PYRAMIDS:
THE SECRET OF iMOTHEP

2004

JEAN-PIERRE PETIT
Now let's go to the antics' museum.

Alright.

There's a funny story about Pharaoh Ramses II.
The graves of the pharaohs located in the Valley of the Kings were quickly desecrated and plundered. The priests who were given custody of those ended up taking all the mummies one night and sheltered those in a cave overhanging the Valley of the Kings.

And so was saved the mummy of Ramses II

The mummy of Ramses II was displayed at the entrance of the museum to attract the visitors. According to the custom, Ramses had his two arms crossed on his chest.

One day, Ramses II moved his left hand 10 centimeters away with a sinister sound. Terrified, the guard ran away and never came back again in the museum, considering this place haunted!
Here is the 4500 years old statues of Rahotep, Khéops half brother and of his wife Nefret, endowed with glass paste eyes, so realistic that when in 1871 the workers discovered them in the necropolis of Meïdoum, they ran away convinced that the graves were hosting living beings.

Isn't it interesting, this statue of the prince with his mustaches? He looks like a Parisian dandy who would have been transported in the old Egyptian empire.

What's wrong Anselme? You don't seem too well since we arrived in Egypt.
I propose a visit in a soukh

Enter, here I have EVERYTHING!

Look, I have magnificent Bastets

Oh Lord, here you are at last! I am going to give you back what belongs to your ancestor.
Anselme, what do you think of this statue of Bastet?

You found anything?

It's a guy over there, he gave me that.

It's a beetle. But what guy?

Well, the seller...

He's got to be in that back-room still

No one!

I don't have a seller. I work alone in my store.

There is no one and this back-room it's just a dead-end.
No, this beetle does not come from my shop.

I saw this man with a long beard and who gave me this beetle.

Anyway this chap couldn't have walked through the walls!

Although it's a beautiful piece indeed.

Anselme, come to sleep, it's already late.

Hours go by in the hotel room...
This dream is totally crazy! Here I am going thru the ceiling of the hotel.

I'm gliding above the Giza Plateau, and the pyramid of Khufu looks intact, with its limestone cover shining under the moonlight.

Khafra’s pyramid is unfinished. And Menkaura’s one is absent.
Who's shouting over there?

It is not necessary to yell like that. I do not understand a single word of what you're saying.

It is crazy that we manage to make dreams so realistic, so detailed

all those details...
What is this kid doing on this stone block?

Even if it's a dream, I absolutely have to sort this out.

I have to look at it closer.

Wow!
What an extraordinary dream! I absolutely have to take notes.

Anselme, what are you doing? It's three o'clock in the morning!

Look, I saw how we used to carry the very big stone blocks in order to build the Great pyramids.

Now that's a very interesting dream!

I spent the night writing down all the details which showed up in this dream.
And here's Anselme Lanturlu starting a new weird adventure right after having seen in his dream a machine which was used by ancient Egyptians to raise up the big stone blocks.

Fascinating

Before describing this machine, we are going to discuss a number of architectural principles of ancient Egypt.

In the former Egyptian empire (2700-2220 BC), the iron is unknown. The country has copper and imports some tin. Hammered and enriched with arsenic, the copper has a sufficient hardness to be able to cut limestone.

translation and graphical set in progress...
Few Egyptologists are aware that intense seismology is the key to understand the major features of antique Egyptian architecture. Let's remember that the temple of Abu Simbel, built by Ramses II, by carving a sandstone mountain, was ravaged by an earthquake in 1245 BC.

Hello, Ramses. I return to what I said. Sculpting in a mountain does not seem like a good solution. An earthquake just happens and I regret to inform you that one of the Colossi is completely destroyed.
A basement consisting of mechanically different layers, as in Giza, is an optimum seat for mitigating earthquakes. This played a major role in choosing the site. When in ... BC Cairo was ravaged by an earthquake, the pyramids remained intact.

They are built on a sculpted hummock, and stairs act as centering pins, keeping the assembly in place during earthquakes.

This is found in various parts of the world, where some kind of "steps" are interpreted as seats of a "board room", while their role is to maintain the construction in place.

Whose stones have disappeared, having been recovered.
The earthquake resistance suggests avoiding any regularity. Examples: the temple which is at the foot of the Sphinx or the famous Inca wall in Cuzco.

This is why the pyramids are still standing?

In part. When people from Cairo had finished removing the cover in fine limestone of Tura, they left what was underneath, which was of a much lower quality.

The general idea is that what is already split will no longer split. The structure of "multi-cracked" pyramids allows them to absorb the energy of the strongest earthquakes.
Still, our architects-priests must do their job properly, by arranging the blocks.

By not applying the "split lintel" technique.

The architect of the Pharaoh Unas (2350 BC) thought that massive blocks were the solution. But the enormous lintel, undergoing shear stress, cracked. Repaired (to the right), it shall split to the next earthquake.
Inclined cut to allow light entrance.

But a little further, his colleague did not make the same mistake.

For whom is a little watchful, all Egyptian architecture is based on the resistance to seismic activity (*).

Rest of the covered floor from the pyramid of Unas (Sakkara).

Pyramidion, Sakkara, 1230 BC.

Even the pyramidion, uppermost piece of the pyramid, was designed to stay in accommodation in strong earthquake.

(*) In the foreground, the blocks of the Bent Pyramid, showing the inclination of the stone, and in the background the Red Pyramid, at Dahshur.
But there is one thing that Egyptologists have not understood:
negotiating the contact surfaces between the blocks, not flat, but distorted,
was not something suffered, but to a formula set by the architects from classical antiquity,
in order to ensure the stability of buildings in an earthquake. Cemented joints would have broken
and planar junctions would have a slip. Only junctions with curved surfaces would allow
an automatic adjustment in micro-earthquakes.

We shall see later
how the most intimate connections
could be made.

