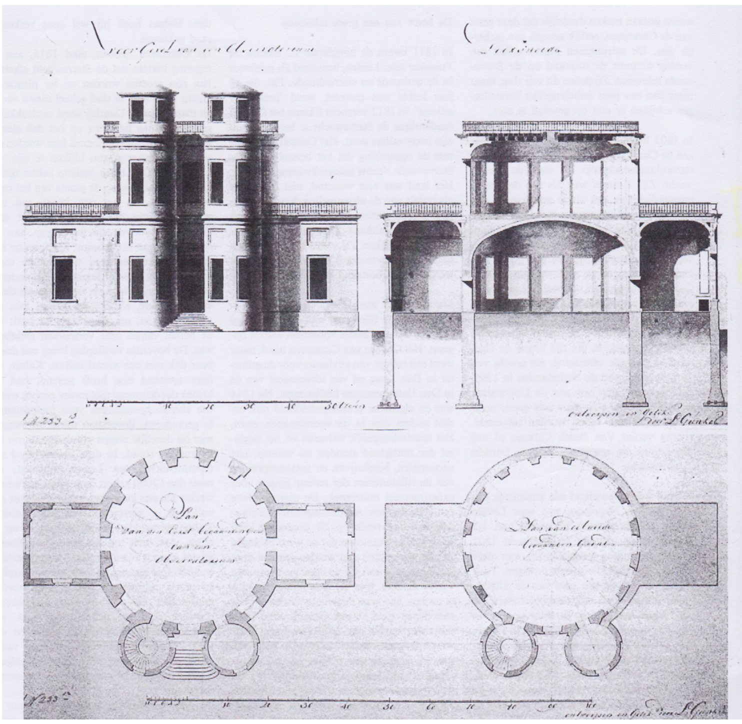


FIGURE 6.3: First proposal for a new observatory, 1786

his plans to as many observatories as possible to ask astronomers for their opinions[1,2,3]. Latest developments in the field of astronomy were transfered in this fashion. When back home, the observatory's plan was drawn up with few substantial aspects changed afterwards, which was the case for both case studies. Kaiser traveled to various observatories abroad, one of them being the Pulkovo Observatory[4]. His visit made such an impression on Kaiser, that he decided to design his proposal after the enormous observatory in Russia. For the Lick Observatory the board of trustees visited several major observatories in Europe[5] and its director visited Simon Newcomb and Edward Singleton Holden (later the first director of the Lick Observatory) in Washington, where "the complete plans of the Observatory buildings proper were settled upon by these gentlemen [...] and these plans, which were well considered, have been closely followed, and have proved themselves to be wise[6].

6.1 The University of Leiden Observatory

6.1.1 History of the Leiden Observatory

The University of Leiden was founded in 1575, but during its first decades, astronomy was only taught as a field of mathematics. It was only in 1629 that two large quadrants of Snellius were acquired[7]. One of them would be among the best in the world for 150 years[8]. To mount this quadrant, a small tower with a platform was built in 1632, only 5,7 by 4,5 meters[9], on top of the main university building, the *Academiegebouw*. Initially the quadrant stood exposed, but a year later, in 1633, a small octagonal room was built to protect it from the weather. With this small construction, Leiden had an observatory. Over half a century later, in 1689, a sextant was acquired and an extra tower was built for it[10,11], connected by an extra platform. In Figure 6.2 the different building phases of the Leiden observatory can be seen[12].

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[1]Enderman, E (2002). *De Sterrenwacht te Leiden.* [Bouwhistorische opgave] Nieuwkoop: -. p14.
[2]Holden, E, (1896). *The Lick Observatory on Mount Hamilton (Lick Astronomical Department of the University of California).* [manuscript] Mary Lea Shane Collection. MS273 Box 1 Holden: Writings. Santa Cruz, CA. McHenry Library. p7.
[3]Ibid., p12.
[4]Kaiser, F, op. cit. p14.
[5]Holden, E, (1896). *The Lick Observatory on Mount Hamilton (Lick Astronomical Department of the University of California).* [manuscript] Mary Lea Shane Collection. MS273 Box 1 Holden: Writings. Santa Cruz, CA. McHenry Library. p7.
[6]Ibid., p12.
[7]Israel, F, Smit, G, and Dekker, F (2011?). *De Leidse Sterrewacht.* Leiden: s.n.. p12.
[8]Van Herk, G, Kleibrink, H, and Bijleveld, W (1983). *De Leidse Sterrewacht: Vier Eeuwen Wacht bij Dag en bij Nacht.* Zwolle: Waanders/DeKler. p17.
[9]Ibid., p14.
[10]Enderman, E, op. cit., p1.
[11]Israel, F, Smit, G, and Dekker, F, op. cit., p12.
[12]Ibid., p11.

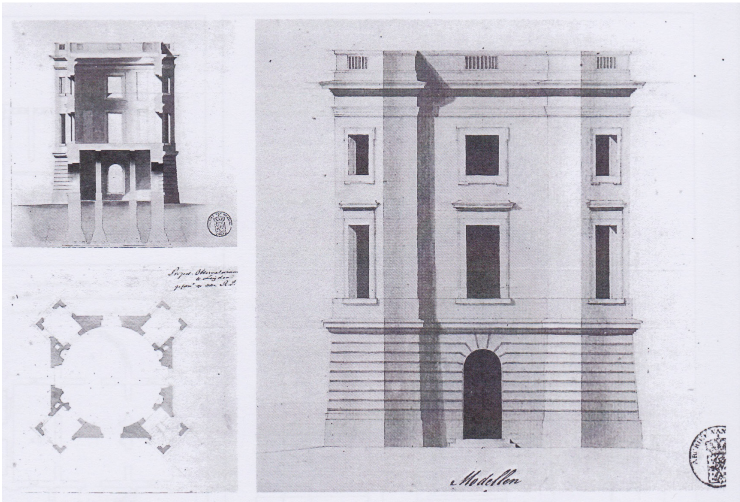

Figure 6.4: Second proposal for a new observatory, 1786

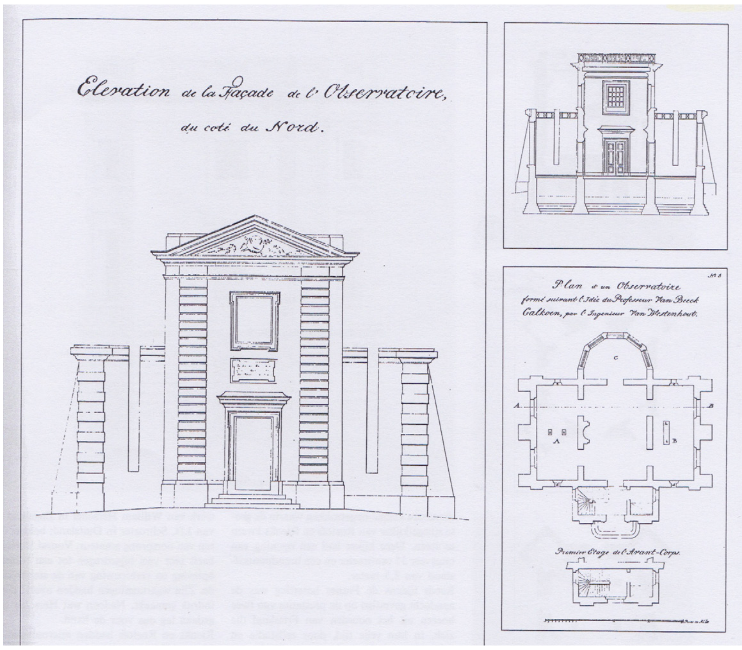

Figure 6.5: Third proposal for a new observatory, 1803

The small observatory never played a significant role in astronomy because it was merely considered as an educational tool and a curiosity for the public. Lulofs, the first actual astronomer in Leiden, in the second half of the eighteenth century complained about how the public, that had free access to the observatory, made observing altogether impossible[1,2]. Lulofs introduced scientific research at the observatory, but it was not until the middle of the nineteenth century that astronomical research had its official place at the university.

In 1785 plans arose to construct a new Academiegebouw that would house all departments. For fire safety reasons the observatory had to be housed in a separate building and two possible plans were drawn up in 1786, Figure 6.3 and Figure 6.4[3,4]. Due to financial constraints the plans were ignored. In 1803, another proposal was made (Figure 6.5)[5] but again money was not available. Just like the observatory on the Academiegebouw, these plans only consist of the bare necessities and do not entail any room for administration, personnel, a library, or a dwelling for the astronomer[6]. In 1817 and in 1845 the observatory was remodeled again. Kaiser had arrived at the observatory in 1826 and the observatory was not much more than a rebuilt version of the observatory after its first extension in 1689[7]. About all this remodeling, that had proven to be quite useless, Kaiser wrote:

> *"In Leiden ist also schon sehr früh ein Beispiel der Neigung gegeben, mehr für den Körper, als für die Seele einer Sternwarte zu sorgen, welche Neigung auch nachher der Astronomie so sehr geschadet hat!"*[8]

Even though the constructions on top of the Academiegebouw looked interesting to the public, instruments were not mounted properly, making it impossible to get good results[9]. The observatory was still a tower observatory, a type that had been replaced by the central dome scheme. Kaiser had his mind set on a new observatory building. He constantly complained that astronomy in the Netherlands was unable to compete internationally due to the building. In 1853 he asked the Dutch government for a new observatory and provided a design proposal. The government did not respond. Kaiser was not only a competent observer, who had received international appreciation with his calculations of Halley's comet in 1835, but also a brilliant lobbyist. In 1856 a new government went into office, and Kaiser knew five out of the nine ministers personally. The minister of internal affairs was an old colleague in astronomy and when this

[1]Israel, F, Smit, G, and Dekker, F, op. cit., p12.
[2]Van Herk, G, Kleibrink, H, and Bijleveld, W, op. cit., p15.
[3]Ibid., pp26-28.
[4]Enderman, E, op. cit., p1.
[5]Van Herk, G, Kleibrink, H, and Bijleveld, W, op. cit., p29.
[6]Ibid., p29.
[7]Ibid., p32.
[8]Ibid., p24.
[9]Israel, F, Smit, G, and Dekker, F, op. cit., p12.

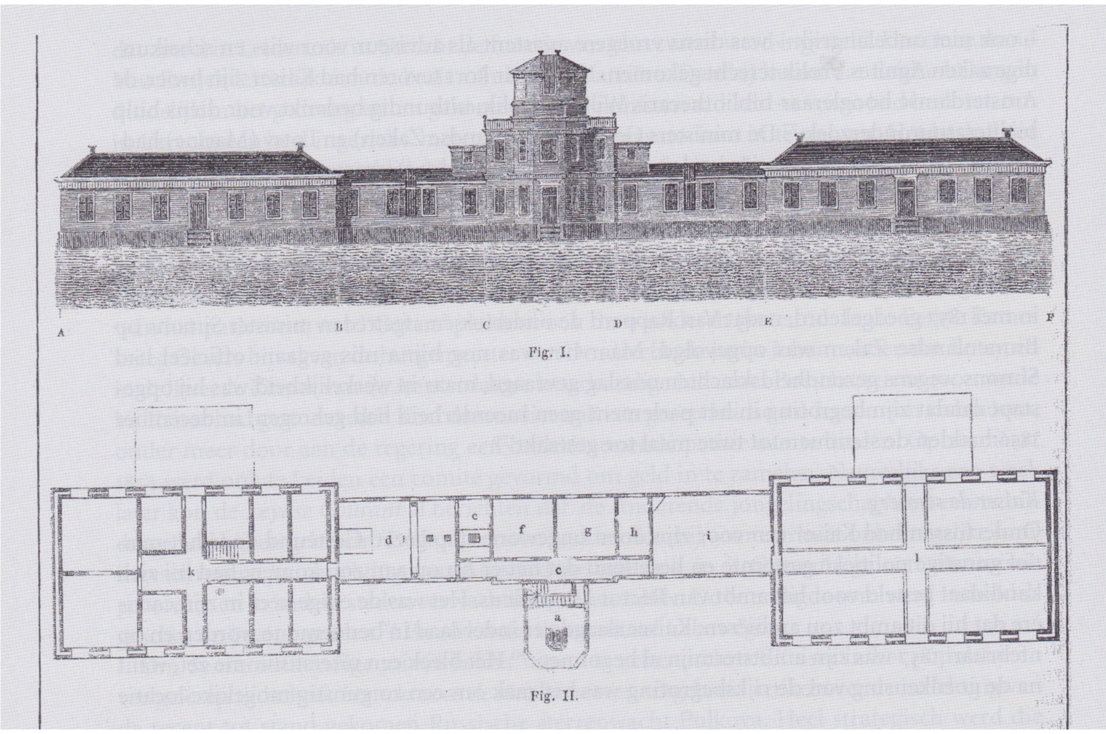

FIGURE 6.6: Kaiser's plan for the new observatory (south points up)

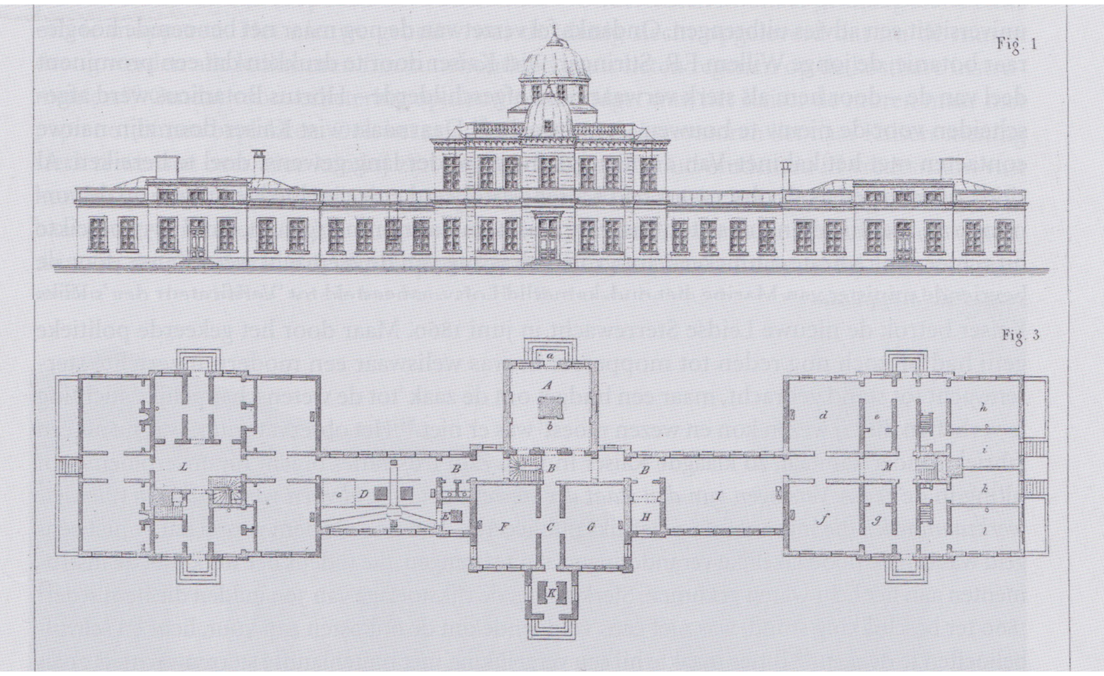

FIGURE 6.7: The final plan for the new observatory (north points up)

minister had to resign, the minister replacing him had witnessed Halley's comet at Kaiser's home in 1835[1]. It may not be surprising that in 1857 the proposal for a new observatory was approved. Comparing Kaiser's plan with the final plan (Figures 6.6 and 6.7[6]), some changes are visibe, but altogether the plan is functionally almost identical.

6.1.2 Kaiser's Design Proposal

As was mentioned earlier, Kaiser designed the Leiden Observatory after the Pulkovo Observatory near St. Petersburg. The Pulkovo plan can be seen in Figure 6.8[2].

The starting point for his design of the new observatory was the relation between work and residence. In a text explaining his design, he states:

> *"Reeds sedert lang is het als een eisch der sterrekunde beschouwd, dat de sterrekundige in zijn observatorium wone en nevens zijne werktuigen leve. Op alle plaatsen, waar wezenlijke sterrewachten bestaan, heeft de sterrekundige zijn studeervertrek nevens de zalen, in welke de waarnemingen geschieden."* [3]

For Kaiser this adjacency of instrument room and residence was important, but he added that the educational program of his proposal and the tranquility needed for observing demanded a clear division between residences and work spaces, resulting in a long and low building[4]. Even though Kaiser's residence was directly next to the main instrument, the meridian circle, his personnel had to take numerous stairs to perform measurements and their dwelling was located next to the lecture room[5].

Where earlier proposals only housed the essential spaces of an observatory, Kaiser introduced additional functions next to the Meridian room and telescope room[6]. He included a large skylight and windows in all directions, used for practicing with portable instruments, in his view of utmost importance for the astronomy student[7] (Figure 6.9). Also a lecture room, a library, and residences are included. His plan is understood as follows. The entire building consists of three parts that are connected by two lower wings. The middle building part is the actual observatory, the western building part is the director's dwelling and the eastern part is for other staffmembers and their families. The two wings house the meridian circle, the main instrument, on

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[1]Zuidervaart, H. (2011). Frederik Kaiser (1808-1872), een Gekweld Man met een Missie. *Studium: Tijdschrift voor Wetenschaps- en Universiteitsgeschiedenis.* 4 (1), p77.
[2]Kaiser, F, op. cit. p12.
[3]Ibid., p23.
[4]Ibid., p28.
[5]Enderman, E, op. cit., p23.
[6]Kaiser, F, op. cit., p28.
[7]Ibid., p21.

