Construction Methods and Building Materials

Introduction

Today visitors often approach the massive pyramids, temples, and obelisks of the ancient Egyptians with wonder and disbelief. The huge blocks of stone used to create these architectural masterpieces were quarried and moved without the aid of modern technologies, and it is difficult for us to imagine how such feats of engineering could be accomplished without the aid of cranes, bulldozers, trucks, and other tools necessary in present-day building projects.

Over 1,500 years of construction at Karnak has witnessed how parts of the temple were built, while existing structures and architectural features were pulled-down, rebuilt, and even left incomplete. The study of these structures, as well as other monuments on the site, provide us with many interesting details on the methods of construction used by the Egyptians. Ancient inscriptions and relief scenes offer other evidence, with vivid description of how some of the more difficult tasks were completed.

Building design

Plans and models

Little is known about how individual buildings at a temple like Karnak would have been designed and planned. Only a very small number of building plans, written on a variety of surfaces such as papyri, stone flakes (ostraca), or wooden panels, have been preserved from ancient times. Among this group, even fewer have enough necessary building information to be considered a true working architectural plan. It is very possible that such aids were not commonly utilized. While models of houses, boats, and one temple have been discovered, the context of these finds makes clear that such objects were for funerary or ritual use, and did not function as construction models.[1]

Buildings may instead have been designed and executed using a grid. The Egyptian measuring system was based on a standardized measurement, the “cubit,” and each cubit would correspond to one grid block (the discovery of ancient examples of wooden cubit rods shows that in the New Kingdom, one cubit was equivalent to about 52.5cm [20.7in]). Architects could assign each wall or feature a length, height, and width in grid squares, aiding builders in creating uniform

1 Arnold 1991: 7-10

structures. Traces of architecture grid lines on building walls have been found at different sites in Egypt.[2] In fact, the use of grid lines for the laying out of painted and relief decoration in tombs and temples was common in certain historical periods, and the sophisticated use of this system suggests that Egyptian workers were highly skilled at using a grid for design and to control proportion.[3]

The laying out of large spaces (such as temple courts and large buildings) may have been aided by the use of surveying cords. Tomb scenes depict the use of these knotted cords for measuring distance within agricultural fields. Used like modern measuring tapes, the knots marked individual measurement units (such as cubits).[4] Temple relief scenes depict a ceremony called "stretching the cord" where the king, assisted by the god Thoth or Seshat, defined the area of a new temple or temple building using cords and stakes.[5] Although this was a ritual event, it may have paralleled the actual practice of measuring out space for the temple's ground plan. Once the location of an important building was established, a foundation deposit (a cache of small items often inscribed for the king sponsoring the construction project) was frequently buried at the site of the future building's corners.[6]

A scene from the Hypostyle Hall showing the "stretching of the cord" ceremony for Karnak.

Proportions

Karnak has been the focus of a recent *metrological* study (the study of units of measurement) that attempted to understand the system of proportions used by ancient Egyptian architects and builders.[7] Investigation of a number of large courts and building spaces, such as the first court of Shoshenq I, the Middle Kingdom court, the hypostyle hall, and the *Akhmenu* festival hall suggested that these areas were generally designed using a square or double-square plan. The proportions of individual buildings and structures, however, showed much variation. Karnak's giant pylons were designed with proportions of 1:4, 1:5, and 1:6, and the temple's small bark shrines included proportions of 1:3, 1:5, and a number of examples close to square (1:1) or double-square (1:2). The temple's many columns, whose proportions were calculated by dividing their height by their diameter, repeatedly appeared in relationships of 1:7, 1:5, 1:4, and 1:3. Two additional approaches used to establish proportion (1. dividing the diameter by the distance between the central axes of neighboring columns, and 2. dividing the distance between the central axes by the column height) showed even more variation.

The *Akhmenu* festival hall.

The results of the study demonstrate that the Egyptian builders did not rigidly adhere to one system of proportion in the design of the architectural features of the temple. Instead, individual features were varied to suit the surrounding space and the desired visual impression.

2 Arnold 1991: 7-10, 251
3 Robins 1997: 107-109, 141-142
4 Arnold 1991: 252-253; Clarke and Engelbach 1990: 64-65
5 Golvin and Goyon 1987: 37-38
6 Golvin and Goyon 1987: 38
7 Carlotti 1995

Architects

The names of individual architects (and frequently even the construction projects they managed) were recorded at different times and places in ancient Egypt. Perhaps the most famous, the architect behind the Third Dynasty step pyramid at Saqqara, Imhotep, was later deified for his wisdom and talent. A number of the individuals who served as architects or directors of construction works at Karnak are known from inscriptions at Thebes or in the quarries where stone for their projects was extracted. Senenmut and Amenhotep, who both served as "stewards" under queen Hatshepsut, recorded their work quarrying obelisks for what almost certainly were the queen's monuments in east Karnak and within the *Wadjet* hall.[8] The former, who took on the title of "great steward," celebrated his role in overseeing construction at both the Amun and Mut temples at Karnak on an inscribed statue of himself found at the Mut temple.[9] Bakenkhonsu, a "director of works" under king Ramesses II, boasted in inscriptions within his tomb that he erected that king's small temple and pair of obelisks in east Karnak. He claimed: "I made for [the king] the Temple of Ramesses-Meramun "Who Hears Petitions" at the upper gate of the Domain of Amun. I set up granite obelisks therein, the tops of which reach the sky."[10] We know the men responsible for the success of construction projects were generously rewarded by the king: a stela commemorating the work on king Shoshenq's court at Karnak explains that the architect Horemsaf was presented with gold and silver.[11] The royal favorite Senenmut, mentioned above, garnered enough wealth or privilege to obtain a huge funerary complex in western Thebes, as well as sponsor (and receive as royal gifts) twenty-five stone statues of masterly quality.[12]

