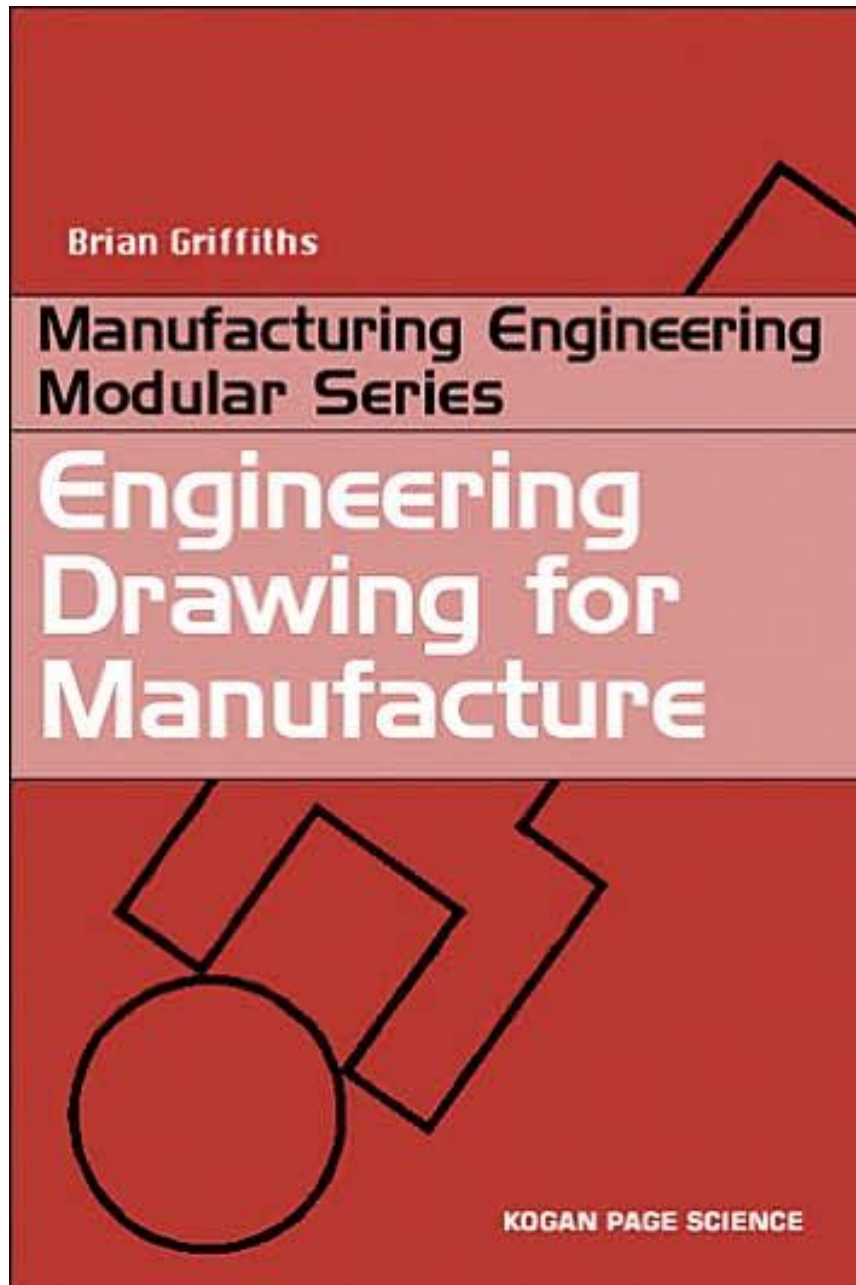


Engineering Drawing for Manufacture

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Introduction

In today's global economy, it is quite common for a component to be designed in one country, manufactured in another and assembled in yet another. The processes of manufacture and assembly are based on the communication of engineering information via drawing. These drawings follow rules laid down in national and international standards and codes of practice. The 'highest' standards are the international ones since they allow companies to operate in global markets. The organisation which is responsible for the international rules is the International Standards Organisation (ISO). There are hundreds of ISO standards on engineering drawing and the reason is that drawing is very complicated and accurate transfer of information must be guaranteed. The information contained in an engineering drawing is actually a legal specification, which contractor and subcontractor agree to in a binding contract. The ISO standards are designed to be independent of any one language and thus much symbology is used to overcome a reliance on any language. Companies can only operate efficiently if they can guarantee the correct transmission of engineering design information for manufacturing and assembly.

