Deductive Model

for the Construction of the Great Pyramid

Massive Logistical Project in the Old Kingdom

Introduction

This work aims to fully and consistently reconstruct the construction process of the Great Pyramid.

The approach is based on a strictly deductive model with clearly defined premises, consequences, and mandatory boundary conditions.
Speculative elements are completely avoided.

The central task is the continuous **mass transport** of 3 million standard blocks, each weighing 2.3 tons, which constitutes 99 % of the building material.
The crucial challenge was quarrying this quantity of stone within 20 years and transporting it to the required height. The construction of the pyramid is therefore understood as a **massive logistical project**.

The construction process follows a continuous and **uniform principle** that works without large ramps, internal ramps, or hybrid solutions.
The individual transport of the 200 huge blocks is also explained.

The model is based exclusively on:

- Geometric properties of the pyramid,
- Simple and verifiable techniques of the Old Kingdom,
- Historical information on work organization.

Archaeological finds do not serve as direct proof of the construction method, but solely for consistency checks.
The model provides criteria for potential falsification.

If there are several technical solutions available in a situation, the one with the **highest efficiency** will be chosen. That was the only way to build the monument within 20 years under humane working conditions.
Thus, efficiency becomes the **second source of information**.

Based on the following **231 premises and consequences,** a consistent model can be developed with which the construction method and construction time of the pyramid can be deductively derived, as in a mathematical proof.
The plausibility of each premise or consequence is explained and categorized separately.

The result is a **reconstruction of the construction process** based on technical and logical criteria.
The model is only viable if the overall process works. This means that all components (ramp design, transport method, number of workers, time constraints) must interact.

To verify the theory of **Multispiral Ramps**, it is therefore sufficient to examine these premises and consequences for technological and historical plausibility.

A concise conclusion can be found on page 22.

This document is explicitly aimed at expert criticism.
Critical feedback that helps clarify, correct, or falsify individual assumptions is expressly welcome.
Contact for expert feedback: mail@rudolfvolz.de

Images, tables and further information can be found on the website
www.cheops-pyramid.net/en

The premises and consequences are **categorized** according to their origin and justification as follows:

(A) Archaeologically proven.
Directly verifiable through archaeological findings, discoveries, or structural features.

(H) Historically documented.
Proven by ancient written sources or contemporary accounts, even if these were written well after the construction phase.

(E) Experimentally supported.
Verifiable through practical trials, experimental archaeology, or reproducible experiments.

(D) Deductively derived.
Necessarily derived from geometric, physical, or organizational relationships.

(T) Technologically necessary.
This was an inevitable consequence of the known technical possibilities and limitations of the Old Kingdom; alternative solutions would lead to contradictions in the overall process.

(P) Plausible, historically and technologically.
Neither directly proven nor conclusive, but within the given historical and technological context, it is plausible and consistent.

The classification serves to ensure the transparency of the argumentation and does not imply any difference in the value of the categories.
Rather, it allows for the targeted examination of individual assumptions as well as the systematic falsification of the model.

Pyramid

What are the dimensions and geometric properties of the Great Pyramid of Giza?

1) The pyramid has a **base width** of 230.33 m. (A)

2) The (calculated) **height** of the pyramid is 146.59 m. (A)

3) The pyramid has 210 horizontal **levels**. (A)

Uniform Pyramid Model

In a uniform pyramid model, all blocks are the same size.
If we consider the Great Pyramid as a uniform model, what are the sizes of the individual blocks, and how many blocks are there?

4) Since there are 210 levels, the **height** of a block is
$146.59/210 \approx 0.7$ m. (D)

5) Each block has a **length** of
$230.33/210 \approx 1.1$ m. (D)

6) The **entire pyramid**, including the outer casing consists of approximately 3 million blocks. The exact number is
$210^3/3 = 3{,}087{,}000$ blocks. (D)

7) The individual levels of the **real pyramid** have different heights. (A)

8) However, the uniform model provides a **measure** of the construction progress. The amount of building material at a given height is identical in both the real pyramid and the uniform model. (D)

Volume fractions

What percentage of the total volume is comprised of the inner stepped pyramid, the outer casing, the huge blocks, and the empty spaces?

9) The **inner step pyramid** consists of 209 levels and approximately 3 million blocks. The exact number is 3,056,198 blocks, which corresponds to 99 % of the pyramid's volume. (D)

10) The **outer casing** corresponds to 22,015 blocks, which corresponds to a volume of 0.71 %. (D)

11) There are about **200 huge blocks** weighing up to 70 tons. (A)

12) The huge blocks are equivalent to about 6,000 uniform blocks, which corresponds to **0.2 %** of the pyramid's volume. (D)

13) The **empty spaces** consist mainly of the Grand Gallery. Additionally, there are the burial chambers and several passageways. (A)

14) The empty spaces correspond to approximately 2,700 blocks, which is **0.09 %** of the pyramid's volume. (D)

Building Material

Where did the material for the construction of the pyramid come from?
What percentage of the material had to be shipped via the Nile?

