Chapter 10

Debunking Contemporary Myths Concerning Engineering

Billy Vaughn Koen

Abstract Efforts to understand the human activity we call engineering and to develop a Philosophy of Engineering are hampered by a number of myths. One oft-heard and over-used example will demonstrate this point. Repeatedly we read in the newspaper or hear on television that “engineering is applied science” in spite of the demonstrable fact that this could not possibly be true. The objective of this paper is to debunk some of the most egregious of the contemporary myths concerning engineering. Rather than rely on conjecture and personal opinion, the strategy employed is to use an inordinate number of direct quotations from classical texts and living experts. This is supplemented by extensive quotations, images, and commentary from documentaries produced by the most reputable sources such as the *History Channel*, the *National Geographic Channel*, the *Discovery Channel*, and the *Smithsonian Encyclopedia* where there would be credible fact checking by content specialists if it was to exist anywhere. At the conclusion of our investigations, we will consider the archetypical engineering project and meet the earliest engineer in history whose name is known and stare directly into his face.

Keywords Engineering myths • Engineering artefacts • Engineering method • Engineering trial and error • Ancient engineering

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D.P. Michelfelder et al. (eds.), *Philosophy and Engineering: Reflections on Practice, Principles and Process*, Philosophy of Engineering and Technology 15,
DOI 10.1007/978-94-007-7762-0_10,

10.1 Introduction

Recently the number of conferences and articles seeking to develop a Philosophy of Engineering has increased significantly. These conferences bring together philosophers and engineers who, although recognized experts in their respective fields, have very different, often contrasting, world-views. As a result, efforts to understand the human activity called engineering are hampered by a number of myths about engineering put forth on both sides of the divide.

This paper brings together some of these misconceptions collected from international conferences that appear naïve from the point-of-view of the engineer, with the sincere hope that someday a philosopher will return the favor and correct the naïve views of the engineers about philosophy to the mutual benefit of the two groups of scholars and the benefit of the development of a Philosophy of Engineering.

This paper is divided into two parts: first, a very brief discussion of a definition of engineering method that has appeared frequently in the literature is given and then an analysis of a series of contemporary myths concerning engineering is proposed.

During these investigations, we will have occasion to meet the earliest engineer who has ever lived whose name is known as an example of an engineer using the engineering method, examine his engineering work, and then—finally—stare directly into his face.

10.2 Definition of Engineering Method

Engineering is most appropriately understood and recognized in terms of behavior: it is an activity, it is something an individual does, it is a creative undertaking. If we look in on an individual and see that he or she is doing certain specific, identifiable things, we can infer that he or she is an engineer actively engaged in engineering work. Therefore, engineering should be understood in terms of *method* instead of in terms of one of the multitude of common, arbitrary, egocentric *definitions* often put forth. The simple fact that engineering is behavior is confirmed by a quotation from one of England's most noted nineteenth century engineers, Sir William Fairbain (Burke 1919):

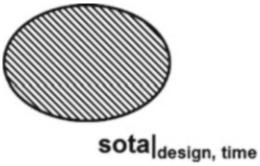
> The term *engineer* comes more directly from an old French word in the form of the verb *s'ingénieur*… and thus we arrive at the interesting and certainly little known fact, that an engineer is anyone who seeks in his mind, who sets his mental powers in action, in order to discover or devise some means of succeeding in a difficult task he may have to perform.

An accurate understanding of what engineering is depends on an understanding of what an individual must be doing to be called an engineer.

As a result we began our investigations with—but not belabor—a slightly revised and improved definition of *engineering method* that has frequently appeared in the literature as a starting point for our considerations, to wit:

> The engineering method is the use of state-of-the-art heuristics to create the best change in an uncertain situation within the available resources.

Fig. 10.1 State of the art



This definition uses many important concepts in highly technical senses. But space considerations are such that focus in this paper is limited to the two terms *state of the art* and *resources.* Those interested in investigating this definition in more detail are referred to the seminal book that forms the basis of this article, *Discussion of the Method: conducting the engineer's approach to problem solving,* published by Oxford University Press in 2003 (Koen 2003). It will be referred to by the acronym *DOM* in what follows.

10.2.1 State of the Art

The noun *state of the art* or the adjective *state-of-the-art* in the definition just given is one of the most important concepts in engineering. In the literature, it has frequently been discussed in conjunction with. but apart from, an analysis of engineering method. But for present purposes it has been absorbed into the definition itself.

Seldom does an engineering project require only one heuristic. This introduces the concept of a collection or set of heuristics that we will call the state of the art or to use an acronym *sota.* Figure 10.1 shows pictorially a set of heuristics or sota. It must have a label and time stamp and can be written as $\text{sota}|_{\textit{design, time}}$ to mean the set of heuristics used in a specific design at a specific time.

The notion of a set of heuristics or sota evaluated at a specific time is a very powerful concept. The sota of an individual both confines and restricts the range of the possible in engineering design for him or her.[1] It can refer not only to the individual, but also to a group of individuals—even to countries. It is reasonable to speak of the sota of French engineers, Japanese engineers, and American engineers and to compare them. It is reasonable to compare the sotas of a developed and an developing country or to talk of technological transfer as a strategy for transferring the appropriate heuristics from one nation to another. It is, also, reasonable to consider engineering education as converting the entry sota of a freshman engineering student to that of a competent, practicing engineer.

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[1] See an article in a previous volume of this series by Springer for more detail (Koen 2010).