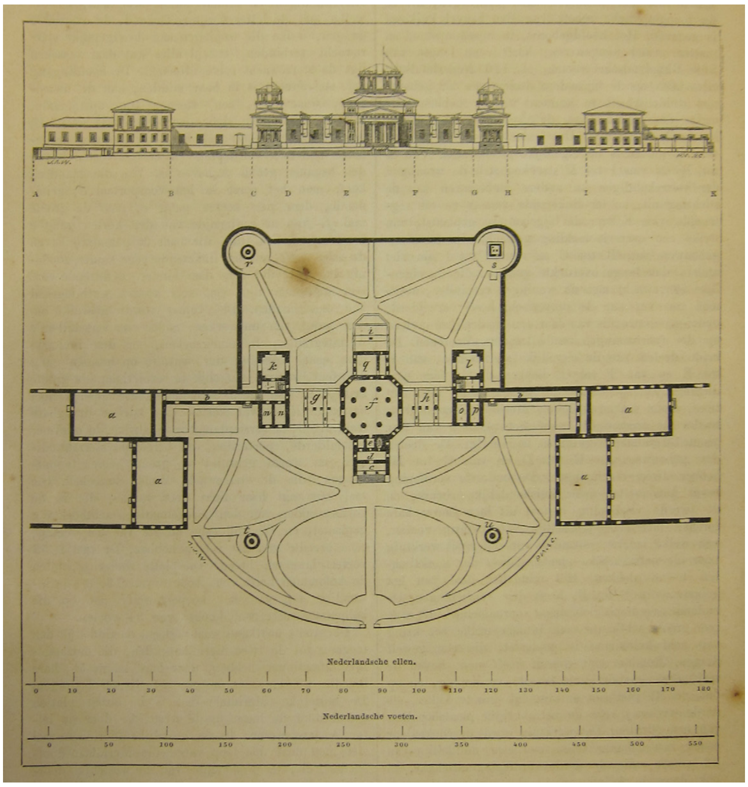

FIGURE 6.8: The Pulkovo plan, 1839

FIGURE 6.9: The large observing room for the practice with portable instruments

the side of the director's dwelling and the lecture room, on the other side. One enters the observatory on the ground floor of the tower, that is placed in front of the building. This connects via a small corridor *a* the staircase to the main hall, that leads to every room of the main observatory. Here there are two large rooms, the director's office, *f*, and the library, *g*, and two smaller rooms, *e,* a storage room and *h,* the workshop. On the first floor, apart from the large room for portable instruments already mentioned (*n*), there are two smaller meridian rooms (*p* and *o*) and the room under the telescope, *m*, used for storing older instruments as some kind of of gallery. On top of room *n* there is a platform[1]. The final plan by architect Camp is rather similar, except for the larger library and director's office, an extra, smaller telescope tower, and the staircase, moved into the main hall.

Kaiser and Camp did not have a good cooperation and according to Kaiser, Camp was led too much by appearance instead of functionality[2]. Ironically, Kaiser himself thinks highly of the observatory's outer appearance and symmetry, and even introduces fake shutters in the lecture room, so its facade visually matches the facade of the meridian room. However, Kaiser defends his choice to place the telescope tower in front of the building instead of on top of it, preventing expensive constructions. He does not deem a representative hall appropriate for an educational observatory[3].

The old observatory was a small, constructionally inappropriate addition to the Academiegebouw only used for education. With the new building, an era of absolute world class research lied ahead. Of course, this was not only because of the building, but also organizational changes introduced by Kaiser. Still, a good building is a vital part of a good astronomy department, as Kaiser said that for an effective observatory there were three requirements: "good instruments, a proper building, and competent observers."[4]

[1]Kaiser, F, op. cit., p31.
[2]Israel, F, Smit, G, and Dekker, F, op. cit., p19.
[3]Kaiser, F, op. cit., p35.
[4]Ibid., p23.

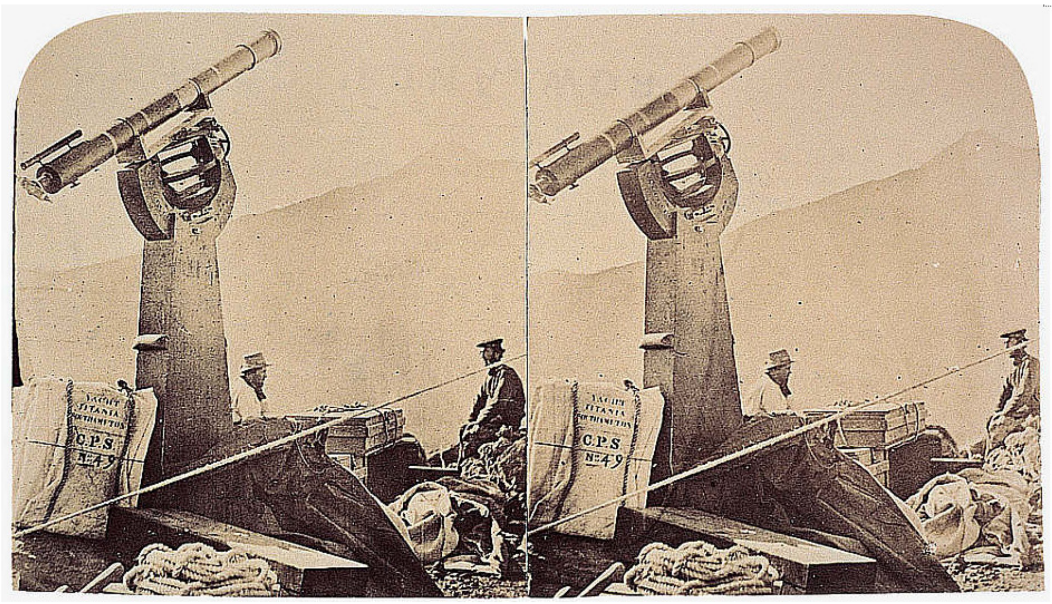

FIGURE 6.10: Piazzi-Smyth's expidition to Tenerife

6.2 The Lick Observatory

The situation in California, only thirteen years after the completion of the Leiden Observatory, was very different from Leiden. Before his death, James Lick decided to donate \$700.000 for a telescope "more powerful than any yet made"; and "a suitable Observatory connected therewith"[1]. In 1874, a first deed of trust was made (followed by a second and a third, both in 1875) and the planning of the new establishment was started. Astronomers advised Lick to have the building constructed on a mountain top[2], which was a growing topic for discussion in the United States in the early 1870s[3].

6.2.1 Mountain Stations

The interest in mountain stations is the result of a series of events. "Galileo and Kepler, (1609), considered the telescope alone. It was an optical instrument. When it was perfect, nothing more needed consideration"[4]. But in 1717, Newton's idea about the constant tremor of the skies, was a fundamental change. It took over a century before it started to have an influence in observatory planning, as Holden wrote:

"In 1821-2-3 Sir John Herschel and Sir James South re-observed a number of Sir William Herschel's double-stars at Sir James South's London observatory. Finding that the conditions existing there were not satisfactory, Sir James South, in 1824, transported his largest telescope (aperture 5 inches) to Passy, in France, where the work was continued. This was, I believe, the first astronomical expedition in search of improved conditions" [5].

Later the expeditions of Piazzi-Smyth to Tenerife (Figure 6.10) gave the topic international attention:

"The results of the expedition were printed in scientific journals and also in a popular book which had a wide circulation. There is no doubt that this expedition served to attract general attention to the matter of choosing suitable sites for observatories; and also to spread the idea that all mountain-stations possessed striking advantages" [6].

[1]Holden, E. (1888). The Lick Observatory. *The Sidereal Messenger.* 7 (2), p49.
[2]Ibid., p49.
[3]Holden, E, (1896). *The Lick Observatory on Mount Hamilton (Lick Astronomical Department of the University of California).* [manuscript] Mary Lea Shane Collection. MS273 Box 1 Holden: Writings. Santa Cruz, CA. McHenry Library. p3.
[4]Holden, E (1896). *Mountain Observatories in America and Europe.* Washington: Smithsonian Institute. p1.
[5]Ibid., p2.
[6]Ibid., p3.

FIGURE 6.11: The history of the Lick Observatory

On top of this, William Lassell's expeditions to Malta in 1852 and 1863 demonstrated that larger telescopes require good atmospheric conditions in order to reach optimal results[1,2].

Just before plans for the Lick Observatory were started, several professors had investigated fitness of mountain sites in the Rocky Mountains and the high Sierras, and Lick was considering a site near Lake Tahoe for the observatory. Because of the severe winters this idea was abandoned[3].

Before a final choice would be made, the conditions of various sites were supposed to be tested[4], but this plan was not carried out until after the site of Mt. Hamilton had already been chosen[5]. Mt. Hamilton was chosen because of its "immense advantages on the score of its nearness to San Jose, where two railways meet"[6], but "that one great reason why Mt. Hamilton seemed to be more favorable than other mountains was that it appeared to be free from fogs"[7]. The choice was still biased; the observatory was built close to where Lick lived and worked and could be seen from his backyard. In his Memorandum, Holden states "how little was generally known in the years 1875-1888 of the principles which should govern the selection of a site for a mountain-observatory; + how little the conditions which must be fulfilled by its buildings etc. were understood"[8], adding that "[i]t may fairly be said that the many mountain observatories now built, or building in all parts of the globe owe much to the experience gained at the establishments on Etna and at Mt. Hamilton"[9].

[1]Holden, E, (1896). *The Lick Observatory on Mount Hamilton (Lick Astronomical Department of the University of California).* [manuscript] Mary Lea Shane Collection. MS273 Box 1 Holden: Writings. Santa Cruz, CA. McHenry Library. p3.

[2]In his document *Mountain Observatories in America and Europe*, Holden explains this as follows: "The changes in focal length due to "air-lenses" are expressed in per cent of the focal length itself, and hence the absolute displacement of the disturbed image, in inches, is greater when long telescopes are employed. It is for these reasons that it is especially necessary to select suitable sites for the emplacement of the large telescopes of modern times."

[3]Holden, E. (1888). The Lick Observatory. *The Sidereal Messenger.* 7 (2), p49.

[4]Ibid., p50.

[5]Holden, E, (1896). *The Lick Observatory on Mount Hamilton (Lick Astronomical Department of the University of California).* [manuscript] Mary Lea Shane Collection. MS273 Box 1 Holden: Writings. Santa Cruz, CA. McHenry Library. p44.

[6]Ibid., p39.

[7]Holden, E, (1885). *Letter to Captain Floyd.* [manuscript] Mary Lea Shane Collection. UA36 Box 25 Folder no.8. Santa Cruz, CA. McHenry Library. p3.

[8]Holden, E, (1896). *The Lick Observatory on Mount Hamilton (Lick Astronomical Department of the University of California).* [manuscript] Mary Lea Shane Collection. MS273 Box 1 Holden: Writings. Santa Cruz, CA. McHenry Library. p5A.

[9]Holden, E (1896). *Mountain Observatories in America and Europe.* Washington: Smithsonian Institute. p5.

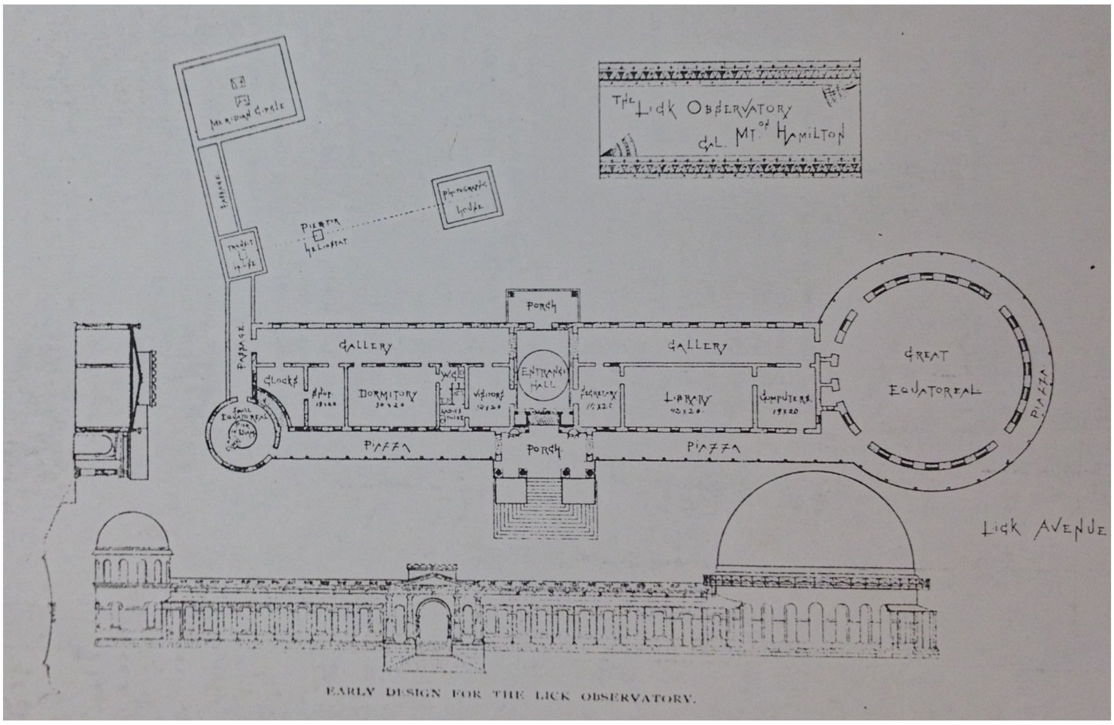

FIGURE 6.13: Holden and Newcomb's proposal

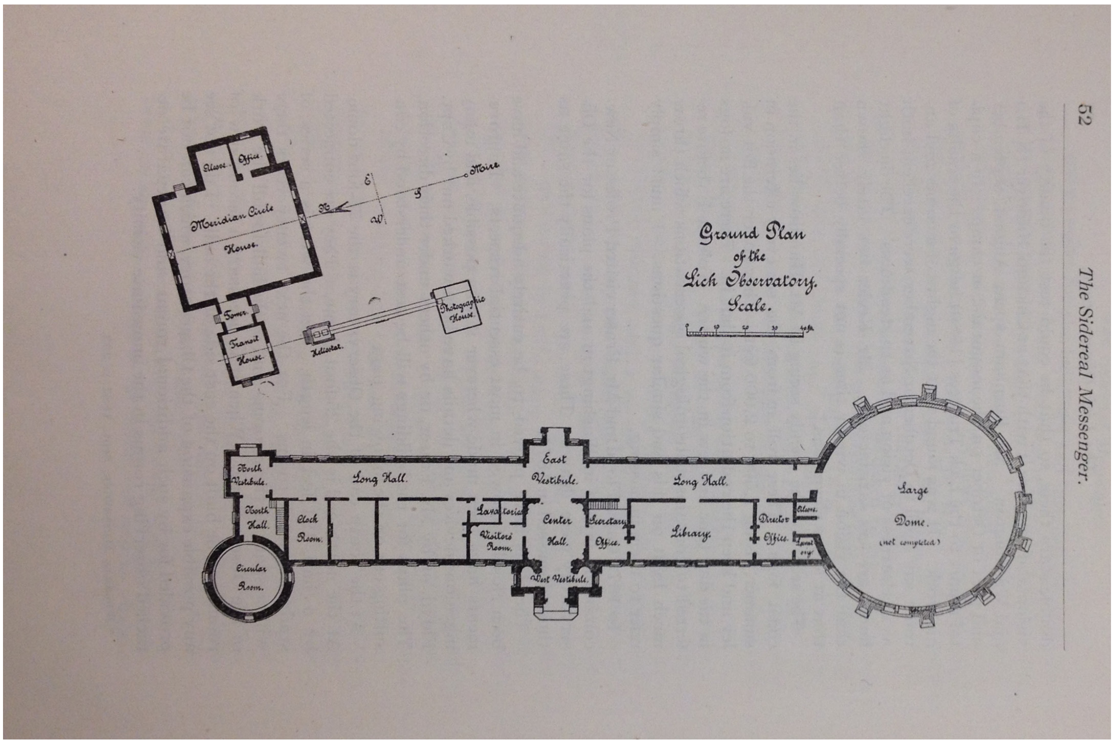

FIGURE 6.14: The final plan for the Lick Observatory

6.2.2 Holden's Design Proposal

The Lick Observatory, stated in the first deed of trust, focused on the large telescope[1]. However (just as in the Leiden plan) other instruments were added; a second, smaller, telescope, a transit circle and a meridian circle. Because of its location, the Lick was also equipped with meteorological and seismological instruments[2,3].

Just like Kaiser, Holden stressed that even though a large sum was readily available, all money should be put on instruments and not be wasted on the observatory's beauty[4]. The earlier plan (Figure 6.13) is slightly different than the final version (Figure 6.14). The final plan consists of a long, wide hall with on each side a dome. The entrance is in the middle of the hall and rooms are situated on only one side. This was done so that in the future the observatory could be expanded by adding an extra row of rooms on the other side of the hall[5,6]. Even though the observatory has been expanded numerous times, a second row of rooms was never added. In the earlier plan, the room next to the great telescope room is wrongly marked as computing room, it was meant to be the director's office, placed in between the main instrument and the library. After the addition of the astronomer's house (discussed below) the dormitory –in the earlier version inside the main building– was moved to another building. The other rooms such as the visitors' and secretary rooms, both understandably located on either side of the entrance hall, remained unaltered. The meridian and transit circle, together with a photographic house were housed in a separate building. This building was originally connected to the main building by a corridor, much like the observatories at Bamberg and Strasbourg. It was made of wood[7,8], as were the surrounding barns, workshops, and quarters.

