The Giza Pyramid : learning from this megaproject

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Abstract

Purpose

This paper demonstrates the contemporary relevance of the management of the Great Pyramid of Giza project.

Design/methodology/approach

The paper uses evidence from the literature from many disciplines concerning both the objectives and construction of the pyramid. It relates this to recent discussion concerned with the issues faced in megaproject management which are core to discussion of success and failure.

Findings

The analysis shows the significance of the "break-fix model" of megaproject management and how having a sequence of megaprojects builds management through a learning process. It demonstrates the significance of innovation arising from the experience of previous projects in solving major technical challenges and illustrates the importance of the organisation and ethical management of a substantial workforce.

Research & practical limitations/implications

There is very limited reliable documentary evidence from the time of the construction of Giza (c 2560 BCE). Many sources concerning ancient Egypt are still widely contested. However, the use of research from a combination of disciplines demonstrates the relevance of the project and the importance of learning from history to contemporary project management.

Originality/value

We believe this is the first paper to analyse the Giza pyramid project from a project management perspective. This was arguably the most significant construction project of ancient history, and the paper explains the lessons which can be learnt which are very significant to today’s megaprojects.

Keywords: Project management history, megaproject, case study, “break-fix model" of megaproject management, Giza pyramid project.

1) Introduction

Flyvbjerg (2014) defines megaprojects as “large-scale, complex ventures that typically costs US $1 billion or more”. Using this definition, he suggested that megaprojects account for 8% of the world’s GDP. This figure is rising. In citing this work Söderlund et al (Söderlund, Sankaran and Biesenthal, 2018) refer to the work of Thomas Frey in predicting that within the next decade megaprojects will increase to 24% of the world’s GDP. In future we will most probably be talking about terraprojects, i.e. projects with a cost exceeding $1,000 billion, for example to tackle substantial global issues such as climate change.

Such projects, however, do not enjoy a successful track record if measured by traditional criteria. Flyvbjerg’s paper estimates that just 10% of these projects are completed within budget, 10% within time and 10% realise the benefits of their business case. We must at the outset acknowledge that there are other criteria by which success can be measured, which are arguably more significant (for example long term benefit to stakeholders). Furthermore, there are many reasons for the initiation of megaprojects beyond their practical use value. Flyvbjerg famously talks about the ‘four sublimes at play’, possibly most significant of which is the ‘political sublime’ conferring immortality on the project sponsor. Nevertheless, by any criteria, megaprojects have a very poor record and are typically characterized by what Flyvbjerg refers to as the “Break-Fix” model of megaproject management. The project commences and then becomes broken in a fundamental way. At this stage it is either abandoned or it is fixed, typically by adding substantial additional resources and time and possibly also by altering the specification. Flyvbjerg suggests that there are 10 characteristics of megaprojects which contribute to this failure – a theme that has been taken up more broadly in the literature (Söderlund 2018). These characteristics are discussed in section 6.

There is clear common ground between Flyvbjerg’s analysis of megaprojects and Morris’s argument (2013) for the development of theory in project management. Morris argues:

> “...in the early 1970s … the discipline [project management], as it had now clearly become, began to be seriously affected by social, economic, political, and environmental issues... The theory-light engineering project management available at this time was just not rich or powerful enough to help managers deal with the uncertainties created by this new generation of externalities.”

He suggests that the adoption of multiple perspectives and reference to research from other disciplines can greatly strengthen project management research and practice. This is supported by other project management researchers. Söderlund (2018) argues that “A wider perspective will most certainly be needed, including research from diverse disciplines following different approaches.” Hodgson and Cicmil (2006) presented the case for more critical project case studies that reflect the political, social, and ethical dimensions of project management work. Morris argues that this approach allows for a much richer analysis, providing more depth than the traditional triple constraint of time, cost and scope.

Flyvbjerg (2014) concludes his paper by discussing the value of research into successful projects which can indicate how we might replicate successful practice. He refers to projects from the previous 70 years which are largely drawn from European and North American case studies. Case studies from history have great contemporary value that can influence and inform our present understanding of project management (Söderlund, 2011, and 2018). Several authors do just this; thus, for example Lenfle and Loch (2018) analyse lessons from twentieth century military and space megaprojects.

There are however megaprojects from a much earlier time representing greater international diversity. Whilst there are limitations to the data available for such projects, analysis of historical case studies can enrich our understanding of megaproject success and failure and empower international scholars (Kozak-Holland and Procter 2014).

The construction of the Great Pyramid of Giza still stands as a testament to effective project management. Until the building of the Lincoln Cathedral in c 1300 (Collins, 2001, P.234), the Giza Pyramid was, for nearly 4000 years, the tallest building in the world, and is the only survivor of the original seven-wonders-of-the-world. It is thought to have been completed in less than 20 years in 2560 BCE without basic tools (such as the wheel) that would be taken for granted today. Bowden et al (2019) talk about "The Egyptian pyramids … remain a perpetual source of wonderment". Although the authors discuss this accomplishment as something cited in first year management courses, there is little or no published work concerning the project management of these projects or how obstacles faced by contemporary projects were addressed then.

The paper provides an analysis of the experience developed by the Egyptians in building pyramids, showing how they developed their expertise in the management of such huge projects. This is developed by a more detailed explanation of the construction of Giza. This evidence is then used to explain how they could address the shortcomings of both their own previous projects and by the discussion of Flyvbjerg's 10 characteristics. Thus, an analysis of this historical project helps to illuminate contemporary practice.

2) Data collection

The textual evidence concerning the construction of the Giza pyramid is somewhat unreliable, as the sole early source is from a Greek traveler, Herodotus of Halicanassus, written 2000 years after the project. Furthermore, the interpretation of evidence from the fabric of the pyramid structure is challenging as it has suffered from earthquake, erosion, defacement, and pillage which has altered the original condition.

A review was conducted of contemporary literature pertaining to both the Giza pyramid construction, and the wide variety of different disciplines beyond Egyptology that make up the study of ancient Egypt. These provide disparate and fragmentary evidence which is pieced together in the paper to reinterpret the case study. For example, geoarchaeologists apply geoscience methods to archaeology and provide critical context, practical clues, and greater meaning to archaeological surveys and excavations. In addition, new insights are being provided by experts who are re-examining and re-interpreting existing evidence using new technologies such as DNA analysis of skeletal remains, CAT scans of mummies, Geographic Information System tracking of the distribution of artefacts and features, satellite imagery and Ground Penetrating Radar (GPR) scans of the Giza Plateau and pyramid. The discovery and archaeological digs of the worker's village (Kemp, 1989, p.141) and cemetery in the last three decades is also significant to this case study. This new research provides more plausible explanations to the workforce involved in the project and a number of unresolved technical challenges that are discussed in this paper. As a result, the case study is dynamic and evolving as new theories are being developed from this accumulated knowledge.