15) The building material for the inner step pyramid (99 %) come from the immediate surroundings, the **limestone quarries** located 300 to 400 m south of the pyramid. (A)

16) The white limestone for the outer casing (0.71 %) was shipped from **Tura**, 30 km away, via the Nile. (A)

17) The 200 huge blocks (0.2 %) are mainly made of granite and come from the quarries in **Aswan**, which are 800 km to the south. The material was shipped via the Nile. (A)

18) In total, only about **1 % of the material** was shipped via the Nile. (D)

Weight

How much does a single block weigh, and how much does the entire pyramid weigh?

19) The **density** of limestone and granite is assumed to be 2.7 tons per m^3. (E)

20) One **block** as a weight of almost 2.3 tons. (D)

21) According to findings at other pyramids, the **pyramidion** weighed approximately 2.7 tons. (A)

22) The weight of the **entire pyramid** is approximately 6.9 million tons. (D)

Ramps

What material were the ramps made of?
What are the advantages of external spiral ramps?

23) The ramps were built from **air-dried mud bricks**, which is an abundant and solid building material.
To prevent the dried bricks from cracking, the moistened clay must be enriched with sand and chopped straw. (P)

24) The ramps rested on the **steps of the inner stepped pyramid**. (T)

25) Plant material was used to **reinforce** the ramps. (P)

26) A **single transport lane** had a width of 3 block widths or 3.3 m. (P)

27) The **surface of the ramps** was kept stable and smooth by limestone slabs. This prevented the wooden rollers of the sledges from pressing into the ramp surface. (P)

28) Instead of limestone slabs, **wooden beams** could also have been laid in the direction of movement. However, since wood was scarce, limestone slabs were preferred. (T)

29) The ramps had **lateral support walls** to prevent slippage. (T)

30) The model uses a **slope angle** of 69 degrees, which also complies with current safety regulations for dam construction.
The following relationship applies:
$\tan(69°) \approx 4 * 0.7 / 1.1$ (P)

31) According to archaeological findings, the ramps had an angle of about **7 degrees**. (A)

32) In the model, a **ramp angle** of 6.6 degrees is chosen.
This means the ramp elements run along the grid of blocks in the inner stepped pyramid. After a transverse length of 5.5 blocks, each 1.1 m long, a height of 0.7 m, or the next higher level, is reached.
The following relationship applies:
$\tan(6.6°) \approx 0.7 / (5.5 * 1.1)$ (P)

33) At a slope of 6.6 degrees, the downward force is 11.6 %.
The rolling friction is very low at 0.4 %.
The **total tractive force** is therefore 12 % of the weight of the stone block. (D)

34) The volume of a **ramp element** of a single lane with 3 block widths is
$3 * 3\ (5.5 * 4) / 2 = 99$ block units. (D)

35) With 210 levels and 20 corners, the **volume of a single lane** can be estimated as
$230 * 99 = 22{,}700$ block units.
This corresponds to 0.76 % of the pyramid's volume. (D)

36) From the calculation in 34), it is evident that the volume of a ramp **increases quadratically with its width**.
If the width of the ramp is increased by a factor of x, the height must also be increased by the same factor of x. The slope and length of the ramp remain unchanged by the increase. (D)

37) This simple but **fundamental relationship** was discovered by the author in 2022.

38) This led him to develop a model consisting of as **many narrow individual lanes** as possible, rather than one wide lane. (T)

39) Consequently, the model was named **Multispiral Ramps**. (P)

40) This model consists only of **outer spiral ramps** and does not use an inner ramp. (T)

41) The model follows a uniform and consistent construction principle and is **not a hybrid solution**. (T)

42) A **detailed ramp model** can be designed by drawing a separate plan for each of the 4 lateral faces of the pyramid.
First, the grid of blocks is drawn onto the pyramid's surface. Then, the ramps can be drawn. When turning at the corners, the ramp path is consistently continued onto the next plan. (E)
(See Table 1 for details)

43) This is strong evidence that this **type of planning** was easily possible even 4,500 years ago.
For example, one could have used 4 vertical walls measuring 2 by 2 m and simulated the ramp's course using strings. Experimentation would have continued until a suitable configuration was found. This way, the decision would have been made before construction began, not on the construction site. (D)

44) The **number of lanes** per height or level can be determined using the 4 side plans.
Since the lateral area of a flank is proportional to the width of the lane, the maximum number of lanes is necessarily determined by the surface area of the inner stepped pyramid. (T)

45) The fact that the volume of the ramp increases quadratically with its width argues against Georges Goyon's **single-spiral model** from 1977, which requires more than 15 % ramp material. (T)