Initially, the main hallway was planned to be in the magnetic meridian[9]. Probably this was changed when the meridian was moved to a separate house, freeing the rest of the plan from this cardinal orientation. The main building, in turn, was positioned in relation to the hillside and San Jose. "[T]he original plan of 1874 contemplated making

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[1]Holden, E. (1892). Note on the Early History of the Lick Observatory. *Astronomical Society of the Pacific.* IV, p144.
[2]Holden, E. (1888). The Lick Observatory. *The Sidereal Messenger.* 7 (2), p63.
[3]Ibid., p64.
[4]Holden, E, (1885). *Letter to Captain Floyd.* [manuscript] Mary Lea Shane Collection. UA36 Box 25 Folder no.8. Santa Cruz, CA. McHenry Library. p5.
[5]Holden, E. (1888). The Lick Observatory. *The Sidereal Messenger.* 7 (2), p51.
[6]Holden, E, (1896). *The Lick Observatory on Mount Hamilton (Lick Astronomical Department of the University of California).* [manuscript] Mary Lea Shane Collection. MS273 Box 1 Holden: Writings. Santa Cruz, CA. McHenry Library. p67.
[7]Holden, E. (1888). The Lick Observatory. *The Sidereal Messenger.* 7 (2), p55.
[8]Ibid., p56.
[9]Holden, E, (1896). *The Lick Observatory on Mount Hamilton (Lick Astronomical Department of the University of California).* [manuscript] Mary Lea Shane Collection. MS273 Box 1 Holden: Writings. Santa Cruz, CA. McHenry Library. p64.

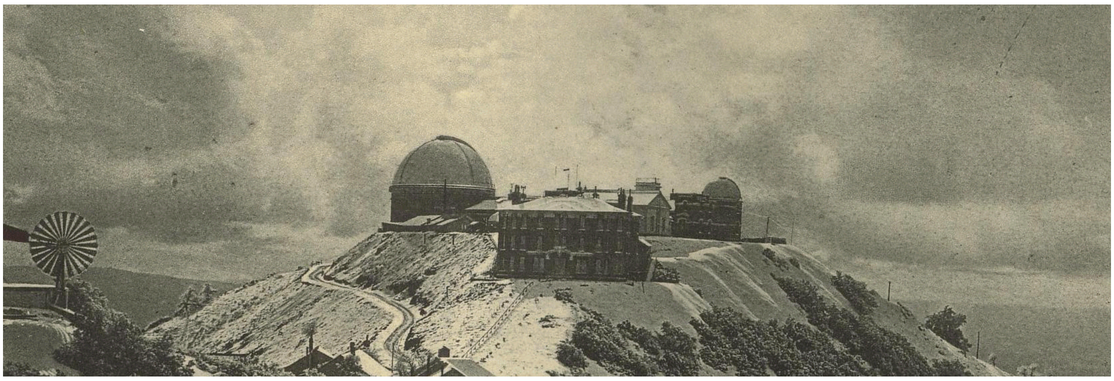

FIGURE 6.15: The astronomer's house in front of the Lick Observatory

a portion of the observatory building of two stories. Surveys made between 1875 and 1879 seemed to show that it would be advantageous to place all the principal rooms on the ground floor. The plan of 1879 was drawn with this modification of the original sketch of 1874. In the actual construction of the observatory it was found necessary to return to the first idea and to place some offices and a photographic laboratory on a second floor"[1]. In the original plan, the (American) second floor also contained a library[2]. This library, of utmost importance because of the observatory's remoteness[3], was moved to the ground floor and only auxiliary functions to the upper floor. The piazza that surrounded a large part of the main building in the early plan was not included in the final plan, to the disappointment of Holden[4].

A separate building was designed as the astronomer's house, Figure 6.15, three stories high and situated a little lower than the observatory[5]. Its upper floor was on the same level as the summit plateau and connected by a bridge, providing easy access to the observatory[6]. This building, that consisted of two identical dwellings, housed around five astronomers and included rooms for photographic work. Other astronomers, students, and workmen lived in wooden cottages around the observatory[7].

The split, that is present for the first time in the Lick's plan, is only to a certain extend an actual split in program. In plans such as the Strasbourg plan, the building is divided in parts for instruments and parts for residences and supporting functions. In the plan of the Lick, the building is divided between a part that needs cardinal orientation and a part that does not. The main building still houses both instrument rooms and offices, a library, etc., only the living quarters are moved into a different building. In that way the plans in Strasbourg and Bamberg might functionally be more innovative than the Lick Observatory.

[1]Holden, E. (1892). Note on the Early History of the Lick Observatory. *Astronomical Society of the Pacific.* IV, p139.
[2]Ibid., p148.
[3]Ibid., p149.
[4]Ibid., p140.
[5]Holden, E. (1888). The Lick Observatory. *The Sidereal Messenger.* 7 (2), p56.
[6]Ibid., p57.
[7]Holden, E, (1896). *The Lick Observatory on Mount Hamilton (Lick Astronomical Department of the University of California).* [manuscript] Mary Lea Shane Collection. MS273 Box 1 Holden: Writings. Santa Cruz, CA. McHenry Library. pp65-6.

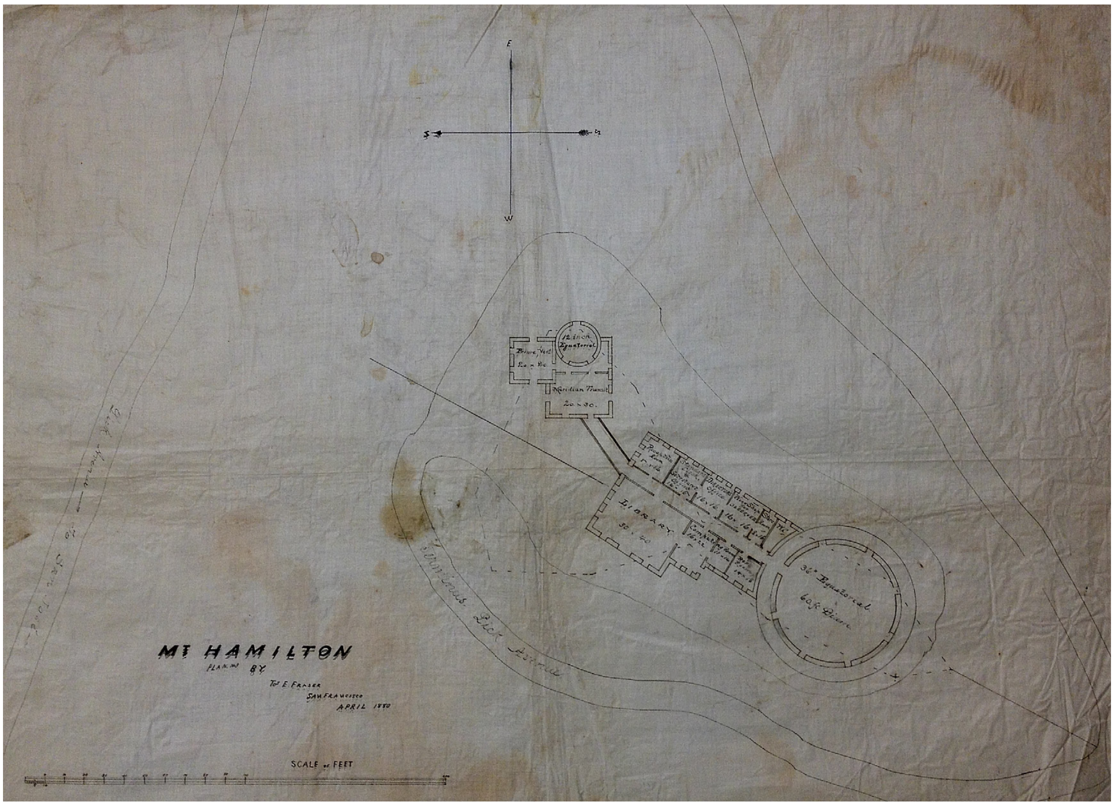

Figure 6.16: Fraser's plan

6.2.3 Fraser's Plan

Another plan for the observatory was found in the archives[1], designed by the superintendent of construction, Thomas Fraser, in 1879 (Figure 6.16). This plan is remarkably different than the plans discussed earlier. It is again set up around a central hallway. However, rooms are on both sides and there is no clear entrance (notice the reception room in one corner of the building). Only the meridian and vertical instruments are cardinally oriented and paired up with the small telescope. The library is by far the largest room, creating an odd serrated wall on the north-west side. The layout of the rooms does not correspond to the other plans; the director's room is not next to the large telescope or the library. Instead it is in between the clock room and observer's workshop. The purpose and influence of this plan in the design process unfortunately remain unknown.

[1] Fraser, E, (1880). *Mt. Hamilton Plan by E. Fraser.* [manuscript] Mary Lea Shane Collection. 1320 Drawer 5 last folder. Santa Cruz, CA. McHenry Library.

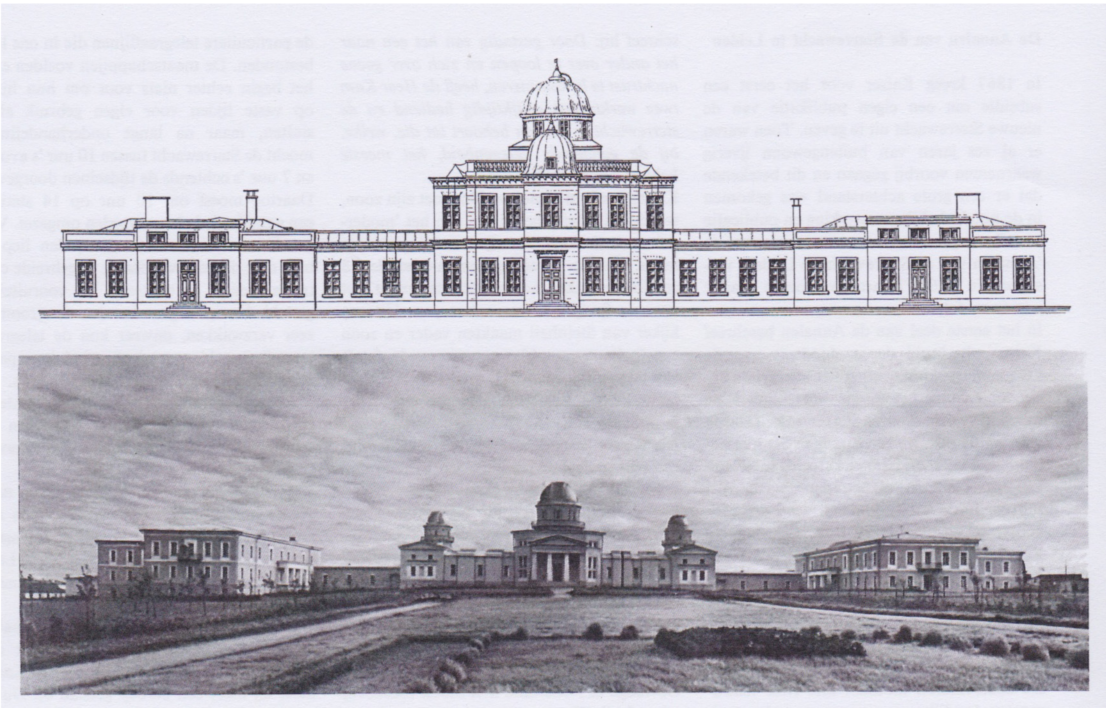

FIGURE 6.17: The Leiden Observatory (upper) compared to the Pulkvo Observatory (lower)

6.3 Conclusions

6.3.1 A Shift from Building to Telescope

The long history of the Leiden Observatory, the world's oldest public observatory, is completely opposite to the Lick Observatory that came into existance by a donation of one single individual. The construction of the new Leiden Observatory has to be considered in relation to the scientific rivalry between the Dutch universities, most notably Leiden and Utrecht[1]. The construction of the Sonnenborgh Observatory in Utrecht in the 1850s threatened Leiden's role in Dutch astronomy. The new observatory had to prevent that Utrecht would be the new center of astronomy in the Netherlands[2]. The result was, even though Kaiser stressed the importance of function over beauty in his design, the Leiden Observatory came to be a representative building, apparent in three ways: high building costs, the use of the Palladian scheme, and the absence of new instruments.

The building costs, 112.500 Dutch guilders, show Leiden's intentions to become the new Dutch astronomical center when compared to the total costs of the Sonnenborgh Observatory, a mere 19.000 guilders[3]. Even though the Lick Observatory had a budget of 700.000 dollars, it does not resemble a palace as the observatory in Leiden does. This shows a clear difference in intentions between the building of the Leiden Observatory and the Lick.

Moreover, the fact that Kaiser based his design on the imperial observatory at Pulkovo does not correspond with his discourse of simplicity either[4]. Even though he tried to reduce the Pulkovo plan to an absolute minimum[5], the statement of the outer appearance is still present (Figure 6.17[6]). The Pulkovo plan (completed in 1839) was in its turn based on examples from sixteenth and seventeenth architecture books from Italy[7,8]. Around 1800, in Russia, but also in other parts of Europe, Palladianism was popular for all kinds of buildings, including the aristocracy's summer residences. With a central building part covered with a dome and flanked on both sides by pavilions, sometimes connected by a corridor[9], the program of an observatory was perfectly suited for this scheme. However, Kaiser goes further than using this representational model and places the appearance of the facade above all else. Even though the meridian is the

[1]Enderman, E, op. cit., p12.
[2]Israel, F, Smit, G, and Dekker, F, op. cit., p16.
[3]Ibid., p16.
[4]Ibid., p16.
[5]Kaiser, F, op. cit., p34.
[6]Van Herk, G, Kleibrink, H, and Bijleveld, W, op. cit., p48.
[7]Israel, F, Smit, G, and Dekker, F, op. cit., p16.
[8]Enderman, E, op. cit., p17.
[9]Ibid., p19.

main instrument in Leiden, the building accentuates the central telescope domes. The meridian is merely situated off centre in one of the wings connecting the building parts, of equal importance as the lecture room.

Compared to the old fashioned Palladian observatory in Leiden, the Lick, completed only 27 years later, looks more modern. But this difference is present in more than the plan's layout alone. What is showing the important shift the most is the difference in instrumentation. The Leiden Observatory was designed without even knowing what instruments would be housed and was at first simply using the instruments from the old observatory[1]. The Lick Observatory, however, was built as the necessary shell around the world's most powerful telescope. Where Kaiser built a building, Holden built a telescope and needed a building to house it.

On top of this, Leiden's main instrument was the meridian, while the Lick was built around the world's most powerful telescope. Around the turn of the century, the telescope made the meridian obsolete. The meridian was used for traditional astronomy (the positions of celestial bodies), the telescope was used for the newly discovered field of astrophysics. Leiden's instruments were tied to the past, whereas the Lick's instruments focused on the future.

Without any doubt the search for more remote locations for observatories added to the shift from representational building to protection of a telescope. The Leiden Observatory was still located on the outskirts of the city where people passed by all the time, but far less people laid eye on the Lick Observatory. This trend continued when observatories were built even further away.

Nowadays modern telescopes and mounts cost millions, but the dome around it is often of cheap materials. The Lick Observatory bears witness to the first step into a new direction where all the attention goes out to the telescope and hardly any care is given to the structure around it. Modern observatories are still impressive, but because of their immensity and engineering rather than their architectural qualities and beauty.

The comparison between the Leiden and the Lick observatories shows one of the most significant changes in the development of the observatory. After growing from observing room to full building earlier, observatories continued to grow but the building lost its prominent role that from then on was played by the telescope.

[1]Enderman, E, op. cit., p4.

6.3.2 Typological Understanding of Kaiser and Holden

Kaiser was interested in the relationship between living and working in the building and categorizes existing observatories into buildings with astronomer's dwellings inside (e.g. the observatory in Berlin) and outside the main building (e.g. Pulkovo). After deciding that an educational program demands a clear split between living and working, he simplified Pulkovo's plan and uses this for his proposal. This way, Kaiser demonstrated awareness of the typology of observatories and let this have influence on his design decisions, e.g. his analysis of the educational program. After making a typological categorization and choosing the category that served his program best, he deduced from the Pulkovo Observatory a model of the type that could be followed to draw up a new observatory.

Unfortunately less information remains on the design process of Holden and Newcomb, but they seem less interested in observatory types and models. The Lick plan follows initially the central dome type, but the astronomers were not afraid to deviate from the type introducing new practical (the split) or necessary (the decentral dome) characteristics.

Kaiser proposed a traditional observatory while Holden drew up a more modern plan. But including typology in one's design does not at all mean that one is bound to end up with a traditional or old fashioned design. This is only the result when one focuses on the model rather than the type.

Chapter 7

Conclusions

Since its reintroduction in Europe after the Middle Ages, the observatory has known a development heavily influenced by the progress in astronomy. Typology has helped to come to an understanding of these developments and can function as guidance when designing a new observatory, whether small or large. The study on the typology of astronomical observatories has lead to new clusters indicating the observatory's typical configurations.

7.1 Discussion

The selection of samples represents about 5% of all existing observatories and is in number sufficient for the study. Albeit formally different, all samples come from a Western tradition of astronomy. Apart from the desired inclusion of modern Western plans such as the Sphinx Observatory (Figure 7.1), the inclusion of observatories from the Western tradition before the temporary disappearance from Europe in the Middle Ages and non Western archaeoastronomical buildings and sites may lead to a better understanding of the philosophy behind the ancient tradition of astronomy and cross-cultural influences.

The influence of astronomy and astronomical instruments on the use of the observatory has shortly been discussed but more research could be done. In his dissertation *Architectures of Astronomical Observation: From Sternwarte Kassel (circa 1560) to the Radcliffe Observatory (1772)*, Kwan explores the relation between instruments and the space enclosing them. This approach could be insightful as an extension of this research, going further than 1772 up to modern time.

Lastly the role of astronomy and of the observatory in society and the relation between the observatory and its environments have not been regarded sufficiently. This could add more insights in an understanding of the type and its position in general history.