Fig. 10.2 Effect of different resources. (**a**) Karnak, (**b**) Parthenon, (**c**) Pantheon

10.2.2 Limitation by Resources

The second concept in the given definition of engineering to be considered is the important notion of the resources and the constraints of those resources on the typical engineering problem. From DOM, page 15:

> An engineering problem is defined and limited by its resources, but the true resources must be considered. Because we tend to think only in terms of depletable resources, because we confuse nominal and actual resources, and because we neglect the efficiency of allocating resources and the probability of exchanging one kind for another, often the true resources are hard to determine.

A recent documentary on the Science Channel (2008) gives an interesting and unexpected example of the importance of resources that appear in the definition of engineering method. The host, Ian Steward, is a Scottish geologist who is interested in the impact of geology on civilizations. He argues that the rocks found in an area influence its art, buildings, etc. This parallels the point that the resources, in this case the rocks, impact the local engineering design. The example Dr. Steward uses is given in Fig. 10.2.

At issue is the design and construction of *enclosed space*. Since the beginning of civilizations, humans have designed houses, meeting rooms, kivas, temples, and so forth from the available materials. Dr. Steward compares the enclosed space in large rooms in Egypt, Greece, and Rome and concludes that the local rocks dictated and constrained their design. Figure 10.2a is a picture of a portion of the hypostyle hall in the Karnak temple in Egypt which consists of 134 huge columns seven stories tall. Only the sedimentary rock, sandstone, was available for its construction. As is well known to engineers, building material such as sandstone is relative strong in compression, but weak in tension. As a result, for Karnak, massive, closely spaced columns were needed to support the architrave or beam that rests on the capitals of the columns. Note the tiny man in the figure to give a sense of proportion. As a result the enclosed space is crowded and has a claustrophobic feeling. Figure 10.2b is a picture of the Parthenon in Greece. Here the stronger metamorphic rock, marble, was available and the columns are slenderer and the enclosed space has a more airy feeling. Finally, Fig. 10.2c is a picture of the Pantheon in Rome. Here the much stronger igneous rock was available to make very strong concrete. As a result of this building material in conjunction with the innovation of the arch, the load of the roof is transferred down the walls to the ground and a truly spacious room with no visible means of support could be designed. The point is that the resources, in this case the indigenous rocks, available to the engineer affect the sota and ultimately the final design.

10.3 Debunking Contemporary Myths

Attention now turns to the second objective of this paper, debunking specific myths concerning engineering. To be examined are the claims that (1) the definition of engineering method previously discussed is vacuous, (2) engineering is a relatively recent human activity, (3) engineering is applied science, (4) engineering is trial and error, and (5) engineering artefacts must be concrete objects that persist over time.

10.3.1 Myth: The Definition of Engineering Method in Terms of Heuristics Is Vacuous

A vague feeling that the definition of engineering method just discussed is vacuous is a concern that was raised concerning the present paper at a recent fPET conference.[2]

The complainant poses an extremely important question that is very subtle, although somewhat outside of the scope of this article. The response has already been extensively developed in a variety of forums, most notably in the philosophical journal, *The Monist* (Koen 2009) and in DOM (Koen 2003). To quote the example given:

> A person placing a wager on the daily double at the nearest race track may also be using state-of-the-art heuristics to create the best change in an uncertain situation within the available resources.

and as a result the proposed definition is vacuous.

This myth results from misinterpreting the nature of the term *state of the art* as can be understood by considering Fig. 10.3. This figure shows a large, grey, irregularly shaped sota labeled $\text{sotal}_{\mathit{Overall},\ t}$ inside of which are two overlapping sotas labeled $\text{sotal}_{\mathit{engineering},\ t}$ and the solid black one, $\text{sotal}_{\mathit{Daily\ Double},\ t}$. While it may be true, that the latter two may share some heuristics in common as indicated by the extent of the overlap between them, it is certainly not true that they are identical.

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[2] The 2010 Forum on Philosophy, Engineering and Technology (fPET-2010) held on 9–10 May 2010 at the Colorado School of Mines in Golden, CO.

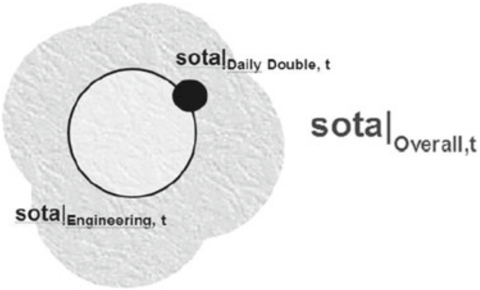

Fig. 10.3 Comparison of sotas of daily double winner and engineer

The interesting subtlety is in defining the heuristics that properly defines each. This is done heuristically.

> Or to quote the cited article in *The Monist,* to define each sota,
>
> Use the heuristics heuristically thought to be appropriate for that domain.

We can anticipate that there could be other sotas representing the method of the novelist, artist, flautist, and so on. Each would appear within the overall sota with varying amounts of overlap.

The astuteness of the critique highlights the similarity of all of these definitions of method that ultimately leads to a definition of universal method given in the cited references.[3]

Properly understood, the definition of engineering given above withstands the criticism and is hardly vacuous.

10.3.2 Myth: Engineering Is a Relative New Human Activity

The feeling that engineering is a relatively new human invention is a notion that once made a curious appearance at a recent international conference on the Philosophy of Engineering.[4]

In a room with several engineers and philosophers who were very well-known in their respective specialties present, the question was asked “Do you believe there were engineers in ancient Egypt?” The philosophers immediately responded “of course not”; the engineers responded “but of course. Why do you ask?”

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[3] For a consideration of this definition and its relationship to other methods, specifically, to universal method from a more philosophical view, an article that appeared in the journal *The Monist* (Koen 2009) might prove useful. Finally, two oral histories, one entitled “The Search for Universal Method” can be found at the persistent URL, http://www.me.utexas.edu/~koen/etc-lecture/ (Accessed Nov. 1, 2011) and the other a keynote address for the Workshop for Engineering and Philosophy at The Royal Academy of Engineering, London, England entitled “Towards A Philosophy of Engineering”(Koen et al. 2008), are available.