This book is meant to be a short introduction to the subject of engineering drawing for manufacture. It is only six chapters long and each chapter has the thread of the ISO standards running through it. It should be noted that standards are updated on a five-year rolling programme and therefore students of engineering drawing need to be aware of the latest standards because the goalposts move regularly! Check that books based on standards are less than five years old! A good example of the need to keep abreast of developments is the decimal marker. It is now ISO practice to use

a comma rather than a full stop for the decimal marker. Thus, this book is unique in that it introduces the subject of engineering drawing in the context of standards.

The book is divided into six chapters that follow a logical progression. The first chapter gives an overview of the principles of engineering drawing and the important concept that engineering drawing is like a language. It has its own rules and regulation areas and it is only when these are understood and implemented that an engineering drawing becomes a specification. The second chapter deals with the various engineering drawing projection methodologies. The third chapter introduces the concept of the ISO rules governing the representation of parts and features. A practical example is given of the drawing of a small hand vice. The ISO rules are presented in the context of this vice such that it is experiential learning rather than theoretical. The fourth chapter introduces the methods of dimensioning and tolerancing components for manufacture. The fifth chapter introduces the concept of limits, fits and geometric tolerancing, which provides the link of dimensioning to functional performance. A link is also made with respect to the capability of manufacturing processes. The sixth and final chapter covers the methodology of specifying surface finish. A series of questions are given in a final section to aid the students' understanding. Full references are given at the end of each chapter so the students can pursue things further if necessary.

List of Symbols

A	constant
B	constant
f	feed per revolution
m_N	amplitude distribution function moments
Ml(c)	sum of the section lengths
Mr1	upper material ratio
Mr2	lower material ratio
Ra	centre line average
Rdc	height between two section levels of the BAC
Rku	kurtosis
Rmr(c)	material ratio at depth 'c'
Rp	peak height
Rq	RMS average
Rsk	skew
RSm	average peak spacing
Rt	EL peak to valley height
Rv	valley depth
Rz	SL peak to valley height
RΔq	RMS slope
TnN	general parameter
σ	standard deviation

List of Abbreviations

ADF	amplitude distribution function
ANSI	American National Standards Institute
BAC	bearing area curve
BSI	British Standards Institution
CAD	computer aided design
CDF	cumulative distribution function
CL	centre line
CRS	centres
CSK	countersunk
CYL	cylinder
D	diameter
DIA	diameter
DIN	Deutsches Institut für Normung
DRG	drawing
EDM	electro-discharge machining
EL	evaluation length
GT	geometric tolerance
HEX	hexagonal
ISO	International Standards Organisation
IT	international tolerance
L	lower tolerance limit
MMC	maximum material condition
PCD	pitch circle diameter
R	radius
RAD	radius
RMS	root mean square
SEM	scanning electron microscope
SF	surface finish

SL	sampling length
SP	spherical diameter
SQ	square feature
SR	spherical radius
S ϕ	spherical radius
THD	thread
THK	thick
TOL	tolerance
TPD	Technical Product Documentation
U	upper tolerance limit
VOL	volume
2D	two dimensions
3D	three dimensions
ϕ	diameter
\cap	arc

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Principles of Engineering Drawing

1.0 Introduction

This book is a foundational book for manufacturing engineering students studying the topic of engineering drawing. Engineering drawing is important to manufacturing engineers because they are invariably at the receiving end of a drawing. Designers come up with the overall form and layout of an artefact that will eventually be made. This is the basic object of engineering drawing – to communicate product design and manufacturing information in a reliable and unambiguous manner.