An impossible technique to use
for large piece statues, which their reliefs
constituted as many sensitive points to seismic waves,
and which were probably reshape over millennia.
The Egyptians were masters in the use of all kinds of imaginable stones from sedimentary rocks such as limestone, the "detritus" rocks like sandstone, and most primitive rocks like granite, basalt, by using abrasives such as quartz, or the percussion with dolerite.

Limestone, "soft stone" could be shape easily with an extremely hard stone: dolerite, which was providing the tools.

The Giza plateau itself was a vast career, providing a relatively coarse limestone, appearing in layers separated by clay.

The blocks were removed by swelling of wooden wedges (Georges Goyon).
From lack of steel, iron and having trouble procuring bronze import, Egyptians of the Ancient Empire (*) practiced efficiently a MACHINING PERCUSSION (**). Granite was containing inclusions in the form of DOLERITE BALLS, which the size could reach that of a man's head.

We found near Aswan's obelisk traces of this technique in the form of what looks like lockers' eggs. We changed the striking points when the curvature of the hollow thus formed became comparable to that of the striker used, reducing the effectiveness of the strike.

The rupture of this obelisk, 41 meters long, 4 meters wide at its base, and weighing 1200 tons, due to an earthquake, interrupted the work. We will see later how such monsters were moved.

(*) From 2700 to 2200 BC.
(**) Efficient on limestone, bronze tools did not attack the "hard stone" like granite.
Acacia wood was a local production. Large parts had to be cut from the trunks of cedar, imported from Lebanon. The resins supplied glues and varnishes. Ancient Empire Egyptians knew very well how to make hemp ropes, as strong as modern strings (*)

But as the wood was something rare and precious, the Egyptians used it in complex arrangements, with "seams" using the rope to retrieve the smallest fragment.

(*) A cord of 50mm diameter can pull 4 tons.
In the Ancient Empire, as practically the only available metal was copper, when the direct strike of materials was not possible (e.g. with a saw with teeth) was used ABRASION.

Quartz powder is then used to operate all kinds of operations: sawing, drilling, digging.

In stone as in wood

Sandstone, composite rock, contains its own abrasive. We then use sandstone polishers.
MEASURING INSTRUMENTS

the plummet

the square

the Groma for targeting

and to check:

the arithmetic rope for angles

2² + 4² = 5²

the compass for evaluation of proportions and angles

the verticality

horizontality

flatness:

The roller, for distances, revealing the number π wherever we evaluate lengths reports
3000 YEARS BEFORE VERNIER (*)

This is a CALIPER, favorite instrument of those who are not Egyptologists but involved in ENGINEERING.

In a word ENGINEERS

On this instrument, two strips are face to face, one with remote graduations of a millimeter, the other with graduations of 0.9 mm. Below, the ruler gives a measurement of 3.6 mm (approximately). But, in seeking a coincidence between two graduations, we read (black arrow) 3.64 mm. With its vernier, calipers is accurate to 2/100° mm.

(*) Pierre Vernier, French mathematician, who (re)invented this item in 1631.
Egyptian cubits wear subdivisions increasingly tightened

From the right, subdivisions "finger" are themselves subject to progressive subdivisions by 2 \( \Rightarrow \), then 3 \( \lt \), 4 \( \rightleftharpoons \), etc. The symbol \( \leftarrow \) "Eye of Horus" resulting in "divided by". The progressive nature of these subdivisions, as well as the fact that it appears only on half of the elbow, had not been explained to now.
LET'S GIVE THE KEY OF THE MYSTERY

A MEASURE, in ancient Egypt, was expressed as the sum of a number and the ratio of two numbers, either to read a map, or to record a data on it. The Egyptians were then using, not ONE cubit, but TWO, by turning the second at 180°.

By shifting the second cubit (by 2.5 cm here), the search of coincidences between two graduations will be found to:

\[
\frac{3}{6} = \frac{4}{8} = \frac{5}{10} = \frac{6}{12} = \frac{3}{16}
\]

Thus the Royal Egyptian cubit has a "MULTI-VERNIER" system allowing accurate measurements at one sixteenth of a finger, thus at 0.116 finger close.

We only know 4 papyruses, more recent, related to Egyptian mathematics, which are in fact only exercises for elementary class.

A granary has the following dimensions...
A GONIOMETER, a tool to measure angles, is a "wrapped caliper" with an angular vernier. Again, we proceed by searching the coincidence between the graduations of two strips, with different spacing graduations. The goniometer allows measurements to a few hundredths of a degree.

Although we have not found Egyptian goniometers, given the great precision attached to their constructions, it is highly probable that they used them in 2600 BC.

(*) The mathematician Pedro Nunes (1502-1568) provided the Portuguese Navy with VERNIER ASTROLABES (a century before he "invented" them...).
When it is not attached to reconstruct the history of ancient peoples, archeology tries to enlighten on the science and technology of the past. It then focuses on the tools, measuring instruments and machines of all sizes and for all uses, which were achieved with these elements. It sometimes has the description of a particular modus operandi in the form of diagrams, drawings or written texts. But the discovery of these is an exceptional event. When ancient people ignore the writing, they are simply absent. So nobody will ever know the recipes of these experienced metallurgists who were the Gauls. Regarding Egypt, the vastness of the elapsed time does not make things easier. Where are the hundreds of millions of pyramids builders' tools? Where are their technical drawings? Where are the calculations of their engineers?

Everything was almost lost during these forty centuries that separate us from the old days. Without clues, our specialists baffled at the enormity, the monstrosity of what history gives to see, construct a paradigm, leaning on a consensus, based on the idea they have of what such people could know, and do not know at the time. All this based on an evolutionary scheme which excludes any recession, a real cult to progress. We then hear phrases like "the ancient Egyptians did not know the chemistry, nor the wheel or the pulley. They did not practice ocean navigation. They were poor mathematicians and poor surveyors. Otherwise they would have managed to leave us all this in writing".

Of course...
METHODS OF TRANSPORTATION

The wheel?
But what about the load on the floor?

Light is not your style

The solution is slipping, on a moist silt bed

Here you have the standard:
2.5 tons and eight men.