It is not clear whether these men were involved in the actual design of new buildings as well as their planning and construction. Titles of men like Senenmut, whose early career included such roles as "overseer of seals" at the royal court and "great steward of the god's wife [of Amun]," suggest training in administration, not principals of design and techniques of construction.[13] We will almost surely never know who first imagined turning the court between Karnak's 2nd and 3rd pylons into a forest of columns unlike anything seen before or after, or whose creativity was behind the unique tent-pole columns seen in the *Akhmenu* festival hall.

The "forest of columns" in the hypostyle hall.

Quarrying and building with stone

Materials

Sandstone, limestone, and red granite were the primary types of stone used for buildings and large decorative features at Karnak temple. Other stones, like red quartzite, black granite, and travertine (calcite or "Egyptian alabaster"[14]) were utilized in much smaller quantities. High quality limestone was shipped to The-

8 Dorman 2005: 107 and fig. 37; Habachi and Van Siclen 1977: 60-68
9 Dorman 2005: 108, 109 (note 13), 124-125
10 Habachi and Van Siclen 1977: 95-98
11 Golvin and Goyon 1987: 96
12 Dorman 2005: 107-108
13 Dorman 2005: 107
14 For a description of different types of commonly used stones, their source and their petrological descriptions, see: Shaw, Aston and Harrell 2000: 20-63

bes from the quarries in the north of the county, Tura and Massara, near modern Cairo. Gebel el-Silsila, located 160 km [99 miles] south of Thebes, was the main source for the temple's sandstone. The obelisks, lintels, door thresholds and colossal statues of red granite decorating Karnak were supplied from the far south of Egypt, in the area around modern Aswan. Material for the calcite/travertine bark shrines and chapels (such as the one-room chapels of Amenhotep I or Amenhotep II) originated in Hatnub, in Middle Egypt. Quartzite, used in the "red chapel" of Hatshepsut, came from Gebel Ahmar, also in Middle Egypt. Many of these quarry sites show distinct signs of their ancient use, with still visible quarrying lines and the remains of abandoned quarrying projects.[15]

The use of a quarry spanned many years, and usually the reign of more than one king. Inscriptions found at the sites supply chronological information about the periods when each quarry was active. At the moment of a quarry's "opening," or first use, an official event would often be held, commemorated by an inscribed and dated rock-cut stele.[16] These stelae might even mention the use for which the new quarry was opened, and building events at Karnak figure into a few of these inscriptions. At Gebel el-Silsila inscriptions dated to the early years of Sety I's reign mention that some of the site's sandstone blocks were intended for Thebes, and it is likely that the hypostyle hall was one of the main destinations.[17] A stele dated to the reign of king Shoshenq I describes the king's orders for stone from Gebel el-Silsila to be sent to Karnak, for what almost surely was the construction of the colonnaded first court and entrance gateway.[18]

The calcite ("Egyptian alabaster") used in the Amenhotep II Shrine came from Hatnub.

Quarrying and dressing blocks

Techniques for quarrying softer types of stones (limestone and sandstone) differed from those for harder types of stone (granite, quartzite, and diorite).[19] In either case, quarrying was both a time and labor-intensive process.

Softer stones were usually extracted from an open quarry located along the top or face of natural cliffs. Workers removed the top layers of poor stone and rubble and then marked off a series of spaces that would form trenches between the intended blocks. The trenches would next be dug out, freeing the blocks from the surrounding material. Tools used for this stage of the process probably included pointed picks of stone or hard bronze. The removal of the blocks at their base may have been accomplished using wooden levers.[20]

Harder stones were even more difficult to quarry. The techniques involved in extracting granite are well known from the remains of the quarries at Aswan. Here, and at other centers, ancient workmen used a process involving pounding hard dolerite balls on the granite stone bed. This apparently was accomplished by hand. Hundreds of these balls, 12.7-30.5cm in diameter [5-12 inches] and weighing about 5.5 kilograms [12 pounds] each, have been found at the site.[21]

15 Golvin and Goyon 1987: 96-98
16 Arnold 1991: 31
17 Brand 2000: 359
18 Golvin and Goyon 1987: 96
19 Arnold 1991: 27
20 Arnold 1991: 30-33; Shaw et al. 2000: 6
21 Arnold 1991: 37; Clarke and Engelbach 1990: 27

Quarry workers cleared the top layers of poor stone until a faultless area was exposed of the desired size. Trenches were then pounded out in sections around the future block, checking to determine that the stone was not flawed. If the material appeared good, separating trenches around the entire block were created. At Aswan, the length of trenches around an unfinished obelisk measured a total of 91 meters [300 feet], with each trench having a depth of more than 75cm [about 2.5 feet]. Approximately fifty workers could have simultaneously operated in the trenches. Within these trenches, individual workmen would squat or kneel, pounding out a section of stone about 60cm long [about 2 feet], shifting position as each section of his square was lowered. The resulting wavy pattern of pounded sections can clearly be seen around the abandoned obelisk.[22]