[4] Workshop on Philosophy and Engineering, Royal Academy of Engineering, London, England, November, 2008.

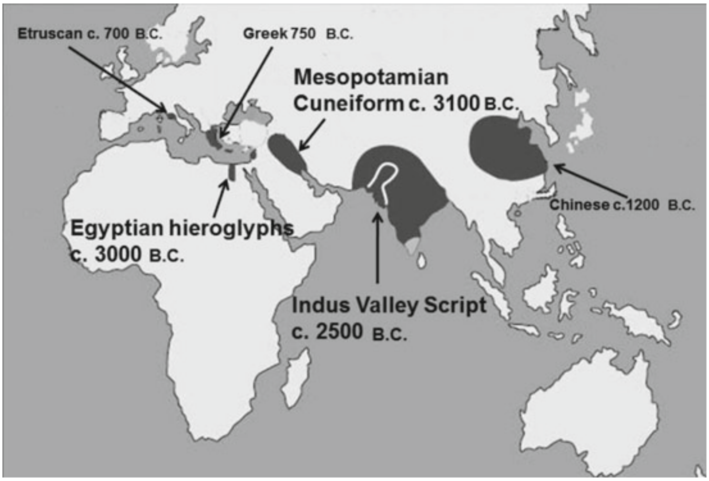

Fig. 10.4 First appearance of writing

The erroneous feeling among some that engineering is a relatively new human activity may derive from the fact that the English word *engineer* first entered the language in the early fourteenth century as "constructor of military engines" (Harper) with the understandable implication that that is when the behavior we associate with engineering first appeared.

Earlier in this paper the notion that *engineering* necessarily has anything to do with engines was challenged by citing Sir Fairbain. A quotation from another etymological dictionary will substantiate Sir Fairbain's view (Spiritus-temporis).

> It is a myth that engineer originated to describe those who built engines. In fact, the words engine and engineer (as well as ingenious) developed in parallel from the Latin root ingenious, meaning "skilled". An engineer is thus a clever, practical, problem solver.

Once again we must insist that we should base the notions, *engineer* and *engineering,* on behavior—on engineering method—and then ask when the behavior we associate with engineering first appeared.

Let's listen in rapid succession to the testimony of a large group of credible witnesses.

We begin with a quotation from the classic book *The Ancient Engineers* by L. Sprague de Camp (1963):

> The story of civilization is, in a sense, the story of engineering—that long and arduous struggle to make the forces of nature work for man's good.

To see that what Spargue de Camp says is true, consider Fig. 10.4. This is a redrawing and simplification of a published map that preserves the essential dates when *writing first appeared* in various countries (Robinson 2009).

Although some of the precise data may be in dispute, Egypt, Mesopotamia, and Indus are arguable the oldest civilizations we know based on one of the common

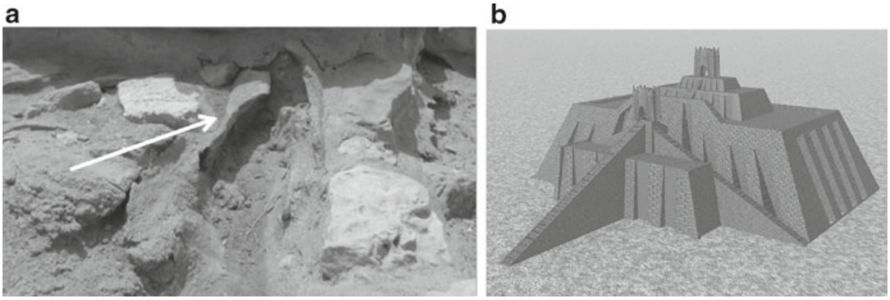

Fig. 10.5 Extant examples of ancient engineering. (**a**) Indus, (**b**) Mesopotamia

standards for the birth of a civilization, the emergence of writing. In all of these three, concrete engineering artefacts are in existence in various stages of disrepair.

Figure 10.5a is a screen capture from the documentary, *What the Ancients Did For Us: The Indians,* produced by the BBC TWO for The Open University (Hart-Davis). The white arrow is pointing to the broken end of a clay pipe in ancient Indus[5]. The moderator reaches down and picks up a broken piece of the pipe and says in a truly astounded voice:

> This is a 4500 year old sewerage bath water collection pot chard.

and then somewhat later in a voice over

> …showing the extraordinary skills in *engineering* and planning.

On this evidence alone, surely we should admit that there were engineers in ancient India.

In Fig. 10.5b we see a modern depiction of the Sumerian Ziggurat at Ur[6] in ancient Mesopotamia. The rubble is still there and efforts are underway to build a reconstruction. If that is not sufficient to win an argument that there were engineers in Mesopotamia, we can turn to another in the series of documentaries produced by the BBC—this time to the one entitled *What the Ancients Did for Us: The Mesopotamians* for added evidence. And finally, an exhaustive and definitive treatment of Mesopotamia, the Ziggurat, and the state of the art of science, mathematics, and engineering works is to be found in a Britannica guide to ancient civilizations in reference (Kuiper 2011). Surely we should admit that there were engineers in ancient Mesopotamia.

Finally, ancient Egypt seals the case that there were engineers in the ancient world. The number of colossal monuments, temples, fortifications, and buildings that have been very well preserved in the dry climate and buried under the sands

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[5] This is in Dholavira in the Western area of present day India.

[6] Located in southern Iraq, the Ziggurat was part of a massive temple complex where the moon god Nanna lived.

