Egypt 4ème Dynasty

# KHUFU’S PYRAMID

## Theory of its construction from inside-out


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**KHUFU, A GIANT IN THE DESERT**

By definition, a pyramid is a large monument with a quadrangular base and four triangular faces. For historians, it's a royal burial site in ancient Egypt. For mankind the three pyramids of Khufu, Khafre and Menkaure, standing on the Giza plateau just outside Cairo, Egypt, are both a treasure and an enigma.

Of these pyramids, we know that they were designed to house the remains of three pharaohs, nearly three millennia BC. While the most impressive of these stone colossi, Khufu’s Pyramid, has been contemplated and photographed countless times, its entrails remain a mystery, evocative of fabulous treasures and legendary curses.

**The last wonder of the world**

The Great Pyramid is said to be the last of the seven wonders of the world still standing, the only one to have resisted the folly of man and the wrath of the elements. At 146 m, it was the highest monument in history until the construction of the Eiffel Tower. Yet we still don't know how it was built, or how long it took, by men who knew nothing of iron, wheels, or pulleys. And we still don't know what unexpected discoveries it may yet conceal beneath its stone walls.

Witness to 4,500 years of history, Khufu’s Pyramid has seen the world's greatest men pass through its doors. Men who have admired the immensity of what it symbolizes, who have dreamed of infinite conquests or an immortal life. Powerful ephemerals and ordinary people from centuries past have come to walk its stones. Some, intoxicated by this strange sensation, have said to themselves that such immoderation could not be human, and that only an unknown, distant civilization could have achieved such a prodigy...

**The mystery of the Great Pyramid**

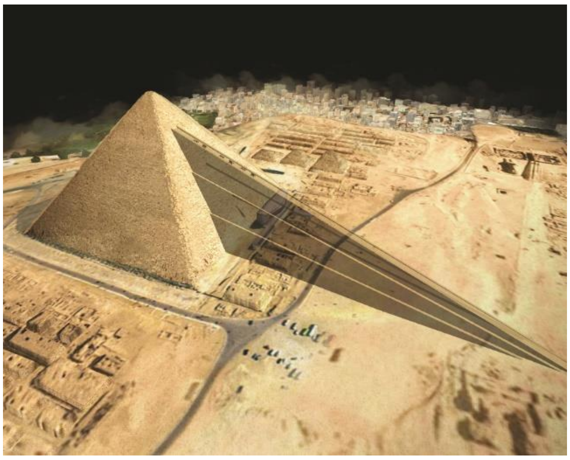
Over the ages, the secret of the construction of Khufu’s Pyramid has been lost. Everything has been imagined about its genesis, from the impossible to the extremely far-fetched. The real clues are few: a few lines about the royal architect Hemiunu, who was supposed to have built it in just twenty years, so that the great Khufu could rest in time in the heart of this limestone and granite vessel. A vessel for the King's eternity.

**A few sentences from Herodotus.**

Another clue may be that the famous Greek historian travelled to Egypt around 450 BC, over 2,000 years after the pyramid's construction. On the spot, he collected the local legends that have endured to this day. In his book, Herodotus describes a tyrannical king, hundreds and hundreds of slaves dragging stones and, curiously, machines placed on the side of the building to lift stones from one floor to another. Four centuries later, another Greek historian spoke of a huge ramp that would have carried all the blocks to the top. Others suggested an external spiral ramp built of mud bricks, which does not stand up to analysis.