Once the entire system of trenches had been brought down to the needed depth, the block then had to be detached along its base. For smaller blocks, this may have been done using wooden wedges, hammered or wetted to crack the stone free (although some Egyptologists have more recently cast doubt on the effectiveness of this technique[23]). For stone monoliths like obelisks, this technique could have unevenly strained the stone and caused it to snap along its length. Instead, trenches would be extended below the level of the block's base and the stone would be undercut with continued pounding. Very large blocks, such as those used in obelisks, were too heavy to be lifted from the surrounding stone. A section of the stone bed would therefore also need to be brought down around the block, to facilitate sliding or levering the monolith from its spot.[24]

Other hard stones, like quartzite, may have been removed instead with stone picks. The difficulty involved with such an undertaking explains the limited amount of this stone used in building construction.[25]

Special skill was needed to dress hard stones, so the task was sometimes accomplished at the area of extraction. This also necessitated stone pounding tools, as the metal tools used during most of the Pharaonic period were not sufficiently hard to work hard stones like granite. Using a mixture of hard grinding stones and sand, the blocks were then polished. In some hard stone quarries, stone features have been found abandoned with polishing and inscriptions already complete. Soft stones however, were more frequently sent to the work site undressed, with the sides often dressed only after the block was laid into a wall or building. This labor saving technique allowed workers to smooth only those sides that would be visible in the finished monument. That different practices were often used in dressing the two types of stone can be extrapolated from Karnak, where both hard and soft stone monuments were left unfinished.[26] In some cases, especially when blocks were to be utilized for special features like statuary or large monoliths, hard stones too were left rough after extraction and only dressed on site.

Red quartzite was used to construct the "red chapel" of Hatshepsut. Black granite was used for the doorways and the base.

22 Arnold 1991: 39; Clarke and Engelbach 1990: 27-28; Shaw et al. 2000: 6-7
23 see: Shaw et al. 2000: 7 for a brief discussion and relevant citations
24 Arnold 1991: 37-38; Clarke and Engelbach 1990: 27-28
25 Arnold 1991: 40
26 Arnold 1991: 48-52

Stone masonry required experience and skill. Those who quarried quartzite or who oversaw the removal of stone for obelisks and statues must have been true experts. Most of the work in the stone quarries, however, was difficult and unpleasant. For the tasks that did not need special expertise, the ranks or workmen appear to have been composed of prisoners of war and criminals condemned to hard labor.[27]

Foundations

Although the dry alluvium soil of Egypt seems to offer optimum conditions for building, the yearly inundation of the Nile, only in very recent times regulated by the Aswan High Dam, regularly flooded the river valley and destabilized the soil.[28] Karnak temple was built in the river valley, and it appears that the temple's expansion westward over time reflected the movement of the ancient river, situated much closer to the temple than it is today. Egyptian builders at Karnak and other sites adopted techniques to assure that foundations addressed the treacherousness of the subsoil in areas of inundation.

Generally, the foundations at Karnak consisted of a trench dug down from ground level and partly filled with clean, dry sand. Courses of blocks were then laid down and leveled, providing a uniform surface for a building's superstructure.[29] The use of layers of sand in building foundations added a great deal of resiliency to a building's support system, as sand very effectively distributes weight and absorbs vibrations or shock. The foundations for the great hypostyle hall consisted of one-half meter of sand contained within an outer stone lining, topped by a layer of stone. Despite the use of small, friable blocks in the foundation courses above this sand layer, the columns stood for over 3000 years.[30] When the columns began to lean and eventually fell in 1899, some scholars blamed the use of small sandstone 'talatat' blocks (found crushed by the weight of the huge columns) for the upper foundation layer. They suspected that these blocks had been weakened from years of exposure to ground water salts.[31] More recently, one Egyptologist has suggested that it was instead the intervention of archaeologists who dug trenches in the area to drain water from the flooded hall that disturbed the sand layers beneath, destabilized the foundation, and caused the columns to topple.[32]

Nevertheless, it seems that later ancient architects strove to improve the stability of foundations, and for buildings of the Ptolemaic and Roman eras (such as Karnak's first pylon), more substantial blocks were used to support the superstructures.[33]

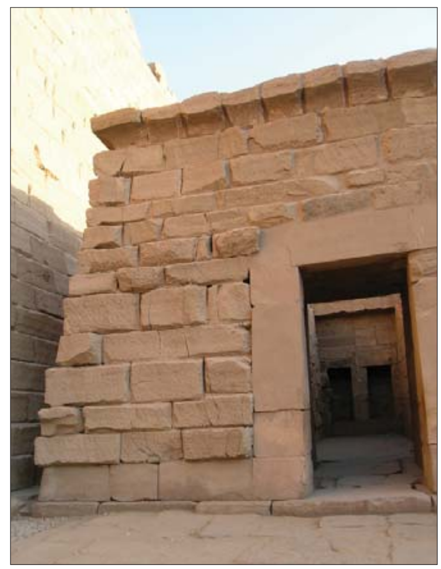
Building techniques

Building materials were shipped to the construction site via boat. Ostraca (pot sherds or limestone flakes with writing) from the reign of Ramesses II provide an