3) Prior megaproject experience

3.1 Water resources

When Ancient Egypt was united from two separate kingdoms in 3150 BCE it became the world’s first nation state (Silverman, 2003, p.22). The new nation state led to the rise of a complex society, resulting from the increasing economic exchange and integration between formerly autonomous villages (Kemp, 1989). For the ruling class the primary objective was to maintain unification and strengthen this state through a powerful centralised government which used major public works to tackle national problems and focused resources where most needed. These projects helped to maintain its unity through the benefits realised and enhance its position with neighbours through trade and procurement. Major projects, including the pyramids, involved the co-ordination, organisation, and management of huge numbers of workers. State resources were distributed as rations to workers, officials of the state, and army personnel on public works projects. Thus, the state-controlled bureaucracy kept the economic system functioning for the benefit and wellbeing of the nation as a whole. Duiker and Spielvogel (2015) show how the political importance of each new monument increased as a symbol of Egypt's growing power in the ancient world.

According to Kemp (1989), ancient Egypt experienced “massive institutional intervention in the agricultural economy” [p. 319]. In particular huge irrigation projects were carried out to build ditches and canals and divert the river Nile. According to Angelakis et al (2012, p130), in 3000 BCE water management was so sophisticated that King Menes diverted the course of the Nile to build the city of Memphis through the construction of basins to contain flood water, digging canals, irrigation ditches, and dams. The seasonal flooding of the Nile was managed to ensure an abundance of food in a naturally arid country. They managed projects for the diversion and conservation of water building canals and irrigation ditches, flood water basins, dams, water supply tunnels, water purification, and even sanitation systems. Vast repositories were created for storage of food surplus. The Fayoum project (Angelakis et al 2012, p132) diverted millions of gallons of Nile water wasted in the deserts of Fayoum.

3.2 The History of Pyramid Building

Prior to Giza, the Egyptians had up to 300 years of experience in pyramid building that started with the building of underground tombs. Many of the clues as to why and how the Great Pyramid of Giza megaproject was completed lie in this lineage of pyramids. Many challenges thought unique to the project were overcome in this evolution to greater structures, as the Egyptians kept pushing the limits of materials, equipment and men. They adjusted practices during these projects reflecting their experience and changing conditions. Indeed, the resilience of the Giza pyramid can be attributed to the responsiveness of the Egyptians to their previous experience of pyramids, suggesting a culture of organisational learning (Senge, 1990) which in contemporary terms could be likened to agility.

The succession of pyramids was built as tombs for the Pharaohs, probably to protect their journey after death, and as symbols of power. They are thought to have served a secondary purpose as astronomical observatories (Fernie, 2004). They were designed on a scale quite different to previous tombs.

Originally sand was removed down to the bedrock and then a 3-4 metre tomb was carved out. A mastaba, or rectangular building, was erected above the tomb, made up of mudbrick walls rising to 6 metres (Houdin, 2010). These older burial practices were essentially sand-pit burials but were uncovered by wind and wild animals.

The Egyptians reflected on their work and made adjustments to the structure. Thus, the Pharaoh Djoser's architect, Imhotep, stacked mastaba on mastaba to create a step effect and combined the old separate elements of underground burial complex and ceremonies in one location (Dodson, 2011). From this method the first step pyramid was completed at Saqqara in 2880 BCE, at a height of 109 metres, and base of 125 metres. The pyramid is comprised of six separate 'steps', or layers, that were faced with limestone. As the Egyptians progressed from the single mastaba to the pyramid there was a major shift in construction, from mudbrick to a limestone structure encasing a crude core of rough stones. It also had an inner granite burial chamber, a non-local material that had to be excavated by hand using dolerite pounders and then transported from over 1000 kilometres away (Bloxam, 2011). The Saqqara pyramid was very grand in size and probably larger than any other previous stone building in history (National Geographic, 2015).

The next pyramid, named after the Pharaoh Sekhemkhet, was built, although never completed, in 2648 BCE, to a height of 7 metres and a base of 125 metres. It was initially planned as a step pyramid with six or seven steps and to a height of 71 metres. It was built of limestone blocks like Saqqara. Only the first step of the pyramid was finished, leaving a monument in the shape of a large mastaba. It is thought that the pyramid was never completed owing to the early death of the Pharaoh (Houdin 2013).

The second completed pyramid was the collapsed pyramid of Snefru at Meidum, c.2620 BCE, to a height of 92 metres, and a base of 144 metres. The Meidum pyramid was the first true pyramid (i.e. with sloping sides at an angle of 51° incline) designed and built with steps. These were filled in with limestone, although over time the limestone casing was not stable and collapsed. The pyramid's granite burial chamber had a vaulted ceiling built above ground that was corbelled of 10 layers to prevent its collapse by distributing the weight of the large stones above.

The third pyramid was the Bent pyramid of Snefru, ca.2600 BCE, to a height of 105 metres, and a base of 189 metres. This is a very apt example of how the Egyptians responded to a setback, through a process of framing the situation, experimenting with a solution, reframing and trying again. By reflecting on their work, they made adjustments to the angle of inclination several times during the construction phase as the project conditions changed. The pyramid started out at angle of inclination of 60° but the base began sinking in clay and the ground gave way under the weight and damaged the casing. Thus, another outer layer of casing was added, and the angle was changed to 54°. Further structural problems developed with the subsidence, as one of the corners was built on unstable ground and began to sink. The casing slipped, and more damage occurred. Structural changes were necessary and thus the angle was drastically lowered to 43°. Cracks developed in the walls of its burial chamber and cedar logs were wedged between the walls to keep the pyramid from collapsing inward.