But if needed, we have much bigger.
The statue of Djehudihotep (his name is on the sign, simple provincial governor) sixty tons, seven meters high, pulled by 172 haulers.
1200 tons, forty meters long. We'll have to provide a river routing.

Are you, you can release the obelisk.

For these hyper-heavy transports we use barges specially designed for such loads. They have a background in boxes, intended to better distribute the load. The external shape don't need to be hydrodynamic, the barge has to be hauled over a channel along the Nile.

(thanks to Thiéry Pierre for his remarks)
We size the barge in a way that, when it will bear its load, the level of the bag floor matches the waterline.

Then we brought the barge in an OVERFLOW LOCK, after loading it with an equivalent quantity of stones.
THE SAND LOCK

Lock's water is saturated with sand, until the medium loses all fluidity, and behaves as a solid (such as "wet sand").

It's good. Now it is firm. You can unload the stones.

"Wet sand" quasi-solid

All Egyptian ships had hulls made of planks, whose elements were bound by ropes, so-called "SEWED HULLS".

Egyptians sewing (Cheops' carrack)

resin layer for sealing

clipboard
The sand lock allowed loading of the obelisk by rolling it, or sliding it on a wet clay bed to the floor of the barge.

It only remained to "sew" the front of the barge, then replace the wet sand with water, so the barge can float again, and then borrow the channel and be routed to destination.

There unloading is performed by using another sand lock and doing the operations in reverse order.
All this being big trick strength and magic.

1830:
Two thousand years later

5 Pin!

the "Luxor"

The French, for the transportation of the obelisk of 23 meters and 230 tons, which was installed Place de la Concorde, used a flat-bottomed boat, specially designed for this purpose (five pins) with a removable front. Initially this obelisk was resting on a square base decorated with four times four baboons, standing on their hind legs. As their sexes were apparent, another carrier was carved in pink granite.
Historians have documented that this mode of loading and unloading was used in ancient Egypt. Furthermore this technique of sewed hulls allowed the transport of units, completely disjointed, from Nile to the Red Sea, where we found in several units stored in caves (*). A 43 meters long vessel was discovered in 1954 as detached and numbered parts, in a pit close to the pyramid of Cheops (**). This possibility of quick detachment excludes an assembly by ankles. Combining economy of wood, lightness and strength, this technique had to be abandoned when the ship had to face the tidal phenomenon, typical of the northern seas.

Which involved the phenomenon of GROUNDING.

Besides, access to large wood resources, from various essences, allowed the end of WORKING COATING HULL in favor of a hull-keel assembly with HATCHES for loading and unloading cargo.

A beach? No, here we have DOCKS.
Despite the light that represents the present work, the Great Pyramids retain a large pan of mystery, the largest and most elaborate achievements paradoxically being the oldest. So that scientists are struggling to build a standard scheme involving a "progress from the beginning." Whatever we do, these buildings will survive to our future conflicts, even thermonuclear, and will continue to stand intact, among vain and trivial debris of our reinforced concrete, where metal constitutes as many access points to rust, completing the destruction of the concrete. Designed to withstand the worst natural disasters the Great Pyramids can calmly face the coming millennia.
About the internal structure we are faced with two ways of thinking. If the pyramids are an extension of graves that are **MASTABAS**, then some might see them as successive stacks of them. In contrast, in 1930, the German Egyptologist Borchardt considered a juxtaposition of stone layers, on slopes, supported one under each other. But this would have meant, for the pyramid of Cheops, two million and a half blocks.

underground grave with Mastaba.

Djoser pyramid at Sakkara: classical interpretation

Borchardt model with "accretion".

debris

Model confirmed by the remains of the pyramid of Meidum
Given the difficulty to reconstruct the techniques that allowed building the pyramids, we have seen emerging sententious theories involving external aid.

In France, since 1975, the architect JEAN-PIERRE ADAM, ubiquitous on all media, fights vigorously any theory that does not come from the Egyptologists community.

The precision and sharpness of the cut stones clearly show that we use a laser.

Only a device using antigravity can ensure the handling of such charges.

We must end the ARCHEOMANIE (*)

To take such an incisive speech, we must be able to oppose a credible model. But this is far from being the case.

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Adam begins to join the **MACHINISTES CLUB**, by proposing to raise the stones with a model derived from the oriental **SHADOOF**. This drawing, from his book, is physically absurd, the ratio of the **LEVER ARMS** is 1.6: to lift a block of 2.5 ton, we should use a stone load of 2500/1.6 = 1562 kilos, which is clearly not the case.

In addition, the articulation, on Adam's drawing, allowing only vertical movements, we cannot see how to file the charge on the next sitting.

Perhaps that represents an ancient form of leverage?
Always relying on his imagination, and what he considers his GOOD SENSE, Adam becomes RAMPASTE. He opts for a contiguous ramp on one of its faces, with a slope of 11°.

To get 60 tons on a slope of 11° it takes three tons of strength, so 150 haulers. To deploy them, the ramp must be at least 15 meters wide.

And cornering, how do we do?

How do we hang the ramp on the wall of the pyramid?
Whatever we do, one question is unavoidable: how to mount these blocks to 70 meters high?

The first idea was a linear ramp in mud bricks, armed with wood beams.

(*) Pronounced "Koufou" (Cheops)
The Cheops pyramid being built on a rocky plateau overlooking the Nile from 40 meters high, the proposed LINEAR RAMP, for a long time defended by Lauer, would involve a length of over three kilometers, and especially a volume of bricks equivalent to several times the pyramid itself, and which we should find a trace somewhere.

Otherwise the MACHNISTES offer to move to a MULTI-SHADOOF system where the beam is always working in BENDING.
Georges Goyon, official Egyptologist of King Farouk, propose a helical ramp in mud bricks, completely enveloping the pyramid, wide enough (15 meters) to allow 200 haulers to move.

But the mechanical strength of such a ramp attached to the reliefs of the cover stone, is problematic.

Another disadvantage: we lose contact with the surface of the pyramid.