27 Arnold 1991: 39-40
28 Clarke and Engelbach 1990: 69
29 Arnold 1991: 13; Clarke and Engelbach 1990: 73
30 Josephson 2005
31 Golvin and Goyon 1987: 95
32 Josephson 2005: 404
33 Clarke and Engelbach 1990: 73, 76; Golvin and Goyon 1987: 95

example of what may have been a typical delivery schedule. These documents recorded the shipment of quarried blocks to the king's mortuary temple on the west bank of Thebes. Each transport barge brought five to seven large stones (about 15-20 tons, or over 2000 pounds total) from the quarry at Gebel el-Silsila to the temple. Ten ships delivered blocks in one day, totaling sixty-four large blocks.[34]

Once the quarried stone arrived at the construction site, it would be given an initial dressing on any side that would later come into contact with other stones (usually the base and one of the short sides). In most periods, the stones of one course would be then placed together in a row and each individually cut along their sides, sometimes with irregular or oblique angles, and fitted together. Scholars think these irregular joints were made to conserve the amount of stone used, although it must have cost stonecutters a good deal of time to cut and match so many distinct blocks. The stones were next moved to the wall that was under construction and placed by the stonemasons. The cutters then returned, reaching the top of the wall via mud brick ramps to dress the upper face of the blocks. As the wall grew vertically, workers increased the height of the access ramps around it.[35] The interior sides of the blocks would therefore have been left undressed, while the outer faces (which formed the visible section of the wall) were dressed and then smoothed once the entire wall was complete.[36] To create a uniform wall surface, this last dressing was done using chisels and pounders, with a final smoothing by grinding stones.[37]



Undressed blocks still visible on the Sety II Shrine.

Undressed wall surfaces are still visible at Karnak. In the temple's first court, a number of features show varying stages of completion. The bark shrine of Sety II, for example, was partially dismantled and later repaired during the construction of a new temple entrance to its west. The shrine's smooth walls and finished inscriptions can be seen on its eastern half, while the undressed blocks of the repair on its west side were left without a final dressing. The first pylon itself, never completed, also clearly documents the process of stone dressing. On the external (west) side of its southern tower, one can see both dressed and fully smoothed blocks, as well as undressed stones. Only preliminary work was done on the torus molding along its southern edge, and it is readily apparent how the stone blocks would have been carved back to create the angled rim of the molding.

In general, the Egyptians tried to conserve the amount of high quality stone needed for a project by using these blocks strictly as the outer casing of larger walls and pylons. The core of the wall itself was often composed of local, poorer quality materials, or reused blocks of destroyed structures.[38] The reuse of older buildings as building fill was extremely common at Karnak, and many of the shrines and chapels now reconstructed on site were discovered in modern times within other structures.

34 Arnold 1991: 65-66; Clarke and Engelbach 1990
35 Golvin and Goyon 1987: 109-110
36 Arnold 2003: 232-233
37 Arnold 1991: 44
38 Arnold 2003: 60

Builders occasionally used cramps and dowels when they perceived a join of two blocks to be particularly strained. The first examples of these date to the 4th Dynasty (in the Old Kingdom), and they appear increasingly in the constructions of the following Middle and New Kingdoms. The most common of these aids in the was the "dovetail" cramp, an hour-glassed shaped piece of wood set into carved notches along the faces of connecting stones. At Karnak, these have been found in the architraves and column drums of the hypostyle hall, as well as within the colonnade of the first court.[39]

Change in techniques and materials over time

Construction at Karnak temple spanned the reigns of many kings and included numerous changes in building techniques and materials. In the Middle Kingdom and early 18th Dynasty, limestone was the material of choice. Due to the alluvium's annual cycles of flooding and drying however, limestone rapidly deteriorated. By the reign of Thutmose III, sandstone replaced limestone as the primary building material at the temple.[40] A number of that king's renovations, such as the replacement of the limestone shrines of Amenhotep I, were carried out to refurbish the crumbling temple areas with more humidity-resistant sandstone. From this point on, fine limestone was used principally in statuary.[41]

Courses of blocks in a standardized height.

During most of the Pharaonic period Egyptian builders used large rectangular stones of slightly differing shapes and sizes, set together with irregular joints. These were set in courses of varying height. The 18th and 19th Dynasty walls and pylons at Karnak provide good examples of this typical form of construction. Ashlar masonry, a technique in which blocks are cut to a uniform size and walls assembled in courses of parallel heights, was used occasionally. The red chapel of Hatshepsut was designed this way.[42] Ashlar masonry was adopted on a large-scale only with the construction program of Amenhotep IV/Akhenaten. In order to quickly erect a series of cult buildings in east Karnak, the king's engineers opted to utilize easily handled and rapidly assembled blocks known to Egyptologists as "talatat." Thousands of these light sandstone blocks, measuring about 50cm x 25cm x 25cm [about 20" x 10" x10"], formed the king's huge cult complex before he abandoned Thebes for Tell el-Amarna.[43]

The use of regularized blocks was immediately discontinued in the New Kingdom, but the technique was taken up again at Karnak during the 25th Dynasty, albeit with larger sized blocks. Instead of including courses of varying height, walls were now composed of standardized courses. These uniformly sized blocks could be much more easily interlaced, and wall cohesion was thus improved. The buildings of Taharqo (Dynasty 25) and various kings through the 30th Dynasty show this new style of architecture.[44]