Fig. 10.6 Examples of Egyptian engineering

should leave no doubt. See Fig. 10.6. This figure shows us the huge monuments at Abu Simbel, the Temple at Karnak, and the sphinx and pyramids as just a few samples of the fruits of the engineers labor in ancient Egypt.

In fact, an entire documentary produced for the History Channel aptly entitled *Engineering an Empire: Egypt* (Cassel 2006) is completely dedicated to these ancient achievements.

Dr. Kent Weeks, American University of Cairo claims that:

> Twenty-five hundred years before the reign of Julius Caesar, the ancient Egyptians were deftly harnessing the power of engineering on an unprecedented scale. Egyptian temples, fortresses, pyramids and palaces forever redefined the limits of architectural possibility.

and from the same documentary, Dr. Zahi Hawass, Secretary General, The Supreme Council of Antiquities says:

> The Egyptians put the foundation of engineering—they were the people who invented engineering.

This importance of engineering in Egypt is a sentiment Dr. Hawass has repeated in numerous documentaries produced by a wide variety of organizations.From another documentary called *Secrets of Egypt: The Valley of the Kings* produced by Five TV (Halliley), an archeologist and practicing engineer, Steve Macklin who is a professional tunneling engineer with Tunnelling & Geology, Arup appearing *in situ* in the documentary and shows us:

> [how]he recognized the technique [being used] because it is one the engineers still use today.

Surely we should admit that there were engineers in ancient Egypt.

Considering the evidence in Indus, Mesopotamia, and Egypt, it is hard to dispute the claim in Wikipedia (Wikipedia: Civil Engineering) that

> Engineering has been an aspect of life since the beginnings of human existence.

Or as was succinctly stated in DOM, page 7:

> **To be human is to be an engineer**.

Based on these comments by professional engineers, comments from credible documentaries, extant engineering artefacts in the earliest civilizations (and we have only scratched the surface), we must conclude that there were engineers in ancient times—and the claim that there were no engineers in ancient Egypt is a myth.

10.3.3 Myth: Engineering Is Applied Science

"Engineering is applied science." This is undoubtedly the most common definition of engineering. It appears frequently in the newspaper; on the television; and from the lips of the sophisticated, of the uneducated, and even, unfortunately, on occasion, of the engineer. Some credence, or more appropriately blame, for this myth should be given to the definition of engineering of the Engineering Council for Professional Development (ECPD) around 1932 (with emphasis added) (Wikipedia: Engineering):

> [Engineering is] the creative application of *scientific principles* to design or develop structures, machines, apparatus, or manufacturing *processes*, or works utilizing them singly or in combination; …

The problem is that the definition of engineering in terms of science is not true—in fact, it cannot possibly be true. To see this, we need only return to Fig. 10.4 and this time focus attention on the appearance of Greece as a civilization based on the appearance of writing in that country. This figure shows, in a smaller font, that writing in Greece appeared about 750 BC.

Although there are minor disputes in the literature, science made its appearance somewhat later in about the sixth century BC with the Ionian Philosophers—Thales, Anaximander, and Anaximenes. See DOM (Koen 2003).

There is a rich literature in the History of Science concerning the birth of science, several quotations are representative (Burnet 1930):

> …it is an adequate description of science to say that it is thinking of the world in the Greek way. That is why science has never existed except among people who came under the influence of Greece.

and from another scholar

> The Greeks were the first scientists and all science goes back to them.

For comparison as to age, what is one of the earliest examples of engineering on a significant scale in the literature? A likely candidate would have to be the city of Memphis, the capital of Egypt during the Old Kingdom, founded by the pharaoh

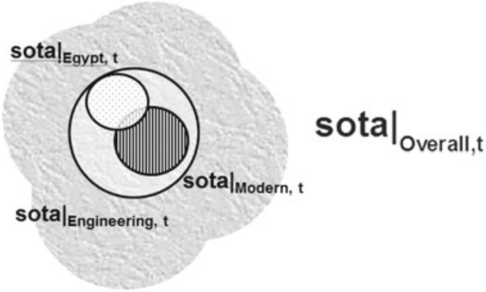

Fig. 10.7 Comparison of Egyptian and modern sotas

Menes around 3000 BC. The ruins of Memphis are 20 km (12 miles) south of Cairo, on the west bank of the Nile.

Memphis has had several names during its history of almost four millennia. Its Ancient Egyptian name was Inebou-Hedjou, and later, Ineb-Hedj (translated as “the white walls”), because of its majestic fortifications and crenellations (battlements). These historical fortifications were certainly the work of engineers (Wikipedia: Memphis).

Clearly, engineering predated science—by millennia. Science cannot logically be used as a definitive definition of engineering as it existed throughout history.

At best, we might try to argue that engineering and its relationship to science is as given in Fig. 10.7.

This figure is interpreted as follows. Modern engineering, represented by the crosshatched circle indicated by $\text{sotal}_{Modern,\ t}$ contains science, the use of modern tools, and contemporary design techniques. The small plain circle indicated by $\text{sotal}_{Egypt,\ t}$ would contain the skills for working with copper tools and other appropriate heuristics used by Egyptian engineers but long forgotten in the present day. On this basis the overall definition of engineering would be represented by the large circle surrounding both of them, but it is somewhat larger to account for other engineering traditions.

One disclaimer concerning this view of engineering is worthy of note. As a matter of fact, even *modern* engineers do not *always* use science as we see in the design of the Mars rover, the deep space probe, and more recently a deep water oil exploration where the exact scientific conditions are impossible to know and what science that does exist is used more as heuristics.

If we forsake science as the *sine qua non* of engineering and try mathematics instead as some have tried to do, we again run into trouble.