Nowadays, companies operate over several continents. Engineering drawings need to be language-independent so that a designer in one country can specify a product which is then made in another country and probably assembled in yet another. Thus, engineering drawing can be described as a language in its own right because it is transmitting information from the head of the designer to the head of the manufacturer and indeed, the head of the assembler. This is the function of any language. The rules of a language are defined by grammar and spelling. These in turn are defined in grammar books and dictionaries. The language of engineering must be similarly defined by rules that are embodied in the publications of standards organisations. Each country has its own standards organisation. For example, in the UK it is the British Standards Institution (BSI), in the USA it is the American National Standards Institute (ANSI) and in Germany it is the Deutsches Institut für Normung (DIN). However, the most important one is the

International Standards Organisation (ISO), because it is the world's over-arching standards organisation and any company wishing to operate internationally should be using international standards rather than their own domestic ones. Thus, this book gives information on the basics of engineering drawing from the standpoint of the relevant ISO standards. The emphasis is on producing engineering drawings of products for eventual manufacture.

1.1 Technical Product Documentation

Engineering drawing is described as '*Graphical Communications*' in various school and college books. Although both are correct, the more modern term is '*Technical Product Documentation*' (TPD). This is the name given to the whole arena of design communication by the ISO. This term is used because nowadays, information sufficient for the manufacture of a product can be defined in a variety of ways, not only in traditional paper-based drawings. The full title of TPD is '*Technical Product Specification – Methodology, Presentation and Verification*'. This includes the methodology for design implementation, geometrical product specification, graphical representation (engineering drawings, diagrams and three-dimensional modelling), verification (metrology and precision measurement), technical documentation, electronic formats and controls and related tools and equipment.

When the ISO publishes a new standard under the TPD heading, it is given the designation: ISO XXXX:YEAR. The 'XXXX' stands for the number allocated to the standard and the 'YEAR' stands for the year of publication. The standard number bears no relationship to anything; it is effectively selected at random. If a standard has been published before and is updated, the number is the same as the previous number but the 'YEAR' changes to the new year of publication. If it is a new standard it is given a new number. This twofold information enables one to determine the version of a standard and the year in which it was published. When an ISO standard is adopted by the UK, it is given the designation: BS ISO XXXX:YEAR. The BSI has a policy that when any ISO standard is published that is relevant to TPD, it is automatically adopted and therefore rebadged as a British Standard.

In this book the term 'engineering drawing' will be used throughout because this is the term which is most likely to be

understood by manufacturing engineering students, for whom the book is written. However, readers should be aware of the fact that the more correct title as far as standards are concerned is TPD.

1.2 The much-loved BS 308

One of the motivating forces for the writing of this book was the demise of the old, much-loved 'BS 308'. This was the British Standard dealing with engineering drawing practice. Many people loved this because it was the standard which defined engineering drawing as applied within the UK. It had been the draughtsman's reference manual since it was first introduced in 1927. It was the first of its kind in the world. It was regularly revised and in 1972 became so large that it was republished in three individual parts. In 1978 a version for schools and colleges was issued, termed 'PD 7308'.

Over the years BS 308 had been revised many times, latterly to take account of the ISO drawing standards. During the 1980s the pace of engineering increased and the number of ISO standards published in engineering drawing increased, which made it difficult to align BS 308 with ISO standards. In 1992, a radical decision was reached by the BSI which was that they would no longer attempt to keep BS 308 aligned but to accept all the ISO drawing standards being published as British Standards. The result was that BS 308 was slowly being eroded and becoming redundant. This is illustrated by the fact that in 1999, I had two 'sets' of standards on my shelves. One was the BS 308 parts 1, 2 and 3 'set', which together summed 260 pages. The other set was an ISO technical drawings standards handbook, in 2 volumes, containing 155 standards, totalling 1496 pages!