39 Arnold 1991: 124-125, 2003: 60; Clarke and Engelbach 1990
40 Golvin and Goyon 1987: 116
41 Golvin and Goyon 1987: 116
42 Arnold 1991: 151-153
43 Redford 1984: 66-67
44 Golvin and Goyon 1987: 111-112

Ptolemaic and Roman builders introduced a different building technique. Layers of liquid plaster were added to courses of stone to assist with the placement of the following layer. Channels carved into some of the blocks allowed the excess plaster to ooze out, securing all the contacting blocks tightly.[45]

While the use of large, irregular blocks with oblique joints never completely disappeared, the advantages in efficiency and stability of these new types of masonry were clearly recognized and promoted.[46] The instability of New Kingdom walls and pylons, often built of two separate courses of stone and filled with a separate core, must have been apparent at these later periods. Indeed, the ninth pylon, filled with thousands of talatat blocks, collapsed at some point due to its precarious internal bonding and uneven stone courses.[47]

Tool technology also changed dramatically during the years of activity at Karnak. Quarry workers and stonemasons utilized copper and various forms of bronze through the New Kingdom. The use of iron tools, which had been introduced at the end of the 18th Dynasty, increased enormously in the 26th Dynasty. The hard stones from this moment onward show signs of working with tools of this new material.[48]

Column construction

Egyptian columns were formed of three or four basic elements: a base, a shaft, a capital (present or not present, depending on the column type), and an abacus. The column base, which provided a stable and flat support for the rest of the column, could be a round or square block separate from the floor, or alternatively, a raised section of the paving slabs of the floor itself.[49] Egyptians architects apparently considered bases as primarily a structural element of the column, as they did not usually receive the decorative treatment seen on column shafts, capitals, and abaci.

Column shafts and capitals were typically formed out of stacked stone drums or half drums. These could be centered atop each course by the use of plumb lines, either aligning the drums using markings at their centers or via vertical grooves along their sides. The western most columns in the Karnak's first court, disassembled and later reconstructed for the placement of mud brick ramps along the first pylon, retain such vertical, exterior grooves for placement.[50]

Decorative elements on shafts and capitals could be cut directly from the stacked blocks once in place. That the two elements were not usually designed and cut from separate blocks before construction is demonstrated on those columns where the springing of the capital does not align with the joint of two blocks.[51]

Columns in the Shoshenq I Court. The columns closest to the first pylon were later repaired and never fully finished. One can still see the stacking of stones used to create the columns.

45 Golvin and Goyon 1987: 111-112
46 Arnold 1999: 96
47 Golvin and Goyon 1987: 111
48 Arnold 1991: 257
49 Clarke and Engelbach 1990: 130-131
50 Arnold 1991: 19
51 Clarke and Engelbach 1990: 141

Once a column was carved and topped with an abacus (the element which made direct contact with the ceiling architraves) it could then be dressed and smoothed.[52] The remains of colorful paint on columns at Karnak, such as the tent-pole shaped columns in the *Akhmenu* festival hall, show that the final decoration of some columns included extensive painting.

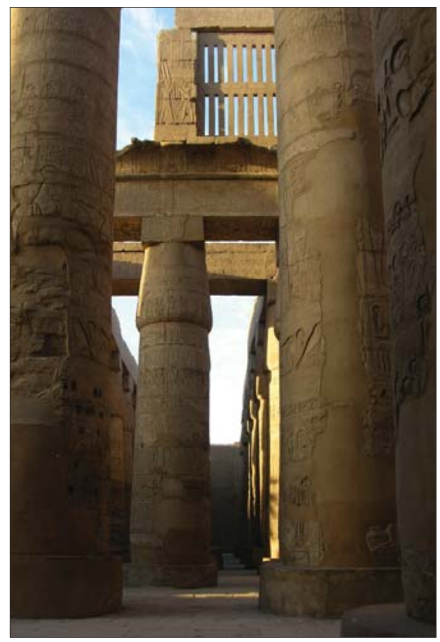
Columns were constructed to support various types of loads, and their design and construction reflected this function. The columns in the hypostyle hall, meant to carry heavy sandstone architraves and ceiling blocks, were composed of massive stone drums. However, the giant columns of the Taharqo kiosk, similar in height to those of the hypostyle, were not intended to support a roof. Their shafts, capitals and abaci were built from many small stones, and they would have collapsed under any truly substantial weight.[53] Although not preserved today at the temple, textual sources tell us that wooden columns were also utilized at Karnak. These would have supported much lighter coverings, such as the wooden roof of the *Wadjet* hall in the reign of Hatshepsut.[54]

Roofing and lighting

Roofing

Egyptian buildings were roofed by a limited number of methods. Most common at Karnak was the flat roof, supported by walls and columns. The distance between these supportive elements limited the size and material of a structure's roof. Constructions at Karnak benefited from the fact that by the New Kingdom, engineers had learned to confidently span large spaces with sandstone slabs. The ceiling blocks of the magnificent hypostyle hall, for example, measured 9 meters [25.5 feet] in length, 1.25 meters [4 feet] thick, and bridged up to 6.7 meter [21.9 foot) wide aisles between columns. Even larger were the lintels of the gates of the first and second pylons, possibly formed of granite blocks, which spanned 6.9 meter [22.6 foot] and 7.25 meter [23.7 foot] doorways. These appear to be the longest possible distances deemed safe for the use of stone roofing by the Egyptians, and larger spaces were covered with wooden ceilings.[55]

The difficulty in quarrying and transporting blocks large enough to serve as architraves for wide spaces was prohibitive. The Egyptians solved this problem by stacking two or more thinner blocks together. In the hypostyle hall, architraves are composed of up to four separate blocks, arranged in upper and lower courses of two (although some architraves were single blocks of stone). While easier to transport and set up in the hall, the composite blocks would not bear the same load as a single block of the same size.[56]



A view of the architraves and clerestory window in the hypostyle hall. The ceiling slabs would have run perpendicular to the architraves.