FIGURE 7.1: The Shinx Observatory on the Jungfraujoch

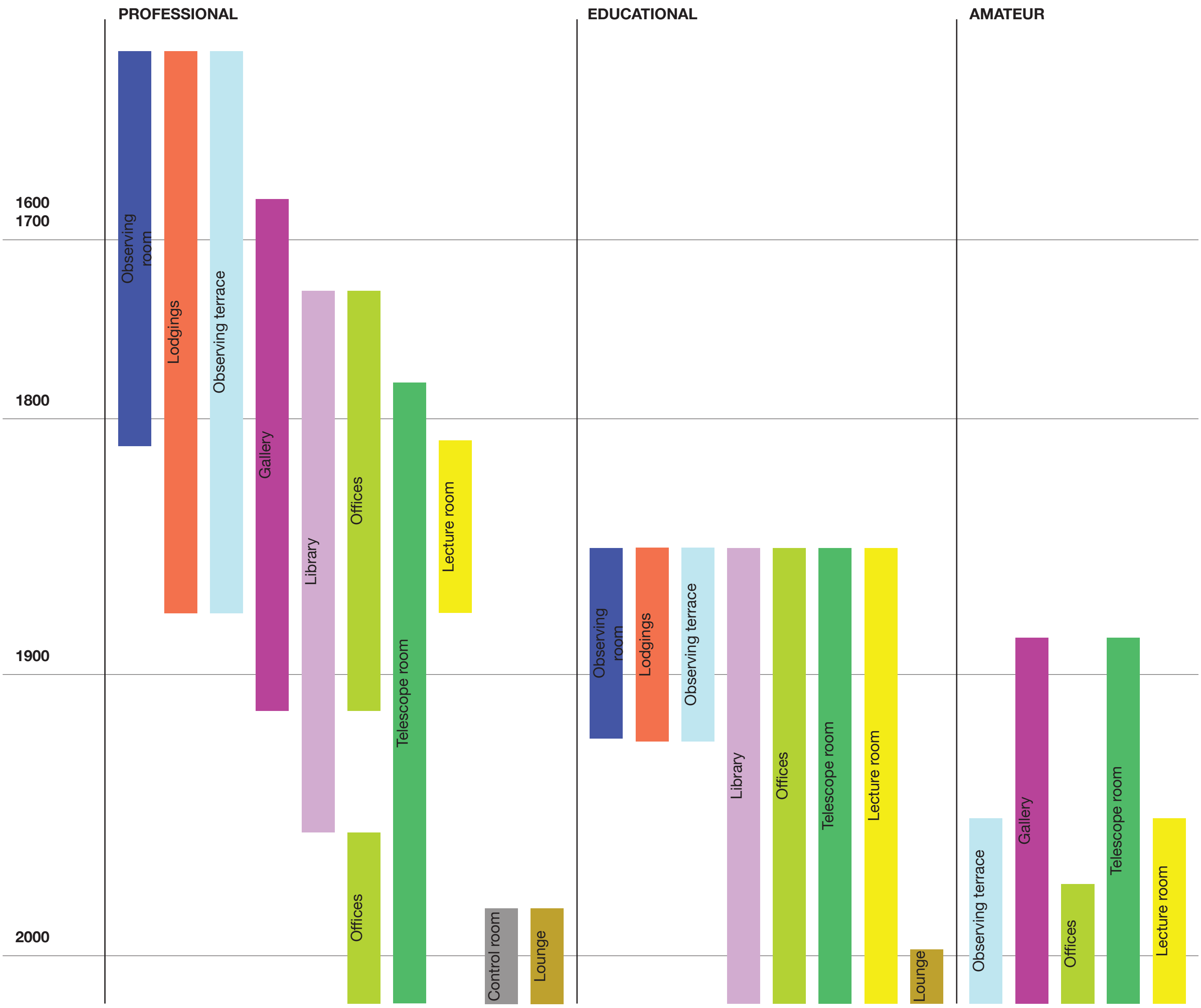

FIGURE 7.2: The building envelope per kind of observatory

7.2 Research Questions

Going back to the introduction, we can restate the subquestions of the research coming together in the main research question:

> *What functions come and go through the ages, do these functions have special characteristics, and is there a development in their layout?*
> *What developments in astronomy caused changes in the type?*
> *Is there a type?*
>
> *What trends can be found in the development of the observatory type since 1579?*

The following paragraphs will each answer one of the subquestions, ending in an overview of the general development of the observatory type.

7.2.1 What Functions Come and Go Through the Ages, Do These Functions Have Special Characteristics, and is There a Development in Their Layout?

An overview of the functions in the observatory through time can be seen in Figure 4.1. From this overview it becomes clear that the functional core of the observatory consists of the observing room, observing platform, lodgings, and storage. The telescope room, into which the observing room evolved over the centuries has the most requirements within the observatory plan. It has to be the highest point in order to have uninterrupted views of the skies, and is sensitive to interferences as has been discussed before. Other functions are less bound to specific requirements. Over the centuries, the program of the observatory has expanded, and especially the library, offices, and lecture room started to play more prominent roles in the plan since their instroduction. Functions with an open character such as the lecture room and library are often used as distribution spaces. Public functions such as the exhibition gallery and the lecture room are located in more prominent places in the plan than supporting functions such as offices, storage, or dark rooms.

In Figure 7.2 the different functions are divided over the three kinds of observatories (professional, educational, amateur). This shows that some functions, e.g. the library, are no longer present in professional observatories, yet have kept their importance in educational observatories. It becomes clear that new functions are introduced by professional institutes and later adopted by educational and amateur observatories, giving the figure the resemblance of a cascade. A good example is the lecture room, that was dropped from the professional program and taken over by the newly emerging

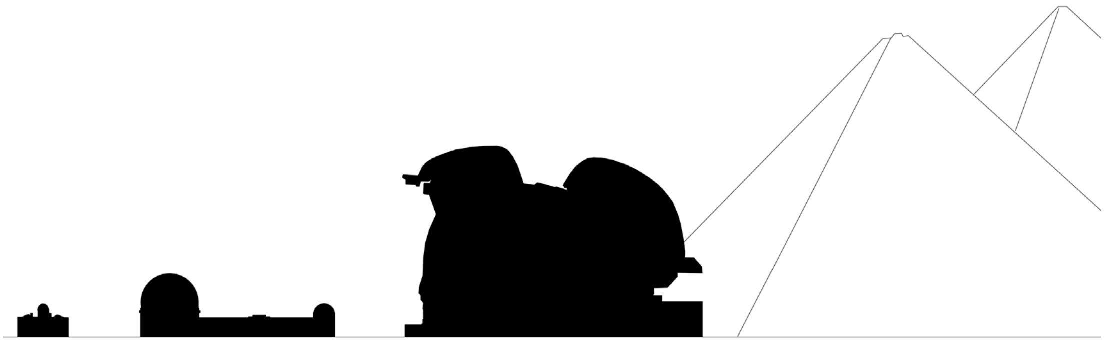

Figure 7.3: Growth of the telescope through the ages: the silhouets of the Dunsink, Yerkes and E-ELT observatories next to the pyramids of Gizeh

Figure 7.4: Scale difference between telescope and the rest of the program in modern observatories

educational observatories. Later, amateur institutions also introduced lecture rooms to educate the local community. The diagram clearly shows the disappearance of auxilary functions in the professional observatory plan, caused by more remote locations and the trend to only house functions needed for observation.

The observing terrace, however, is introduced rather late in amateur observatories. An explanation for this could be that at first amateur institutes could only together buy one telescope, but as instruments became cheaper, enthusiasts were able to buy their personal equipment, introducing the need for a place to set up their equipment at the amateur institute.

Also, the offices in professional observatories seem to have disappeared for some decades before reappearing again in the second half of the twentieth century. This is most likely because of the introduction of the control room that made it possible to reunite instrument control and workspace.

With the help of Figure 7.2 it is possible to predict trends in the building envelope of educational and amateur observatories when designing a new observatory.

7.2.2 What Developments in Astronomy Caused Changes in the Type?

Four trends in astronomy explain certain developments in the type. These are: from portable to fixed instruments, internal conflict as a result of more precise instruments, excessive growth of the telescope, and the introduction of the control room.

The transition from using portable instruments to instruments fixed on piers lead to the transformation of the observing room into the instrument room (later exclusively the telescope room). The result was the transition of the tower type into the central dome type.

More precise instruments and the development of astrophysics demanded more from the telescope room's climate. This introduced a conflict between a telescope room, that had to be free from disturbances (including people), and the astronomer's workspace, preferably in proximity to the telescope. The conflict introduced the "Complete split" and the "Warm / cold split" subtypes.

In the decades around the fin de siècle, the telescope grew from a lens of several inches in diameter to the 60 and 100 inch mirrors of the Mt. Wilson observatories in the 1910s. With this growth, telescopes moved to decentral places in the plan, resulting in new configurations and a new subtype. This had formal consequences for the observatory

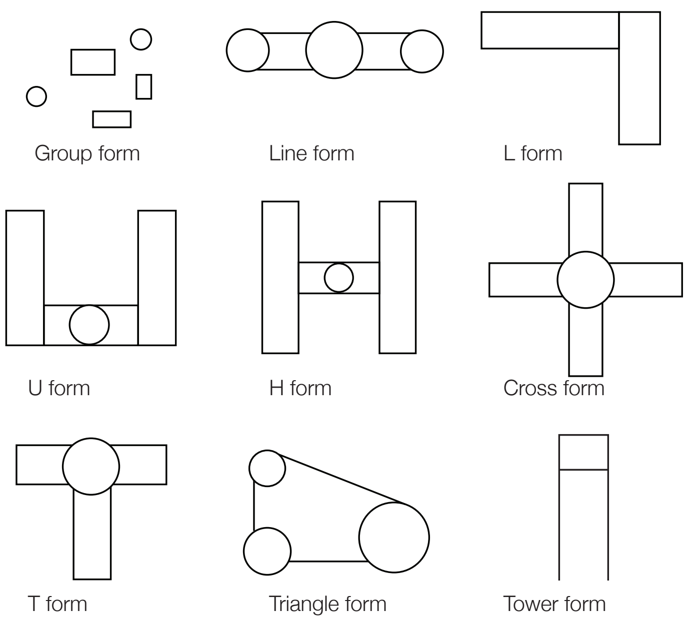

FIGURE 7.5: Clusters as proposed by Müller

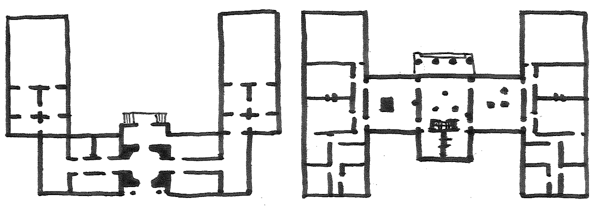

FIGURE 7.6: Functionally almost identical observatories from different clusters according to Müller's categorization: the Göttingen Observatory and the Royal Observatory, Cape of Good Hope

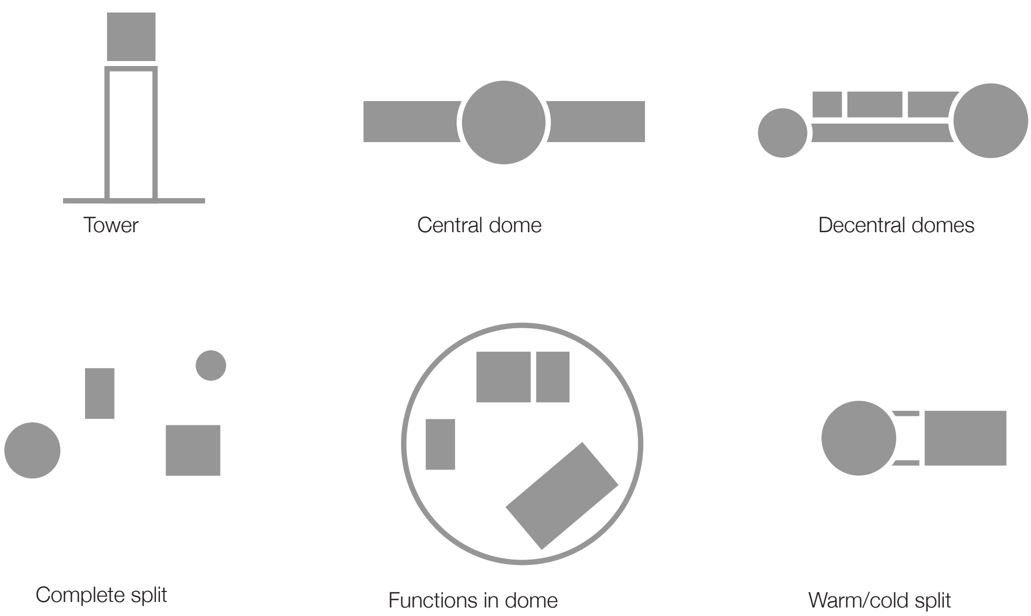

FIGURE 7.7: Graphical representations of the different subtypes

and the new subtype “Functions in dome” was introduced to make use of the excess space. During the last century telescope sizes increased even more, up to mirror sizes of up to 40m across for planned observatories[1] (Figure 7.3). This resulted in a scale difference between the telescope room and other functions, that has so far not yet been solved (see the design of the Subaru Telescope, Figure 7.4).

The functional problems caused by the internal disjunction were only fully solved almost a century later, with the introduction of the control room. In the control room, the astronomer can operate a telescope remotely. This could eventually result in almost inaccessible observatories, changing the characteristics of the observatory and its building envelope once again. The control room uses the earlier developed subtype “Warm / cold split” to eliminate disturbances of the telescope as much as possible.

7.2.3 Is There a Type?

Type is a vague concept. This research uses Argan’s interpretation, defining the type as the building’s inner formal structure. Yet when we interpret the concept of type in a broader sense, it could even be a word describing an underlying thought.

Müller, the only author in the literature that defines clusters, focuses too much on outer formal characteristics, as can be seen in his clusters in Figure 7.5. On one hand this results in clusters that are functionally identical – e.g. the U and H forms, see Figure 7.6 – on the other hand he does not recognize a difference in plans that are formally similar, but functionally different (e.g. the difference between the Palomar and Nice observatory, both in Müller’s “group form” cluster). Müller does not sufficiently focus on the developments in the twentieth century that resulted from the excessive growth of the telescope, and the revolutionary functional changes made possible by the introduction of the control room. Müller’s clusters are thus seen as incomplete and new clusters are formulated. The graphical representations of these types can be seen Figure 7.7. These representations are not based on actual plans, but show the subtypes’ essence and this research’s notion of different observatory subtypes.

These six subtypes are not limited to merely formal characteristics like Müller’s, but also entail the functional differences in the observatory plans up to the beginning of the twenty-first century. In contrast to Müller’s clusters, the six clusters in this research all have their own specific characteristics, advantages, and disadvantages that can guide towards the right fit for the design brief. It is important to realize that none of the clusters exclusively describe an astronomical observatory. In their turn, however, most observatory plans can be described by one of the six subtypes. This is demonstrated

[1] anonymous. (2013). *The European Extremely Large Telescope (“E-ELT”) Project.* Available: http://www.eso.org/sci/facilities/eelt/. Last accessed 16th March, 2013.

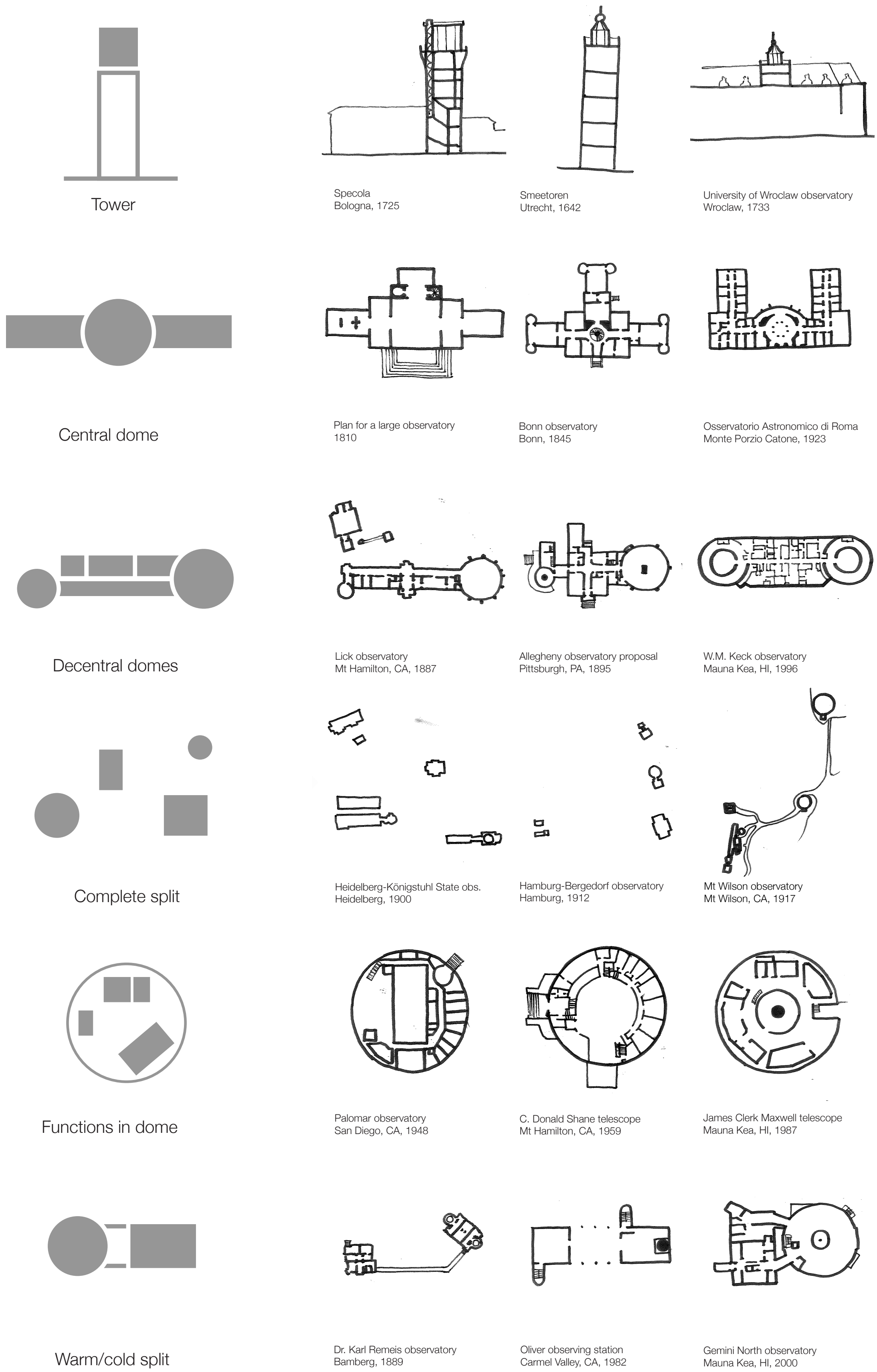

FIGURE 7.8: Sample plans next to the graphical representation of their subtype

in Figure 7.8, where sample plans are shown next to their describing subtypes. The complete categorization of sample plans in the six subtypes can be seen in the Cluster Matrix, Appendix C.