46) In the initial phase of construction, or on the lowest levels, there were a total of 13 transport lanes.
As the pyramid rose, the **number of lanes decreased** until only one remained at the top. (T)

47) The wide ramp started at the **southwest corner** of the pyramid, as this was closest to the quarries. (T)

48) Until the construction of level 55, or until the second turn of the wide ramp, the wide ramp could be built to any desired width.
This corresponds to the bottom quarter of the pyramid.
During this phase, there were sufficient transport lanes, and the project was limited only by the maximum number of 20,000 workers.
This means that the project was **capacity-limited** up to that point. (D)
(See Table 3 for details)

49) Level 55 marks the **turning point of the limitation**.
In terms of height, this corresponds to the lower quarter of the pyramid.
By this point, 60 % of the material had been used, and the construction time was 8 years. (D)

50) As the pyramid grew taller and the space became increasingly narrow, all the **single lanes** had to end at different heights. (T)

51) From the second turn of the wide ramp or from the construction of level 56, the project was limited by the maximum number of physically possible transport lanes. This means that the upper three quarters of the pyramid were **space-limited**. (D)

52) Only the **wide ramp** led to the top of the pyramid. (T)

53) Initially, the wide ramp had a width of 7 lanes.
In a later phase, the outer 5 lanes could be removed and the material further up used to extend the lanes.
A large portion of the ramp material could thus be **recycled**. (T)

54) A wide ramp was not only necessary in the initial phase of construction, but also had to remain functional at least up to half the height of the pyramid to ensure sufficient **logistical flexibility**.
This allowed large granite blocks for the King's Chamber and the sarcophagus to be delivered even after 15 years. (D)

55) A construction process without this **flexibility reserve** would not have been viable for a major state project with an absolute obligation to complete it. (D)

56) The ramps ran **counter-clockwise**. This was the only way to ensure that the north entrance remained accessible during the construction phase. Otherwise, the wide ramp, which started on the south side, would have completely blocked the north entrance. (D)

57) Therefore, a **wide single-spiral model** like Goyon's is incompatible with an accessible north entrance. (D)

58) The **total ramp volume** was 6 % of the pyramid's volume. (D)
(See Table 7 for details)

Construction method

Was the pyramid built in horizontal planes or in layers parallel to the outer casing? Was the outer casing applied all at once from the beginning, or was it added later from top to bottom?

59) The **inner stepped pyramid** with 209 levels was built from bottom to top. (T)

60) The construction method was based on **horizontal levels** and not on layers parallel to the outer casing. (A)

61) The wide ramp, which was the only one leading to the top of the pyramid, also had a **constant ramp angle** of 6.6 degrees in its upper section. (T)

62) If the ramp angle increases in the upper area, the towing team must also be enlarged, even though the space there becomes increasingly limited, inevitably leading to a **dead end**. (D)

63) This argues against the model by **Georges Goyon**. (D)

64) In Jean-Pierre Houdin's model, this leads to an irresolvable contradiction, since the **inner ramp** is located inside the pyramid and the space is much narrower than for the outer ramp. (D)

65) In the upper quarter of the pyramid, the wide ramp partially rested on the **lower circumambulations**.
Since the wide ramp was 10 m wide in total, a transport lane of 4.5 m width remained in the outer area of the ramp. (T)

66) On this outer transport track, the few blocks at the top and the **pyramidion**, weighing 2.7 tons, could be installed. (T)

67) The sharp edge lines in the lower part of the pyramidion were **chamfered** or beveled. (A)

68) The chamfering prevented the outer edges from **breaking off**. When the pyramidion was installed, wedges had to be driven under these edges to remove the rollers underneath. This resulted in high compressive forces in this area. (D)

69) By wrapping the wide ramp, a **platform** measuring 8 by 8 m was created at the top. This provided a good base for working at the narrow summit. (T)

70) The raising of the pyramidion probably represented a **sacred concluding act** of the construction project. The pharaoh was carried on a litter to the platform at the top. High-ranking officials and priests were present on all the ramps. (P)

71) After the pyramidion was erected, the ramps were dismantled from top to bottom. Simultaneously, the **outer casing** was installed from top to bottom. The remaining ramps provided a good working platform. However, this process was only carried out up to a height of 15 m. (T)

72) At a **height of 15 m**, the ramps were completely dismantled. Then the outer casing was built from the bottom up using heavy blocks, reaching a height of 15 m, and connected to the upper part of the casing. Afterwards, all remaining ramp components were removed. (T)

73) The reason the casing in the lower section was applied from bottom to top was probably that stacked stone blocks inevitably create **thinner joints**. This made it impossible to see the brown inner stepped pyramid through the joints.
As a result, the building appeared as if cast from a single mold and looked more magnificent. (D)