52 Arnold 2003: 55-56
53 Clarke and Engelbach 1990: 141-142
54 Carlotti and Gabolde 2003: 289-291
55 Arnold 1991: 184
56 Arnold 1991: 184

Lighting

Natural light filled the open-air courts at Karnak. Within the temple's covered buildings, however, other means of illumination were necessary. One of the architectural solutions was the use of clerestory windows. In the temple's hypostyle hall, the raised central nave was lined with grilled windows. The high openings (24 meters/80 feet above the hall's floor) allowed sunlight to enter the hall, while maintaining the privacy and secrecy of the space.[57] The grills were composed of two sections, one stacked atop the other, and secured in place by being fitted tightly into grooves in the side of the bordering piers.[58] The *Akhmenu* festival hall included similarly conceived clerestory lights above the building's central columned hall.[59]

Less prominent, but very common lighting and ventilation solutions included cutting angled slits or square holes into a temple's roof slabs, allowing daylight to enter through these small gaps. Both the Opet temple and the hypostyle hall utilized this lighting method.[60]

Flooring

Stone floor slabs paved the interior of many of Karnak's stone structures. Often these were formed by the upper course of a building's stone foundations (frequently composed of the same stone as the walls of the building).[61] Unlike at royal palaces, where plastered and brightly painted floors with geometric and natural world motifs have been discovered, temple floors appear to have been usually left unadorned.

In a few structures at Karnak, however, colored stone pavements were utilized to add extra emphasis to the building. The huge kiosk in the temple's first court and the columned entrance porch before the eastern temple of Ramesses II, both constructed by Taharqo (Dynasty 25), were lined with these special pavements. The interior of the kiosk was paved with small red granite blocks,[62] while the entrance porch utilized black and red granite stones in its central nave and limestone along its side aisles.[63]

Hatshepsut's "red chapel" also had an elaborately decorated floor. The grayish-black granite paving was inscribed with a repeating pattern of four hieroglyphic signs, symbolizing the queen's wish for "all life, stability and dominion."

Reuse of building materials

The reuse and repurposing of older monuments as building material occurred frequently in Egyptian building projects, and Karnak temple offers many interesting examples of this practice. As touched on previously, pylons were a main

Small red granite blocks used as pavers inside the Taharqo kiosk.

The white chapel, which was dismantled by Amenhotep III and used as fill in Pylon III, has been reassembled in the Open Air Musuem.

57 Brand 2004
58 Personal communication, Peter Brand
59 Carlotti 2001
60 Clarke and Engelbach 1990: 170-171; Personal communication, Peter Brand
61 Arnold 1991: 141-147
62 Golvin and Goyon 1987: 103
63 Barguet 1962: 225-226

location for such reuse. The third pylon, erected under Amenhotep III, was found to contain part of a pillared peristyle court and calcite chapel of Thutmose IV, Amenhotep I's calcite chapel, the limestone white chapel of Senusret I, and the blocks of Hatshepsut's red chapel.[64] It appears that these structures, most of which were originally located within the festival court of Thutmose II, were dismantled by Amenhotep III during his restructuring of the area for his new pylon. The destruction of these many monuments must have been deemed necessary for the renewal of the area, and no one former king's works were isolated.

The second, ninth, and tenth pylons, built by the pharaoh Horemheb, were also discovered to contain reused building materials from Karnak as internal fill. In this case, however, the reused blocks did not originate in the area of the new constructions, but far away in east Karnak. The east Karnak temples of Amenhotep IV/Akhenaten, made of sandstone "talatat" blocks of uniform size, were systematically dismantled and destroyed by Horemheb as part of a larger assault against Akhenaten's religious innovations.[65] The reuse of this material, although similar in execution to that of Amenhotep III, can be understood as intended to eradicate the architectural legacy of an individual king.

Building components were reused or repurposed in more visible ways at Karnak as well. Ramesses II, for example, adapted a series of fluted column drums (probably of Thutmose III) at the temple of "Amun-Ra who-hears-prayers" in east Karnak. The fluting was filled in with plaster and rounded off, disguising the earlier polygonal shape.[66] In another case, large wall slabs from the calcite shrine of Amenhotep II were removed and reused as stelae by Ramesses II. The wall slabs were turned over, their blank sides inscribed, and then placed at the temple of Mut, slightly to the south of the Amun precinct.[67]

At her mortuary temple in Deir el Bahri, Hatshepsut records the raising of her 2 obelisks in east Karnak.

Obelisks

Transport

The erection of an obelisk at the temple not only demonstrated the piousness of the king, it also displayed his power and wealth to the populous. But this was no simple task. As discussed above, the quarrying of a flawless monolithic block of stone was fraught with difficulties. Once this was accomplished, new technical challenges had to be overcome to bring the obelisk to the temple.