The fourth pyramid was the Red pyramid of Snefru, ca.2580 BCE, to a height of 104 metres, and a base of 220 metres. Following the lessons of the Bent pyramid the architects laid a secure foundation platform of several courses of limestone to prevent the problem of subsidence from recurring (Mendelssohn, 1974). This encouraged construction of the pyramid with stones laid in level, rather than inclined, courses at the similarly modest angle of 43° to a lower height of 104 metres. The pyramid has a similar size base to the Giza Pyramid (230 metres) but is approximately 66% of the volume because it is lower in height. Table 1 below summarises the sequence of pyramids that led to the Giza pyramid project;

Table 1: Summary of key pyramid projects

Table 1 The sequence of pyramids

Approximate completion date BCE	Pyramid name	Project summary
2886	Saqqara	Step pyramid, built by architect Imhotep, 109 m high and 125 m at the base. Six layers faced with limestone instead of previously used mudbrick
2648	Sekhemkhet	Incomplete. Built to 7 m high with base of 125 m. Planned as a step pyramid, most likely abandoned as a result of the early death of the 'project sponsor' pharaoh
2620	Meidum	Collapsed pyramid, also considered the first 'true' step pyramid, built from filled limestone but unstable
2600	Bent pyramid	Also at Snefru. 105 m high and base of 189 m. Subsidence resulted in change to the original inclination of 60°. Continued problems resulted in further change from 54° to 43° after one of the corners began to sink
2580	Red pyramid	Also at Snefru, 104 m high, base of 220 m. Lessons from the Ben pyramid resulted in several courses of limestone to prevent the problem of subsidence
2560	Great pyramid of Giza	Completed in approx. 20 years. 146.5m high and base of 230m. Two further massive pyramids (which still stand) were subsequently built at the Giza site.

The progression in pyramid building demonstrates the development of building techniques and project management from experience.

The Egyptians evolved their practices with each pyramid project improving:

- materials (mudbrick to limestone to basalt and granite)
- the pyramid type (mastaba to step to true pyramid with sloping sides)
- steepened angles of inclination

These incremental improvements were small but accumulated into significant results that allowed them to increase the external size of the pyramids and the complexity and size of the internal passages and chambers.

4)Scope and New Technical Challenges of the Giza Project

The previous pyramid projects, whilst substantial endeavours in their own right, laid the way for the far more significant Giza megaproject, with a significant increase in both the size of the final deliverable, as well as the project scope in the required workforce, materials, and supply-chain.

The scope of the Giza pyramid was more substantial than anything previously attempted. It covered the delivery of the pyramid itself and the surrounding funerary complex including a causeway, temples (valley and mortuary), and pits for two sun boats (see Figure 1 below).

Figure 1: A transparent view the Giza pyramid

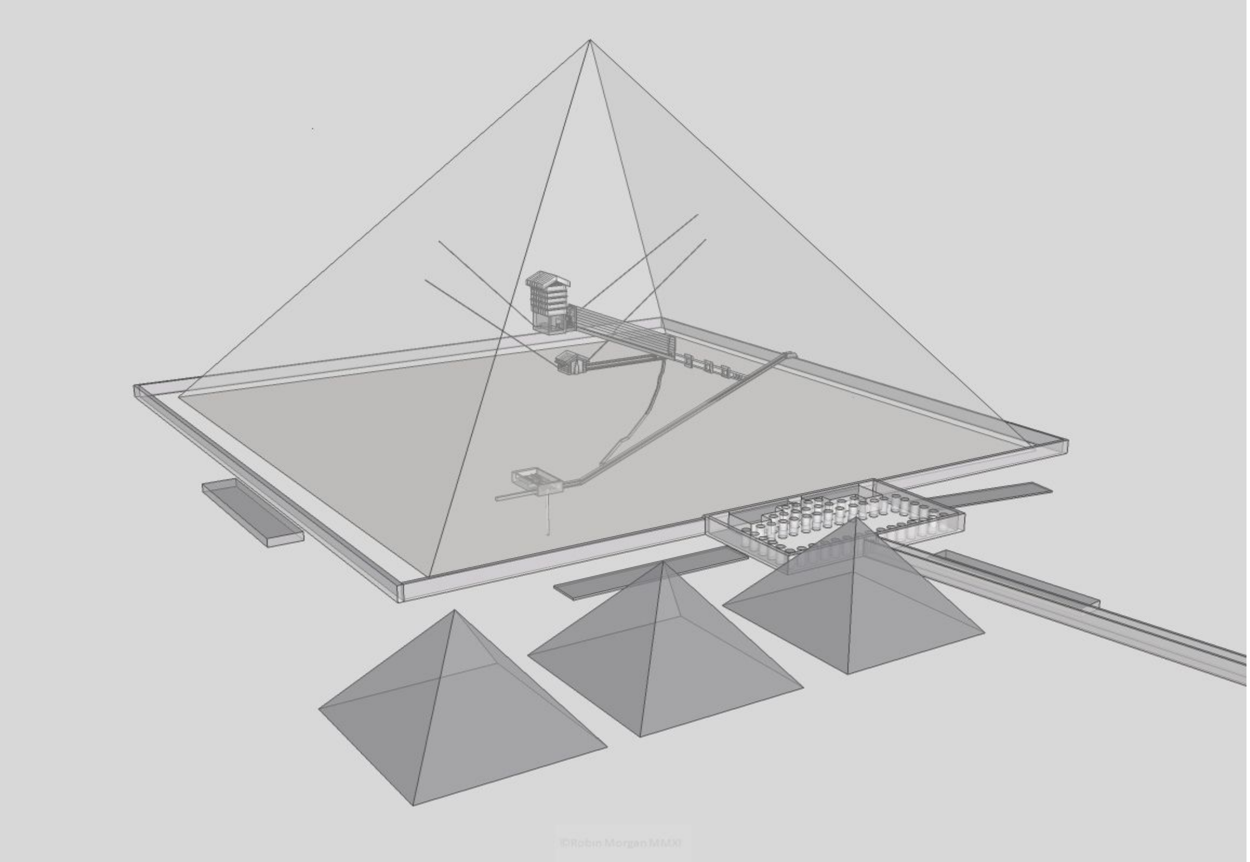


Figure 1: Highlights through a transparent view the size and scale of the pyramid exterior, and the complexity of the pyramid interior (Morgan, 2013). The underground burial chamber in the bedrock, like in other pyramids, was never finished.

