Surveying: The Second Paradigm

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SUMMARY

Surveyors in classical antiquity knew about surveying and surveyors were held in high regard (Brock, 2012). Their methods were such that they were able to lay out plots and calculate areas, mostly for taxation purposes. However they also were competent to layout and supervise the construction of major engineering works such as pyramids, aqueducts and roads using basic technology and geometry. In a relatively short period about 1600 CE a variety of developments occurred that advanced the capability of the surveyor to carry out their work. The consequences of the Renaissance brought a number of advances in technology that changed the way in which surveying could be carried out. Political changes also meant that a new form of property market developed in England. This was also the period of colonisation, first in America, but then in other parts of the British Empire such as Canada, Australia and finally New Zealand. The combination of these developments brought about a paradigm shift in the nature of what would become, in the 19th century, the profession of surveying.

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1. INTRODUCTION.

Land surveying is an occupation for which records go back to antiquity. Current evidence of surveying field records and calculations of areas of allotment shapes and sizes from the times of the Sumerians have been discovered (Cooper 2009). As an aspect of work and study it has developed incrementally through time and has been influenced by many and diverse factors. In its early development these were focussed on the gradual improvement in measuring equipment, but increased in pace as science, and particularly mathematics and physics, progressed. It also extended its ambit as the world was explored and new explanations were offered for the extent and nature of the world of human habitation. New skills were added to meet the demands of the exploration and the expansion of colonial empires. The advent of high speed electronic computing and digitisation has accelerated the changes in technology available to land surveyors.

2. LAND SURVEYING IN ANTIQUITY – THE FIRST PARADIGM.

The practice of land surveying, and practicing land surveyors, existed in early settled societies. The control of domesticated plants and animals produced the concept of ownership of the means of food production and in turn became a major source of wealth and power. Brought about through the Agricultural Revolution c.10,000 BCE, particularly domestication of plants and animals, the development of irrigation and the invention of the plough, this allowed mobile hunter-gatherer tribes to evolve into stationary and stable settlements. (Shultis, 1991).

As civilisation developed, claims to ownership of resources could indicate the amount of tax that a citizen might owe to their rulers, as taxes were often related to amount of land "owned", grain produced or beasts farmed (Cooper, 2009). These resources were essential for survival and stability. Additionally, ownership led to wealth through trade. With surpluses of food, early societies developed sophisticated means of communication as well as writing, mathematics, theology and philosophy and a class system evolved that allowed labour specialisation, freeing some of the population from the necessity of spending a major part of their time finding food. Scribes were able to record their history in writing rather than simply through oral tradition (Shultis, 1991).

In the Babylonian and Egyptian eras the land measurers were government officials and boundary marks were highly regarded. In some cases they were protected by religious taboos – "Cursed be he that removeth his neighbour's landmark. And all the people shall say Amen" (Bible, 1611). Early mariners had been navigating the seas for thousands of years, and were established as traders in the Mediterranean by c.2800 BCE (Columbia Encyclopaedia, 2013). The finding of position by the use of stellar observations, both on land and sea is, therefore, a long established tradition by those seeking their own precise location as well as those wishing to travel to some other known place, or to explore to unknown places.

2.1 The Egyptians

The accuracy with which the Egyptian surveyors laid out the Great Pyramid attests to their competency in geometry, angular and linear measurement as well as some understanding of astrological or astronomical alignments. They achieved accuracies of 20 cm over a horizontal distance of 230 metres and 6mm to14 mm in vertical difference or level. They aligned their structure within 5½ minutes of arc of true compass directions, indicating that they also had some understanding of geodesy (Dilke, 1971). The Egyptian authorities were interested particularly in crop yields as this formed the basis of their taxation system but also developed systems of irrigation to utilise their available water to best advantage in the process of food production. However there is little written confirmation or detail of this as it is thought to be a matter only of local interest only (Kemp, 2006). Such land management techniques were necessary as Egypt had suffered severe famines as a result of drought in the past (Hassan, 1997). Other implications of the measurement of land was to produce topographical maps essential to the Egyptian farmers, and involved establishing gradients that would allow water to flow for irrigation, calculation of the quantities to be removed for channels or canals, and computing the number of bricks or blocks needed for a building (Cooper, 2009). The important status of the Egyptian surveyor is observed in their appearance in hieroglyphics, the surveyor being depicted with his rod of office supervising his workers as they use their knotted rope to make measurements (Brock, 2013).