The earliest extant treatise on mathematics showing mathematical calculations is the celebrated Rhind papyrus and to a lesser extent, the Moscow papyrus, shown in Fig. 10.8. One can just make out a triangle on the former and a truncated pyramid on the latter. Actually, there are three other minor papyri that could be vaguely relevant here (Darling). But the mathematics depicted in all of these is very imperfect

Fig. 10.8 Rhind and Moscow papyri

and used more as heuristics than the more certain mathematics we think aids the engineers of today.

In any event, the persistent claim that engineering is applied science rests on an irresponsible anachronism.

10.3.4 Myth: Engineering Artefacts Must Be Concrete Objects

Whether or not an engineering *artefact* must be a concrete object as opposed to the claim that a *process* would also qualify as the result of engineering design caused discussion at a recent conference[7]. Some philosophers present insisted that an artefact must be a physical object—something a person could touch. This view is not consistent with engineering practice.

First, refer back to the definition of engineering by the ECPD given in the previous section on page 10. The engineers who developed that definition specifically give a *process* as one of the specific ends of engineering design.

Second, the etymology of the word *artefact* makes it clear that an artefact is "anything made by human art" which would, of course, included a process and then

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[7] Norms, Knowledge and Reasoning in Technology Conference at Boxmeer, the Netherlands, sponsored by University of Technology, Eindhoven, 2005 (Koen 2005).

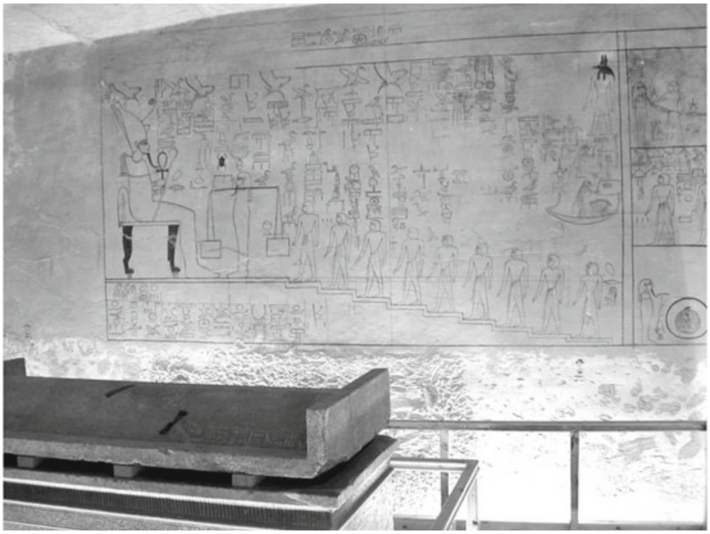

Fig. 10.9 Egyptian wall painting

specifically singles out the archaeological connotation of the word as having entered the language at a more recent time, certainly millennia after the Egyptian engineers lived. To quote the etymological dictionary (Harper):

> (artefact) "anything made by human art," from It. artefatto, from L. arte "by skill" (ablative of ars "art;" see art (n.)) + factum "thing made," from facere "to make, do".
>
> Archaeological application dates from 1890.

Third, there is a branch of engineering called Operations Research that specifically deals with the best way to carry out operations to achieve a goal. It includes such topics as the design of assembly lines, supply chain management, queuing theory, and the best way to attack the traveling salesman problem.

Consider the *assembly line* as one example to make the point that the creation of processes are an important part of engineering. We are all familiar with the assembly line and usually attribute its invention to the Ford Motor Company in the manufacture of the automobile in 1908 AD. What is less well known is that the Egyptians used an assembly-line technique as sophisticated as the ones we use today in the creation of the famous wall paintings in their tombs and tunnels. Figure 10.9 shows a sample of one passage way in the tomb of Horemheb known as KV5l dated to about 1319 BC and Fig. 10.10 shows a detail from another place in that tomb (Wikipedia 2008).

The second figure is a screen capture from a television documentary that has a voice over by Dr. Kent Weeks, whom we met earlier saying (Halliley):

We have examples of almost every stage in the process of smoothing the walls, outlining the decoration, covering the decoration, modeling the details of the relief, and painting the relief. Almost every single step is shown.

Fig. 10.10 Egyptian wall painting (detail)

The color version of the figure given clearly shows the first preliminary sketch of figures in black, and finally the corrections by the master artist in red made by teams that moved along the wall one after the other.

In an extremely relevant and interesting documentary entitled *Engineering an Empire: Egypt* (Cassel 2006) that describes the assembly line in detail, we find the voice over statement by the narrator, Michael Carroll and then the comment by Salima Ikram of the American University of Cairo:

> …the work took on the efficiency of an assembly line…. Some people would specialize in hands, some would do faces…

It is clear that the design of strategies to achieve specific purposes has been a part of engineering for a very long time.

These process strategies are as important to our understanding of how an engineering design was achieved as the concrete object itself. They are also passed on from generation to generation. As one well-documented example, consider the construction of the Empire state building in New York and the construction of the Great Pyramid in Egypt. At the time of its construction, each was the tallest man-made structure.

We have almost complete knowledge of how the Empire state building was built. It is a 1,453-ft, 103-story structure built in just over 13 months. Time had to be scheduled down to the minute. Workers would swing the girders into place and have them riveted as quickly as 80 h after coming out of the furnace and off the roller. The frame of the skyscraper rose at the rate of four and a half stories per week, or more than a story a day (Grabianowski 2001; Tauranac 1995).

On the other hand, almost nothing exists that preserves the state of the art or set of heuristics used in the construction of the Great Pyramid apart from the concrete engineering structure itself. To quote Robert Partridge, chairman of Manchester Ancient Society (History Channel 2004):

> There are no representations whatsoever of building the pyramids.