Much of the project scope was dictated by the immense size of the Giza Pyramid, which was a logical progression from the Red pyramid. The planned Giza Pyramid at 146.5 metres and a base of 230 x 230 metres, was a 50% scale up over the Red Pyramid. Technical innovations were essential to control the scope, the size of the project workforce and how it was organized. Giza was an infrastructure megaproject of its time, involving a workforce of up to 40,000. According to Flyvbjerg (2014, p3):

> “Megaprojects are large-scale, complex ventures that … take many years to develop and build, involve multiple public and private stakeholders, are transformational, and impact millions of people.”

It was another in a line of public works megaprojects that also created an iconic and symbolic structure; a showpiece to demonstrate the power of the ruling class and primary stakeholders in the project. As Flyvbjerg (2014, p3) suggests, megaprojects are:

> “... designed to ambitiously change the structure of society. They are a completely different breed of project in terms of their level of aspiration, lead times, complexity, and stakeholder involvement.”

The Giza pyramid clearly met this definition. The objectives of the project were to:

- Surpass the previous pyramids (and all previous structures built by mankind) in size and magnificence
- To deliver a pyramid before Pharaoh Khufu died to facilitate his journey to the afterlife: this would both boost the political power of the pharaoh and ensure his immortality
- Boost the economy and the nation's wealth and unity, and thus the power of the state

4.1 King's Chamber & Grand Gallery

In the progression of pyramids there is a consistent architectural legacy between the Red and Giza Pyramids. A significant difference is the King's Chamber (built 43 metres above ground versus underground) and Grand Gallery. Within Giza the King's Chamber was started deep underground but was never finished. Dr Aidan Dodson (2011) suggests:

> "At first, the burial chamber was to be placed deep underground [like the Red Pyramid], with a descending passage and an initial room being carved out of the living rock. It seems, however, that it was decided that a stone sarcophagus - not previously used for kings - should be installed. Such an item would not pass down the descending corridor, and since the pyramid had already risen some distance above its foundations, the only solution was to place a new burial chamber-uniquely-high up in the superstructure [43 metres above ground], where the sarcophagus could be installed before the chamber walls were built. The architects of later pyramids ensured that there was adequate access to underground chambers by using cut-and-cover techniques rather than tunneling."

The project had to address a new problem: the roof of the chamber needed to span a void of 5.2 metres and required relief from the full weight of the pyramid above. The roof had to absorb the pressure and redirect it into the surrounding stones.

4.1.1 King's Chamber Roof

The builders progressed from corbelling, as in previous pyramids, to a unique design mixed with lintels, which allowed for a flat ceiling, according to (Dodson, 2011):

> "An impressive piece of architecture, this granite room was surmounted by a series of 'relieving' chambers [with lintels] that were intended to reduce the weight of masonry pressing down on the ceiling of the burial chamber itself."

This was the first time that hard granite was used on such a scale. The huge beams, weighing between 40 and 70 tons (43 were over 60 tons) for the chamber, gallery, passages and sarcophagus (stone coffin), were transported by boat from the Aswan granite quarries. Above the chamber roof there are five relieving chambers, capped by a gable to divert the forces sideways. The chamber is freestanding within the packed internal core and not anchored to anything.

4.1.2 Grand Gallery

They also designed a Grand Gallery, and an unusual wear pattern provides clues to large-scale kinetic activity that once took place there. Houdin (2010) suggests that a counter-weight system was built that slid along wooden rails. Its downward movement was carefully controlled, through a bearing stone (early pulley) and ropes, and then transferred outside to provide an extra pulling force to haul the 130 granite blocks up a short and steep external ramp onto the pyramid, to a height of 43 to 65 metres, and into position over the King's burial chamber. This system reduced the size of the pulling teams required. Further according to Greshko, M., (2017):

> "Thanks to the use of muon radiography, a technique that uses cosmic rays to detect cavities in massive structures, scientists have discovered a large, previously unknown opening within the Great Pyramid of Khufu. The cavity has a cross section similar to the Grand Gallery, the major corridor running through the pyramid, and is at least a hundred feet long."

According to coauthor Mehdi Tayoubi:

> "Since the void aligns with the Great Pyramid's upper chambers, which were put there to relieve pressure on the King's Chamber below, Spence suggests that the void may have been an internal ramp used to move the massive roof blocks into place. As construction continued, she says, this ramp could have been left empty or loosely backfilled."

Once all the granite was in place the short external ramp was dismantled and reused. The galleries were a major product innovation that would have reduced the scope and size of the workforce by simplifying the hauling of these beams to great heights.

4.2 Creating a Perfect Square of Limestone Blocks

The base had to be perfectly square and right-angled over 53,014 metres^2 (13.3 acres or 5.4 hectares); otherwise the four triangular sides would be difficult to align to a single point in the sky. Any imperfection in the right angles of the square would cause the apex to drift away from a true centre.

The discovery of geometry in ancient Babylonia provided the Egyptians with the ability to measure (lengths, angles, areas, and volumes) which had been widely used in surveying irrigation projects and building drainage ditches on land flooded by the Nile. For centuries "inspectors" (surveyors) had used this geometry to survey the work completed by the waterhouses (central offices). The land was checker boarded with small basins, defined by a system of dikes (Mays, 1999). Engineers had developed surveying instruments and a practical geometry to help them place boundary stones marking the edges of fields and irrigation basins. They transferred this skill and experience in measuring and surveying to the pyramid projects.

4.3 A Level Pyramid Base

A perfectly level pyramid base was required as inaccuracies of centimetres at the bottom would translate into metres at the top which would make the structure unstable. The builders also had to choose the building ground very carefully for its stability and ensure it was not susceptible to subsidence. To level the base the workers cleared the sand down to bedrock and carved channels that were filled with water, much like a carpenter's level. Egyptologist Mark Lehner (2010), using GPR, produced a meticulous plateau map of various holes and channels cut into the rock around the pyramid. He discovered that they had created a square base with perfect 90° (within 1 minute) angles, and the four sides are perpendicular to 58 millimetres of a 230 metres length. As the pyramid progressed upward by layers, plumb-lines were used to maintain a perfectly level base. Only small deviations of under a centimetre were tolerable for each layer otherwise distortions occurred (figure 2).