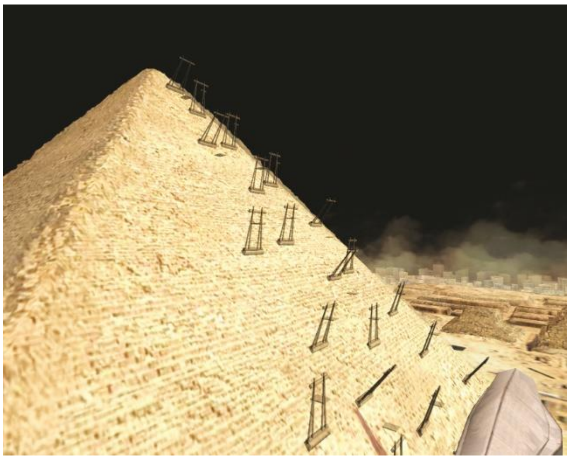
**The main theses proposed.**

**The great ramps thesis.**



These immense ramps require a volume of stone almost equivalent to that of the pyramid itself. What's more, they require constant work stoppages to expand them. The ramps are either short, but too steep to be usable, or gently sloping, but several kilometers long. And what happened to the materials used? It seems unreasonable to build the entire pyramid with one ramp...

**The machine thesis.**



This is the hypothesis reported by Herodotus: these machines would have enabled the blocks to be lifted from one course to the next. One theory also describes the use of levers and wedges to lift each block about ten centimeters with each push. But how could 63-ton blocks be lifted in this way? Would men act as counterweights to lift the block, which would then be pulled into position? A slow, dangerous operation, inoperable for large blocks... What's more, these machines require a flat surface. This means that the facade has to be repaired when the work is finished, and the timeframe is far too short for such a task. Machines may have been used, but they are not the basis of the construction method.

**The wrap-around spiral ramp thesis.**

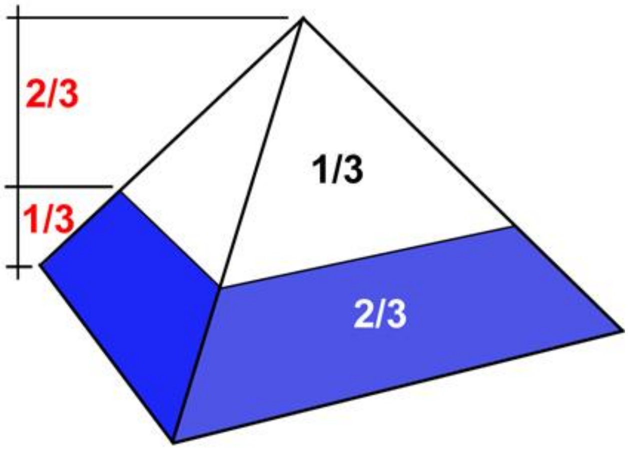
This is the most popular hypothesis today. An external spiral ramp would have been built around the pyramid. It has three advantages:
 - it's made of unbaked bricks, using relatively few materials.
 - Its gradual construction keeps pace with the construction site, without slowing it down too much.
 - it offers a gentle, constant slope of 8%. In practice, however, this doesn't work, as it's impossible to control the geometry of the pyramid, which is masked by the ramp. What's more, the ramp is fragile and regularly collapses, rotation around corners is hazardous and the passageway is narrow. It is out of the question to run the 63t beams through it.

**Theory in pictures**

**Preamble**

The construction of Khufu's pyramid was divided into two separate phases:

- On the one hand, to build the volume of the pyramid, i.e. 5.5 million tons of limestone blocks, taking into account a major parameter: any pyramidal volume with a square base, whatever the slope of the faces, contains 2/3 of this volume in the first 1/3 of its height and the remaining 1/3 in the last 2/3 of its height. The challenge is to build the volume and reach the summit.
- Secondly, to build the King's Chamber, comprising more than 70 monoliths, beams in granite or Turah limestone, weighing from 25 to 63t.



Only the implementation of several independent processes made it possible to carry out these two projects: the volume was built from the inside using two types of ramps, an external ramp and an internal ramp, while the construction of the King's Chamber made use of an ingenious counterweight traction system.