In the early Renaissance when the observatory was reintroduced, there was a clear type, the tower observatory. Over the centuries this type was replaced by the central dome with wings, the main type up to the first half of the nineteenth century. The last two centuries, newly introduced clusters have not replaced existing ones but must be seen as additions to the collection of subtypes. Nowadays there is not one prescribing type for new observatories anymore, but different subtypes that suit the design brief, depending on properties and location.

Thus, recognizing that there are multiple subtypes for the observatory (their graphical representations shown in Figure 7.7), it is impossible to state that (since the nineteenth century) there is *a* type under Argan's definition. However, following Moneo's broader thoughts on typology and with the exception of the "Functions in dome" cluster, all subtypes are dominated by decentrality in the plan, combined with a prominent role of the main instrument. Therefore instead of one type, we can recognize six subtypes with an underlying thought of decentrality and an emphasis on the instrument.

7.2.4 What Trends Can Be Found in the Development of the Observatory Type Since 1579?

The observatory was reintroduced in Europe in the shape of small observing rooms. These unicellular rooms were often additions on top of existing buildings such as towers or large educational buildings. With the evolution of the observing room into the instrument room and the differentiation of the program because of added functions, the observatory proved to be a good program for the Palladian scheme of a central, domed, building with wings spreading out. From the end of the eighteenth century this would be the main type for one and a half century, albeit with different wing configurations. From this type, a variant with decentral domes connected by wings started to form in the nineteenth century, when domes became too large to take a central position in the plan. Functionally the type was the similar, with corridors connecting the telescopes that were now on the end of the wings that housed auxiliary functions, such as lecture rooms, offices, a workshop, lodgings, and instrument rooms. The Palladian scheme turned the observatories into representational buildings celebrating developments in Western science.

The development of astrophysics in the second half of the nineteenth century and the consequential need for better observing conditions introduced an internal conflict in the observatory plan. Instrument rooms had to be free from any disturbances such

FIGURE 7.9: Dunsink Observatory, the central room on the ground floor is almost entirely filled with the telescope pier

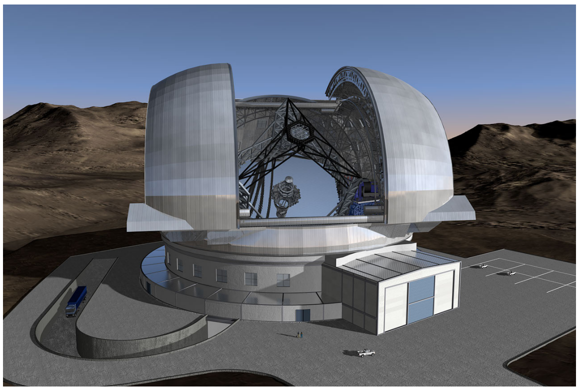

FIGURE 7.10: The European Extremely Large Telescope

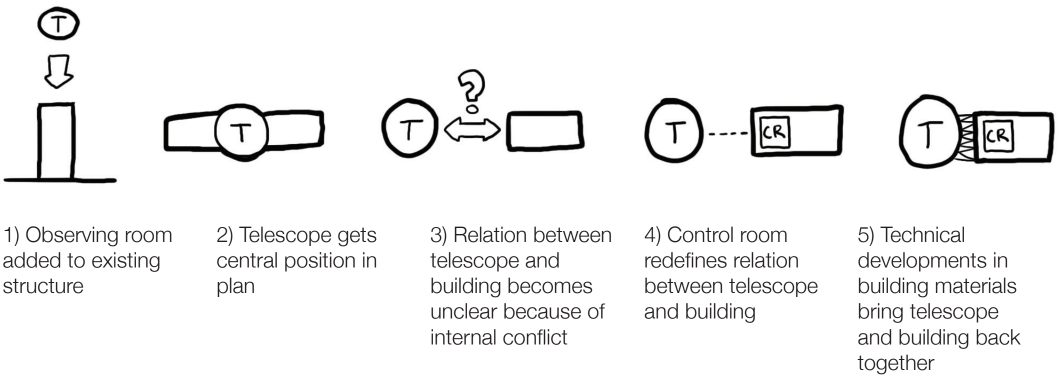

FIGURE 7.11: The developing relation between instrument and building

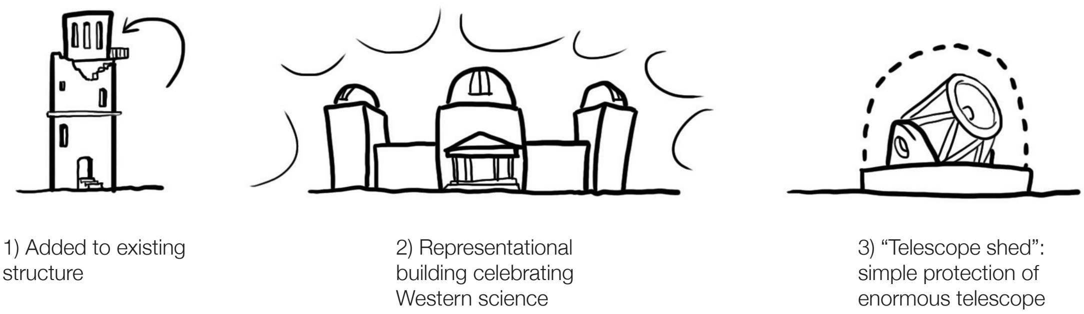

FIGURE 7.12: The character of the observatory building

as heat, vibrations and smoke, while at the same time the astronomer still preferred to be comfortable. Instruments required distance from people, astronomers required proximity to instruments. Different approaches tried to solve the issue. At first, long corridors connected different building parts, that were either dedicated to instruments (observing) or people (working and living). This evolved into building clusters such as the Nice Observatory (see Appendix A), where instrument rooms were completely isolated, disconnected from other instrument rooms and other building parts.

Because the telescope became the most important instrument for observations, buildings started to be designed in a supporting role for the telescope. This was started by the Dunsink observatory in Dublin, where one of the central rooms in the building is completely filled by the pier that supports the telescope (Figure 7.9). This trend continued and as observing locations became more remote, functions (e.g. the lecture room and library) disappeared from the building site.

The increasing size of the telescope – by this time the only surviving observing instrument and used for both the position and properties of stars – demanded more formal changes in the type. Unexpectedly, this lead to the inclusion of the other functions in the enormous dome, antipodal to the split. Though sometimes still used for observatories (such as the European Extremely Large Telescope, planned to be completed in 2018, see Figure 7.10), this scheme was replaced by a reintroduction of the warm/cold split, the result of the introduction of the control room in the 1970s. Because the astronomer did not require proximity to the instruments anymore, the instrument could have its required remoteness. The cold instrument part of the building is only virtually connected with the warm part for offices by the control room, that finally brings a solution for the internal conflict after more than a century. This relation between instrument and building is a striking characteristic of the observatory and its development is schematically shown in Figure 7.11.

As the result of the growth of instruments the observatory started to play an even more supporting role, leading to the "telescope sheds" of today: almost the complete budget is spent on the telescope and its mounting. The observatory itself often consists of cheap materials and with little attention, being nothing more than a simple shell. This development of the observatory's character is shown in Figure 7.12.

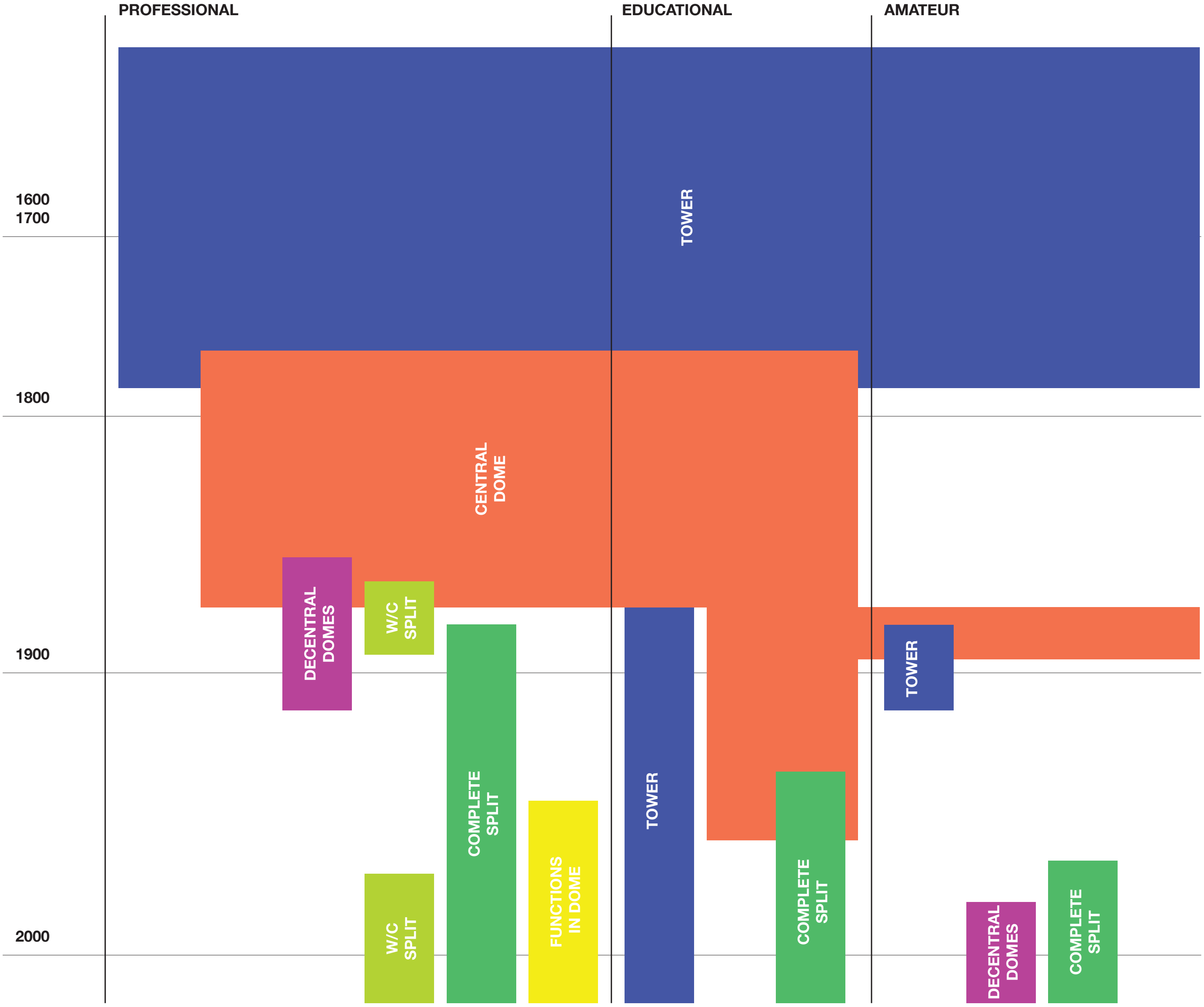

FIGURE 7.13: Chronological overview of the clusters

7.2.5 Subtypes for Different Kinds of Observatories

During the second half of the nineteenth century, with the development of the professional scientist, a distinction emerged between professional research institutes, educational institutes, and citizen institutes. Earlier so-called amateurs, like Herschel, had already contributed to astronomy, but in these early years amateurs were exclusively wealthy upperclass enthusiasts and were not much different from professional astronomers. In 1889, with the founding of Urania in Berlin, lower social classes united to bring astronomy to the masses. From this point on, citizen astronomy developed parallel to professional astronomy, and because of the enormous amount of celestial data that had to be gathered, professionals welcomed the extra aid. Technology became more affordable towards the end of the last century, and amateurs now have the opportunity to build observatories in their backyard, resulting in an explosive growth of tiny observatories.

At the same time a difference between professional and educational observatories emerged. More remote locations were sought as conditions of university campuses were not sufficing anymore, professionals moved away building more advanced telescopes in better locations. At universities the need for an observatory remained.

Due to extreme difference in instrument size, location, and target group, these three kinds of observatories differ from each other formally and programmatically. In Figure 7.13 a chronological overview is given per kind. The diagram shows that until the 1850s, one observatory type covered all target groups. But as professional equipment grew, formal differences became visible. For example, the functions in dome cluster only suits professional observatories since it is the result of the protection of enormous instruments. The "Tower" subtype was reintroduced for citizen observatories located in city centres, and on university campuses to extend the view beyond surrounding buildings. The "Decentral domes" subtype nowadays suits the amateurs observatories, yet a century ago professional institutes had such a plan. Similarly the typical observatory with the central dome and extending wings might nowadays be built as an educational observatory (or citizen observatory), but the subtype is now unfit for a large professional institution.

Just as in Figure 7.2, cascade characteristics emerge in the figure. Subtypes that developed to suit professional institutes were replaced and used for educational observatories, and subsequently citizen observatories. This can help designers to predict developments and to anticipate to future needs.

7.3 Future

Is the differentiation of the observatory type into subtypes a trend that will continue in the future? The further increase in size of large professional institutions and developments in other fields such as radio astronomy seem to support this assumption. Just like the control room caused a new subtype to emerge, new discoveries may introduce more subtypes. At the same time developments such as better insulation draw different clusters together and good qualities of different subtypes are combined.

Because of the differentiation of the observatory into educational, citizen, and professional observatories, it seems unlikely that the observatory will ever evolve into one type for both small and large scale plans. Professional institutes might in the future evolve into one type, since all observatories in this category are dominated by creating optimal observing conditions and are dealing with the same technical requirements, disproportion, and dominating role of the main instrument. Citizen and educational observatories however, seem to have too much difference in size, program and location, that one general type for each of these categories seems unlikely. Yet the limited envelope of subtypes may remain, guided by the underlying thoughts of decentrality and the prominent role of the telescope in the plan.

The search for the optimal location bringing better measurements will continue. With the introduction of adaptive optics, earthbound observatories have been able to improve their observational powers and the technical difficulties and astronomical costs of orbital observatories have not yet made terrestrial observatories obsolete. Even though recent developments seem to drive the observatory further away from the people, a new invention might turn this all around. Because of the enormous influence of astronomy on the design and layout of the observatory, its future will always be hard to foresee.

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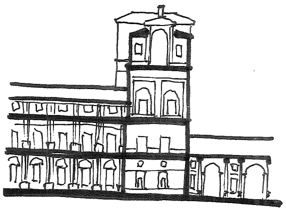
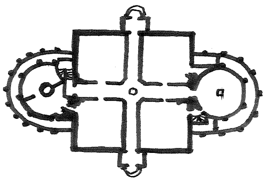
Appendix A

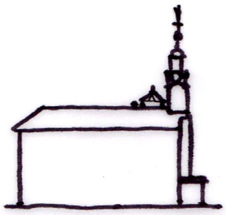
Sample plans



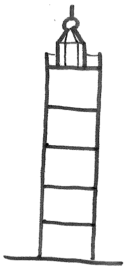
Tower of the winds
Vatican, 1579



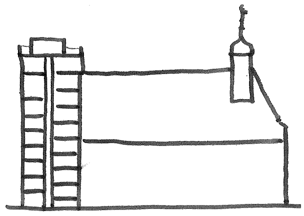
Uraniborg
Hven, 1581



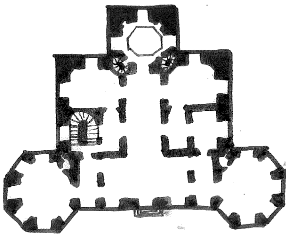
Leiden observatory
Leiden, 1633



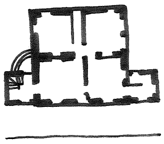
Smeetoren
Utrecht, 1642



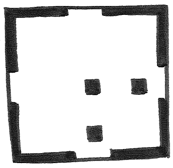
Rundetårn
Copenhagen, 1642



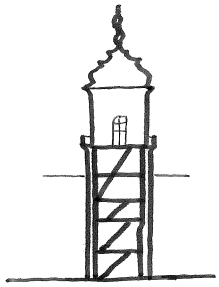
Observatoire de Paris
Paris, 1671



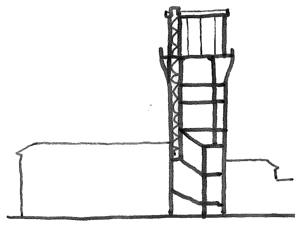
Flamsteeds House
Greenwich, 1676



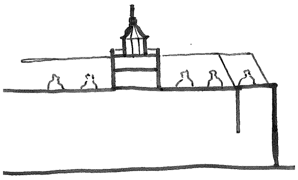
Obsrevatorium Tusculanum
Vridsløsemagle, 1704



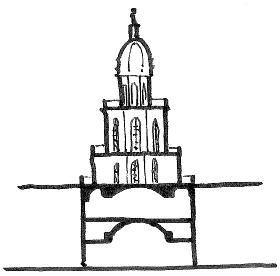
Clementinum observatory
Prague, 1723



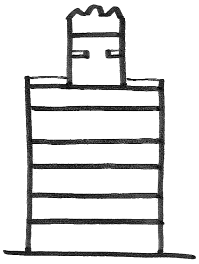
Specola
Bologna, 1725



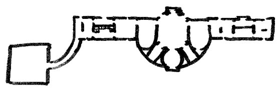
University of Wroclaw observatory
Wroclaw, 1733



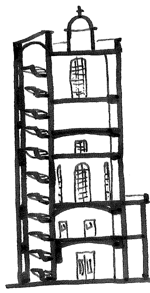
Kunstkamera observatory
St. Petersburg, 1734