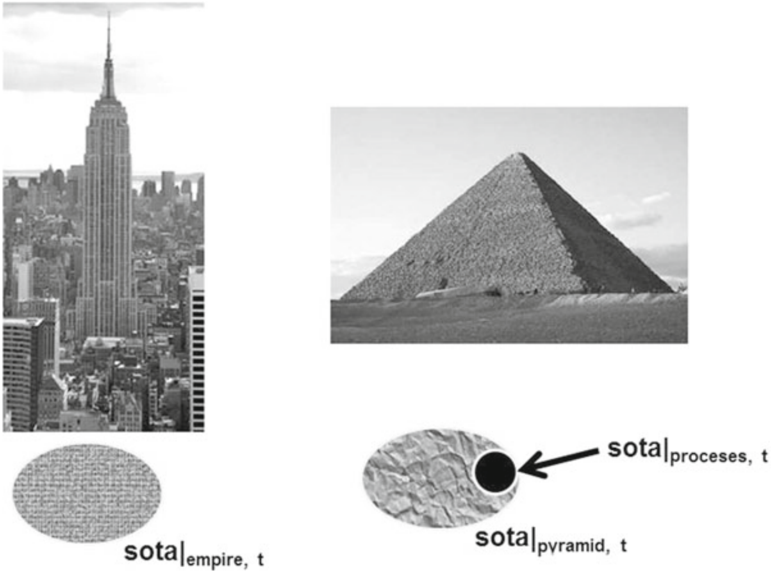

Fig. 10.11 Comparison of the sotas of the Empire State Building and Great Pyramid

Modern engineers are convinced that they could not reconstruct the Great Pyramid using the tools of ancient Egypt and knowledge gleaned from the completed design as it stands. On the other hand, they are confident they could exactly duplicate the Empire State Building in the same period of time required in the original using the same tools based on examination of the building and the heuristics used in its construction. This situation is shown in Fig. 10.11. The complete sotal$_{empire, t}$ is known in one case; the sotal$_{pyramid, t}$ or set of heuristics needed for the construction of the Great Pyramid are not all known in the other. What is missing is the set of heuristics represented by the small black circle, the sotal$_{process, t}$. The process by which an engineering object is made is certain something "made by human art" and, hence, qualifies as an artefact in the true meaning of the word. It is not, however, a "concrete" object.

10.3.5 Myth: Engineering Is Trial and Error

It is undeniable that on occasion engineers make errors, sometimes even very dramatic ones. One of the most celebrated failures from the past was the Tacoma Narrows Bridge failure in 1940 shown in Fig. 10.12. It is also undeniable that engineers will not build an exact duplicate of the Tacoma narrows bridge in the future. But the issue here is whether or not *trial and error* is a legitimate definition or valid characterization of engineering. That it is not is evident for a variety of reasons.

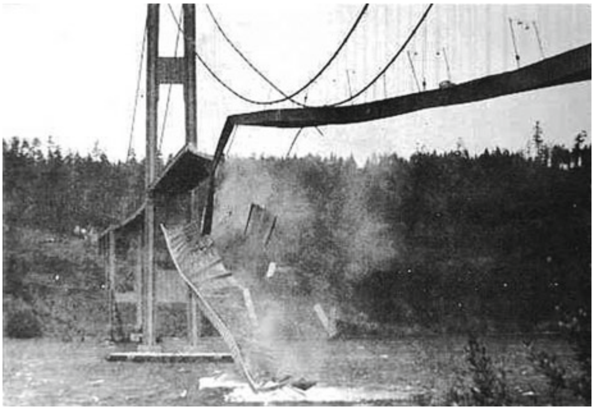

Fig. 10.12 Tacoma narrows bridge failure

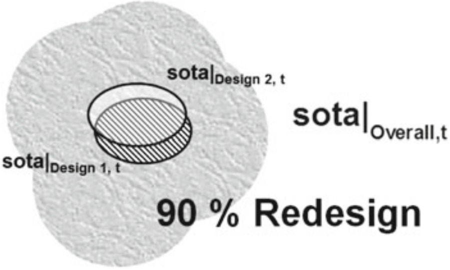

Fig. 10.13 Redesign

First, there are a very large number of engineers in the world. The exact number is hard to determine and depends on who is doing the counting and whether one is counting engineers in general, professional engineers, or only practicing engineers, etc. One Internet search engine reports that the Bureau of Labor Statistics data for the number of engineers in the U.S. as 1,512,000 in 2006.[8] Daily these individuals are making decisions, solving mathematical problems, sizing equipment, testing designs, and marketing the product, etc. It is hard to believe that a significant percentage of the truly huge number of engineering decisions made world-wide every day are errors.

Second, limiting ourselves to the overall design of a finished product, credible engineers have estimated that 90 % of all engineering designs are redesigns (Otto and Wood 2000). Figure 10.13 illustrates this point. The set of heuristics of a later design, $\text{sotal}_{design1,\ t}$, is based on or just a small tweak of a previous set of heuristics 90 % of the time.

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[8] Reported by Semerich, a computer engineer, from Google on 12/4/2010 in answer to the query, “What is the number of engineers worldwide?” A defensible number for the engineers worldwide appears difficult to obtain.

Third, by its nature engineering is a risk taking activity. As stated in DOM:

> To qualify as design, a problem must carry the nuance of creativity, of stepping precariously from the known into the unknown, but without completely losing touch with the established state of the art. This step requires the heuristic, the rule of thumb, the best guess.