Thus, by 1999, it was becoming abundantly clear that the old BS 308 had been overtaken by the ISO output. In the year 2000, BS 308 was withdrawn and replaced by a new standard given the designation BS 8888:2000, which was not a standard but rather a route map which provided a link between the sections covered by the old BS 308 and the appropriate ISO standards. This BS 8888:2000 publication, although useful for guidance between the old BS 308 and the newer ISO standards, is not very user-friendly for students learning the language of engineering drawing. Hence this book was written in an attempt to provide a resource similar to the now-defunct BS 308.

1.3 Drawing as a language

Any language must be defined by a set of rules with regard to such things as sentence construction, grammar and spelling. Different languages have different rules and the rules of one language do not necessarily apply to the rules of another. Take as examples the English and German languages. In English, word order is all important. The subject always comes before the object. Thus the two sentences '*the dog bit the man*' and '*the man bit the dog*' mean very different things. However, in German, the subject and object are defined, not by word order but by the case of the definite or indefinite articles. Although word order is important in German, such that the sequence 'time-manner-place' is usually followed, it can be changed without any loss of meaning. The phrase '*the dog bit the man*' translates to: '*der Hund biss den Mann*'. The words for dog (Hund) and man (Mann) are both masculine and hence the definite article is 'der'. In this case the man being the object is shown by the change of the definite article to 'den'. Although it may seem strange, the word order can be reversed to: '*den Mann biss der Hund*' but it still means the dog bit the man. The languages are different but, because the rules are different, clear understanding is achieved. Similar principles apply in engineering drawing in that it relies on the accurate transfer of information via two-dimensional paper or a computer screen. The rules are defined by the various national and/or international standards. The standards define how the shape and form of a component can be represented on an engineering drawing and how the part can be dimensioned and toleranced for manufacture. Thus, it is of no surprise that someone once described engineering drawing as a language.

Despite the fact that there are rules defining a language, whether it be spoken or written, errors can still be made. This is because information, which exists in the brain of person number one is transferred to the brain of person number two. The first diagram in Figure 1.1 illustrates the sequence of information transfer for a spoken language. A concept exists in brain number one that has to be articulated. The concept is thus constrained by the person's knowledge and ability in that language. It is much easier for me to express myself in the English language rather than German. This is because my mother tongue is English whereas I understand enough German to get me across Germany. Thus, knowledge of how to speak a language is a form of noise that can distort communication.

The voice is transmitted through the air which in itself can cause distortions due to, for example, the ambient noise level. This is then received by the ears of the second person and transmitted to the brain. Here there is another opportunity for noise to enter the communication sequence. The game 'Chinese whispers' is based on the fun that you can have as a result of mishearing things. If there is no noise entering the communications sequence, then brain two receives the same concept that brain one wishes to transmit. However, as we all know to our cost, this is not always the case! Perhaps all the above can be summed up by a poster in New York which read, 'I know you believe you understand what you think I said, but I am not sure you realise that what you heard is not what I meant'!

The same sequence of information transfer applies to drawing (see the second diagram in Figure 1.1). In this case the brain instructs the hands to draw symbols which the receiver's eye observes and transmits to their brain. Again noise can distort the flow of information. Note that this does not depend on language and a design can be transmitted via a drawing even when the two people do not speak the same language. In the case of engineering drawing the symbols are defined by the various ISO standards which are the engineering drawing equivalent of dictionaries and grammar books.