2.2 The Greeks

The Greek surveyors, who understood the importance of the reestablishment of boundaries from the regular River Nile floods of Egyptians, “as Herodotus shows, thought of themselves as having learnt the principles of surveying from the Egyptians” (Dilke, 1971). They were also competent in tunnelling and in the laying out of towns in accordance with the plans of those such as the architect and planner Hippodamus. Additionally, the understanding of geodesy allowed Dichaearchus to establish a line of latitude from the Himalayas to Gibraltar in the 4th century BCE. This was based on work done by those such as Pytheas of Marseilles in circumnavigating Britain and the description of the Ganges valley by Megasthenes. In the 3rd century BCE Eratosthenes was able to make a remarkably accurate estimate of the Earth’s circumference, against the prevailing flat-earth beliefs of the time (Dilke, 1971). The true size of the planet, as well as its relationship with the sun and with the other planets, remained a matter of interest to Greek philosophers and mathematicians until the time of Ptolemy c.150 AD (Encyclopaedia Britannica, 2013).

2.3 The Romans

In the era of Roman dominance the *agrimensores*, the “measurers of the land” (Dilke, 1971), were recognised as professionals who received special education and training (Cooper, 2009). The Roman land surveyors were trained and educated in cosmology, astronomy, geometry, orientation, sighting and levelling. They were also knowledgeable in land law, centuriation, t land legal status, the allocation of land, mapping and recording. (Dilke 1971). Their status was high in the Roman bureaucracy as they had “. . . expertise in land law and . . . advise judges in disputes over land ownership . . .” and the land surveyors were held in high esteem (Cooper, 2009 p.4).

During the establishment of the Roman Empire, the *agrimensors* fulfilled other tasks. As the empire spread it required both a network of roads for communication purposes and for the speedy deployment of troops to maintain order within the expanding territories. They were also required for the setting out of the rectangular-patterned garrison settlements across the vast Roman Empire, which needed to be controlled by suppression of the local inhabitants. The land surveyors were also necessary for the laying out of roads, aqueducts, bridges and drains (Cooper, 2009). The Roman land surveyors therefore had important practical functions in the expansion of the Roman Empire, beyond the demarcation of land boundaries and the establishment of early cadastral records.

Greek and Roman surveyors also developed a number of specialised instruments to assist them in their work. These included the groma, for surveying straight lines and turning right angles, measuring rods of various lengths, the chorobates and the dioptra for levelling, and the hodometer (possibly the first odometer) a mechanism attached to a wheel for measuring longer distances (Dilke, 1971).

These land surveyors of classical antiquity were held in high regard. From Egyptian times their position was one of authority and status, and the educated and trained surveyors supervised other less qualified assistants to carry out their measurements. Their abilities and competencies remain obvious with such monuments as the Great Pyramids, the Roman roads of Europe and the aqueducts that can still be seen and marvelled at, as well as the patterns of settlement that can be seen in European landscapes several millennia later.

Their influence at this micro level of land measurement was important to transportation and urban and rural development, and also involved aspects of surveying at the macro scale when they extended their mathematics and philosophy to attempting to measure the size of the planet and explain the movement and relationship of the heavenly bodies. The collapse of the Roman Empire during the early part of the first millennium BCE brought the Western world into what is now commonly referred to as the Dark Ages, a time of famine, pestilence and conflicts between neighbours and invaders in attempts to establish territorial dominance (Shultis, 1991). One outcome of the pursuit of territorial dominance was the need to fund wars through taxation of land owners or tenants. This lead to the creation of cadastral records, as monarchs attempted to assess the territory, and consequent wealth, they had accumulated through conquest.