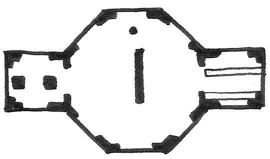
Observatory of Kremsmünster
Kremsmünster, 1758



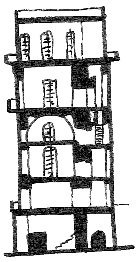
Radcliffe observatory
Oxford, 1771



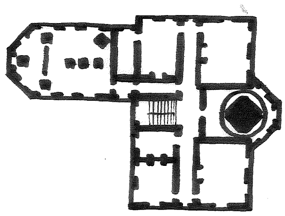
Mannheim observatory
Mannheim, 1774



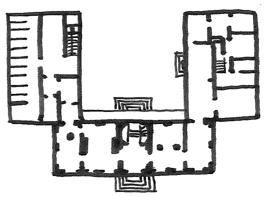
Copenhagen observatory
Copenhagen, 1780



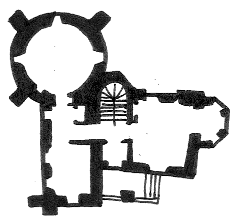
Zwehrenturm
Kassel, 1785



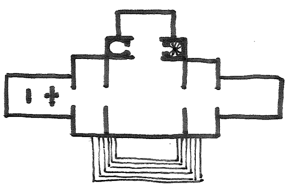
Dunsink observatory
Dublin, 1785



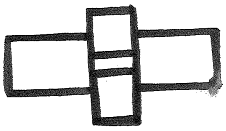
Gotha observatory
Seeberg, 1790



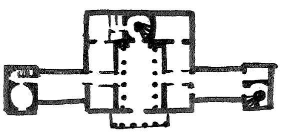
Old observatory house
Edinburgh, 1793



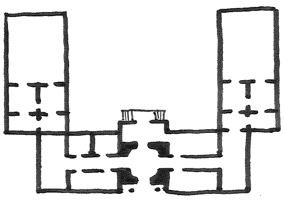
Plan for a large observatory
1810



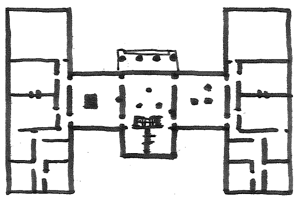
Tartu observatory
Tartu, 1810



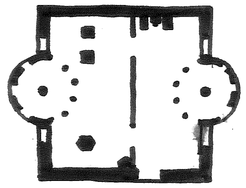
Osservatorio astr. di Capodimonte
Naples, 1812

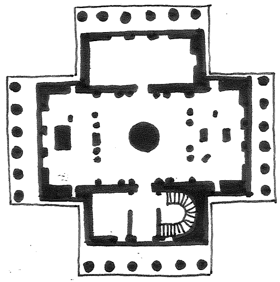


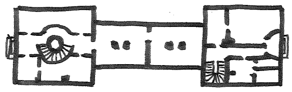
Göttingen observatory
Göttingen, 1816

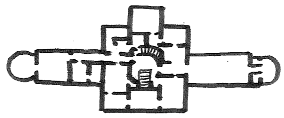


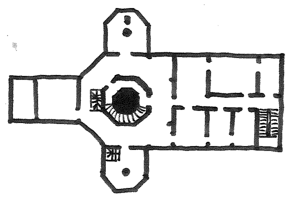
Royal observatory, Cape of Good Hope
Cape Town, 1820

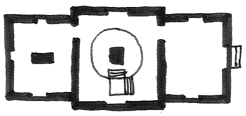

Parramatta observatory
Sydney, 1822

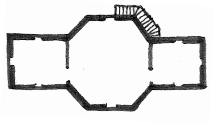

City observatory
Edinburgh, 1824

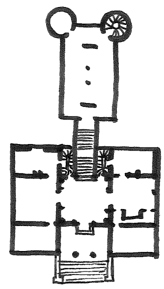

Hamburg observatory
Hamburg, 1825

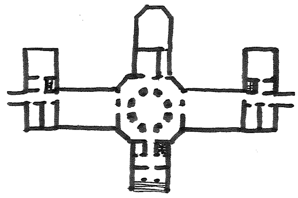

Helsinki University observatory
Helsinki, 1834

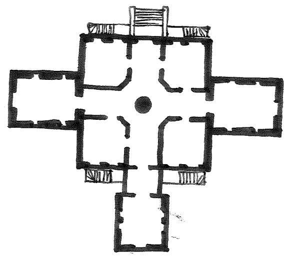

New Berlin observatory
Berlin, 1835

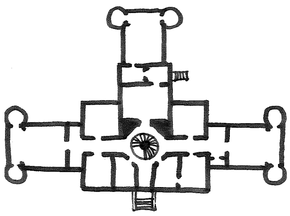

Loomis observatory
Hudson, OH, 1838

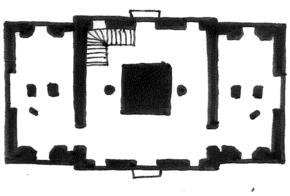

Hopkins observatory
Williamstown, MA, 1838

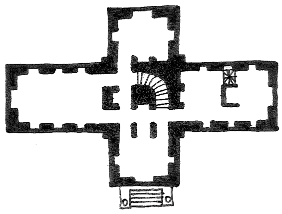

Observatoire de Toulouse
Toulouse, 1838

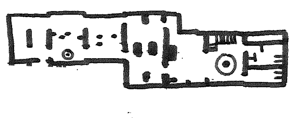

Pulkovo Astronomical observatory
St. Petersburg, 1839

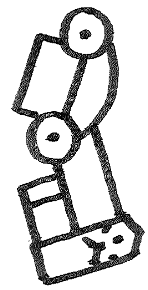

Old Naval observatory
Washington, DC, 1843

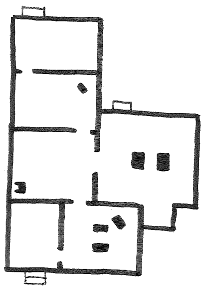

Bonn observatory
Bonn, 1845

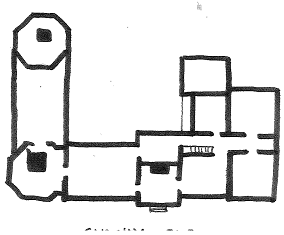

Georgetown University observatory
Georgetown, DC, 1846

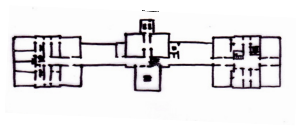

National observatory of Athens
Athens, 1846

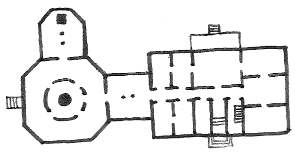

Meridian building
Greenwich, 1850

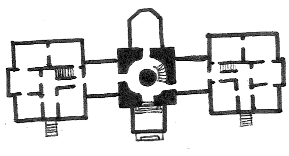

Sonnenborgh observatory
Utrecht, 1853

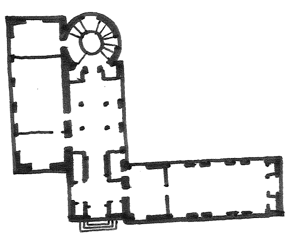

Williamstown observatory
Melbourne, 1857

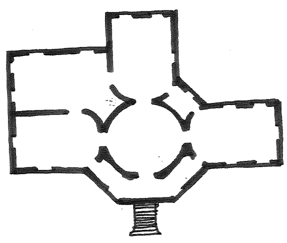

Sydney observatory
Sydney, 1858

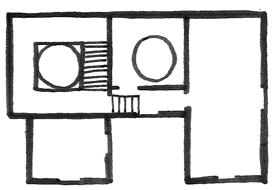

Leiden observatory
Leiden, 1861

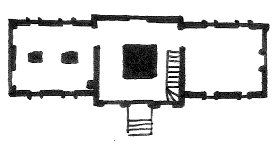

Leipzig observatory
Leipzig, 1861

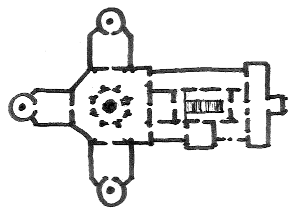

Copenhagen University observatory
Copenhagen, 1861

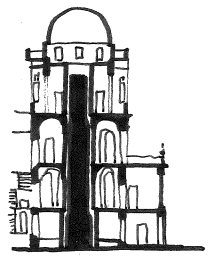

Eidgenössische Sternwarte
Zürich, 1864


Vassar College observatory
Poughkeepsie, NY, 1865

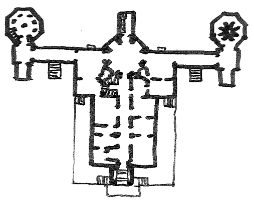

Hurbanovo observatory
Hurbanovo, 1871


Astronomical observatory at Ogden
Ogden, UT, 1873

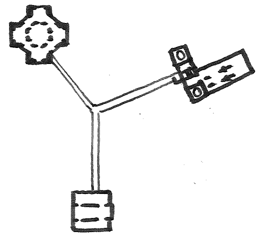

Vienna University observatory
Vienna, 1874



Orwell Park observatory
Ipswich, 1874

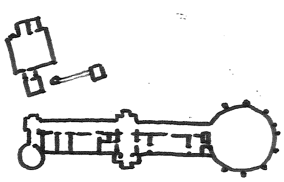


Astrophysical observatory Potsdam
Potsdam, 1879

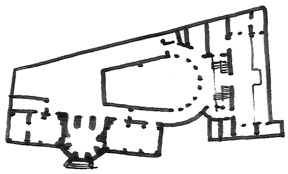


Observatory of Strasbourg
Strasbourg, 1882

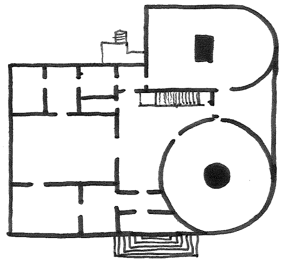
Observatoire de Nice
Nice, 1886



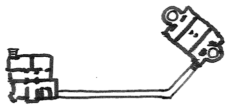
Lick observatory
Mt Hamilton, CA, 1887



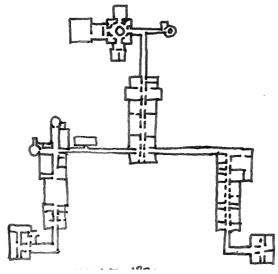
Urania
Berlin, 1889



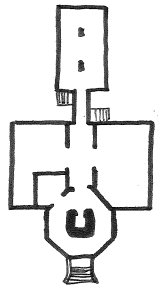
Dearborn observatory
Evanston, IL, 1889



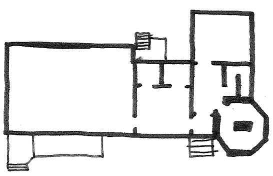
Dr. Karl Remeis observatory
Bamberg, 1889



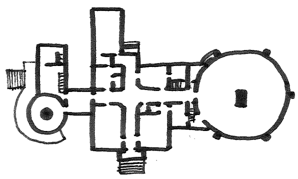
Royal observatory of Belgium
Uccle, 1891



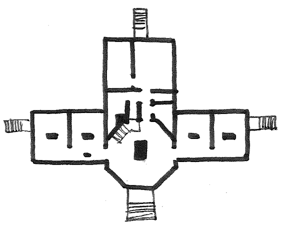
Ladd observatory
Providence, RI, 1891



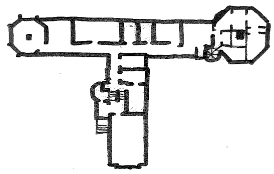
Theodor Jacobsen obs.
Seattle, WA, 1895



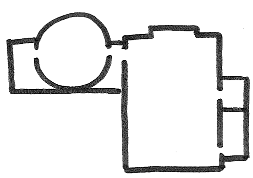
Allegheny observatory proposal
Pittsburgh, PA, 1895



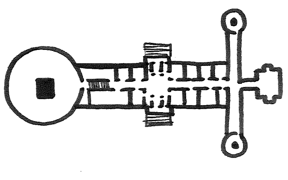
University of Illinois observatory
Champaign, IL, 1896



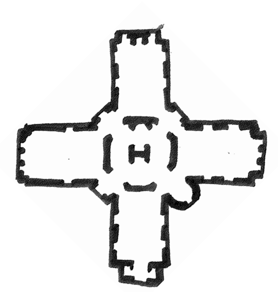
Royal observatory, Edinburgh
Edinburgh, 1896



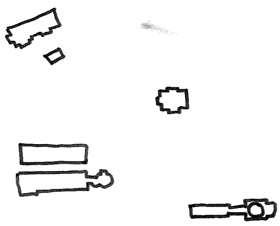
Old Perkins Astr. observatory
Middletown, CT, 1896



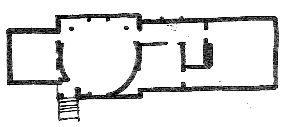
Yerkes observatory
Williams Bay, WI, 1897



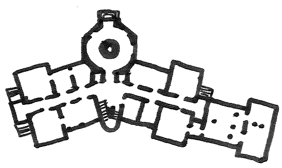
Thompson Building
Greenwich, 1899



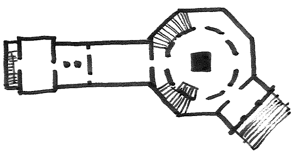
Heidelberg-Königstuhl State obs.
Heidelberg, 1900



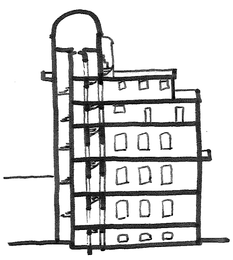
Whitin observatory
Wellesley, MA, 1900



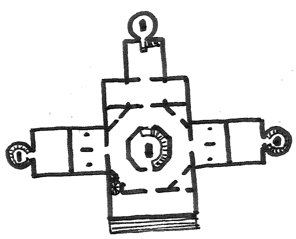
Dominion observatory
Ottawa, 1902



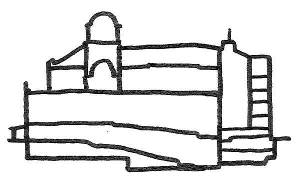
Fabra observatory
Barcelona, 1904



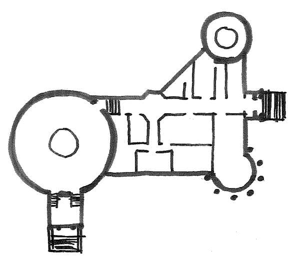
Physikalischer Verein observatory
Frankfurt am Main, 1906



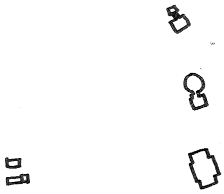
Tacubaya observatory
Mexico City, 1908



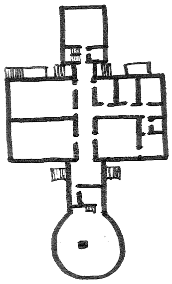
Palace Urania
Vienna, 1910



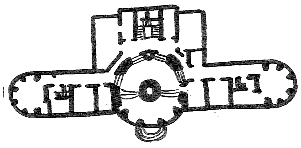
Allegheny observatory
Pittsburgh, PA, 1912



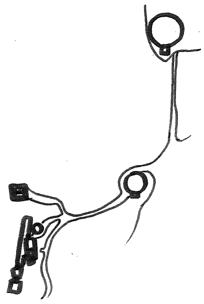
Hamburg-Bergedorf observatory
Hamburg, 1912



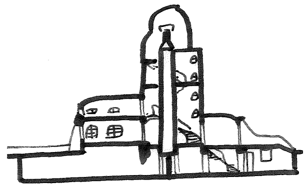
Van Vleck observatory
Middletown, CT, 1914



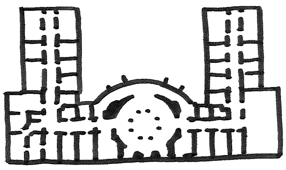
Babelsberg observatory
Potsdam, 1915



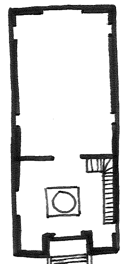
Mt Wilson observatory
Mt Wilson, CA, 1917



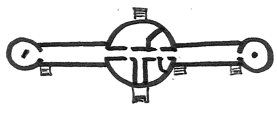
Einsteinturm
Potsdam, 1921



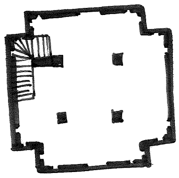
Osservatorio Astronomico di Roma
Monte Porzio Catone, 1923



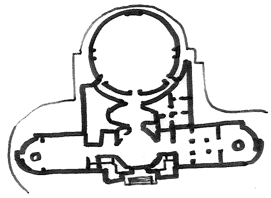
Hale Solar laboratory
Pasadena, CA, 1923



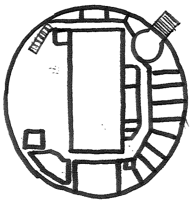
Ricard observatory
Santa Clara, CA, 1928



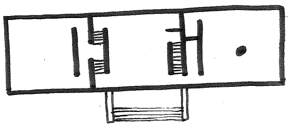
N.A. Richardson observatory
San Bernardino, CA, 1930



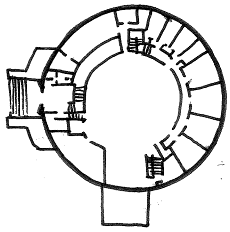
Griffith observatory
Los Angeles, CA, 1935



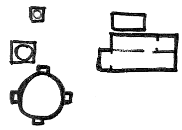
Palomar observatory
San Diego, CA, 1948



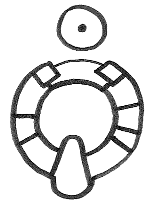
Holcomb observatory
Indianapolis, IN, 1953



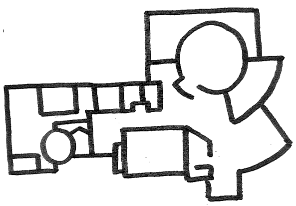
C. Donald Shane telescope
Mt Hamilton, CA, 1959