And, finally, since human life is often involved in engineering design and creativity is the essence of engineering, some risk of tragic error is unavoidable. $\text{Sotal}_{\textit{Modern, t}}$ shown in Fig. 10.7 on page 11 contains very powerful heuristics developed over at least seven millennia to reduce risk to an acceptable level. A small, but representative, sample of risk avoidance engineering heuristics includes:

- Make small changes in sota
- Give yourself a chance to retreat
- Develop a project by successive approximations
- Allocate resources to the weak link
- A project usually squeaks before it fails
- Do a feasibility and pilot study

For all of these reasons, we are compelled to conclude that it is inadequate to characterize modern engineering as trial and error and to do so grossly misrepresents the true state of affairs.

10.4 Conclusions

The preceding sections have considered the following contemporary claims concerning engineering: (1) a popular definition of engineering method is vacuous, (2) engineering is a relatively recent human activity, (3) engineering is applied science, (4) engineering is trial and error, and (5) engineering artefacts must be concrete objects that persist over time and have given reasons why they should be considered as myths.

By way of conclusion, let's look at a positive unifying characterization of engineering, instead of lingering on these negative myths. Now the archetypical engineering project, the construction and evolution of the Egyptian Pyramids over four centuries, will be examined in some detail to demonstrate what engineering is really all about and the folly of the contemporary myths just considered.

As this is being written, 138 pyramids have been found with almost certainty that another one has been located. Others undoubtedly await discovery and still others have surely degraded and vanished from the earth forever. Out of the 138 only 6 of the most characteristic and well-known will be described. Refer to Fig. 10.14 for pictures of this selection and to Table 10.1 on page 20 for the specific design criteria of each.

Then a brief discussion of the implications of this review of Egyptian engineering design will be given, and, finally, we will meet—face to face—so to speak the image of the very *first* engineer whose appearance, name, works, and reputation is positively known in the historical record.

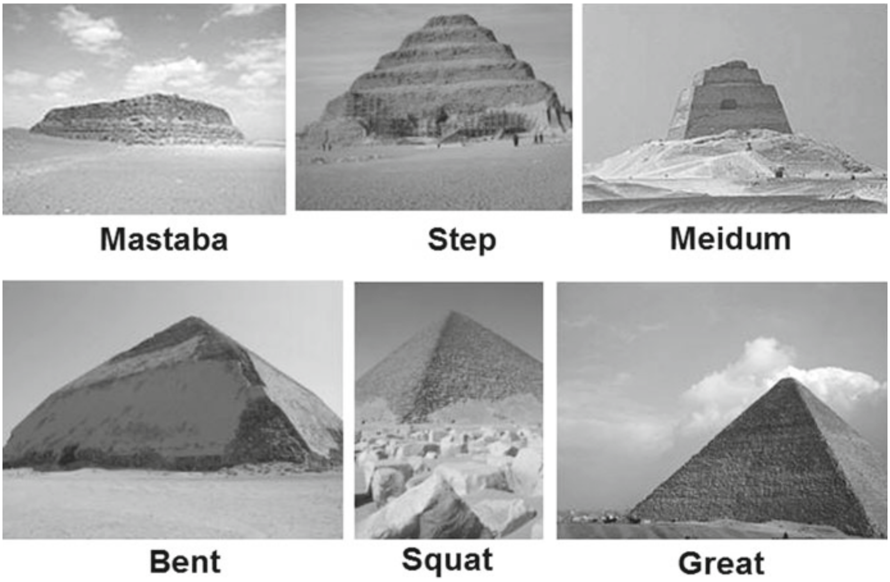

Fig. 10.14 Evolution of Egyptian Pyramids

Table 10.1 Egyptian Pyramid design data

Name	Date	Height (m)	Slope
Mastaba	c. 2649 BC	–	–
Step Pyramid	c. 2630 BC	62	–
Meidum Pyramid	c. 2630 BC	92	–
Bent Pyramid	c. 2600 BC	104	Started 60°; then shallower angle of 55°; finally, slope reduced to 43°
Squat (Red, North) Pyramid	c. 2600 BC	104	Slope of 43°22′
Great Pyramid	c. 2250 BC	141	Slope of 51°52′

Nothing in Egyptology is beyond dispute because of the age of the ancient Egyptian civilization. The following outline drawn from highly credible sources is sufficiently accurate for present purposes and we will leave the often contentious squabbles to others. Except as noted, information comes from The National Geographic (2008), the Encyclopedia Smithsonian (2008), or the MSN Encarta (Nolan 2008).

An abbreviated history of pyramid construction is as follows:

Mounds of Sand During the 1st dynasty which began in 2920 BC and the 2nd dynasty, the Egyptian Pharaohs were buried in graves topped with piles of clean sand inside low-lying walls.

Mastaba In the 3rd dynasty, the Pharaohs were buried under *mastabas* See Fig. 10.14;

Step Pyramid The *Step Pyramid* is considered Egypt's first pyramid. The Step Pyramid and later pyramids of the 3rd dynasty were constructed of small, almost brick-sized stones that were laid in vertical courses and inward-leaning to create the sloped sides; Patterned after the Step Pyramid are other smaller step pyramids, for example: the Seila Pyramid, the Zawiyet el-Meiytin Pyramid, the Sinki Pyramid, the Naqada Pyramid, the Kula Pyramid, the Edfu Pyramid, and the Elephantine Pyramid.

Meidum Pyramid The *Meidum* Pyramid was influenced by the step pyramid and is considered the first "true" pyramid. A step pyramid was built, the steps filled in with stones, and a smooth casing was added. It was a straight-sided pyramid whose inward-leaning walls ultimately collapsed;

Bent Pyramid The bottom of the *Bent Pyramid* looked like a mastaba, but the middle and upper portions resembled a true pyramid. This came about from purely engineering considerations.