The erection of the pyramid involves at any time centimeter-tracking of all its components, which implies access to its axis, with a plumb line in a central well.

(*) "Le secret des bâtisseurs des Grandes Pyramides-Kheops", reissued in 1997. Editions Pygmalion, France
In 2006, the architect Jean-Pierre Houdin developed with a lot of computer graphics, the idea of an INTERNAL RAMP, initially proposed by the Italian engineer Elio Domedi. To ensure the rise of very large blocks, following up the idea of Pierre Crozat, Houdin uses a counterweight sliding along the Grand Gallery, with an inclination of 50°. So a forklift, using a counterweight operating in the Grand Hall, would have allowed this ancestor of the funicular to run.

even if not true, it is well-found
VISION OF ANSELME (*)

It's exactly that

(*) See video http://www.jp-petit.org/VIDEOS/pyramide_montage.mov
I saw two arms going up and down.

What was moving them?

I climbed the ramp to see and that's when I had trouble with this guy with a shaved head, wearing a panther skin.
Six men

Okay, okay, calm down

I interrupted the work in progress
So what are you doing?

And all those who were on the platform have worshiped.

I flew away.

And I went back at the hotel, to take notes.
This machine, could you describe it entirely?

Even rebuild it!

This was done in 2006 at the Palais de la Découverte in Paris, at the \( \frac{1}{4} \) scale. Thanks to this, ten years old kids could pull a 500 kg stone block on an inclined surface.
In your machine, the installation amplifies a lot the traction force, but as a result, when the bars are lowering, the load does not move more than 20 centimeters. Each time everything has to be put back in place to allow a new strain, right?

This is a modern application of the lever (*).

As the nutcracker

You forget that there are TWO machines, working alternately.

A kid, perched on the block, moves two self-locking knots

A modern application of knots.

You again!

(*) Authentic.
You can try with a broom handle and a string, it works very well.

The block went up rather quickly, without a pause.

Yes, but how things go, when you arrive at the corner?

No problem.

The Goyon ramp was in mud bricks. This is stone.
When the block reaches the angle, it is positioned on a horizontal stone platform, made slippery by wet silt. It can then be slewing on this support.
The block can then begin his ascent on the following ramp segment.

Sounds to stick with the text of Herodotus.
Herodotus, the Greek historian, living in the fifth century BC, collected from the tales of the Egyptian priests how the pyramids were built, and made the following account:

"This pyramid was made after the manner of steps, which some call "rows" and others "bases": and when they had first made it thus, they raised the remaining stones with machines made of short pieces of timber, raising them first from the ground to the first stage of the steps, and when the stone got up to this it was placed upon another machine standing on the first stage, and so from this it was drawn to the second upon another machine; for as many as were the courses of the steps, so many machines there were also, or perhaps they transferred one and the same machine, made so as easily to be carried, to each stage successively".

I translate:

Ἐποίησε δὲ ὅσα αὐτὴ ἡ πυραμίδας ἀναβαθμῶν τρόπον, τὰς μετεξέτεροι κρόσσας, οἱ δὲ βωμίδας ἀναμάζοντας ποιοῦν τὸ πρῶτον ἐπείκει ἐποίησαν αὐτὴν, ἤδη τὸν κόσμον ὅλους μηχανήσας ἐξελέφαντον παραπλημματίζοντος, χαμάθειν μὲν ἔπει τὸν πρῶτον σταύχον τῶν ἀναβαθμῶν αείροντες· διὸς δὲ ἀνίκητος ὁ λίθος ἐπὶ αὐτὸν, ἐς ἐξέπεσεν μηχανήν ἐπίστευσαν ἐπὶ τὸν πρῶτον σταύχον, ἀπὸ τοῦτο δὲ ἐπὶ τὸν δεύτερον ἕλκετο σταύχον ἐπὶ ἅλλης μηχανής. Ὁσοὶ γὰρ δὴ σταύχοι ἦσαν τῶν ἀναβαθμῶν, τοσάται καὶ μηχαναὶ ἦσαν, εἰτε καὶ τὴν αὐτὴν μηχανὴν ἔκοσαν μίαν τε καὶ εὐβάστακτον μετεφέροντο ἐπὶ σταύχων έκαστον, διὸς τὸν λίθον ἐξέλεψε τελέσθω γὰρ ἤμιν ἐπὶ ἀναμόρφωσις, κατὰ περὶ λέγεται. Ἐξεποίησε δὲ ὅν τὰ ἀνώτατα αὐτὴς πρῶτα, μετὰ δὲ τὰ ἐξήλευγαν τούτων ἐξεποίησεν, τελεστᾶνα δὲ αὐτῆς τὰ ἐπίγαια καὶ τὰ κατωτάτω ἐξεποίησαν...

"This pyramid was made after the manner of steps, which some call "rows" and others "bases": and when they had first made it thus, they raised the remaining stones with machines made of short pieces of timber, raising them first from the ground to the first stage of the steps, and when the stone got up to this it was placed upon another machine standing on the first stage, and so from this it was drawn to the second upon another machine; for as many as were the courses of the steps, so many machines there were also, or perhaps they transferred one and the same machine, made so as easily to be carried, to each stage successively".
Anselme's system is a combination machine + ramp, with the difference that the ramp is in stone. The Krossai (Kροσσάι) are stones that protrude from the surface of the pyramid, what architects call CORBEAUX. Thus, the entire load rests on horizontal parts.

The bomides (βομίδες) are these angle platforms on which it is possible to cornering heavy loads. As Herodotus says, these stones are then supported by the next machine, etc. Anselme and Sophie have worked a lot with cardboard and glue, to establish the consistency of what Anselme saw in his dream. You'll find all this in the Annex, which will allow you, if you want, to build your own model. As this ramp is in stone, it can withstand loads of tens of tons.