2.4 Cartography

In addition to the application of surveying to matters of land area definition and the alignment of significant structures, measurement was also being used by the Greeks in early recorded history for a larger purpose, that of interpreting the known world, its dimensions and its position in space. Eratosthenes of Cyrene (276 – 194 BCE, third librarian at Alexandria, was able to calculate the circumference of the Earth to within 100 miles, though the known inhabited world he portrayed in a map is confined to Europe, Africa and part of Asia (including India). He is alleged to be the first to coin the term “geography”. The word derives from “geo” meaning “Earth” and “graphien” meaning “written” (Garfield, 2012).

Eratosthenes also was one of the first scholars to render the written word into an illustration, thus founding the art of cartography (Garfield, 2012). There is a written account of the (then known) world, Strabo's 17 volume *Geographica,* but there is no existing map that relates to his text (Garfield 2012). The inhabited world is rendered flat, although Pythagoras had proven that it was a sphere as early as 194 BCE. Cartographic progress appears to have "fallen into the cartographic dark ages for about a thousand years" (Garfield, 2012 p.39). Maps such as the Mappa Muni, the Psalter Map did not start appearing until around the 13th century.

Early examples of cartography, however, appear to be the pictorial representation of descriptions of routes, locations and places, rather than accurate representations of the relative positions of the places shown. That is, they were for illustrative purposes, and while they might indicate how long it may take to travel from one place on the map to another, they did not contain, nor were they based on, measurements taken by the people now known as land surveyors. This was to come at a much later date as standards of measurement were adopted, equipment and techniques of calculation were developed, and greater knowledge of the size and shape of the planet Earth were understood.

3. THE MIDDLE AGES AND THE SECOND PARADIGM

There is no evidence of specific advances in the practice of land surveying through the medieval period in Europe (Wolf, 2002), though this ignores the developments in mathematics outside of Europe. While Europe had descended into what later became known as the Dark Ages, the development of mathematics and science continued in the east, specifically in China, India and the Islamic world. In the view of at least one author (Joseph, 1987) the role of the Arab scholars in this period was crucial. They pursued and developed mathematical knowledge from Jundishapur in South-east Persia, " . . . moving through Baghdad, Cairo and finally, to Toledo and Cordoba in Spain" (Joseph, 1987).

As Staiger points out "The Archaic phase lasted thousands of years and ended in 1590 with the invention of the telescope"(Staiger, 2009). The arrival of the concept of land as private property changed the role of the land surveyor. Additionally, and partly as a result, the standardisation of measurements, the arrival of new forms of mathematics and advances in angular measurement based on the invention of and modifications to the telescope were to provide such change that the shift in practice was revolutionary

3.1 Trigonometry

Trigonometry emerged in Europe in the 16th century as spherical trigonometry and based on the mathematical relationships of sides and angles in triangles, from which its modern name is derived. The term trigonometry was first introduced by the German mathematician Bartholomaeus Pitiscus in 1595. It consists principally of the ability to solve triangles from one linear measurement and then measuring angles (Adamek, Penkalski et al. 2005). It is therefore integral to the practice of land surveying, along with other developments, as it emerged in Europe during the Renaissance period. The period prior to the Renaissance and the Rise of Science represents the end of the first era in the development of the land surveying profession. Land surveyors had been held in high regard during the classical period, but nothing is known of their formal education or training. It is evident, however, that they did have knowledge of mathematics and of astronomy.

3.2 Measurement

William the Conqueror brought a more exacting form of feudalism to England and quantified the land in his new kingdom through the construction of the Domesday Book. Measurement at that time was defined by terms derived from nature for smaller measures, such as thumbs, fingers, palms, feet and cubits (the length of a forearm). The need for measurement effected trade in all manner of commodities from farm produce to manufactured goods so that value could be attached to quantities for the purpose of exchange, either by barter or coin. Larger land areas were defined mostly by how long an area would take to plough or how many people a given allotment of land could support. Thus, an acre of fertile land was smaller than an acre of less productive soil (Maitland, 1897). Other weights and measures for produce and for manufactured items such as cloth were equally based in dimensions related to the human body.

3.3. The concept of land as property

According to Linklater land management practice was undergoing change in England as well. As a result of inflation, land owners were attempting to maximise the production from their lands and the process of "enclosure" was underway. Tenant farmers had managed their lands in strips or rigs and were under pressure to consolidate areas and separate them with hedges so that crops would not be trampled. In the publication "The Boke named the Governour" Sir Thomas Elyot, giving advice to land owners on how to run their estates, advised that the first essential step was to "draw a map or 'figure'" of the estate so that the governor knows of what it consists," (Linklater, 2002) p.3. Linklater asserts that by drawing maps of their holdings, land owners were asserting ownership, and that this is the foundation of "land as private property" (Linklater, 2002) p.5.