74) When two heavy blocks lie flush against each other, the stones naturally grow together. This is due to the rock's slight **water solubility** and the subsequent recrystallization in the joint area. This is the automatic smoothing and filling of the joints. (T)

75) Over time, one notices that not even a **piece of paper** fits into the joints. However, this wasn't necessarily the case in the initial phase.
This phenomenon also applies to other precision structures, such as Machu Picchu. (D)

76) The pyramid's faces are folded inwards. Therefore, the pyramid has **8 sides**. On the north side, the inward curvature measures 94 cm. (A)

77) The north entrance was moved 7.29 m eastward from the center line, as the highest-pressure loads occur along this line. (A)

Precision

How was it possible for the pyramid to have this perfect geometric shape?
How could the north-south direction be determined so precisely?

78) When building the inner step pyramid, it was only important that the **center of each level** moved vertically upwards. (T)

79) With the placement of the pyramidion, the **exact proportions** of the pyramid were determined. (T)

80) Then the real **precision work** began with the installation of the outer casing. Large perpendiculars were used to accurately determine the ramp angle. (P)

81) The workers had a **clear view** upwards and to the sides. (D)

82) This is why this process took **1.6 years**, even though only 0.7% of the material was used. (D)

83) To determine the **north-south direction**, a shadow stick similar to the Indian gnomon was used. Since a single measurement is subject to errors, the high precision could only be determined statistically over many measurements. (T)

84) Precise **horizontal planes** could be determined by flushing them with water. (T)`

85) A long, **precise line** along the base edges of the pyramid was determined using a floating string. The average value was calculated from several measurements. (T)

Workers

How many workers were there at the construction site?
Why were there more workers during the Nile flood?

86) There were **10,000 workers** at the construction site at any given time. (H)

87) During the **Nile flood**, an additional 10,000 farmers were employed for over 3 months. Therefore, there were 20,000 workers during this period. (A)

88) For ¾ of the year, there was only **half the workforce**, or half the productivity. For the remaining ¼ of the time, there was full productivity. (H)

89) The **number of transport lanes** therefore had to be designed to accommodate the full workforce. This was easily possible in the lower third of the pyramid, but further up, the full workforce could no longer be deployed due to space constraints. (T)

90) The **productive part** of the workers was employed in the quarries or with towing. This amounted to 66 % of the total workforce. (P)

91) The productive part could only be considered as a **sum**, because the division into quarries and towing depots depended on the level of construction progress of the pyramid. (D)

92) The **overhead**, at 34 %, was comprised as follows:
construction and maintenance of the ramps 12 %,
sleds, tools, and repairs 4 %,
planning, supervision, doctors, priests 7 %,
catering 8 %,
sick leave 3 %. (P)

Transportation

Why could only human power be used and not animal power?
Transport methods included sliding sleds, sleds on wooden rollers, and using human chains. Where were these different transportation methods used?

93) **Animal power** could not be used directly at the pyramid. Animals are uncontrollable due to their fear of heights and the confined space. In a timed mass transport with serially coupled towing teams, the uncontrolled behavior of even a single animal would be enough to interrupt the flow of an entire track. Therefore, animal power is systemically unsuitable under these conditions. (T)

94) A **towing team** for a block weighing 2.3 tons consisted of 20 workers. (T)

95) The towing team had a **range of movement** of 18.75 m including a buffer of 6 m. (T)

96) Facing backwards, 12 workers towed simultaneously with **23 kp** for 1.3 seconds. (P)

97) In doing so, they generated a movement of the sled by 25 cm. (E)

98) The workers then had 2.7 seconds to **reposition themselves**. (P)

99) In this way, the team moved at a **speed** of 3.75 m/min. (D)

100) At the **corners** and for 10 m before them, the ramps had no incline. (T)

101) Therefore, the workers in this area only had to pull with **10 % of their usual force**. (D)

102) This allowed the team to **move more quickly** in this section and compensate for the turning maneuver at the corner. (D)

103) This compensated for the slowdown caused by the turning maneuver and prevented a **traffic jam** at the corners. (D)

104) The turning maneuver is like parking a car. (T)

105) Of the transport lanes, one was always used as a separate **way back**. This created a circular movement without collisions. (H)

106) The **speed** on the way back was 5 times greater than during the uphill transport. (P)

107) The **timed mass transport** comprised 99 % for the stepped inner pyramid and 0.7 % for the outer casing. (D)

108) These blocks weighed less than 5 tons, which is why they could be transported using **wooden rollers**. (D)

109) The large blocks (0.2 %) were placed on the **horizontal surface** of the truncated pyramid via the wide ramp on the south side during the first 5 years. (T)

110) There they covered less than **15 % of the surface**. (D)

111) Since wooden rollers can break under weights exceeding 5 tons, transport on **wooden beams with Nile mud** was used here. (T)