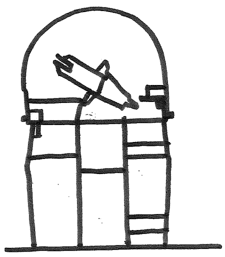
San Fernando observatory
San Fernando, CA, 1960



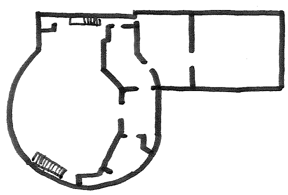
Krause Center for Innovation
Los Altos Hills, CA, 1965



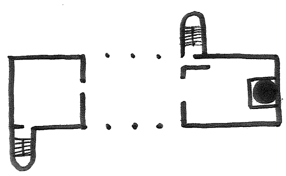
Stardome observatory and planetarium
Auckland, 1967



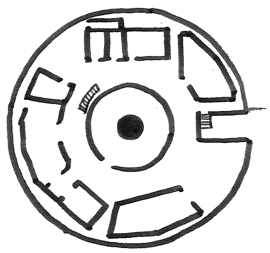
Nicholas U. Mayall telescope
Kitt Peak, AZ, 1973



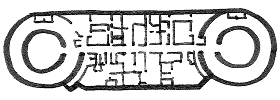
United Kingdom Infrared telescope
Mauna Kea, HI, 1978



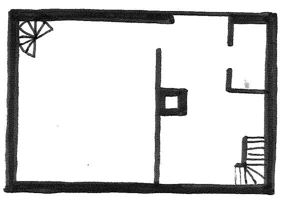
Oliver observing station
Carmel Valley, CA, 1982



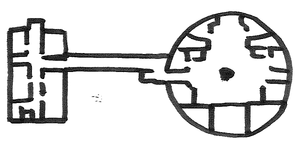
James Clerk Maxwell telescope
Mauna Kea, HI, 1987



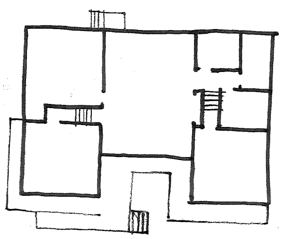
W.M. Keck observatory
Mauna Kea, HI, 1996



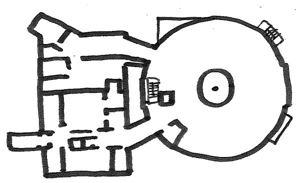
Ritchie observatory
Bainbridge Island, WA, 1997



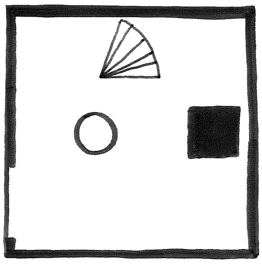
Subaru telescope
Mauna Kea, HI, 1998



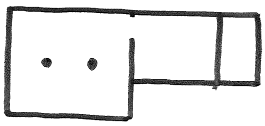
Robert Ferguson observatory
Sonoma, CA, 1999



Gemini North observatory
Mauna Kea, HI, 2000

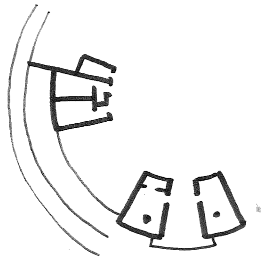


Dekalb observatory
Auburn, IN, 2004

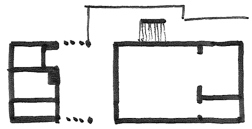


Observatorio de Ballona
Riverside, CA, 2004

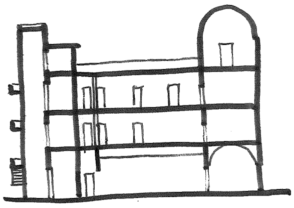
Kielder observatory
Kielder, 2008



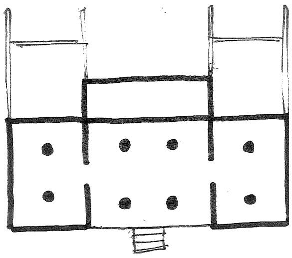
Murillo Family observatory
San Bernardino, CA, 2011



Craigengillan Dark Sky obs.
Galloway Forest Park, 2012



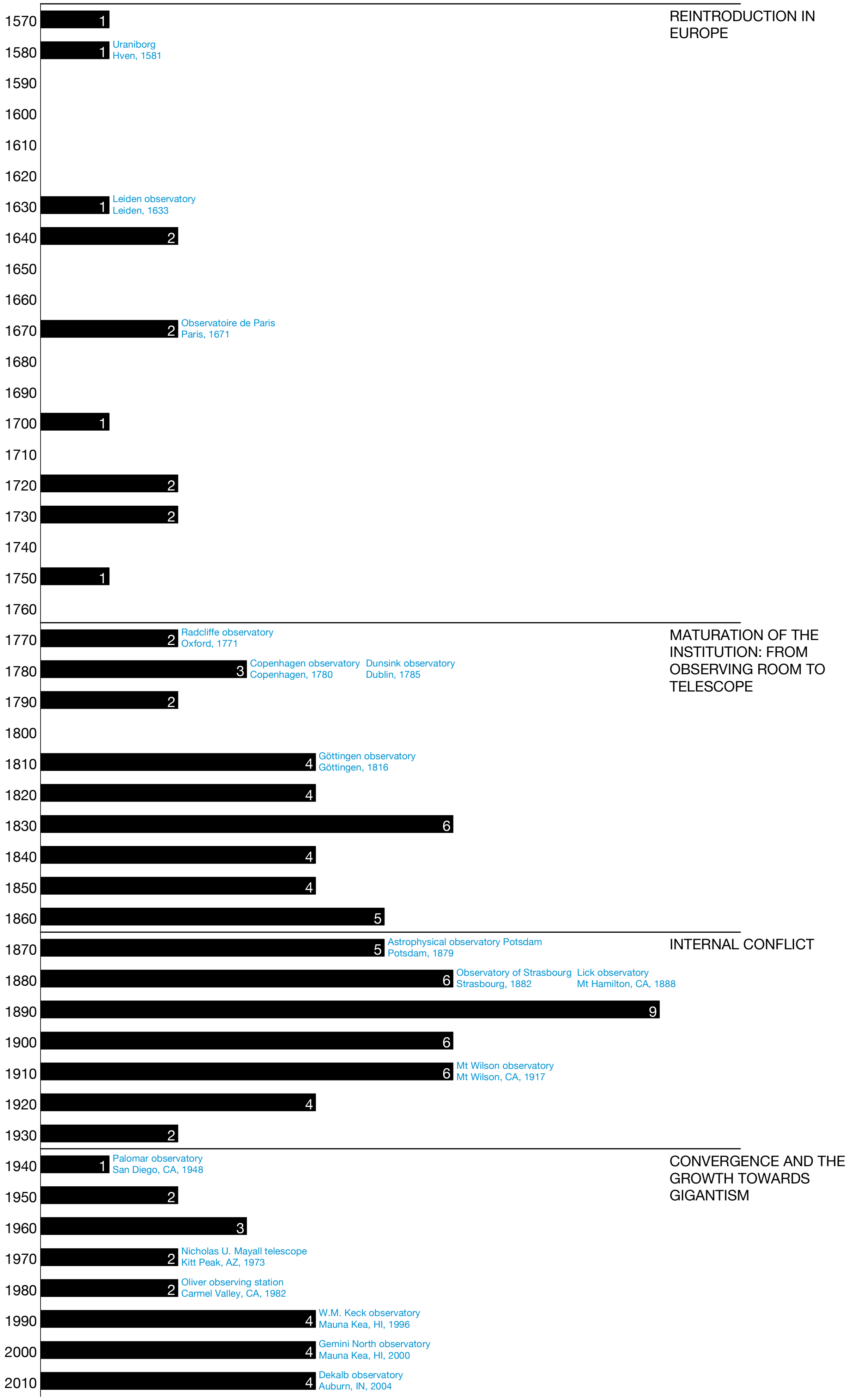
Stocker Astroscience Center
Miami, FL, 2012



Kansas State University Observatory proposal
Manhattan, KS, 2012

Appendix B

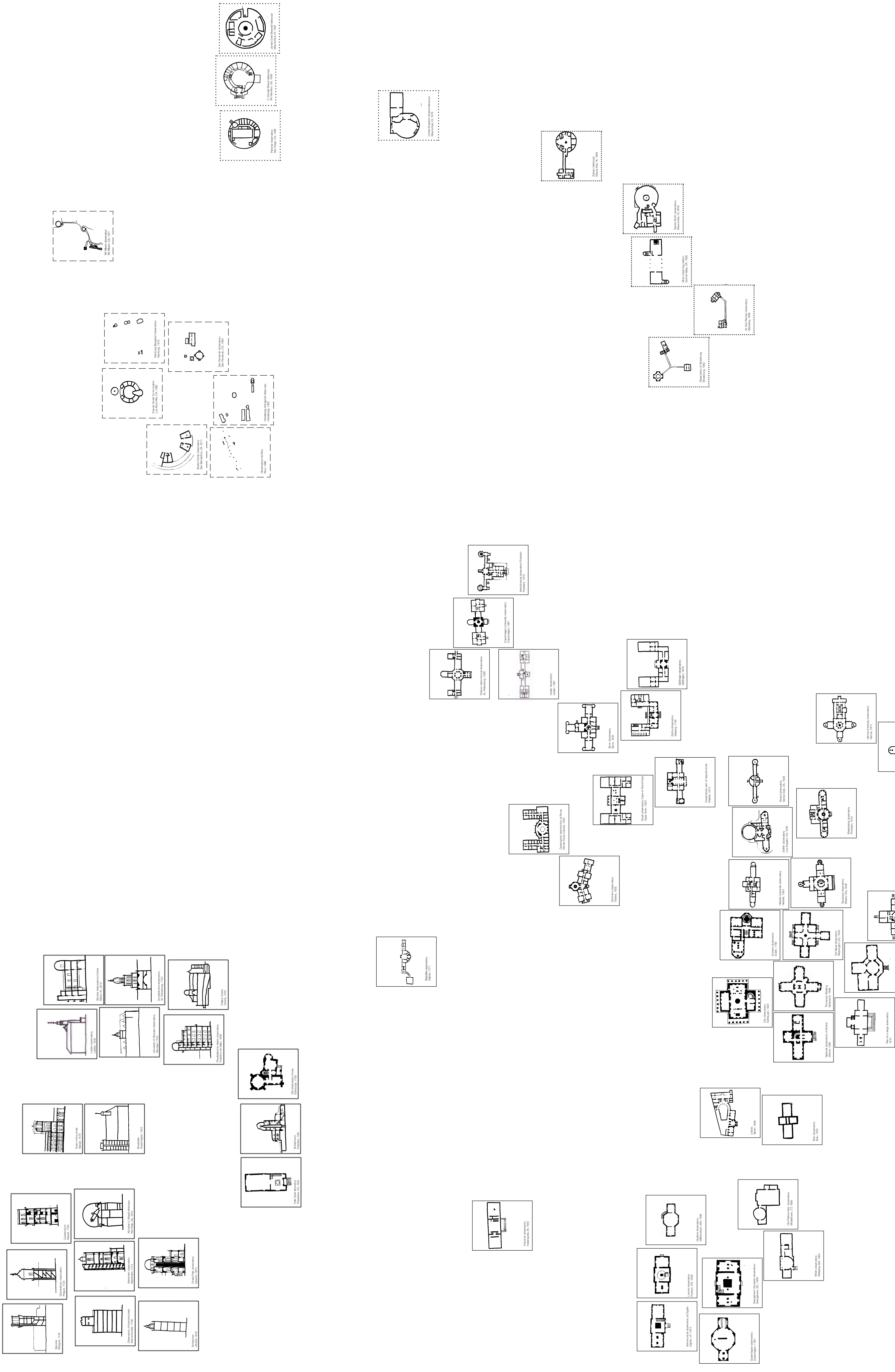
Samples per Decade Diagram

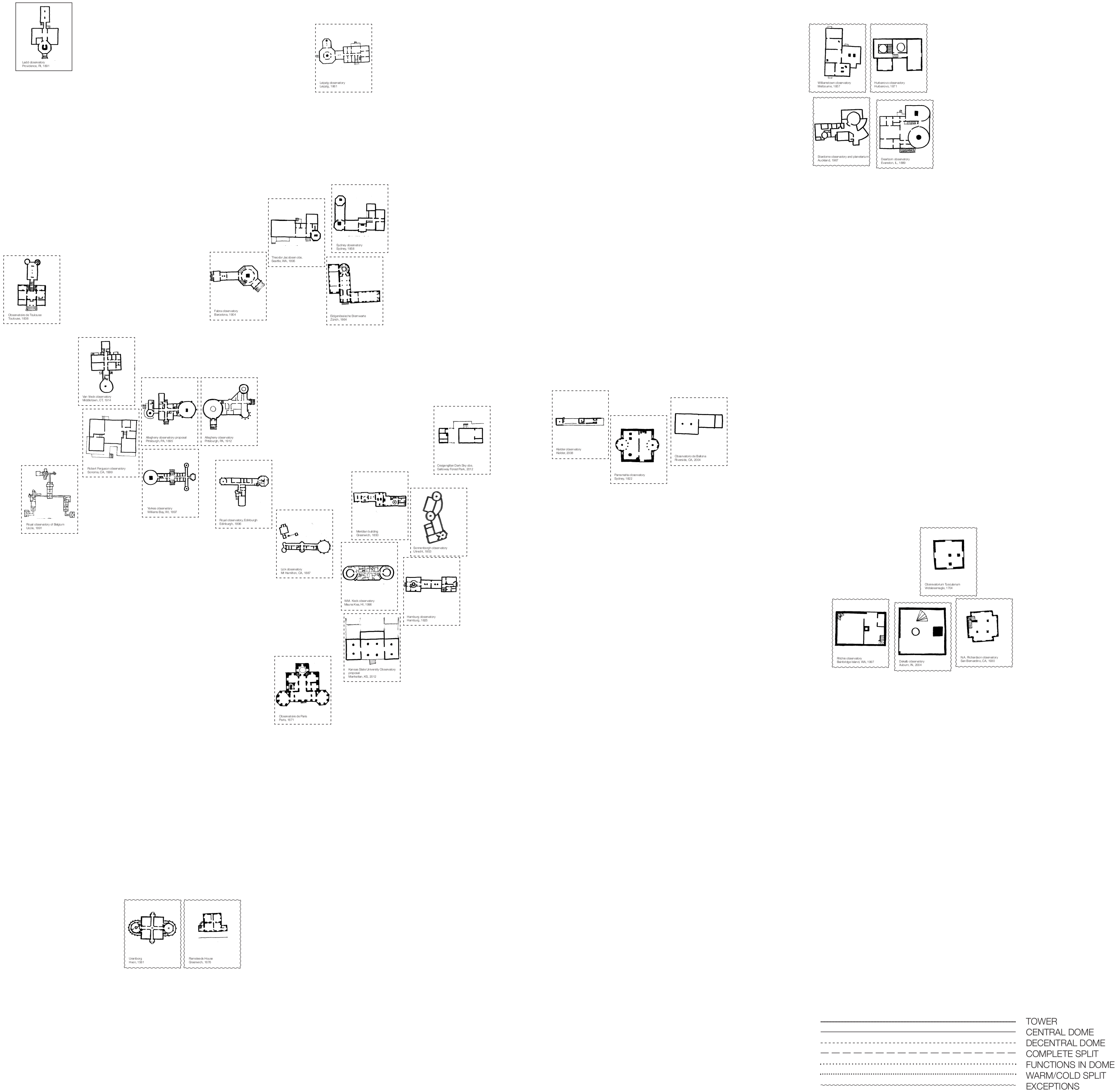


REINTRODUCTION IN EUROPE
MATURATION OF THE INSTITUTION: FROM OBSERVING ROOM TO TELESCOPE
INTERNAL CONFLICT
CONVERGENCE AND THE GROWTH TOWARDS GIGANTISM
1570 1
1580 1
Uraniborg
Hven, 1581
1590
1600
1610
1620
1630 1
Leiden observatory
Leiden, 1633
1640 2
1650
1660
1670 2
Observatoire de Paris
Paris, 1671
1680
1690
1700 1
1710
1720 2
1730 2
1740
1750 1
1760
1770 2
Radcliffe observatory
Oxford, 1771
1780 3
Copenhagen observatory
Copenhagen, 1780
Dunsink observatory
Dublin, 1785
1790 2
1800
1810 4
Göttingen observatory
Göttingen, 1816
1820 4
1830 6
1840 4
1850 4
1860 5
1870 5
Astrophysical observatory Potsdam
Potsdam, 1879
1880 6
Observatory of Strasbourg
Strasbourg, 1882
Lick observatory
Mt Hamilton, CA, 1888
1890 9
1900 6
1910 6
Mt Wilson observatory
Mt Wilson, CA, 1917
1920 4
1930 2
1940 1
Palomar observatory
San Diego, CA, 1948
1950 2
1960 3
1970 2
Nicholas U. Mayall telescope
Kitt Peak, AZ, 1973
1980 2
Oliver observing station
Carmel Valley, CA, 1982
1990 4
W.M. Keck observatory
Mauna Kea, HI, 1996
2000 4
Gemini North observatory
Mauna Kea, HI, 2000
2010 4
Dekalb observatory
Auburn, IN, 2004