This ramp is wide enough for the teams who are going down to cross carts which are holding the blocks. Finishing work leave very few non-recoverable waste (triangular blocks), the rest can be re-used to build other pyramids, as part of their external ramps. That's how Sneferu, father of Cheops, built his two pyramids at Dahshur. In the same way his son Cheops, his grand-son Kepren and his great grandson Mykerinos built their own.
It is fantastic, the Grand Gallery, with all its setbacks.

The ancient Egyptians were perfectly capable of doing vaults. They have built many, in ensembles that were not made to last. As stores of the Ramasseum at Thebes.

Another anti-seismic measures

It happens that this one has escaped from earthquakes. Otherwise it would have immediately collapsed.

I think back to the stones of the Grand Gallery. We could not even pass a razor blade in the joints of the stones.

There is a first way to eliminate this (*)

(*) 2004 J.P. Petit
In 2004 Jean-Pierre Petit suggested that workers were able to treat in situ the joints by abrading the opposing faces with a copper strip and quartz dust (*). For vertical joints, this abrasive paste that can be mixed with silt, to obtain an abrasive paste.

At the end of the operation, the two blocks are intimately joined, possibly in a curved surface, which increases their stability in the event of micro-earthquake.

Awesome!

You can illustrate this concept by taking two blocks of balsa. Start by destroying the flatness of two opposite faces, using any instrument. Then abrade the two opposing faces using a strip of "dual face sandpaper" you have made by sticking two strips.

(*) Of corydon, very abundant in Aswan, in southern Egypt.
two strips of abrasive paper and pasted against each other

Result: the two blocks have two sides with curved surfaces, parallel, and closely joined.
From ancient constructions in South America, Jean-Pierre Petit suggested (2004) that the abrasion of the two opposite faces could be achieved with a wool blanket filled with abrasive powder.

It should be tried

What do you remember yet?

I saw... a lot of things...
While these two machines were working alternately and mounting a wooden cart, with skis slipping on a wet clay bed, I noticed that the ramps were made of layers.

In these ramp systems we always have the same problem: how to hang them on those foundations, with a general slope of 52°?

This ramp was in STONE

Right, but where are the hundreds of thousands of cubic meters that constitute it, and that would remain after the removal of this STONE SCAFFOLDING?
On the plateau I saw a lot of blocks, arranged by type.
    Some, cut carefully, were in fine limestone.
    Others, made of a coarse limestone, only had
    two parallel horizontal faces, perfectly flat.
    There was also a mass of size debris
    that workers put in bags.

Let see the archaeological side.
We found many of these stones on the site.
What you say suggests that the stones of
the coating were brought to the site
ALREADY ROUGHLY CARVED.

Coating of the pyramid of Unas,
at Saqqara

Cheops, the base

Coating of the Bent Pyramid
On Giza site, we found in abundance TRIANGULAR STONES.

The site used to be a quarry for the city of Cairo, very close, they remained there, because you couldn't do anything with.

Impossible to use them as coating element.

This could be a residue of cutting of your stone ramp.
What do you say about that ramp model, consisting of three components: type A and B blocks and a parallelogram P. Those I have seen in dream.

When the pyramid is completed, we just have to remove both components A and B, and to conduct the cutting of the shaded area to get the face of the pyramid.

But what do we do with these blocks A and B?

It would explain the presence of those triangular blocks.
We keep them for the next pyramid!

From what you say, Tiresias, the pyramids were built in kit!

That explains why Cheops could have built his own in just 25 years.

The stone structure is strong enough to support a load of tens of tons.

The mud brick coverage gives a very gentle slope. With this system where parts of the ramp are PRE-CUT, the amount of scrap is minimal.

57% of the stone which constitutes the ramp becomes the COATING. The following 34% will be for the next pyramid. There are only 6% of waste.
It remains to understand how this ramp (Krossai) is closing at the corners on these platforms (bomides).

**THE STONE RAMP BY JEAN-PIERRE PETIT**

Sophie and Anselme started by building models using Bristol paper with a grid of 5 mm by 5 mm.

We will also start there.
THE ALGORITHM

It is the solution of the following geometric problem:

How to create by RECURSION an object with a symmetry of order 4 (a pyramid) by using an object following an uphill trajectory and spiraling at the same time?

Then we want this object, stick to the foundations of an underlying pyramidal structure, to be both a STONE SCAFFOLDING, enabling the delivery of blocks on an uphill ramp and, once the building completed, the coating. And this with minimal non-reusable scrap (*)

We will start by working with grid Bristol paper.

(*) The triangular blocks, abundant on Giza site.
You are the new Pharaoh Cheops. Snefru, your dad, has left you a mountain of stones already cut, which itself has used to build his RED PYRAMID and his BENT pyramid, further south, on the site of DAHSHUR. A real kit, that can be used as a stone scaffolding; these stones will allow you to build a super-pyramid in just twenty years. Thanks also to other stones, easily extracted from the quarry of Giza, which have readily horizontal flat faces, since they come from sedimentary layers of coarse limestone, which are separated by clay layers.

You will be making type A blocks and type B blocks (*).
These lengths are only indicative. This is unit $u$.

In passing back and forth a pen or a marker on the folds you will facilitate the folding of the Bristol paper.

By placing four elements of type $A$ and four elements of type $B$ you’ll get the set $C$ which is the corner platform on which monolith of 20 to 60 tons (52 in total in the Cheops pyramid) will be cornering at 90° on a wet bed of clay, a technique mentioned in a relief where we see 172 haulers pulling the statue of Djezudihotep. See page 29.

If you doubt about the effectiveness of this technique, sprinkle dishwashing liquid on the floor of your bathroom. Then try to cross the room without smashing your face!
The CORNER PIECE consists of four layers of precut stones.

Below is how to make the next layer, the layer D, still from standard A and B blocks.

In all the following, we will act like the faces of the slope are the unity, they make a 45° angle with the horizontal. But the pyramids had more inclined faces. The slope of Kheops' is 14/11, which corresponds to an angle of 51 degrees 30 minutes 34 seconds. Purists shall enter this data by replacing the unit value for horizontal grids by 11/14 i.e. 0.7857.
The set $E$ consists of two blocks of type $A$, three parallelepipeds $P$ with sides $u \times u \times 2u$ and a block with its cutting below gives you the form.
The cutting of this piece of type E provides the only identifiable scrap, resulting from this block: a TRIANGULAR BLOCK, as found on Giza site in abundance.