112) Using a **temporary 2-degree ramp**, the blocks were moved to the next higher level, which was partially built upon. The blocks did not need to be rotated or turned. (T)

113) This method is called **zigzag lifting**, because the lifting is only done by moving back and forth. (P)

114) From **60 %** of the height onwards, all the huge blocks had been built in. (A)

115) Therefore, huge blocks could be decoupled from mass transport and did not have to be transported on the outer ramps.
These were **individual transports**. (D)

116) Erecting the **gable roof** on the north side was an individual operation. This was done by controlled lowering of sand and the use of catch rails. The opposing blocks were tied together at bosses so that they would straighten up accordingly during the lowering process. (E)

117) The 8 kg clay bricks for the ramps were transported using a **human chain method**. This method did not require ramps and was therefore flexible. (T)

118) This method was 6 times more efficient than heavy transport using sleds. (D)

Working Conditions

How many hours were worked per week?
Were the working conditions as harsh as in slavery, or did they meet our current humane standards?

119) There were **300 working days** in the year. The rest were Saint days. (D)

120) Work was carried out in **2 shifts** per day. (H)

121) In summer, the **first shift** ran from 4 to 10 a.m. and the second shift from 4 to 10 p.m. This avoided working in extreme heat. (P)

122) This results in an average working time of just under **35 hours** per week. (D)

123) Only the blocks in the **outermost layers** were regular. Most of the blocks were completely irregular. (A)

124) There were 6 working days estimated to produce a 2.3-ton block. Most of the blocks were completely irregular. (E)

125) The **convoy** of towing teams could not be stopped during a shift. Restarting would take too long. (T)

126) Therefore, the workers took **rotating breaks**. (D)

127) A worker for towing had to pull for the equivalent of over **1.5 hours** a day with a force of 23 kp. (D)

128) This workload combined with a 35-hour week corresponds to **humane working conditions** even by today's standards. (E)

129) The workers building the ramps took **collective breaks**, as the restart was rapid. (T)

130) Each shift consisted of 6 units of **45 minutes of work** and 15 minutes of break time. (T)

131) During mass transport, 99 % of the material, consisting of blocks weighing less than 5 tons, was transported.
Had **sliding sleds** been used for this transport, the construction time would have increased to 26 years, assuming the same workload for the workers.
This represents a 30 % loss of efficiency compared to the transport method using sleds on wooden rollers. (D)
(See Table 8 for details)

132) Therefore, the transport method of sleds on wooden rollers was a **necessity** to achieve the construction time of 20 years under humane working conditions. (T)

133) The **inefficiency** of sliding sleds is not mainly because the friction on sliding sleds is 12 times greater than with sleds on wooden rollers. (D)

134) The first important reason is the large number of **water carriers** required, as all towing teams on one track must be continuously supplied with Nile mud. (D)

135) Since the water carriers move 4 times faster than the towing teams, the following observation can be made:
The 4th team needs 1 water carrier, the 8th team 2 water carriers, the 12th team 3 water carriers on the lane, etc.
If you add up the water carriers for all teams, it turns out that the number of **water carriers increases quadratically** with the number of towing teams on a lane. (D)

136) The following formula provides a good estimate for the **number of water carriers** needed to operate a lane over 2 shifts per day. Here, X denotes the number of the current level (1-210) of the construction process:
$20 + X*X / 18 \approx$ water carriers depending on level X.
In the middle of the pyramid at level 105, the number of water carriers is determined to be 632.
At the top at level 207, the number increases to 2,401 water carriers, representing an increase of almost 4 times as much. (D)
(See Table 8 for details)

137) The second important reason is that the water carriers move 4 times faster than the towing teams and therefore require their own transport route.
Consequently, the ramps would need to be 20 % wider, which would increase the **ramp volume by 44 %**. (D)

138) The constant wetting with Nile mud would leave a **slippery coating** on the surfaces of the ramps. The barefoot workers would therefore constantly slip and have generally unpleasant working conditions. (E)

Deductive Reconstruction

Why is production planning so heavily dependent on the current construction height? Why is it not sufficient to consider only a single towing team for the calculation?