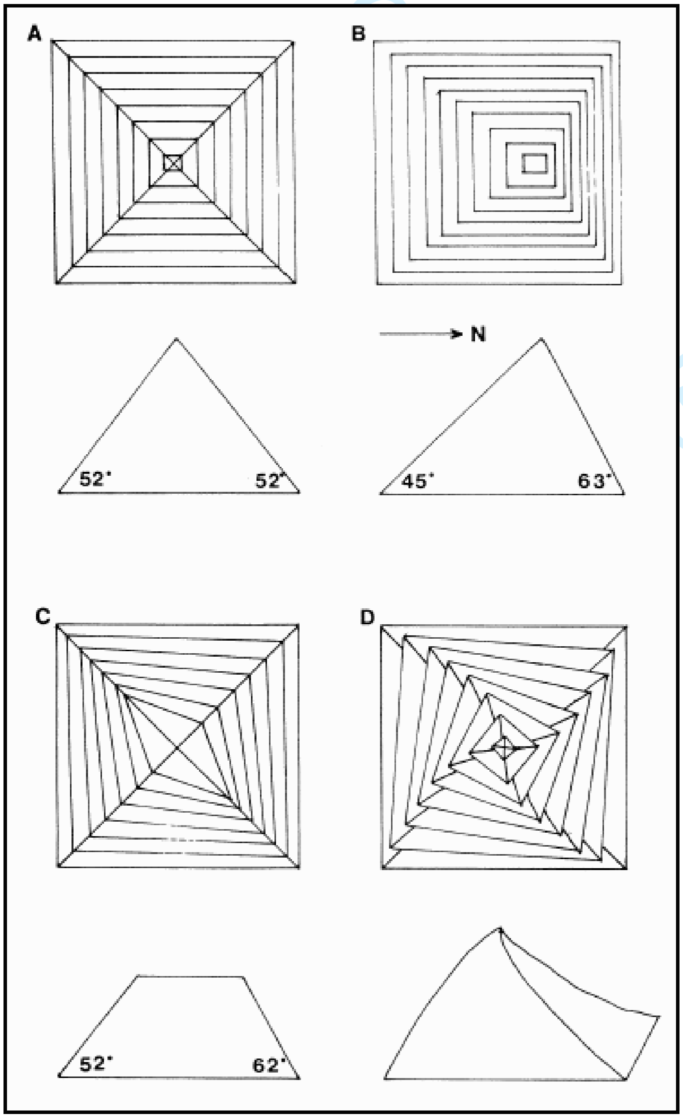
According to Boorstin (1992) "the pyramid builders had now learned to increase stability by laying the stones of the inner limestone base at a slope, and in other ways, too."

The builders used hewn blocks of limestone on a mass scale, roughly 2.3 to 2.6 million blocks. The pyramid base was enclosed in a limestone casing (now missing). The cornerstone foundations of the pyramid had ball and socket construction capable of dealing with heat expansion and earthquakes (Zajac,1989).

4.4 Perfect Pyramid Shape

Throughout the construction they would have to measure and calculate the position of the corners to the centre, the angle of inclination of the ridges and the lateral surfaces. The cornerstones guided the geometrical accuracy of the four right angled corners and the outer stones. If the four corners were not at a perfect 90° then the centre could drift off centre and the overall pyramid shape could be distorted where lateral surfaces can become convex or concave (Figure 2: D). Without perfect geometry the pyramid would slope as had happened in the Bent pyramid project.

Figure 2: External views of the pyramid demonstrating how distortions can occur (Sampsell, 2001)



With Figure 2: C the pyramid corners are either greater than or less than 90°, and the diagonals are equal. Intersection of the diagonals remains centred, but the square of the base becomes more distorted at each level. With Figure 2: D the pyramid corners are right angles, but the two diagonals are unequal. The intersection of the diagonals shifts where each course is twisted or rotated.

In spite of these problems, the team found solutions to the project technical challenges from their understanding of previous pyramid projects. Maintaining the position of the corners to the centre and the angle of inclination of the ridges was difficult and was done using special wooden measuring gauges. According to Petrie (1883, P.37-39) the primary purpose of the cornerstones was to fix the diagonals of the pyramid and ensure the geometrical accuracy of the four right angles. With the Red pyramid they had struggled to maintain the angle of inclination on all four sides: Egyptologist Rainer Stadelmann found that each side had a slightly different angle (Isler, 2001, p.120) leading to continuous adjustments as the pyramid went higher. Learning from this, the Giza pyramid surveyor team continuously measured and calculated the lateral surfaces and maintained the four right-angles at 90° so that the centre did not shift and distort the pyramid shape. The four faces of the pyramid are slightly concave, the only pyramid to have been built this way and according to Edwards (1975, p. 207):

> "In the Great Pyramid the packing-blocks were laid in such a way that they sloped slightly inwards towards the centre of each course, with a result that a noticeable depression runs down the middle of each face -- a peculiarity shared, as far as is known, by no other pyramid."

Kunkel (1962) likened each pyramid face to an arch dam where each side bends towards the force of the water it holds back, the same structural principles as the arch distributing pressure horizontally to the sides. This new practice very likely evolved from the experiences of previous projects.

4.5 Spiral ramp

Throughout the construction the workforce had to deliver limestone blocks, weighing 1.5 tons each, to substantial heights and a precise position. For the first few pyramid layers, delivering blocks was relatively easy. Beyond these layers a solution was required, and one plausible explanation is an internal spiral ramp (Brier, 2007) within the pyramid that allowed the building of the pyramid from inside out. The ramp idea was substantiated by French archaeologists who analysed microgravimetry scans of the pyramid: it begins at the bottom, is 2 metres wide, and winds through the pyramid like a square corkscrew at a gradient of 7%. The Egyptians realized that the total volume of material required decreases rapidly with the height of the pyramid, for example, at 50 metres of the 146.5 metres structure 82% of the total material was in place, and at 100 metres 97% of the material.

5. Supporting Infrastructure for Pyramid Building Projects

5.1 Ports and Transportation

The recent (Stille, 2013) find of the papyrus journal of a previously unknown official named Merer, in a set of 30 honeycombed caves provides an insight into the workers who participated in the building of the Giza Pyramid project. Merer led a crew of some 200 men, travelling across Egypt, picking up and delivering goods of one kind or another. The 30 gallery-caves carefully dug into the mountainside, cut by hand (50 to 100 feet in length) were used to store their boats during the winter when the Red Sea was not calm. Within close proximity is an ancient harbour for the boats with a L-shaped stone jetty (600 feet) to protect them; an enterprise on a truly grand scale.