The last layer F consists of 7 blocks of type A and a block that corresponds to the cutting below. All are part of the coating. There are combinations of such blocks in the remains of the upper part of the pyramid of Kephren.
To understand how these angle blocks lie, compared to foundations ones, it is essential to build a model. For the foundations it is easier to create them from wooden sticks.

And to do this, here is the needed hardware:

- Saw
- Guide
- Cleats
- Glue

\[ u = 2 \text{ cm} \]
\[ 2u = 4 \text{ cm} \]
We assume that you have now several ANGLE SETS of this type. We will now see how they take over, from a base to the other, in constituting the resistant support of an uphill path, a HELICOIDAL RAMP STONE. For this you will need to make the foundation.

There are two kind of foundations geometry, illustrated by the following drawings. The sides are identical. The pyramids differ only in the arrangements of the last elements of their top parts.
Here is a model with some foundations, made from slats of 2 cm by 4 cm, a saw and glue.

And corner pieces made of wood
This form provides a solution to the problem. Let start from his position 4, enveloping the foundations. We slide it along the base. At the next angle we give it a rotation of +90° and a vertical movement equivalent to a foundation height (position 5). We do the operation again in 6, 7, and 8. The part is then positioned against the 4, as indicated. Through this RECURSIVE scheme we get the algorithm generating the STONE RAMP. (*)

(*) RECURSION is a concept that will appear in mathematics in the nineteenth century.
THIS CUTTING ALLOWS TO UNDERSTAND HOW THE CORNER PIECES ARE JOINING, MATERIALIZING THE EDGE OF THE PYRAMID.

Edge of the pyramid

platform

flanks of the pyramid

starting line of mud-brick ramp section.

effective mud brick ramp

reinforced by palm trunks
It is easy to complete the establishment of CORNER BLOCKS 4 to10 with type A and B blocks and parallelepipeds with (u, u, 2u) sides. This is what has been done on the model of the left picture. On the right, shown in white, we added the inclined ramps in mud brick, reinforced with palm trunks. For those who want to understand the sophisticated geometry, we have made an appendix which describes in pictures all stages of a model assembly process and the final stripping to release the COATING.
Well, let's take a moment. We have a routing system for the pyramid components using a narrow stone ramp, but wide enough to allow a double movement of workers, some pulling uphill trolleys carrying blocks of two tons and a half, and other going back down with the empty trolleys. In the 4/5 of the climb, the slope of the ramp is less than 1%, in a way that the towing force needed is essentially to overcome the friction on the wet silt bed. It can then be created by only few men. At the corners, the rotation can be provided by shifting. This ramp of about thirty laps sees its slope increase in the last laps, in its upper part. The complete course on the ramp for the Cheops pyramid is 13 kilometers.
Hauling of the "standard" blocks on a ramp portion with a very low slope.

When the program involves the setting up of the 52 granite monoliths, we change the technique: machines (see pages 45-53). Thanks to them, two half-dozen of men can create alternating tensile forces of 400 to 1200 kilos.
CREEP AND SEISMICITY

Well, the crucial problem of the loads rising and their climbing rhythm appears to have been mastered. But with all this, what do we do and how?

The designer of a pyramid is facing two problems. The first falls under the SOIL MECHANICS through the CREEP. The second falls under the SEISMICITY.

You ever heard about this stuff in your lodge?

No, though we were introduced to the highest degree. I do not understand.
The volume of the Cheops pyramid is 2.5 million cubic meters. With an average volume of one cubic meter per block, it represents two and a half million blocks, right?

The discovery in the nineteenth century of the TEXT OF THE PYRAMIDS gives to them and to their FUNERAL COMPLEX the nature of metaphysical machinery, associated with a complex theme. This aspect encouraged Egyptologists to decipher these structures in a SYMBOLIC point of view. Thus the reference to a "staircase allowing the Pharaoh to reach heaven" led them to think that this sentence could have been the source of STEP PYRAMIDS.

Is the architecture of pyramids a "hard" translation of a religious theme?

Or, conversely, is the religious texts are not a form of encoding solutions imposed by technical requirements?
The step structures are ubiquitous under the pyramids, for example in the three satellite pyramids of that of Menkaure (which is visible in the background). It seems reasonable to think that such step may also exist under the superficial parts of the Giza Pyramids, less degraded than others, due to the systematic robbery by stone thieves, practiced throughout all the ancient and modern history of Egypt. To the point that we can wonder if the oldest pyramid, the one of Pharaoh Djozer, at Saqqara, built by Imothep, was not initially a smooth pyramid, transformed into a Step Pyramid because of the Stone-Rob game, which would have revealed its underlying steps.
On the sixty identified pyramids in Egypt, most of them, if their underground structures can be very rich, offer a very dilapidated appearance because of the stone robbery, operated even from the Pharaonic period. Below, that of Pharaoh Unas (2320 BC), which the interior (see page 15) contains the TEXT OF THE PYRAMIDS.

Why Giza pyramids have survived to such a plunder?

Their coating of fine limestone has almost completely disappeared, except the top of the Kephren pyramid. But the limestone from the quarries of the plateau, stuffed with shells, was of very poor quality (*).

(*) Limestone is a sedimentary rock.
The fact that some pyramids reveal their internal structure indicates that we mingled "sloping walls", in "Russian Dolls," and carving debris. This led some Egyptologists in 1900, as the German Ludwig Borchardt, to consider the diagram below.

Angles clearance of the unfinished pyramid (105 meters square) (*) of Sekhemket, successor of Djoser, currently completely covered by sand.