139) In the literature, a **single towing team** is usually used as the starting point for the calculation. (H)

140) However, this is problematic because the quantity delivered is very **closely linked** to the level of construction progress.
Furthermore, the number of workers for towing, production, and overhead are linked. (D)

141) Therefore, a **fully staffed delivery lane** must be considered the smallest unit of calculation. (D)
(See Table 2 for details)

142) With a fully occupied lane, **144 blocks** could be delivered per day. (D)

143) The following formula provides a good estimate for the total number of workers required to operate one lane.
Here, X denotes the number of the current level (1-210) of the construction process:
1.800 + 24*X = number of workers depending on level X. (D)
(See Table 2 for details)

144) The **number of delivery lanes** can be calculated based on the number of workers per lane and the total number of workers.
The corresponding delivery lanes, plus a separate return lane, must of course physically exist. (D)
(See Table 3 for details)

145) The number of delivery lanes is a measure of the **overall performance** of the system.
Half a lane here does not mean that the lane was half the width, but rather that there were only half as many towing teams on the lane and the distance between the towing teams was correspondingly greater. (D)

146) The construction method followed a consistent and uniform principle and is not a **hybrid solution**. (D)

147) The **uniform building principle** was common in the Old Kingdom. (H)

148) This was the only way **thousands of workers** could work on a single project. (T)

149) The aim of this theory is to completely describe and analyze a **construction process involving mass transport**. (P)

150) If there are **several possibilities** at some points in the process, the most efficient one should be preferred. (T)

151) Thus, in addition to the sparse archaeological finds, a further guiding principle emerges, and with it a **second source of information**.
This source of information is the criterion of efficiency in accordance with the technical and political-religious customs of the time. (T)

Simple Estimate of the Construction Time

How can the construction time of a level be determined?
Can the construction time of the pyramid be estimated using simple calculations?

152) In the following **calculation example**, the construction time of level 109 is determined using simple, elementary calculation methods.
This level lies slightly above the center of the pyramid and can be used as a good average value.

According to the formula in 143), the number of workers required to operate a single track can be calculated:
1,800 + 24*109 = 4,416 workers per lane.

Outside of the time of the Nile flood,
10,000 / 4,416 = 2.26 lanes
could therefore be used.

During the Nile flood, the workers could have operated twice the capacity, namely 4.52 lanes.
However, since there were only 5 lanes physically available at that stage, and one of them was used for the way back, only 4 lanes could be used.

The annual average was
(9*2.26 + 3*4) / 12 = 2.7 lanes.

Thus, on each working day
144*2,7 = 389 blocks
could be produced, delivered and installed.

Level 109 consists of
(210-109) * (210-109) = 10,201 blocks.

Therefore, the construction of level 109 requires
10,201 / 389 = 26.2 working days.

If this construction time is taken as the average duration for one level and 300 working days per year are assumed, the construction time for the inner stepped pyramid including the pyramidion is
210 * 26.2 / 300 = **18.34 years**. (D)

153) Overall, it is more than astonishing that this result can be obtained in such a simple way.
No electronic calculators are needed.
All that is required is a **piece of paper** on which to perform basic arithmetic operations. (E)

154) This is strong evidence that this **form of thinking** was easily possible even 4,500 years ago. (P)

155) The preceding example shows that during the construction of the pyramid, there were on **average 2.7 transport lanes** with a width of 3.3 m in the central area per year, plus a separate return lane. (D)

156) This contradicts Jean-Pierre Houdin's 2003 theory of the **internal ramp**, which posits a transport lane only 2.6 m wide in the upper two-thirds of the pyramid. With this limited transport capacity, construction would have taken more than 30 years. (D)
(See Table 4 for details)

157) As the height increases, the volume of each level decreases quadratically.
On the other hand, as the height increases, the number of workers required for hauling increases linearly, and the number of transport lanes decreases linearly.
Therefore, **two opposing phenomena** are at work. Due to the quadratic decrease in the volume of the levels, the construction time for each level decreases with height.
Level 1, 43.8 days construction time,
Level 109, 26.2 days construction time,
Level 200, 0.7 days construction time. (D)

(See Table 4 for details)

Archeology

What archaeological finds and evidence exist regarding the Great Pyramid?

158) The construction period of 20 years was given by the two historians **Herodotus and Diodorus**. (H)

159) Cheops probably had a **reign of 23 years**. (H)

160) The fact that Cheops was still alive at the **end of the construction** independently supports the claim of a construction period of 20 years. (D)

161) If Cheops had died before the pyramid was completed, then the construction would probably **not have been finished**. (D)

162) Overall, this is the **longest known construction time** for a pyramid. (H)

163) The **Red Pyramid** is the predecessor of the Great Pyramid of Giza. It is somewhat smaller and probably took 15.5 years to build. (H)

164) **All techniques**, resources, and working practices were known at that time. (T)

165) Diodorus mentions that there were **no lifting devices** in the Old Kingdom. (H)

166) Diodorus also mentions that the stones were transported using **sloping earth embankments.** (H)

167) These were flexible **lifting and transport devices** in the Old Kingdom. (A)

168) Diodorus also mentions that the stones were transported using **sloping earthen embankments**. (H)

169) These were flexible **lifting and transport devices** in the Old Kingdom. (A)

170) To surpass his father, the pyramid builders had to construct the **largest possible pyramid** within 20 years. (P)

171) To fulfill this task, it was essential for the pyramid builders to choose the **most efficient method** at every stage of the process. (T)