5.2 Materials and Logistics

The project required substantial building materials, tools and equipment. To meet this need, the Egyptians had to organise complex and massive project supply-chains across the Eastern Mediterranean, which would also have had a significant effect on scheduling. Some raw materials like limestone were quarried relatively close (within 20 kilometres), although basalt was 80 kilometres away and granite was 1000 kilometres away (Bloxam, 2011). It took ten years to quarry these beams from Aswan, and this had to be carefully synchronised with progress on the pyramid construction, so it was at the correct height for installation. This required tight co-ordination between the teams.

Other raw materials posed logistical challenges as these were only procured through trade well outside of Egypt's borders. Copper from the Sinai Peninsula, wood from Lebanon, gypsum from the Red Sea coast, silver and tin from Crete and Cyprus were procured in great quantities by trading domestically produced export goods. Egypt had an active policy to seize control of lucrative trade routes like the Byblos Run (Egypt to modern-day Lebanon).

A complex infrastructure around the Giza site was required to support the project and had to be in place prior to pyramid construction according to a schedule. It included a harbour and canals (Hawass, 1997) to receive building materials, equipment and tools, and provisions from the supply-chains. Trackways and a building-yard were needed to transport and finalise the materials, whilst a new village was constructed to house the workers.

Government procurement was substantial (Bloxam, 2011) boosting the economy through a sharp increase in food production. The surplus food was used both for trade and across Egyptian society.

5.3 Workforce

Just as important as developing the construction expertise was the organisation of the workforce. For the Egyptians to build projects of monumental scale required a complex supporting infrastructure which in more recent years has been the focus for archeologists. According to Gadalla (2018, p128)

> "Motivating and organizing these activities was a bureaucracy of elite scribes, religious leaders, and administrators under the control of a Pharaoh who ensured the cooperation and unity of the Egyptian people in the context of religious beliefs (James, 2005; Manuelain, 1998)".

The project workforce was composed of skilled and unskilled workers. Between 4,000-5,000 skilled craftsmen (Powell, 2002, p.79), were part of trade and craft guilds (Carroll, 2007). These stonecutters, masons, surveyors, mortar makers, and carpenters worked year-round, either on-site or in the quarries. The unskilled workers were not slaves but mostly farmers sourced from communities across Egypt on a rotational basis. The villages provided a steady stream of workers between July and November when the Nile flooded their fields, the annual inundation. In small teams led by a soldier/foreman they provided the labour to excavate, carry, and haul the vast number of blocks from quarry to site as no wheel or pack-animals were available to the project (Vinson, 2013). The overall workforce benefited from a system of privileges being fed, clothed, and housed. Daniel et al (2007) surmised that there was an average workforce of 13,200 peaking at 40,000 over 10-years.

The discovery of Heit el-Ghurab or "the Lost City of the Pyramid Builders" (Kemp, 1989, p.141) in 1972 that was constructed to house the workers, has provided insights into the workers lives. A massive supply-chain of food and drink, from villages and farms, was constantly flowing into the project site for the workers. The physical demands of the project and the harsh environment meant that workers required a higher than normal caloric daily intake. Each day 21 buffalo and 23 sheep were sent to site (Hawass, 2010) where the workforce feasted at night from a massive catering operation where there was an abundance of bread, beer, and meat (Murray, 2005). This provided the energy and nutritional value required to meet the demands of the project. In society at large meat was strictly the diet of the middle classes. Findings from the worker's village excavations include industrial sized bakeries and breweries (large ceramic deposits), a hospital, and a corral with slaughter areas with vast piles of animal bones (Shaw, 2003).

Research suggests that the project treated the workforce ethically, with a positive impact on morale. Unlike a system of slavery, workers had rights and stopped working when they were not being paid enough (Powell, 2002). The control mode for these workers within the project was akin to clan control which according to Liu et al (2014, p.793):

> "...refers to the regulation of goal setting, behaviour, evaluation and administering of consequences by a group of individuals who share similar goals, values and norms….. It typically requires joint problem solving, participatory decision making, open and honest information sharing, and keeping promises."

They approached authorities with grievances, which resulted in the punishment of supervisors who treated them unfairly. The best health practitioners and resources were available to the workforce (National Geographic, 2016). Skeletal remains from the worker's cemetery show signs of trauma associated with building site accidents. One skeleton had several leg fractures but with treatment the leg had been set and healed perfectly straight. Evidence has been found of amputated limbs, broken hands treated by binding, and even brain surgery which was a common practice among physicians for physical injuries using metal (bronze/copper) surgical tools.

The quality of the experience for the project workforce positively influenced the project outcome. According to Morell (2001):

> "On two blocks in the highest chamber of Khufu's Great Pyramid, for example, a gang of workers painted hieroglyphics that read "Friends of Khufu." And in Menkaure's mortuary temple another group displayed its insignia: "Drunkards of Menkaure"."

and:

> "The workers were organised into competing teams, he [Lerner] explains, which may have helped them psychologically. You know, 'Let's see whose team can do this job faster.'"

5.4 Broader societal impact

Bard (2015) argues that this massive investment and growth in resources increased the wealth and health of the nation as a whole. It had an impact on all strata of society, engaging them, and unifying the population to a common cause (Bard, 2015). The project thus unified the stakeholders. For example, the villages supported the project with labour in lieu of payment of taxes (Nova, 1997), and benefitted from both the supply chains and employment opportunities that were provided. Skilled workers were employed in good conditions on a long-term basis, and unskilled workers on a seasonal basis which gave farmers work when the Nile flooded.

The organisation of the workforce was determined in two ways. First, by how the aforementioned technical challenges were met with a finite workforce and without slaves (Shaw, 2003). Second, by the project's most significant constraint; completing the pyramid before the Pharaoh died, which required closely monitoring the schedule and potentially crashing the critical path to complete the project sooner. Based on tomb inscriptions and workers' instructions on walls inside Khufu's pyramid and Menkaure's mortuary temple (Morell, 2001), researchers have drawn a modern personnel chart for the workforce. According to Egyptologist Ann Roth:

> "Every project like a pyramid had a crew of workers, and each group was responsible for one part of the pyramid complex. There was one group for building the interior granite roofs and separate groups for raising the chamber walls. Each crew of workers was divided into four or five smaller units, which Egyptologists call phyles (after the Greek for "tribe"). Each phyle carried a name, such as "Great One" or "Green One." The phyles too were broken into forces of 10 to 20 men…"

This closely fits Sayles and Chandler's (Söderlund, 2012) definition of an effective organisational structure: the Giza project structure was based on a hierarchical military structure (institutional affiliation), delivering the pyramid before the Pharaoh died (clear objectives), with a varying mix of is skilled and unskilled labour (based on the work-flow stage as above), and reducing the scope through technical innovations and engineering (type of technology).