Section of Sahure pyramid according to Borchardt. Before degradation 47 meters. Today: 36 meters

(*) It is the same size as that of Djoser.
As in the pyramid of Unas, the wish is to locate the sepulchral chamber as high as possible, outside the ground level. This has prompted designers to use "voussoirs" for laterally redistribute the tremendous compressive forces created by the mass of stones located above. This is a very effective system in case of earthquake and accommodates well with a distribution "in bulk" of the materials located above. But this desire to place higher imposed that it is based on a pillar of paired stone, this leading to:

Many specialists and experts still believe that pyramids designers of the Ancient Egyptian Empire (2700-2200 BC) proceeded by EMPIRICISM. Determined to create sustainable structures and aware of the major importance of SEISMICITY, they knew rather well where they were going, involving as sophisticated and original solutions, ingenious at all levels.

But none had probably expected that the survival of a pyramid was based mainly on the choice of a stone of very poor quality.
But Borchardt idea did not make time and with the years, with little justification, and inconsistent with the observations made on site, arrived the paradigm that step pyramids, inspired by MASTABAS, that predated them, should be STACKS OF MASTABAS.

Two million five hundred thousand blocks for Cheops? I can reduce this by using carving debris (*)

Let's take back Borchardt idea, with a STONE FRAME, plus a filling with quarry debris stone.

(*) Debris that are strangely absent on pyramids sites.
It fits with what I saw in my dream (page 48).
These concentric squares are made of stones from the quarry of Giza, with their horizontal surfaces fully contiguous, allowing, due to friction, to counter the tendency of the mass of the pyramid to spread by Creep.
To obtain the slope, it is only necessary to slightly shift the stones to the axis, at each new layer.

But your quarry debris stone will settle. It will not be stable.

Not if we pour PARGET progressively, to fill the gaps and make this inhomogeneous medium INCOMPRESSIBLE.
It makes me think of one thing. It is classically considered that the Bent Pyramid was initially planned to have a slope greater than fifty degrees. But this structure would have proved unstable.

The architects-priests then decided to reduce the slope to 43°, hence its peculiar geometrical shape.

But another idea is to imagine that the pyramid, once completed, was plundered, affecting its first foundations.

And its current form would result from reparation, plating facing stones on the apparent oblique foundation.

Without such undressing and the reparation that followed, it would have been a copy of the Red Pyramid (in the background).
What is possible, we do it now. For the impossible, we ask for a delay.

Getting up monoliths is not all. How you would handle them, sci-dventurer of my heart?

I would use the traction machine, to lift them and I would use shims.
By doing so, you presuppose that the nail puller and the crowbar existed at the time of the Ancient Empire.

I would rather see it like that.

I think we should show this to Antoine.

It's a long time ago that he invited us to Luxor. OK, we do our luggage and we go.
You said Antoine has a great house

In felucca it's more romantic

Welcome to lovers

Hi Antoine

We arrive at the village
The object described by Anselm, in his machine, which avoids strings wear, exists. Made of basalt, it was discovered in 1932 in Giza by Egyptologist Selim Hassan near the ruins of the pyramid of Queen Khenkhaoues.

I looked at the notes that you sent me.

We checked. Except when the rooms are underground, in all the pyramids, they are always off the axis.

The stone ramp: not bad. And you pick up the idea of the central pillar. But how do you place the rooms inside the pyramid of Cheops?
The triangular blocks? I rather see them as cutting residues carried out by robbers, at the ground. But it is only an opinion. It would be simpler to consider a facelift at loss, on the top. As for the "withdrawal blocks," I go instead for a deterioration of the stone. This is not nearly as stable and consistent as you think. Blocks already carved, yes, but with bosses which must disappear during finishing.

And concerning arguments based on the absence of mud bricks, you should know that unlike the carving debris, it is a reusable material. I made the experience at Karnak.

Well, the one who knows the stone, it's you. That is why we came to see you.
Antoine brings us tomorrow to his site. He says he has something nice to show us.

About the sawing of joints (page 57) the idea is old, mentioned by Choisy and Petrie in the nineteenth century. To know more I wanted to make the experience with blocks of sandstone.

Sandstone is a rock resulting from the agglomeration of 80% silica grains with a limestone cement. Therefore it contains its own abrasive.
At all times, including the Ancient Empire, we see that stones of all sizes are joined so tightly that we cannot drag a razor blade in the joints. Moreover, these joints are sinuous. Since the nineteenth century, Egyptologists have suggested that these seals have been "worked". Antoine has focused his attention on relatively recent buildings (the Ptolemaic period (*), in sandstone. The examination showed traces of tool (saw joints)). The facing stones were not worked through their entire contact surface but only on their periphery, on 3 to 5 cm deep. The rest of the surface was "refined". We create on both opposite faces concavities of 3 to 4 mm. The sawing of the joint is then undertaken.

In the sandstone, silica particles detaches and provide the desired abrasion resistance. The tool progresses by 4 cm per minute. We place copper shims progressively.

When the loop is made, the shims are removed and the joint is then perfect. Through a channel created for this purpose, we pour pargep into the inter-joint space. The contact between the two blocs is both intimate and total over the entire surface.

A final sinuosity of a few millimeters is sufficient to guarantee the wedging of the blocks.

(*) From 300 BC to 30 BC.
I see you used soft iron.

The idea was to reconstruct what was done at that time.

Well we have saws for wood. But no stone saw was found.

There are not only that soft copper because it is pure. Pure metals always have lower mechanical properties than their alloys. The Egyptians had copper with arsenic, which mechanical properties are close to those of bronze.

We have only half a dozen of simulacra in soft copper, found within the graves.

Saws with teeth made of this copper can be used to cut stones considered as tender, including limestone.
For hard stones like granite, we have toothless saws, which its copper makes an abrasive powder.

We know that the Egyptians were digging hinges holes with copper pipes and abrasive.

This tube, it is a rolled saw.

I’ll show you a nice little trick. You know that in Karnak we spend our time for a long time to climb up lots of stuff. You see those blocks that form the ceiling of the chapel of Tutmosis III, pharaoh around 1450 BC. They each weigh seventy-two tons. Well, we get them up.