Linklater further asserts that "the "greatest real-estate sale in England's history" (Linklater, 2002 p.6) occurred when Henry VIII dissolved some 400 monasteries in the 1530s and their lands reverted to the Crown. Henry's need of cash meant that, rather than allocating his regained estates in the feudal manner that had predominated until then, he choose to sell the land. Thus instead of having the feudal rights of the service of his tenants, he was able to sell the land for cash, principally to pay for the defence of his realm. This new type of rights in land required that those purchasing land needed to know exactly what they had acquired. It was no longer adequate to define land areas by how many people it could support. Areas had to be defined by measurement. By measuring the sides of regular and irregular figures and calculating the area there from (Linklater, 2002). That is, by the defining of boundaries in the ways in which land surveyors do to this day.

At about this time a number of important discoveries were being made and inventions developed. These included more accurate angular measurement, standardised linear measurement, adoption of standard units for distance and areas, and the development of the telescope. At the same time computational methods were being adopted that would ease the calculations required of the land surveyor, including Arabic numerals, decimal systems and logarithms.

3.4 Angular Measurement

Surveying textbooks of the early 16th century dealt mostly with methods for conducting audits and valuations and were only beginning to consider issues of actual land measurement (Turner, 1991). Bennett observes that in the 16th century the symbol of office was a pole, but also that the surveyor's work involved "other kinds of measurement" (p.345) and valuations, and that linear measurement was still accomplished using poles and ropes. He further asserts that the success of mathematics, specifically geometry and arithmetic, had proved so successful in navigation that the advocates of the mathematical sciences found surveying their next target (Bennett, 1991).

In 1570 a work appeared by an English surveyor, Leonard Digges (or Diggs), entitled "Pantometria which describes an instrument called a "theodolitus". It was used in topographical surveying and incorporated a graduated horizontal circular disc of 12-14 inches in diameter and divided into 360° (Wolf, 2002). It included a vertical semi-circle and a magnetic needle (presumably for compass bearings) and could be used for the determination of heights and distances (Wallis, 2005). At some point the new instrument moved from being mounted on a pole to the more stable tripod. With the improvements in telescope design by Galileo, and its addition to the prototype theodolite, the utility and accuracy of the device was improved (Wolf 2002).

The evolution of this new instrument continued with the addition of scales by Pierre Vernier, and described in a Brussels publication in 1631. This allowed for the more precise reading of the graduated circle thereby achieving more accuracy, though these did not become universal until the 18th century. A better sighting mechanism was developed using telescopic sights, modifying the original astronomical instruments by William Gascoigne, possibly about c.1644 (Hacking, 1989). A further refinement by Jean Picard added crosshairs to the telescope and Melchisedech Thevenot introducted a "level bubble" in 1666 (Wolf, 2002), further improving accuracy.

The final refinement to the early basic design of the theodolite was the mechanical division of the 360° circle to further improve the accuracy of readings by Jesse Ramsden in 1770 (Wolf, 2002). Ramsden's invention has also been dated as being in 1773 . Subsequent improvements were made by to his dividing engine by surveying instrument manufacturers such as Edward Troughton in 1793 and William Sims in 1843 (Cox, 1986). The final improvements came in the 20th century when Heindrich Wild improved the internal focusing of the telescope in 1908 (Cox, 1986) and glass graduated circles replaced metal ones about 1920 (Staiger, 2009). Staiger maintains that what he refers to as the "optical era" reached its peak with the work of the Swiss theodolite designer Heindrich Wild and the arrival of the first completely enclosed glass-circled theodolites.

The developments in angular measurement brought greater accuracy to the measurement aspects of the 16th century land surveyors and their successors through the following 300 years. In parallel there were equally important developments in the associated requirements for more precise linear measurement. These were required to enable the surveyor to accurately and consistently define the boundaries of specific tracts of land and calculate their areas. Such accuracy was also required in order to establish equitable valuations for both exchange in the land market and for the levying of taxes by the Crown or the government.