> The architects had designed it with an angle of 60° (to the ground), but as the pyramid rose, it started to sink because of the weight and angle of the stones. To solve this problem, the builders put up an outer supporting wall, giving the half-finished pyramid a shallower angle of 55°. After this, the architects finished the upper portion of the pyramid off with a slope of only 43°. This shift in angle from 55° to 43° gives this pyramid its name—the Bent Pyramid. (Nolan 2008)

Another engineering innovation was made during the construction of the Bent Pyramid's upper portion. Instead of leaning the stones inward, they were laid down in horizontal layers with each level slightly smaller than the one it lay upon;

Squat (Red, North) Pyramid The stones of the *Squat Pyramid* were again laid down in horizontal layers suggesting that the ancient engineers followed the state of the art of the upper portion of the Bent Pyramid design. This gave the pyramid an unpleasing squat look;

Great Pyramid The *Great Pyramid* and all of the pyramids built during the 4th dynasty were built based on the heuristics previously used. It is the largest pyramid ever built and incorporates about 2.3 million stone blocks, weighing an average of 2.5–15 tons each. The workers would have had to set a block every two to two and a half minutes for 20 years according to both James Allen from the Metropolitan Museum of Arts (Allen 2008) and National Geographic (2008). Some recent estimates of the number of workers are as low as 10,000 individuals. Carefully placed shafts pierce The Great Pyramid and are thought to have been situated to aid the dead pharaohs journey into the afterlife.

Later Pyramids By the 5th dynasty (Nolan 2008),

> The quality of royal pyramid construction declined. The cores were made of smaller blocks of stone, laid more irregularly and by 2134 BC, the pyramids had a core of shoddy masonry and debris covered with a veneer of fine limestone.

This decline is thought to be from changing economic conditions and the tendency of the pyramids to become less secure as a resting place for the Pharaohs.

This abbreviated chronology of the evolution of the Egyptian pyramids reveals many of the interesting characteristics of the engineering method that have already been discussed and the importance of the engineering concept of the state of the art. Consider the following by way of review.

- No science was involved in the construction of the pyramids, yet engineering problems were solved. With science nonexistent, we might ask: during the years of pyramid design, what changed? What changed was the set of heuristics of pyramid design—that is, the sota.
- The sota of one pyramid was clearly a function of the sota of previous ones. The angle of the top of the Bent Pyramid is the same as the next "squat" one.
- The designs were defined and limited by the resources of money, talent, pharaoh's pride, and organization, not by some external, true norm.
- Engineering failures do happen when the engineer exceeds the range of applicability of the current heuristics, but he quickly retreats to a solidified information base and strikes out again.
- Trade-offs clearly existed between the aesthetic and the technical heuristics. The squat pyramid was surely a function of the earlier bent pyramid that failed. When technology improved i.e. stones were no longer laid at an angle, but put in courses, the angle increased again.
- The importance of the sota is hard to overstate. With no extant records of means of construction, even today we have no idea how the huge number of engineers was organized to build the pyramids. In technical terms, we do not know what the engineering artefact called *supply chain management* in modern terminology was like.
- Reality as conceived today had nothing to do with the placement of the shafts that pierced the walls of the later pyramids. They were, however, clearly important to the Egyptian civilization of the time. Constructing a pyramid is a complicated and difficult task, but doing so when the design of each level is constantly changing so that a straight shaft will pierce the completed structure at an angle is almost unbelievable. The engineer designs, not for the truth about the afterlife as we think we know it in the *twentieth century*, but as it was understood at the time the design was made.

Far from just building engines, the Egyptian engineers were certainly "clever, practical, problem solver[s]".

Even this abbreviated example of the evolution of the Egyptian pyramids shows that the definition of engineering:

> *The engineering method is the use of state-of-the-art heuristics to cause the best change in an uncertain situation within the available resources.*

is valid.

As mentioned in the introduction, this paper concludes with an introduction to the earliest engineer in history whom we know by name and to an example of his most famous engineering achievement. We can even look into his eyes. His name is

Fig. 10.15 Imhotep with name in hieroglyphs

Imhotep and Fig. 10.15 is a small statue in the Louvre, Paris, France. A large number of similar statues have been found throughout Egypt.

According to Wikipedia (emphasis added) (Wikipedia: Imhotep):

> Imhotep (2655–2600 BC)… was an Egyptian polymath, who served under the Third Dynasty king, Djoser, as chancellor to the pharaoh and high priest of the sun god Ra at Heliopolis. He is considered to be the first architect and engineer and physician in early history.

The full list of his titles translated into English from the hieroglyp (probably by way of French) is (with important emphasis added):

> *Chancellor of the King of Egypt, Doctor, First in line after the King of Upper Egypt, Administrator of the Great Palace, Hereditary nobleman, High Priest of Heliopolis,* ***Builder****, Chief Carpenter, Chief Sculptor, and Maker of Vases in Chief.*

Certification that he was indeed an engineer is undoubtedly derived from his title as *builder* emphasized in the quotation of his titles above since, of course, the word *engineer* did not exist in the twenty-seventh century BC.

And the greatest achievement of the first engineer in history known by name? He dreamed, designed, created, and built the very first pyramid in Egypt—the Step Pyramid. Note the size of the people beside it in Fig. 10.16 to establish the scale.

The example of the evolution of the Egyptian pyramids from the Step Pyramid to the Great Pyramid is one of the greatest sustained examples of the practice of

Fig. 10.16 Imhotep's step Pyramid

engineering over a long period in history. It should aid philosophers in avoiding the myths in the literature as they collaborate with engineers to develop a cogent Philosophy of Engineering. We can only hope that the future will bring a philosopher willing to return the favor and aid engineers in achieving their side of the bargain by debunking the myths concerning contemporary philosophy that engineers surely believe.

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