With a crane?
Our crane at Karnak has a maximum lifting capacity of 23 tons. But I like challenges. I wanted to know if I could negotiate it with simple hydraulic jacks, wooden beams and stones.

We did play alternating uprisings by hydraulic jacks, the use of wooden blocks and accompaniment based on a stone wall mounted progressively. When the block was at 4.25 meters, we dragged it and finally we dismantled all the extra masonry.

Awesome, but Tutmosis III did the same without hydraulic jacks!

Hmm ... mud brick ramp, ropes and people!
The Greeks and Romans had all kinds of machines. We attribute the invention of the muffle to Archimedes. What do we know about machines of the ancient Egyptians? It remained only rare specimens of the tools they used to carve stone.

Finally, for heavy loads there are two solutions: to act continuously by leveraging the strength, or by sequences, as did Antoine. Without a solid metal to make pins, the ropes system with self-locking knots is logically necessary.

This is what alpinists use.

It's not by pulling that we can drag these knots: the rope breaks before.
Your model is nice.
It's a very nice puzzle. But something is missing. The pyramid stones are not nearly as regular. Successive foundations have heights that vary within a factor from one to three! It depends on the thickness of the vein from which they are extracted. You need an accurate tracking system for blocks positions.
Well, welcome back to you both!

Say, I thought to what Antoine said about the problem of identifying the blocks. Is a small turn in this past life...?

Stop with this nonsense, want you?

Me, what I was saying, it was for Egyptology...

You are back in Cairo. Good, because when you left you had forgotten something.
What was that, the thing we had forgotten?

That's... what gave me a guy in the soukh.

The beetle

Are you coming?

I am coming
Let me sleep!

Sleep... what does that mean?

(*) translation of the hieroglyph: "Every man who has done this (the tomb) for me, he will never have to repent; sculptor or carrier, I will reward him."
The identification of blocks? It's over there

Here.
And you indicate to the guy of the surface the exact position of the plumb line.

A little further west and it's good

Now we turn the rotating table using these sights and by targeting a marker indicating the north, installed kilometers away (*).

With that, we have the pyramid axis, with a pointing positioned on a mark arranged on the rocky plateau

(*) The use of such tracking system (plumb + viewpoint) was conjectured by the Egyptologist Georges Goyon.
Then we use weighted wires, part of the rotary table, which are arranged such that, taken in pairs, they point with great precision towards the four cardinal points N-S-E-W.

But these pointing directions don't pass through the pyramid axis?

Even if the foundations exhibit some irregularity, if the angle blocks are positioned regularly, then a tracking becomes possible, then we can situate with precision the position of the corners of the blocks in space.
Indeed, if we know the precise position of the platform corner, we can use it to position the edge, from one to the other.

The advantage is that as the construction goes, we can locate these corners with centimeter accuracy in relation to the ground, and not with each other, otherwise errors would eventually accumulate.

The line of sight goes through the corners of successive platforms.

This gives ONE pointing direction but we need others.
A pointing table like that allows to locate with great accuracy any point supposed to belong to the surface containing the angles of block corners, if they are aligned and equidistant. The diagonals of the upper faces of the corner blocks are parallel to the projection of the edges of these faces and the major diagonals of the parallelepiped corner block are parallel to the edges of the pyramid.

The large diagonals of the corner blocks are parallel to the edge of the pyramid

The angles of the corner blocks are positioned on a sight line parallel to the edge of the pyramid

Pointing table located on the axis of the pyramid

Slide strip

L = diagonal of the face of the corner block

Pyramid edge

The visible parts of edges "pierce" the faces of the corner blocks in identifiable locations

Ground pointing
If you want to live, you must die.

Anselme, what happens? First you talk alone, and then you keep screaming "how much twenty-four baboons?"

We will return in twenty-four baboons.

I'll tell you everything.

Hee hee
You say that the ceiling was an inverted V, with setbacks. This is called a **CORBEL ARCH**, allowing to sustain a large mass of stone that be above.

From what you say, it could be at Dahshur, either in the red pyramid, or in that of Meidum.

You say that one put you in a stone sarcophagus so that you stay there for... twenty-four baboons.

Despite the presence of sarcophagi in the pyramids, some doubt that they can be seen as graves since we never found remains that could prove it. The dream of Anselm could mean that they were **PLACES OF INITIATION**.
You know, Sophie, I think of two things:
Firstly if there is an axial well in the pyramids, this could explain why the rooms, when they are not underground, are all outside of the axis.

Mykerinos  Khafre  Bent  Cheops

Secondly all the "descents" and "ventilation tubes" are oriented almost exactly in the same direction and the same angle, which is convenient to be able to illuminate with mirrors.
In the corner of a wall we cross the stones to increase strength

To ensure the strength of the well and avoid that it can be closed, made unusable in the event of an earthquake, which would be catastrophic, the stones should be arranged as follows.

So what means this arrangement of stones at the top of Cheops pyramid (*)?

(*) Images taken with a drone would be welcome.
All this seems to respond to the criticism of Antoine, on the centimetric marking of blocks. It requires access by the bottom or the one who positions the plumb-line be quickly short on oxygen.

What’s weird is that the pyramids of Cheops and Khafre both have what looks like a sealed access at the height of the stone hummock, on a few meters, on which they were built.

THE END
There we go again!

I do not understand a thing to what you're saying, buddy.

TO BE CONTINUED
The temples were surrounded by a wall structured as a corrugated sheet to better withstand earthquakes.

Franck Monnier (*): Why use huge monoliths in the construction of temples and pyramids? To minimize the volume of the carving debris.

(*) www.egyptian-architecture.com
Go away! Go away!

Be careful!

The earth trembled

A cubit is seven palms

Hurry up!

Pull, comrade!

I do!

Pull hard!

Pay attention!

May I understand!

How did you come back?

Insolent!

Is on this that I'm going to spend the day?

Thanks to Thierry Bergerot and his daughter, Egyptologists.