Appendix C

Cluster Matrix





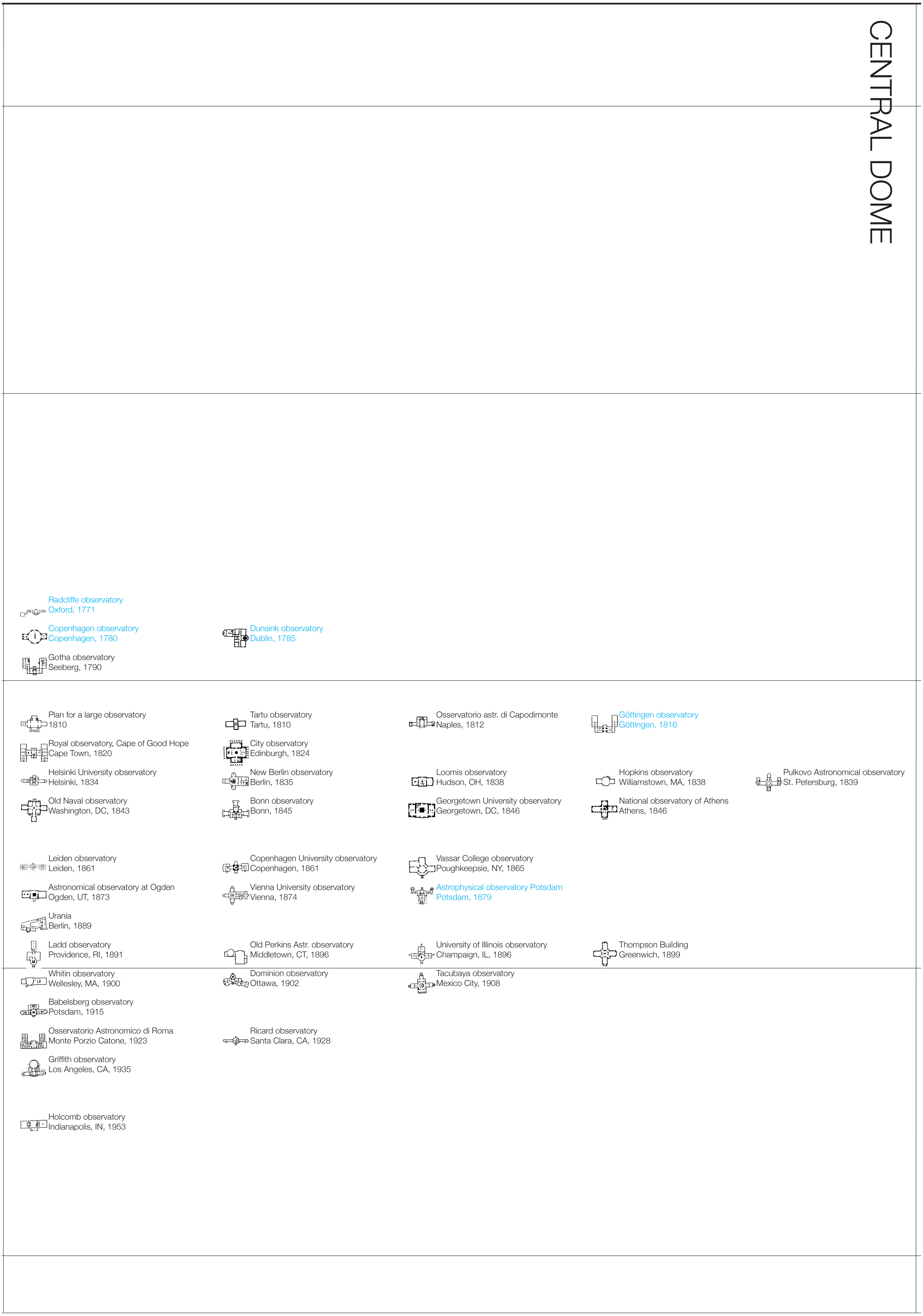
Ladd observatory
Providence, RI, 1891
Leipzig observatory
Leipzig, 1861
Williamstown observatory
Melbourne, 1857
Hurbanovo observatory
Hurbanovo, 1871
Stardome observatory and planetarium
Auckland, 1967
Dearborn observatory
Evanston, IL, 1889
Theodor Jacobsen obs.
Seattle, WA, 1895
Sydney observatory
Sydney, 1858
Observatoire de Toulouse
Toulouse, 1838
Fabra observatory
Barcelona, 1904
Eidgenössische Sternwarte
Zürich, 1864
Van Vleck observatory
Middletown, CT, 1914
Allegheny observatory proposal
Pittsburgh, PA, 1895
Allegheny observatory
Pittsburgh, PA, 1912
Robert Ferguson observatory
Sonoma, CA, 1999
Yerkes observatory
Williams Bay, WI, 1897
Royal observatory of Belgium
Uccle, 1891
Royal observatory, Edinburgh
Edinburgh, 1896
Lick observatory
Mt Hamilton, CA, 1887
Meridian building
Greenwich, 1850
Sonnenborgh observatory
Utrecht, 1853
W.M. Keck observatory
Mauna Kea, HI, 1996
Hamburg observatory
Hamburg, 1825
Kansas State University Observatory proposal
Manhattan, KS, 2012
Observatoire de Paris
Paris, 1671
Craigengillan Dark Sky obs.
Galloway Forest Park, 2012
Kielder observatory
Kielder, 2008
Parramatta observatory
Sydney, 1822
Observatorio de Ballona
Riverside, CA, 2004
Obrevatorium Tusculanum
Vridsløsemagle, 1704
Ritchie observatory
Bainbridge Island, WA, 1997
Dekalb observatory
Auburn, IN, 2004
N.A. Richardson observatory
San Bernardino, CA, 1930
Uraniborg
Hven, 1581
Ramsteeds House
Greenwich, 1676
TOWER
CENTRAL DOME
DECENTRAL DOME
COMPLETE SPLIT
FUNCTIONS IN DOME
WARM/COLD SPLIT
EXCEPTIONS

Appendix D

Chronological Matrix

TOWER

1570	Tower of the winds Vatican, 1579	
1580		
1590		
1600		
1610		
1620		
1630	Leiden observatory Leiden, 1633	
1640	Smeetoren Utrecht, 1642	Rundetårn Copenhagen, 1642
1650		
1660		
1670		
1680		
1690		
1700		
1710		
1720	Clementinum observatory Prague, 1723	Specola Bologna, 1725
1730	University of Wroclaw observatory Wroclaw, 1733	Kunstkamera observatory St. Petersburg, 1734
1740		
1750	Observatory of Kremsmünster Kremsmünster, 1758	
1760		
1770	Mannheim observatory Mannheim, 1774	
1780	Zwehrenturm Kassel, 1785	
1790	Old observatory house Edinburgh, 1793	
1800		
1810		
1820		
1830		
1840		
1850		
1860		
1870	Orwell Park observatory Ipswich, 1874	
1880		
1890		
1900	Physikalischer Verein observatory Frankfurt am Main, 1906	
1910	Palace Urania Vienna, 1910	
1920	Einsteinturm Potsdam, 1921	Hale Solar laboratory Pasadena, CA, 1923
1930		
1940		
1950		
1960		
1970	Nicholas U. Mayall telescope Kitt Peak, AZ, 1973	
1980		
1990		
2000		
2010	Stocker Astroscience Center Miami, FL, 2012	


CENTRAL DOME
Radcliffe observatory
Oxford, 1771
Copenhagen observatory
Copenhagen, 1780
Dunsink observatory
Dublin, 1785
Gotha observatory
Seeberg, 1790
Plan for a large observatory
1810
Tartu observatory
Tartu, 1810
Osservatorio astr. di Capodimonte
Naples, 1812
Göttingen observatory
Göttingen, 1816
Royal observatory, Cape of Good Hope
Cape Town, 1820
City observatory
Edinburgh, 1824
Helsinki University observatory
Helsinki, 1834
New Berlin observatory
Berlin, 1835
Loomis observatory
Hudson, OH, 1838
Hopkins observatory
Williamstown, MA, 1838
Pulkovo Astronomical observatory
St. Petersburg, 1839
Old Naval observatory
Washington, DC, 1843
Bonn observatory
Bonn, 1845
Georgetown University observatory
Georgetown, DC, 1846
National observatory of Athens
Athens, 1846
Leiden observatory
Leiden, 1861
Copenhagen University observatory
Copenhagen, 1861
Vassar College observatory
Poughkeepsie, NY, 1865
Astronomical observatory at Ogden
Ogden, UT, 1873
Vienna University observatory
Vienna, 1874
Astrophysical observatory Potsdam
Potsdam, 1879
Urania
Berlin, 1889
Ladd observatory
Providence, RI, 1891
Old Perkins Astr. observatory
Middletown, CT, 1896
University of Illinois observatory
Champaign, IL, 1896
Thompson Building
Greenwich, 1899
Whitin observatory
Wellesley, MA, 1900
Dominion observatory
Ottawa, 1902
Tacubaya observatory
Mexico City, 1908
Babelsberg observatory
Potsdam, 1915
Osservatorio Astronomico di Roma
Monte Porzio Catone, 1923
Ricard observatory
Santa Clara, CA, 1928
Griffith observatory
Los Angeles, CA, 1935
Holcomb observatory
Indianapolis, IN, 1953

DECENTRAL DOMES

1570						
1580						
1590						
1600						
1610						
1620						
1630						
1640						
1650						
1660						
1670	Observatoire de Paris Paris, 1671					
1680						
1690						
1700						
1710						
1720						
1730						
1740						
1750						
1760						
1770						
1780						
1790						
1800						
1810						
1820	Parramatta observatory Sydney, 1822	Hamburg observatory Hamburg, 1825				
1830	Observatoire de Toulouse Toulouse, 1838					
1840						
1850	Meridian building Greenwich, 1850	Sonnenborgh observatory Utrecht, 1853	Sydney observatory Sydney, 1858			
1860	Leipzig observatory Leipzig, 1861	Eidgenössische Sternwarte Zürich, 1864				
1870						
1880	Lick observatory Mt Hamilton, CA, 1888					Observatoire Nice, 1886
1890	Royal observatory of Belgium Uccle, 1891	Theodor Jacobsen obs. Seattle, WA, 1895	Allegheny observatory proposal Pittsburgh, PA, 1895	Royal observatory, Edinburgh Edinburgh, 1896	Yerkes observatory Williams Bay, WI, 1897	
1900	Fabra observatory Barcelona, 1904					Heidelberg-K Heidelberg, 1
1910	Allegheny observatory Pittsburgh, PA, 1912	Van Vleck observatory Middletown, CT, 1914				Hamburg-Be Hamburg, 19
1920						
1930						
1940						
1950						
1960						San Fernand San Fernand
1970						
1980						
1990	W.M. Keck observatory Mauna Kea, HI, 1996	Robert Ferguson observatory Sonoma, CA, 1999				
2000	Observatorio de Ballona Riverside, CA, 2004	Kielder observatory Kielder, 2008				
2010	Craigengillan Dark Sky obs. Galloway Forest Park, 2012	Kansas State University Observatory proposal Manhattan, KS, 2012				Murillo Famil San Bernardi

COMPLETE SPLIT	FUNCTIONS IN DOME	WARM/COLD SPLIT	EXCEPTIONS
			Uraniborg Hven, 1581
			Flamsteeds House Greenwich, 1676 Obsrevatorium Tusculanum Vridsløsemagle, 1704
de Nice		Observatory of Strasbourg Strasbourg, 1882 Dr. Karl Remeis observatory Bamberg, 1889	Williamstown observatory Melbourne, 1857 Hurbanovo observatory Hurbanovo, 1871 Dearborn observatory Evanston, IL, 1889
önigstuhl State obs. 1900 rgedorf observatory 912 Mt Wilson observatory Mt Wilson, CA, 1917 o observatory o, CA, 1960 Krause Center for Innovation Los Altos Hills, CA, 1965	Palomar observatory San Diego, CA, 1948 C. Donald Shane telescope Mt Hamilton, CA, 1959 United Kingdom Infrared telescope Mauna Kea, HI, 1978 James Clerk Maxwell telescope Mauna Kea, HI, 1987	Oliver observing station Carmel Valley, CA, 1982 Subaru telescope Mauna Kea, HI, 1998	N.A. Richardson observatory San Bernardino, CA, 1930 Stardome observatory and planetarium Auckland, 1967 Ritchie observatory Bainbridge Island, WA, 1997
y observatory no, CA, 2011		Gemini North observatory Mauna Kea, HI, 2000	Dekalb observatory Auburn, IN, 2004

Appendix E

Compact Chronological Matrix

Year	TOWER		CENTRAL DOME						
1570	Tower of the winds Vatican, 1579								
1580									
1590									
1600									
1610									
1620									
1630	Leiden observatory Leiden, 1633								
1640	Smeetoren Utrecht, 1642	Rundetårn Copenhagen, 1642							
1650									
1660									
1670								Observatoire de Paris Paris, 1671	
1680									
1690									
1700									
1710									
1720	Clementinum observatory Prague, 1723	Specola Bologna, 1725							
1730	University of Wroclaw observatory Wroclaw, 1733	Kunstkamera observatory St. Petersburg, 1734							
1740									
1750	Observatory of Kremsmünster Kremsmünster, 1758								
1760									
1770	Mannheim observatory Mannheim, 1774	Radcliffe observatory Oxford, 1771							
1780	Zwehrenturm Kassel, 1785		Copenhagen observatory Copenhagen, 1780	Dunsink observatory Dublin, 1785					
1790	Old observatory house Edinburgh, 1793		Gotha observatory Seeberg, 1790						
1800									
1810			Plan for a large observatory 1810	Tartu observatory Tartu, 1810	Osservatorio astr. di Capodimonte Naples, 1812	Göttingen observatory Göttingen, 1816			
1820			Royal observatory, Cape of Good Hope Cape Town, 1820	City observatory Edinburgh, 1824				Parramatta observatory Sydney, 1822	Hamburg observatory Hamburg, 1825
1830			Helsinki University observatory Helsinki, 1834	New Berlin observatory Berlin, 1835	Loomis observatory Hudson, OH, 1838	Hopkins observatory Williamstown, MA, 1838	Pulkovo Astronomical observatory St. Petersburg, 1839	Observatoire de Toulouse Toulouse, 1838	
1840			Old Naval observatory Washington, DC, 1843	Bonn observatory Bonn, 1845	Georgetown University observatory Georgetown, DC, 1846	National observatory of Athens Athens, 1846			
1850								Meridian building Greenwich, 1850	Sonnenborgh observatory Utrecht, 1853
1860			Leiden observatory Leiden, 1860	Copenhagen University observatory Copenhagen, 1861	Vassar College observatory Poughkeepsie, NY, 1865			Leipzig observatory Leipzig, 1861	Eidgenössische Sternwarte Zürich, 1864
1870	Orwell Park observatory Ipswich, 1874		Astronomical observatory at Ogden Ogden, UT, 1873	Vienna University observatory Vienna, 1874	Astrophysical observatory Potsdam Potsdam, 1879				
1880			Urania Berlin, 1889					Lick observatory Mt Hamilton, CA, 1887	
1890			Ladd observatory Providence, RI, 1891	Old Perkins Astr. observatory Middletown, CT, 1896	University of Illinois observatory Champaign, IL, 1896	Thompson Building Greenwich, 1899		Royal observatory of Belgium Uccle, 1891	Theodor Jacobsen obs. Seattle, WA, 1895
1900	Physikalischer Verein observatory Frankfurt am Main, 1906		Whitin observatory Wellesley, MA, 1900	Dominion observatory Ottawa, 1902	Tacubaya observatory Mexico City, 1908			Fabra observatory Barcelona, 1904	
1910	Palace Urania Vienna, 1910		Babelsberg observatory Potsdam, 1915					Allegheny observatory Pittsburgh, PA, 1912	Van Vleck observatory Middletown, CT, 1914
1920	Einsteinturm Potsdam, 1921	Hale Solar laboratory Pasadena, CA, 1923	Osservatorio Astronomico di Roma Monte Porzio Catone, 1923	Ricard observatory Santa Clara, CA, 1928					
1930			Griffith observatory Los Angeles, CA, 1935						
1940									
1950			Holcomb observatory Indianapolis, IN, 1953						
1960									
1970	Nicholas U. Mayall telescope Kitt Peak, AZ, 1973								
1980									
1990								W.M. Keck observatory Mauna Kea, HI, 1996	Robert Ferguson observato Sonoma, CA, 1999
2000								Observatorio de Ballona Riverside, CA, 2004	Kielder observatory Kielder, 2008
2010	Stocker Astroscience Center Miami, FL, 2012							Craigengillan Dark Sky obs. Galloway Forest Park, 2012	Kansas State University Ob Manhattan, KS, 2012

DECENTRAL DOMES	COMPLETE SPLIT	FUNCTIONS IN DOME	WARM/COLD SPLIT	EXCEPTIONS
				Uraniborg Hven, 1581
				Flamsteeds House Greenwich, 1676 Obsrevatorium Tusculanum Vridsløsemagle, 1704
Sydney observatory Sydney, 1858 Allegheny observatory proposal Pittsburgh, PA, 1895 Royal observatory, Edinburgh Edinburgh, 1896 Yerkes observatory Williams Bay, WI, 1897	Observatoire de Nice Nice, 1886		Observatory of Strasbourg Strasbourg, 1882 Dr. Karl Remeis observatory Bamberg, 1889	Williamstown observatory Melbourne, 1857 Hurbanovo observatory Hurbanovo, 1871 Dearborn observatory Evanston, IL, 1889
ry	Heidelberg-Königstuhl State obs. Heidelberg, 1900 Hamburg-Bergedorf observatory Hamburg, 1912 Mt Wilson observatory Mt Wilson, CA, 1917 San Fernando observatory San Fernando, CA, 1960 Krause Center for Innovation Los Altos Hills, CA, 1965	Palomar observatory San Diego, CA, 1948 C. Donald Shane telescope Mt Hamilton, CA, 1959 United Kingdom Infrared telescope Mauna Kea, HI, 1978 James Clerk Maxwell telescope Mauna Kea, HI, 1987	Oliver observing station Carmel Valley, CA, 1982 Subaru telescope Mauna Kea, HI, 1998	N.A. Richardson observatory San Bernardino, CA, 1930 Stardome observatory and planetarium Auckland, 1967 Ritchie observatory Bainbridge Island, WA, 1997
servatory proposal	Murillo Family observatory San Bernardino, CA, 2011		Gemini North observatory Mauna Kea, HI, 2000	Dekalb observatory Auburn, IN, 2004