3.5 Linear Measurement

Until the 16th century linear measurements were arbitrarily defined and there were no consistent definitions on which to base calibrations. Weights and measures had been bequeathed to Europe by the Romans. They were largely defined in relation to parts of the human body such as thumbs, palms and feet. In order to achieve fair trade, in land as well as other commodities, standardisation was necessary. It is in this period of the rising volume of trade, both local and international, that there was much interest in establishing agreed standards of measurement, both linear and volumetric. Nations began to legislate for their own standards, and to proscribe the use of one set of standards for selling and another for buying commodities. This was a widespread practice alluded to as long ago as biblical times. With the emergence of a land market following the redistribution of land after the dissolution of the monasteries by King Henry VIII, land areas could no longer fluctuate according to such variables as fertility. The new land owners were requiring exactness of their surveyors (Linklater, 2002).

Linear measurement of land was traditionally based on the rod, pole or perch, varying names for the same unit of length. It is asserted that the origin of the pole lies with the stick used by ploughmen to control their oxen as they worked the land. The stick needed to be long enough to reach from the back of the plough (the position of the ploughman) to the nose of the furthest oxen (Anonymous, n.d.). Whatever the true origins of the name and the selection of its dimension, the standard unit was a rod or pole, and its length was 16.5 feet (Linklater, 2002).

In this system four rods made a chain. A field of an acre, sufficient to support one family, was deemed to be a furlong (40 poles or 220 yards) deep by 22 yards wide. The standard measurement of 22 yards is also the length of a "chain", a measure used as the basis of plane land surveying in many countries, and that persisted well into the 20th century in many places. It is still in use in the United States of America. The standardisation in the time of Henry VIII, and legislated for by Queen Elizabeth I in 1588, was an integrated system that defined relationships between lengths (inches, feet, yards, poles, chains, furlongs, and miles) and areas (acres, roods, perches and square miles). In 1601, in order to standardise the measurements for the country, a brass yardstick of 36 inches was constructed (Linklater, 2002). These measures formed the basis of the Imperial System for several hundred years. It was only superseded by the extensive adoption of the metric system in the 20th century.

It was against this background that Edmund Gunter appeared, born in Wales, educated at Oxford University, and later to become Professor of Astronomy at Gresham's College, London. Gunter had a passion for mathematics, and in particular ratios and proportion. This enabled him to design and construct a variety of instruments, including an early slide rule. He was also familiar with decimals, logarithms and trigonometry (Linklater, 2002). His development of a device that was not only a chain in length but a chain in physical reality, was to establish his name in the annals of surveying history, and the Gunter's Chain was used for centuries following its invention. The Gunter's Chain was replaced in the late 1800s by the continuous steel band, but the principles in embodied remained the same.

Gunter's Chain was 100 physical links in length, each of 7.92 inches, and made of heavy steel wire. The links had loops at each end enabling the links to be joined together, had brass markers at every tenth link, and as a whole was easy and flexible to use. In the view of Linklater, this was ". . . a brilliant synthesis of two otherwise incompatible systems; the traditional English land measurements, which were based on the number four, and the then newly introduced system of decimals, based on the number ten" (Linklater, 2002 p.12). That is, four rods equalled one chain, which in turn equalled 100 links. Thus it was that the variable units of rods, acres and miles became fixed in the 16th century.

While the development of surveying measuring equipment was a critical development at a fortuitous time of change, the arrival of new concepts in mathematics also contributed to the rising importance of the surveying of land, the calculation of areas, and the ability to calculate distances from angular measurement using a single measured base – geometry and triangulation.

3.6 Mathematics

The computation of areas using the newly standardised system was achieved by relatively simple arithmetic using the dual systems based on the traditional base of four and the new decimal system based on ten. These early surveying devices relied heavily on the physical measurement of distances in order to define the land and to draw maps or plans to scale. "Angle measurement and trigonometry presented much greater challenges. It was here that a struggle was developing for the proper practice of surveying and the legitimate image of the professional surveyor" (Bennett, 1991. p.346).