172) In the Old Kingdom, **efficiency was not a luxury**, but a necessity. (T)

173) Herodotus describes work assignments of **10 times 10,000** workers, which is usually given as 100,000 workers. These work assignments are said to have lasted 3 months. (H)

174) This can probably be interpreted as meaning that during the Nile flood, a total of **10 groups** of 10,000 workers each were formed throughout Egypt, which corresponded to about one third of the farmers at that time. (P)

175) **One of the groups** was additionally used for the construction of the pyramid. (T)

176) Since the maximum number of workers at the pyramid was 20,000, it can be concluded that **only 10,000** workers were employed during the remaining 9 months. (D)

177) Diodorus writes of the ominous number of **360,000** workers. (H)

178) This is impossible, however, because that would correspond to about a **quarter** of the population of all Egypt at that time. (D)

179) The intended meaning is that if one takes the construction time of 20 years and adds the 10 years for building the causeway, one arrives at a total of 30 years for the project.
With an average of 12,000 workers, this number represents the **working years** for the entire project. (T)

180) Among the graves, a picture was found depicting the transport of a statue weighing at least 10 tons on a **sliding sled**. (A)

181) This represents a **political-religious ceremony**, as only religiously motivated themes were depicted in the graves. (H)

182) For this reason, it is understandable why there are no depictions of **sleds on wooden rollers** in the graves. The grave images were meant to help the deceased reach the afterlife and not to explain why rolling friction is better suited for mass transport than sliding friction. (D)

183) This also explains why there are no **finds of sleds** and wooden rollers in the graves. (D)

184) There are also no archaeological **finds of wooden rollers** outside the pyramid. (A)

185) This is understandable, since wooden rollers were **valuable tools** and were reused in other locations after the pyramids were built. Even if the rollers had been old and broken, the material would still have served as valuable fuel. (T)

186) The **ramp material** was dismantled in parallel with the installation of the outer casing. (T)

187) Since the ramp material constituted only 6 % of the pyramid's volume, 12 % of the workers could **easily remove** it within 1.6 years. The ramp material was transported using human chains, which is 6 times more efficient than transporting the stone blocks on sleds. (D)

188) After the outer casing was installed, a **perimeter wall** was built around the pyramid at 10 m. The area between the pyramid and the wall was paved.
Later, a second perimeter wall was added at 20 m to better separate the surrounding mastabas. (H)

189) After the pyramid's completion, the area within a 20-meter radius was worked and built upon. This was the area where the spiral ramps rested on the earth's surface. Therefore, it is now completely impossible to find any **remains of mud bricks** or plant material in this area. Should individually fragments of limestone be found, it is impossible to determine whether these are remnants of a ramp or not. (T)

190) In the immediate vicinity of the southern quarries, there are **finds of ramp remains** with an angle of about 7 degrees, pointing towards the southwest corner of the pyramid. (A)

191) Over a period of 20 years, a total of 6.9 million tons of rock were transported from the quarries to the pyramid.
Therefore, for reasons of efficiency, it was essential to construct a **massive transport route** here, which also had to overcome slight differences in elevation. (T)

192) The transport route also served as an **intermediate storage area**, as up to 1,600 blocks per day were used in the initial phase.
Although the scheduled transport only began with the ramps at the pyramid, a continuous supply of materials had to be always ensured to avoid downtime. (T)

193) Mark Lehner interpreted the finds in the southern quarries as the remains of a **large ramp** leading to the pyramid. This ramp would have been approximately 320 m long and comprised 9 % of the pyramid's volume. Jean-Pierre Houdin adopted this theory in his tunnel theory. (H)

194) If this large ramp had existed, then more significant finds would have been made.
Overall, this is not archaeological evidence, but rather an **interpretation** that contradicts efficiency and a uniform construction principle. (D)

Archaeological Check of the Multispiral Ramps

Do the few findings and evidence support or contradict the Multispiral Ramps?

195) The explanatory model of the Multispiral Ramps is consistent with the few finds and evidence and is therefore **archaeologically neutral**. (D)

196) The theory uses only **techniques** that were known in the Old Kingdom. (H)

197) The ramp material from 6 % had to be completely removed when the outer casing was installed.
Therefore, there can be **no archaeological remains** here. (T)

198) The **lack of large-scale ramp remnants** argues against classic large ramps, but in favor of temporary, smaller ramps with recycling. (D)

199) This argues against a **straight outer ramp**, which, at an angle of 6.6 degrees, would have had a length of 1.3 km and a volume of 160 % relative to the pyramid's volume. (D)

200) Spiral ramps rested flat on the steps of the inner stepped pyramid. The ramps served not only as supports but also as mechanical buffers. This prevented point loads and thus also prevented **deformation of the subsoil**. (T)