5.5 Administration

Accounting and counting were critical to public works projects with their sheer size and existed as a core competency within Egypt (Ezzamel, 2009), used within all aspects of the project including managing the complexities of the supply chain and the flow of materials, equipment and provisions. In the quarries and building-yards 2.3 million blocks were carefully counted and tracked. The scribes used a highly structured and rule-bound numbering system with specific, technical vocabulary (e.g., revenues, expenditures, receipts, remainders) for preparing accounts in an orderly manner (Ezzamel, 2009). Accounting inscriptions were super-imposed on the outside and inside of temples for public view and accountability.

6) Flyvbjerg's 10 Characteristics of Megaprojects/ Discussion

What then is the contemporary relevance of the management of this project? We now relate the Giza pyramid project to the 10 characteristics of megaprojects that Flyvbjerg (2014) argues cause problems are typically overlooked or glossed over when the megaproject format is chosen for delivery of large-scale ventures. These are listed below, followed by our discussion on each point.

1. Megaprojects are inherently risky due to long planning horizons and complex interfaces

The Giza pyramid project's most significant constraint was time, as the pyramid had to be completed before the Pharaoh's death and be ready for his funeral (Brier, 2007). Based on the Pharaoh's age at the start of the project (40) and his life expectancy (60), the likely window of 20 years was feasible as the Red pyramid had taken 17 years to build (Romer, 2007), deduced from the dates inscribed on the back of every twentieth stone-block. This appears to be a difficult constraint to work with, a high risk. The project director, Hemienu, designed a schedule that was agile enough to respond quickly if the Pharaoh's health suddenly deteriorated. His strategy was to build several burial chambers at different heights as the project progressed. With this contingency a chamber was always ready should the Pharaoh die during the project (Houdin, 2013).

The project did have numerous complex interfaces with over 1 million citizens involved in the project and supply chain. The preceding sections have explained how the ability to manage such a scale of stakeholders had evolved with previous projects.

2. Often projects are led by planners and managers without deep domain experience who keep changing throughout the long project cycles that apply to megaprojects, leaving leadership weak.

The appointment of Hemienu, who was also the Vizier or Prime Minister (so he held significant power), as project manager and lead architect, firmly established the political significance of the project and gave it a high priority. As the brother of the Pharaoh and royal prince, his appointment straightaway mitigated one of the most common risks in megaprojects, which is a lack of senior political support and power at critical stages. In his privileged position he had substantial power and resource to effect change and influence stakeholder groupings at all levels. Brier (2007) shows how Hemienu had been prepared for this role all his life with extensive knowledge of previous pyramid projects, and thus came to the project fully understanding the challenges involved. He managed the project for its entire duration, with close control over the schedule, scope, cost, and organisation.

The deep domain experience is reflected in the decisions made by planners and managers, for example:

- The site itself was very carefully selected on a raised plateau so that it was unaffected by the flooding of the Nile. Through meticulous planning the best ground on the plateau was selected as it needed a solid bedrock foundation.
- To save on materials and transportation costs the base was built around a rock outcropping 8 m high to provide an anchor for the structure. The area around it formed the bottom layers of the pyramid, about 10% of the total volume;
- the main limestone quarries were only 200 m (650 ft) south from the pyramid site;
- the use of lower cost materials in less visible areas of the pyramid.
- The angles of inclination were de-steepened to 43° and steepened back to 51° once there was confidence in the solidity and firmness of the base, becoming a standard.

The lessons from the Bent Pyramid were ingrained into the project for example, the base was perfectly leveled to a few millimeters over the entire 13.1-acre base, remarkable considering the tools and technology available.

3. Decision-making, planning, and management are typically multi-actor processes involving multiple stakeholders, public and private, with conflicting interests (Aaltonen and Kujala, 2010).

The management of the project involved much more than dealing with technical challenges, substantial as they were. The project involved immense logistical problems, including the organisation of the supply chain and re-organisation of the environment. It involved complex social issues, including the management of multiple stakeholders, and the organisation of a large workforce involving all strata of

Egyptian society. The administration for the project was provided by the scribes who worked for the state (Kemp, 1989) and who had substantial prior experience of megaproject support and the organisation of a large workforce and massive supply chains. The project was possible only because the Egyptian state enjoyed massive control of the resources of the nation. However, the cost of the project was offset by the benefits of the overall economic impact of this public works project boosting the economy.

We have shown how the establishment of such a megaproject gave a substantial boost to the Egyptian economy (Moriarty, 2008, p.95) and therefore, it was not just symbolic, a tomb; its economic benefits touched all citizens and made it indispensable over time.

In summary, conflicting interests of stakeholders would have been checked or superseded by the state hierarchy. The stakeholders were united in their economic and political interest in the success of the project, given the economic impact it had.

4. Technology and designs are often non-standard, leading to "uniqueness bias" amongst planners and managers, who tend to see their projects as singular, which impedes learning from other projects.

The paper has shown in detail how the technology for Giza evolved from the experience of previous pyramids, and how a culture of technical innovation had developed. The project was not singular but rooted in a very long 300 year tradition. The Giza Pyramid was very much a copy of the Red Pyramid but scaled up in height and with accommodations made for the increase in weight, with some adjustments to the internal chambers with an added grand gallery. Learnings from previous project were absolutely critical and the Egyptians were wholly reliant on previous experience as they did not have the analytical-mathematics knowledge in the static behaviour of structures and the strength of materials to calculate stresses, pressures and thrusts.

5. Frequently there is overcommitment to a certain project concept at an early stage, resulting in “lock-in” or “capture,” leaving alternatives analysis weak or absent, and leading to escalated commitment in later stages. "Fail fast" does not apply; "fail slow" does

There was much flexibility in the plan based on the hard lessons from the Bent Pyramid that required immediate proactive actions (supporting timbers, lowering height of pyramid and slope inclines) to prevent a catastrophic failure. Through all the pyramid projects small incremental improvements were made to both product (materials, tools) and process (practices) in all areas of the project, as they were between projects. Section 4 above has shown how a combination of learning from experience together with technical innovation succeeded at Giza. These changes and adjustments demonstrate the builders "capacity to reflect on action so as to engage in a process of continuous learning" (Schön, 1983) and flexibility in the plan that avoided locking the project into certain concepts at an early stage.