After extraction from the granite or quartzite quarries, the monolith had to be moved to a large river barge for shipment. Wooden sledges, depicted in Egyptian relief scenes, were vital in the dragging of the stone needles to the water. The weight these sledges bore was clearly considerable: the small obelisks of Thutmose I at Karnak are estimated to each weigh 143 tons, while two of the extant obelisks of Hatshepsut and Thutmose III weigh it at about 323 and 455 tons

64 Lauffray 1979: 49
65 Redford 1984
66 Clarke and Engelbach 1990: 149
67 Larché 2007: 478

respectively[68] (for comparison, a large minivan or SUV can weigh 2 to 2.5 tons). Draft animals and hundreds of workmen were employed for such a strenuous task.

After preparing the surface of the pathway with mud or lime to reduce friction, the sledge was dragged, with the obelisk securely tied to its crossbeams, to a waiting barge. In order to minimize the amount of overland movement necessary, canals were no doubt dug connecting the Nile to locations nearer the quarries.[69]

Hatshepsut's temple of Deir el Bahri depicts the shipment of two obelisks to Karnak from Aswan (likely her first pair of obelisks raised in the temple, located in east Karnak). Based on the estimated size of the obelisks and sledges shown in the relief, the sledges themselves must have measured more than 30 meters in length.[70]

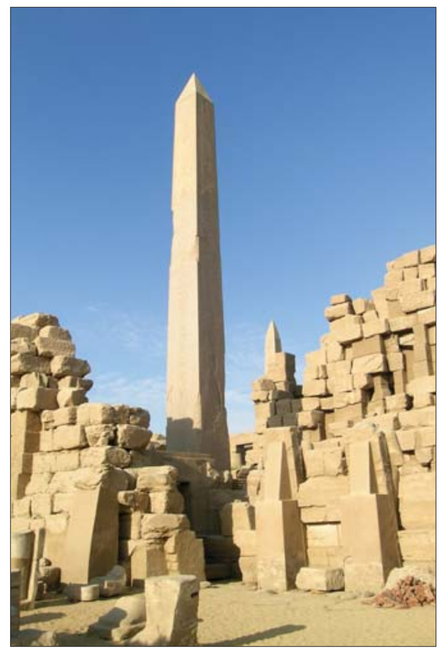
Dragged onto the boats, the sledges and obelisks then floated downstream to Karnak. The reliefs at Hatshepsut's temple suggest the barges were controlled by a vast number of rowboats connected to the ship by ropes, but the exact logistics remain unknown.[71]

Erecting the Obelisk

After arrival at the temple, the obelisk was dragged to its desired location. The exact method of raising an obelisk has not been firmly reconstructed because a number of plausible theories fit the information available. Grooves have been found on the surfaces of obelisk pedestals at Karnak and Luxor temples, and the most prominent theories use these physical traces to envision the technique for raising the monument.[72]

One theory suggests that the obelisk was dragged up a high ramp constructed next to and over the desired location of the obelisk. A large funnel-shaped hole was left in the ramp directly above the pedestal/socle, and the obelisk's base was lowered into position as sand was removed from this funnel. The obelisk's edge was carefully maneuvered to align with a groove carved into the socle as it was eased downward. Ropes could have been used to then pull the monument vertical, while the socle's groove stabilized the stone as it was slowly raised.[73]

A second technique positions the monolith's shaft on a short ramp, the edge of its base along the socle's groove. Wooden beams placed between the pedestal and the base of the obelisk (kept in place by grooves running perpendicular to the one for the obelisk) could have been used to help keep the edge of the monument in place until it had been raised far enough to catch in its groove. Workers would have pulled the monument slowly towards a standing position, levering



Hatshepsut's obelisk in the *Wadjet* hall.

68 Arnold 1991: 62-64
69 Arnold 1991: 243, 276-280
70 Arnold 1991: 280
71 Engelbach 1923: 64-65; Naville 1894
72 Arnold 1991: 66-71
73 Arnold 1991: 66-71

the length of its shaft with wood scaffolding with each raise upward to prevent its fracture from stress. Indeed, representations of the erection of small obelisks on temple reliefs depict the king pulling them up with long ropes.[74] However, these representations are within a ritual context, and they may be merely symbolic. Many scholars doubt that the use of ropes and levers would have provided enough support for the length of a long and thin obelisk.

It is possible that a variety of means to erect obelisks were employed, with the method chosen depending on the space available in the area, the size of the obelisk, and the area where the monolith was to be placed.[75]

Pylons, gateways and doors

Karnak is one of the main sources of information for understanding the construction of monumental stone pylons typical of the more elaborate Egyptian temples. Around the temple's unfinished first pylon, vestiges of large mud brick ramps are still visible today, despite partial removal of the brickwork in the nineteenth century. These ramps stood against both the internal and external faces of each tower, providing access to the upper courses of stone as the next layer would be put in place. As the walls grew in height, workers raised the neighboring ramps, about one meter at a time.[76]

The mud brick ramp used in the construction of pylon I can still be seen today.