**The principle of the inside-out construction**

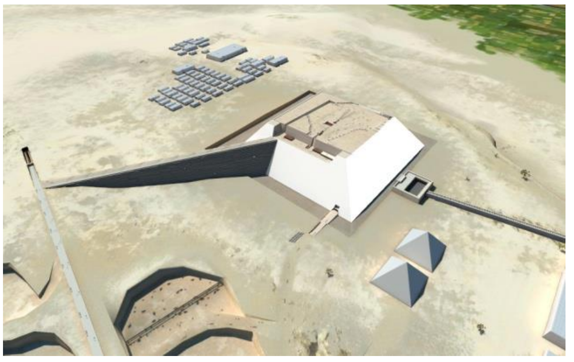
From the outset, all attempts to explain the construction of Khufu’s Pyramid have failed for one simple reason: the "Pensée Unique" was that it was built "from the outside", as indicated in the paragraphs above devoted to the main theories proposed. The changeover to a constructive approach, imagining construction "from the inside", immediately sweeps away all the obstacles that prevented a rational and realistic explanation. For the first project on Khufu’s Pyramid, building the volume, this quick, simple, and logical solution means that all the blocks can be put in place, from base to summit, guaranteeing that the pyramid will be finished as it rises; this means that the façade blocks, already cut and polished to match the slope of the monument, must never be leaned on. It is then imperative to bring all the blocks into the monument's enclosure and lay them in a precise sequence, course after course: first, the row of perfectly cut Turah limestone façade blocks, then a twenty-meter-thick supporting belt of simply squared local limestone blocks, and finally the filling of the body with rough quarried blocks from the same local quarries.

By building from the inside-out, the faces are completed as construction progresses, so there's no need to come back at the end of the project to resurface 84,000m2 of faces, which means years of extra work.

**Volume construction processes**

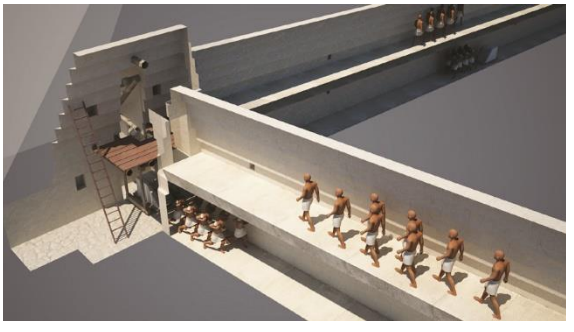
**An external ramp**

This external ramp with double carriageway, resting on the west side of the South face, enables a massive supply of the materials needed for the first 1/3 of the pyramid's height. Limited to a height of +43m, the base of the King's Chamber, with a slope of 8.5%, it is relatively short, around 325m in length, thanks to a clever use of the terrain's topography. It is built from the same limestone blocks as the pyramid, making it a reserve of materials. From the +43m level, this ramp extends into the body of the monument in an open trench, developing in quarter-turns up to the +70m level. Unable to extend beyond this level, the external ramp can no longer be used and will be dismantled; the whole of the external ramp plus its trench extension will have made it possible to reach almost half the height, with 85% of the volume now in place. Although only 15% remains to be built, there are still more than 76m to go before the summit is reached. Another process is imperative: the answer**, the internal ramp**.

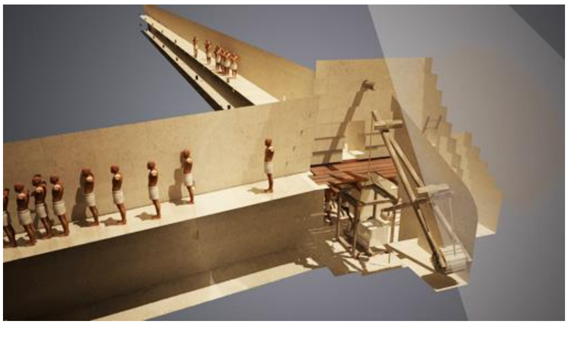


Aspect of the building site and external ramp at the time of construction of the King's Chamber

**The internal ramp**



This internal ramp, with a gradient of around 7%, is built right at the base of the pyramid; it develops over more than 1,800m, in rotating quarters, in some twenty sections to get closer to the summit. Built with a corbelled roof, it has two levels: the lower level is used to pull the sledges loaded with limestone blocks, while the upper level allows the pulling teams to return to their starting base. Each team is assigned to a section of the ramp and pulls the sledges back and forth across the section.