6. Due to the large sums of money involved, principal-agent problems and rent-seeking behavior are common, as is optimism bias

Section 5 has demonstrated how a worker’s village was set up by the state to support the project and offset principal-agent problems and rent-seeking behaviours common to megaprojects. Given the previous pyramid experience the optimistic targets for the Giza project were realistic. Unlike a contemporary project viewed as one off and unique, the Giza pyramid design was built upon the experience of 300 years.

7. The project scope or ambition level will typically change significantly over time.

The most significant change at the project outset was that the Giza was 50% scaled up over the Red Pyramid. We have shown how the Egyptians had the confidence to return to 51° angle once a solid base was secured.

There is no evidence or indication that scope or ambition level changed during the project, but we have explained how a culture of innovation allowed the project to adapt to new challenges. In all probability Egyptians had learned not to change scope through the project, from previous experience, and avoid increasing the risk.

8. Delivery is a high-risk, stochastic activity, with overexposure to so-called "black swans," i.e., extreme events with massively negative outcomes (Taleb, 2010). Managers tend to ignore this, treating projects as if they exist largely in a deterministic Newtonian world of cause, effect, and control.

The duration of the project created challenges and risks to the project. One very bad harvest was anticipated in the course of a 20 year project. Two very bad harvests would be a "black swan" extreme event. This risk of food shortages was mitigated by storing a percentage of the previous year's grain in deep silo granaries (Lehner, 2010), in a huge storage facility in the Royal Administrative Building of the worker's village, to provide a buffer for one season (Murray, 2005).

Although less likely, the Egyptians would have known that an earthquake in the region could have had a catastrophic impact on the project. Major earthquakes in the region occurred every few hundred years. This could affect not just the workforce but the whole worksite, the pyramid and supporting infrastructure.

Other impacts were war, or other external factors like epidemics of infectious diseases (Sandle, 2013). For example, in the region tuberculosis, schistosomiasis and malaria[1] could affect the workforce and be a major threat in crowded areas like the worker's village. Thus, overexposure to (and failing to budget for) extreme events owing to the project size was planned for.

9. Statistical evidence shows that such complexity and unplanned events are often unaccounted for, leaving budget and time contingencies inadequate.

One unplanned event that was unaccounted for was a catastrophic wadi surge that swept over the worker's village and liquefied the mud-brick buildings creating a mass of mud. The village was built across a normally dry wadi course (an ephemeral stream course that flows only briefly after a period of rainfall in the immediate locality). At least once every 20 years flash floods affected the Giza plateau. Urban geoarchaeologists recently studying drill-cores for site accumulation, collapse, weathering and erosion, discovered that flash floods hit and destroyed the worker's village (Kröpelin, 2013). Butzer

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[1] Medical anthropology has found traces of these diseases in mummies.

(2013) found "layer after layer of foundations and then rubble", attesting to frantic rebuilding following four or five flash floods. The floods did not originate from the Nile but were caused by excessive, monsoonal rains from the Red Sea hills. The village was rebuilt at least twice which indicates that these unplanned events was likely unaccounted for, but there were budget and time contingencies in place to make rapid repairs.

10. As a consequence, misinformation about costs, schedules, benefits, and risks is the norm throughout project development and decision-making. The result is cost overruns, delays, and benefit shortfalls that undermine project viability during project implementation and operations.

The decision to abandon the deep underground burial chamber and build a new burial chamber high up in the superstructure, supported by a Grand Gallery, was a major change that required a unique design and building approach for the roof (gable). This probably had an impact on the project, but it appears to have still been on time and meeting its scope, delivering benefit to a very broad range of stakeholders both at the time and through subsequent generations.

Summary to Discussion of Flyvbjerg's 10 Characteristics of Megaprojects

In summary, the analysis demonstrates how the 10 characteristics of megaprojects, which Flyvbjerg argues are typically overlooked and thence lead to failure, were addressed through the development of experience in previous projects.

7 Conclusions

By reinterpreting a major historical project for a modern audience, we have explained how major risks were mitigated both through the evolution of experience together with a culture of innovation. First, the paper puts into perspective elements of the megaproject not prevalent in current literature such as why it was initiated (the intended and achieved benefits), and by whom (stakeholders) and who delivered it (organisational structure).

Second, the paper has examined in detail how the project was managed and executed. It shows how Hemienu and his team developed complex solutions to very difficult technical challenges facing the project. For example, they managed down the scope with innovations and engineering breakthroughs like the internal spiral ramp and the Grand Gallery counter-weight system. Although more complex to build, these elegant solutions reduced the volume of materials and the workforce size, making it easier to manage.

Third, the paper examines how the success of this major project was directly attributable to the Egyptian track record in the management of public works projects. With up to 300 years of experience in pyramid building, the Egyptians kept pushing the limits of materials, equipment and men to build larger and more complex pyramids. They took lessons learned and reflected on their work adjusting practices during the project as conditions changed. They incorporated continuous improvement with transitions from the fabric of the buildings, to the pyramid type, to the angle of inclination, to the position of the interior chambers in the pyramid, to the roofing in the chambers. The Egyptians leveraged abundant skills (administration of scribes, surveying, organisation of the military) which worked in the project's favour, and resources (Nile, canals, harbours, grain storage).

According to Marshall and Bresnen (2013) 'muddling through' unpredictable, unplanned, and unplannable events of a project requires problem-solving capabilities, trial-and-error learning, and the benefits of experience, intuition, and wise judgement. The Egyptians combined their historical experience with reflection-in-action in the Giza pyramid megaproject.

The advances made subsequent to each project indicated a learning process, in much the same way that modern project management encourages post project reviews as a learning exercise (Koners and Goffin, 2007). It was symptomatic of a culture of organisational learning (Senge, 1990) where feedback and reflection was a recipe for agility in the construction, leading to responsiveness and resilience in each new project.

This is not only the first paper to discuss the Giza pyramid from a project management perspective, but also demonstrates how both the combination of historical analysis with recent theoretical work allows for a richer discussion than the limitations of process and technique in existing bodies of project management knowledge.

Through this analysis we can see the significance of reaching back into history to illuminate the pressing contemporary issue of megaproject failure.

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