In this respect, surveying was closely affected by the developments in astronomy and navigation, both utilising similar instruments of observation and the same principles of geometry. The inducement for surveyors to take up geometrical principles was that of trigonometry. Being able to solve triangles by measuring one baseline and then merely observing distant points from either end, there was no longer any need to physically measure all distances, especially longer ones. They could, instead, be calculated using trigonometrical formulae. This technique became known as triangulation, and was explained in 1533 in the Gemma Frisius edition of "Cosmographia" by Apianus (Bennett, 1991).

In this way, the theodolite changed the principal practice of surveying from one of solely linear measurement, although it retained considerable importance, to the combination of angular and linear measurement enabled by the use of trigonometry for triangulation. The introduction of the use of Arabic numerals (Turner, 1991), decimal notation (in a paper by Steven Stevin in 1585), and logarithms by John Napier in the early 1600s, who also worked to improve Stiven's decimals (Linklater, 2002), were of great computational value to land surveyors. They were in a period of transition from simple arithmetic to the mathematics needed using geometry and trigonometry (Bennett, 1991).

The uses of these new developments in mathematics, and the instruments developed for measurement purposes, were not confined to land surveying. The renewed interest in astronomy as a result of the development of the telescope and the dependence of navigation on stellar and solar observation also were closely related to these. The need for greater accuracy in navigation in the period when Europe was discovering the rest of the world and developing maritime trade and commerce, meant that all of these advances were of keen interest to a much larger audience.

3.7 The nature of the 2nd paradigm.

Land surveying underwent a revolution during the late16th century and early 17th century. The revolution was spurred by the development of a market as land became an item of private property. The nature of measuring land up to this time had changed little since the times of classical antiquity. The revolution that took place in land surveying was brought about by three principal factors. The first and underlying factor was the arrival of geometry and trigonometry, acquired from the progression through Arabian scholarship and originating in China and India. Reaching the universities in Spain through the conquest of the Iberian Peninsula by the Moors, they were brought to the northern Europe by travelling scholars. The introduction of the decimal system and the invention of logarithms further enhanced the ease of calculation for the new type of land surveyor.

The second influence was the standardisation of measurements. Moving away from areas that were defined by fertility and distances that were defined by parts of the human anatomy, standards were set for linear measurement. Additionally, Edmund Gunter produced the chain that still bears his name, and enabled those carrying out measurements to produce consistent measurements, which could be repeated, to an accuracy that satisfied the needs of the time. This chain was used for the following four centuries, and was only replaced in very recent times by the spring steel band. This measuring tool, however was merely a development of the original Gunter's Chain into a more accurate, manageable and flexible form.

The third factor was the burst of developments that took place with respect to optics and angular measurement, though driven largely by the advances made principally for astronomical and navigational purposes. The telescope, the compass, Vernier scales, instruments on levelled tripods, and mechanical engraving of circular protractors evolved into plane tables and theodolites provided the basis to surveying instrumentation that was also to last well into the 20th century.

The adaption of optical instruments for land surveying purposes provided a major advance to measurement. When combined with the new branches of mathematics and the standardisation of linear measurement, these defined new methodologies for land surveyors as their profession developed. While each of these areas evolved, the principles established as a result of their adoption or creation in the 16th century the nature of land surveying' having once adopted them, changed little over four centuries. Only minor variations in the mathematics, steel measuring bands and optical theodolites were being used to teach the students of land surveying in the 1980 (Neaves, 2014), (Hemi, 2014).

4. CHALLENGES TO THE 2ND PARADIGM

This second paradigm of land surveying persisted through centuries and was only impinged upon in the later part of the 20 century. The developments that were to impact on the traditional practice of land surveying are those that have come to affect every aspect of modern society. The arrival of electronics and the miniaturisation of technology have brought instruments that have had an impact on the very nature of the practice of land surveying. The invention and exponential expansion of the power of computers, along with the diminution of their physical size, have changed work practices. They have also enabled a new dimension in the visualisation of the outputs of the land surveyor's work. Further, the change from finding position by the stars and astronomically derived observations, broken down in to terrestrially observed networks, to the use of satellite systems and their ubiquitous applications, not only by land surveyors but by the public at large, places considerable strain on the accepted definition of the role of the land surveyor in modern society. It does, in fact, provide a challenge the 2nd paradigm in the evolution of the land surveying profession.