In the corners, the 90° rotations to present the sledges in line with the next section are performed in "rotation rooms" using a lifting machine inspired by the Egyptian Shaduf. In particular, 3D science has enabled us to validate this rotation system, taking into account both mechanical and human aspects. With this system, it takes around two minutes to rotate a block.

The internal ramp comes into service as soon as construction begins, and the Turah limestone facade blocks are transported via it to their final location. It therefore helps to supply the site, increasing the delivery rate of the blocks in addition to the external ramp. When the external ramp is no longer in use, when the pyramid reaches the +70m level, it becomes the only means of supplying the site, still from the inside, with Turah limestone façade blocks and local limestone blocks from the dismantling of the external ramp. According to the principle of communicating vessels, the blocks of the external ramp ended up in the upper part of the pyramid, the blocks extracted from the quarries having all been used, which explains why there are no traces of the external ramp on the Giza Plateau. There is no other constructive solution to achieve this result.

Finally, the internal ramp was also used for the funeral of King Khufu.

**The counterweight traction system**

This counterweight system enables all the monoliths in the King's Chamber to be hoisted and positioned with precision. The system is based on the following components:
- a counterweight sliding in a shaft, the Grand Gallery, located in the northern part of the pyramid
- the outside ramp resting on the south face (in a first phase)
- a special slideway, erected in the southern part of the pyramid from level +43m, for the final positioning of the monoliths on the five successive ceilings and the roof (in a second phase)

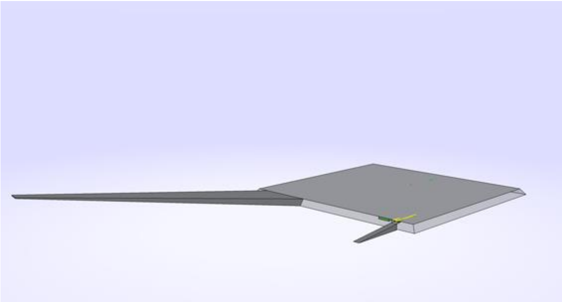
The combination of these elements is highly advantageous:
- the effort required of men is reduced thanks to the force restored by the counterweight
- men, who don't have to lift their body weight on a ramp, can make a very brief effort.

The granite beams forming the King's Chamber are hoisted up by means of the counterweights circulating in the Grand Gallery and installed permanently in each of the ceilings. Ceiling by ceiling, the King's Chamber was built with the help of the counterweight, considerably reducing the number of workers required.

Aspect of the South face at the time of construction of the King's Chamber. The beams for the ceilings and roof of the King's Chamber, stored at level +43m, are waiting to be placed in their final position thanks to the counterweights circulating in the Grand Gallery.

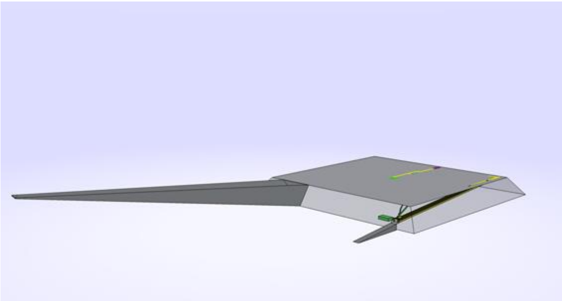
**The two construction sites**

**5th year of reign - Level + 7m**



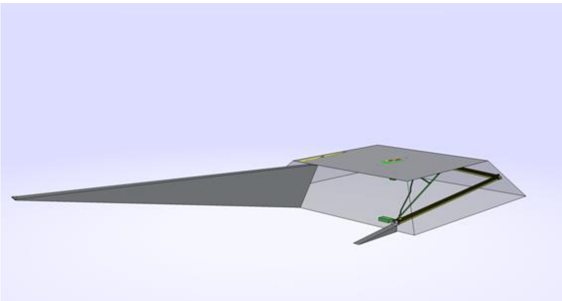
The external ramp, with its double carriageway, rests on the West side of the South face, enabling a massive supply of materials to the site. The entrance to the future internal ramp is visible in the East zone of the South face, with a small external ramp providing access.