To prevent the crushing weight of the pylon from damaging the first pylon's central door, the stone gateway was left unbonded to the towers themselves. While the heavy towers sank into the soil over time, the gate's lintels and doorjambs were not affected. Such methods were not used in every case, however, and the eighth pylon and its gateway were bonded.[77]

The pylon gateways, providing open sight lines through the temple today, in ancient times would have been equipped with large wooden doors. These doors, made of woods imported from countries to the north east of Egypt, were usually hinged to open inwards against the gate's interior thickness. While adding to the splendor of the temple with decoration in bronze, silver, gold, or electrum, they also functioned to restrict access to the sacred space both physically and visually.[78]

The façades of a number of pylons at Karnak were ornamented with huge wooden flagstaffs (reaching 30m [98 feet] in height) capped with colorful cloth flags. Like obelisks, temple flagstaffs were often tipped with precious metals that reflected the rays of the sun. The flagpoles were carved from individual beams shipped to Egypt from the forests of the modern-day Lebanon or northern Syria. The staffs were erected on a stone base, like the thick granite blocks that supported the heavy weight of these poles before the second pylon. Recesses in the

74 Arnold 1991: 66-71
75 Arnold 1991: 66-71
76 Arnold 1991: 95-96
77 Clarke and Engelbach 1990: 164-165
78 Arnold 2003: 183; Clarke and Engelbach 1990: 164; Golvin and Goyon 1987: 60

façade of a pylon allowed the poles to stand flush with the base of the structure, and large holes in the upper portion of the pylons show that the masts were stabilized along their lengths with giant wooden clamps.[79]

Enclosure walls

The temple precinct was always delineated from the outside world by some type of surrounding wall. At Karnak, a huge mud brick enclosure dated to the 30th Dynasty encircles the temple. The wall's irregular trapezoidal shape must have been designed to respect the location of important pre-existing buildings around the Amun temple.[80] Practically, the walls protected the temple's stored wealth and resources. Symbolically, it kept out the forces of chaos from the house of the gods.[81]


The mud brick enclosure wall built by Nectanebo I still surrounds the Amun precinct.

The wall's wavy appearance resulted from the methods of construction. To avoid sagging and increase wall stability, large walls were sometimes built in short individual sections, with the brick courses of alternating sections laid on slightly concave or convex beds.[82] Reeds and grasses were inserted between courses to enhance structural cohesion, level the courses, and give bricks extra cohesive friction. Wooden beams were placed across the wall's thickness every twelve to fifteen courses, offering additional rigidity. The beams helped prevent the cracking of the wall due to uneven load distribution (a problem because the bricks in interior parts of large walls were often laid haphazardly). The construction techniques created an undulating effect that the Egyptians might have equated with the primeval waters from which the world first emerged, appropriate imagery for a temple.[83]

Repairs

As the temple aged, it was incumbent upon the reigning kings to repair or renew the decomposing monuments. In some cases, this meant replacing whole structures with new ones, such as Thutmose III's substitution of sandstone chapels for the decaying limestone structures of Amenhotep I, mentioned previously. It could also involve the repair of broken blocks or the shoring up of a monument's foundations, in hopes of prolonging its total life. The hypostyle hall is one such case. The failure in antiquity of column abaci caused a number of roof slabs to fall and damage the columns on the west end of the nave. Repairs made to the hall during the Late or Ptolemaic Period included the replacement of the crushed and broken abaci and architraves, as well as the use of small sandstone blocks to replace the damaged sections of the large column drums. Similarly, the vestibule to the third pylon and columns on the east side of the nave were endangered when a fire scorched the area. Where the heat had caused the stone drums to crack and break, small stones were inserted into the side of the columns to restore the columns' structural integrity. Strangely, although the column repairs

79 Arnold 2003: 90
80 Golvin 1995: 33-35
81 Golvin and Goyon 1987: 80
82 Arnold 1999: 99; Kemp 2000: 88-92
83 Golvin and Goyon 1987: 80-81; Kemp 2000: 88-92

in both cases were similarly achieved, in the latter case, the replacement stones were left rough and undressed, while in the former example, the stones were dressed flush with the original column surface.[84]

The passageway and gate of the second pylon were also carefully repaired at this time. The western section of the original doorway was lined with new stones and completely redecorated after suffering damage when its giant wooden doors were burned in a fire. Scenes on the eastern part of the passageway (partially mutilated during the roof collapse mentioned above) were repaired and recarved. The Ptolemaic king who re-inscribed this part of the gate copied (and imitated) some of the original 19th Dynasty reliefs.[85]

By the time Egypt was under the rule of the Roman emperors, the foundations and lower sections of the walls of the hypostyle hall, probably weakened by years of exposure to salinated ground water during the annual Nile flood, also needed repairs. In places, the lowest course of blocks was removed and replaced, somehow without destabilizing the entire hall. The new wall sections were frequently left blank, but in some cases, artists tried to re-inscribe the blocks to match the surrounding relief decoration.[86] Clearly, the maintenance of the temple's grand spaces and architectural wonders took commitment, ingenuity, and a great deal of technical skill.

Conclusion

The time, labor, skill, and resources involved in the construction and maintenance of a temple like Karnak were clearly vast. No one king could accomplish such a feat. It was only the continuity of Egyptian society, in which each king relied on his successors to preserve and expand the god's house, which allowed this monumental complex to prosper.

84 Murnane and Brand 2004: 105; Rondot and Golvin 1989: 249-251; Brand 2001
85 Murnane and Brand 2004: 98-102; Rondot and Golvin 1989; Brand 2001
86 Brand 2001

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