5. IS THERE A 3RD PARADIGM?

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REFERENCES

Adamek, T., K. Penkalski and G. Valentine (2005). The History of Trigonometry**:** 18.

Aguirre, J. C. (2014). "The Unlikely History of the Origins of Modern Maps." from http://www.smithsonianmag.com/history/unlikely-history-origins-modern-maps-180951617/.

Anonymous. (n.d.). "Imperial Measures of Length." Retrieved 27 May, 2014, from http://gwydir.demon.co.uk/jo/units/length.htm.

Bible (1611). The King James authorised version. Deuteronomy 27:17. The University Press, Cambridge, The British and Foriegn Bible Society.

Bennett, J. A. (1991). "Geometry and surveying in early-seventeenth-century England." Annals of Science **48**(4): 9.

Brock, John. 2013. The Boundary Stones of Tutenkhamun's Father – Akhenaten's City of the Sun. Proceedings, FIG Working Week. Abuja, Nigeria.

Columbia Encyclopedia. 2013. In "Phoenicia." The Columbia Encyclopedia, 6th ed. 2013. Retrieved 02 June, 2013 from Encyclopedia.com: http://www.encyclopedia.com/doc/1E1-Phoenici.html

Cooper, M. A. R. 2009. Who did they think they were? Or Land Surveyors in Society. London. Royal Institution of Chartered Surveyors. Unpublished address. 9p.

Cox, R. C. (1986). "The Development of Survey Instrumentation." Survey Review **28**(219): 21.

Dilke, O. A. W. (1971). The Roman Land Surveyors: An Introduction to the Agrimensores. Newton Abbot, Devon, UK, David & Charles

Encyclopædia Britannica. "Ptolemaic system." Encyclopædia Britannica Online Academic Edition. Encyclopædia Britannica Inc., 2013. Retrieved 31 May 2013 from http://www.britannica.com/EBchecked/topic/482079/Ptolemaic-system

Garfield, S. (2012). On the Map: Why the world looks the way it does. London, Profile Books Ltd.

Hacking, I. (1989). "The life of Instruments." Studies in History and Philosophy of Science **20**(2): 5.

Hassan, F. A. (1997). Nile Floods and Political Disorder in Egypt. Third Millenium BC Climate Change and Old World Collapse. H. N. Dalfes, G. Kukia and H. Weiss. Heidelberg, Springer-Verlag Berlin**:** 23.

Hemi, R. (2014). Professional Practice Fellow, National School of Surveying, University of Otago, Dunedin, New Zealand. Personal Communication.

Joseph, G. G. (1987). "Foundationhs of Eurocentrism in mathematics." Race and Class(28): 15.

Kemp, B. J. (2006). Ancient Egypt: Anatomy of a civilisation. Oxford, Routledge.

Linklater, A. (2002). Measuring America. London, HarperCollins.

Maitland., F. W. (1897). Domesday Book and Beyond: Three Essays in the Early History of England. Cambridge, Cambridge University Press.

Neaves, A. (2014). Mr. Senior Technical Officer, National School of Surveying, University of Otago, Dunedin, New Zealand. Personal communication.
Shultis, J. D. 1991. Natural Environments, wilderness and protected areas: an analysis of historical Western attitudes and utilization, and their expression in contemporary New Zealand. Unpublished PhD thesis. University of Otago Library.
Staiger, R. (2009). Push the Button - or Does the Art of Measurement Still Exist. FIG Working Week 2009. Eilat, Israel, International Federation of Surveyors (FIG)**:** 18.
Turner, G. L. E. (1991). "Introduction: Some notes on the development of surveying and the instruments used." Annals of Science **48**(4): 4.
Wallis, D. A. (2005). History of Angle Measurement. FIG Working Week "From Pharoes to Geoinformatics", Cairo, Egypt, International Federation of Surveyors (FIG).
Wolf, P. R. (2002). "Surveying and Mapping: History, Current Status, and Future Projections." Journal of Surveying Engineering **128**: 28.

BIOGRAPHICAL NOTES

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