**10th year of reign - Level +21m**



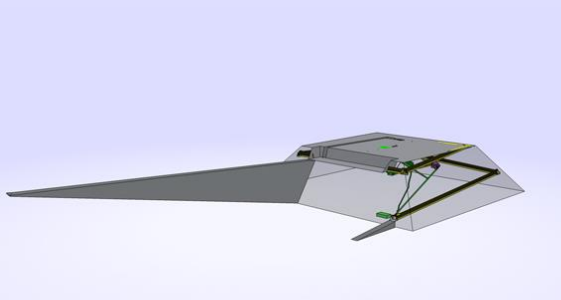
The external ramp rises at the same time as the pyramid, reaching the level of the Queen's Chamber. The 1st section of the internal ramp opens at this level in the North/East corner. The 1st rotation room is about to be built.

**14th year of reign - Level + 43m**



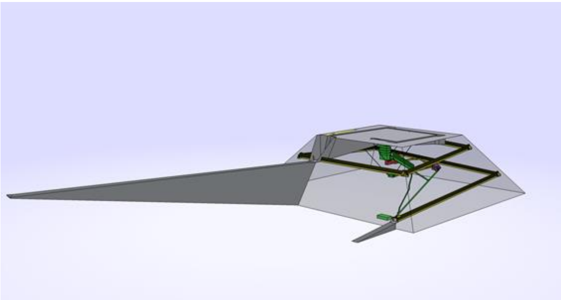
The external ramp reaches its maximum level, the internal ramp, the 3rd section of which reaches the South/West corner; due to its geometry, it does not interfere with the building site's supply. The ceilings beams of the King's Chamber are hoisted to this level with the help of the counterweight circulating in the Grand Gallery.

**15th year of reign - Level + 55m**



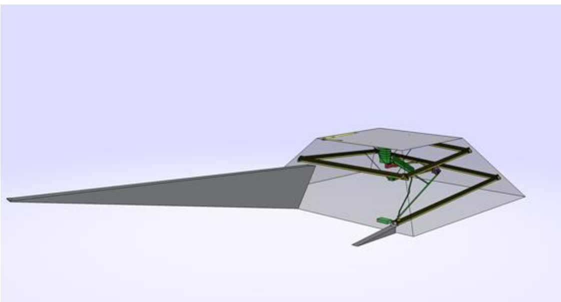
The King's Chamber is under construction, while work on the pyramid continues. Construction of the internal ramp is interrupted in the South/West corner but resumes at the same level in the South/East 5th corner. A 4th horizontal section will later connect the rotation rooms in both corners. This arrangement enables the monoliths in the King's Chamber to be stored, the sledges passing through the internal ramp to continue pulling, and the external ramp to be extended by an open-trench ramp running in quarter-turns, in the opposite direction to the internal ramp, into the body of the pyramid.

**17th year of reign - Level +70m**



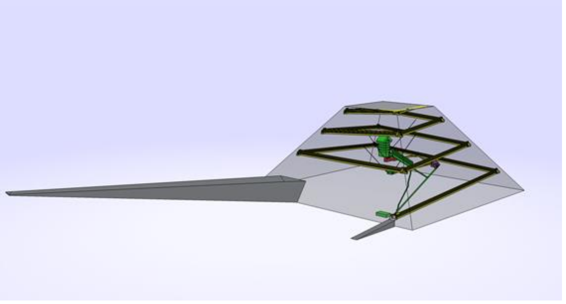
Construction of the King's Chamber has been completed, and the trench ramp extending the external ramp has reached the +70m level; it can no longer travel any further up the body of the pyramid. A large part of the storage area on the South face has been filled in, and most of the 4th horizontal section of the internal ramp has been built. The 7th section runs beneath the West face.