201) Any **signs of wear and tear** at the boundary between the ramp and the pyramid could have been caused by lateral impacts during transport. (T)

202) The explanatory model of the Multispiral Ramps uses as its **argumentative criterion** only the closed and consistent functioning of the overall process, whereby attention is paid to optimizing efficiency at every point. (T)

203) **Archaeological criteria** are used only to test consistency or falsification, never as evidence for the theory. (D)

204) Archaeologists will now have the opportunity to test or **falsify** this theory. In the areas of the pyramid where there were ramps, the concentration of dried brick remains between the joints of the stone blocks should be significantly higher than in areas where there were no ramps. (A)

205) Especially on the **south side**, where there was a wide ramp for a longer period of time, there should be signs of lateral wear and possibly discoloration. (A)

206) The lower 15 m of the outer casing of the **Pyramid of Menkaure** are still preserved. The size of the stones suggests that they could only have been laid from the bottom up. (A)

207) A few stones from the outer casing of the Great Pyramid have survived in the **lowest section**. The size of these stones suggests that they were laid from the bottom up. (A)

208) Overall, the question arises as to why, apart from the structure itself, there are **almost no archaeological finds** with which the construction of the pyramid can be explained. (P)

209) In the relieving chambers above the King's Chamber there are **graffiti** by construction workers, which contain statements such as “Friends of Khufu”. (A)

210) Originally, this place was closed and **inaccessible**. Almost 200 years ago, those involved forced their way in. (H)

211) In 2013, documents made of **papyrus** were found on the Red Sea, about 250 km from Giza. (A)

212) One of the documents is a **parts list** for the construction of the Great Pyramid. This is a clear indication that the construction project, in its structure, resembles a modern-day large corporation, but using the techniques of that time. (D)

213) Of the **only two finds**, one was in an inaccessible place and the other was very far away from the pyramid. (A)

214) The two historians Herodotus and Diodorus received their information more than **2,000 years later** only through oral tradition. (H)

215) From this it can be concluded that the **guild of pyramid builders** was a high caste and kept all their knowledge strictly to themselves. (D)

216) Therefore, they ensured that **no permanent documents** or traces remained. (D)

Conclusion

How should the results so far be interpreted?
Are there any implications of the explanatory model that will enable future archaeological investigations?

217) Despite the monumental construction, there are only **sparse archaeological finds and evidence** that indicate its construction method. (A)

218) Since pyramid construction evolved and changed over the course of 300 years, the **findings at other pyramids** are of little help. (D)

219) In 1981, the archaeologist Dieter Arnold stated:
"*How the Egyptian builders managed to cope* ***can no longer be determined****. However, the examples of the Great Pyramid of Giza and the Pyramid of Khafre demonstrate that they succeeded in solving the problem."* (H)

220) The only way to make progress here is to put oneself in the position of the **chief construction managers**.
They had to erect a perfect, mammoth structure within 20 years. Failure would have been the greatest catastrophe for the Pharaoh and would have resulted in the harshest punishments for the construction managers. (P)

221) In this context, it was more than imperative that the construction managers have opted for the safest and **most efficient construction method**. (T)

222) This creates a **second source of information**, which inevitably makes a decision at every point. (D)

223) This allows a **reconstructed building plan** to be created with the greatest possible efficiency. (D)

224) Overall, this results in a **complete, rational explanatory model** for the construction of the pyramid. (D)

225) But that is also the **maximum** that can be expected at this time. (D)

226) The explanatory model provides archaeology with a verification method to search for ramp traces between the outer stone blocks in the future. This will allow the theory to be **archaeologically confirmed or falsified**. (A)

Historical Context

The following points are not part of the deductive justification of this model and serve solely for historical contextualization.

227) In 1912, **Uvo Hölscher** published a proposal in which lateral ramps are placed on the inner stepped pyramid and wind upwards in a spiral. (H)

228) In 1956, **Dows Dunham** published a model in which a ramp started at each of the 4 corners of the pyramid. (H)

229) The work was created through an **interdisciplinary collaboration** with Walter Vose, a professor of engineering. The result was presented as part of an exhibition, but was not further developed. (H)

230) This **innovative work** failed to gain acceptance due to the following two objections:

- The large blocks cannot be transported on the narrow ramps, (points 107-113)
- Queuing occurs at the corners of the ramps, (points 100-104) (H)

231) The following three **interpretations** were widespread in research. Therefore, they significantly shaped the framework of the discussion in the past, which made the development of a consistent overall logistic model more difficult:

- The outer casing was installed parallel to the inner step pyramid (Goyon, Lehner, Houdin), (points 206-207)
- An external ramp led from the quarries to the pyramid, (Lehner, Houdin), (points 190, 193)
- Transport by sliding sleds is archaeologically compelling (points 180-181). (P)

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