**18th year of reign - Level +70m**



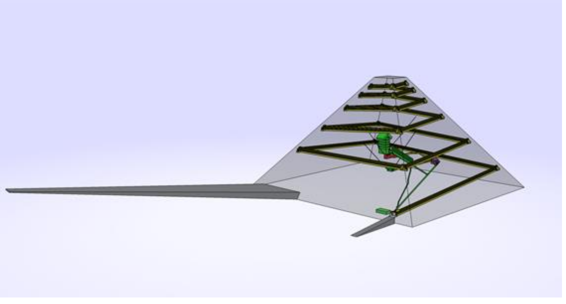
The trench ramp extending the external ramp has been filled in, and the 4th horizontal section of the internal ramp has been fully connected to the whole. Dismantling of the external ramp is about to begin.

**20th year of reign - Level +100m**



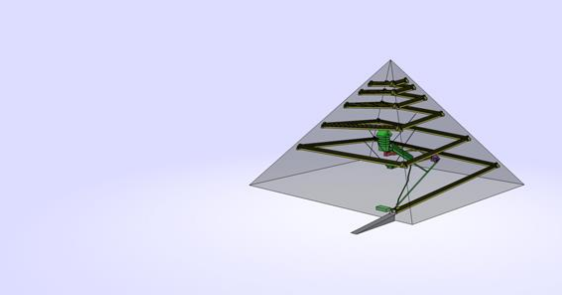
The pyramid is built using materials recovered from the dismantling of the external ramp, whose volume is rapidly diminishing. All the blocks are now transported via the internal ramp to their final location. The pace of construction has slowed considerably, but there is still only a very small volume - 15% - left to build.

**21st year of the reign - Level +130m**



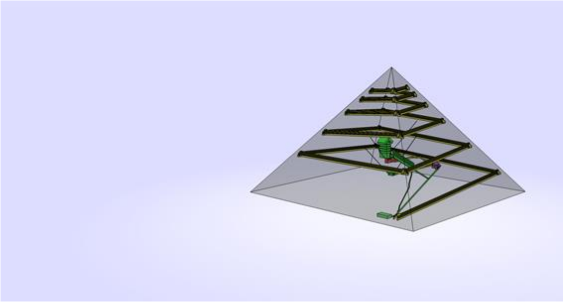
The external ramp has almost disappeared, the internal ramp is close to the top, and the last few meters will be built using a vertical shaft and a hoisting machine.

**22nd year of the reign - Level +146m**

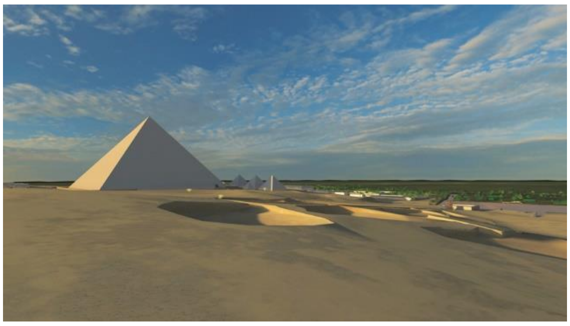


The summit has been reached, and work to complete the consolidation of the rotation rooms will begin from the top and on the way down. The entrance to the internal ramp will remain open until the funeral.

**23rd year of the reign - Level +146m**



Khufu's funeral is over, and the King now lies in the sarcophagus of his burial chamber at level +43m. The entrance to the internal ramp has been blocked off and its small outer access ramp dismantled. No trace remains of the construction site of the Great Pyramid of Khufu. The enigma of its construction can now begin.



The Great Pyramid was to shine on the Giza Plateau, overlooking the entire Nile Valley, symbolizing the eternal life of King Khufu.