The manner in which a designer draws an artefact can vary. One draughtsman may convey the same information using a different number of views and sections than another. This is termed 'draughtsman's licence'. It is comparable to the way a person may express a thought verbally. By the use of different words and

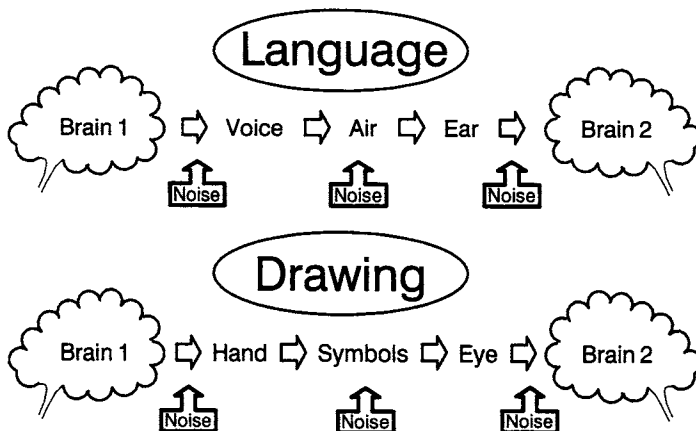


Figure 1.1 Sources of noise in speech and drawing

sentences, the same concept can be presented in two or more different ways. Similarly, in engineering drawing, a design may be presented in a variety of ways, all of which can be correct and convey the information for manufacture.

1.4 The danger of visual illusions

Engineering drawing is based on the fact that three-dimensional objects are presented in a two-dimensional form on two-dimensional paper. The potential problems of trying to convey apparent three-dimensional information on two-dimensional flat paper is shown by the two sets of circles in Figure 1.2. The author drew these 12 circles himself, and they are based on a concept by Ramachandran (1988). Because the circles are shaded, each one is seen as either a bump or a depression. In this case, if one's brain interprets the left-hand set of circles as bumps, the right-hand set appears as depressions (and vice versa). During a recent lecture on engineering drawing, I took a vote and two thirds of the student group saw the left-hand set of circles as bumps and the right hand set as depressions. The reason for this is concerned with the shading of the lower part of the circles. Our visual system assumes a single light source. The single light source that we know best is the sun and it shines from above. Thus, the eye sees the left-hand series of circles as bumps because it assumes the illumination is from above. This is not always the case, because in a recent lecture, one third of the students assumed the light source was from below. So much for what the psychologists tell us about the brain!

The facemask in Figure 1.3 is an interesting example of visual illusions (adapted from Ramachandran, 1988). The face appears eerie. Can you guess why this is so without reading any further?

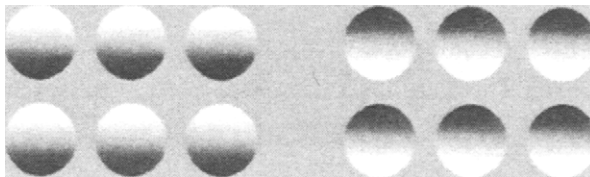


Figure 1.2 *Three-dimensional bumps and depressions*

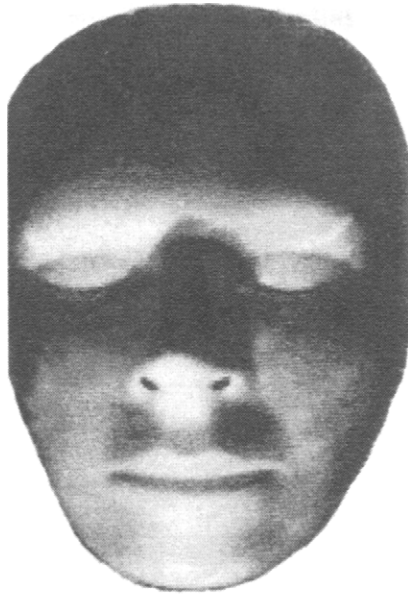


Figure 1.3 *An eerie face mask*

The answer is that it is actually a hollow mask in which the interior is lit from above to produce an eerie impression of a protruding face lit from below. When interpreting shaded images, the brain usually assumes the light is shining from above. Here it rejects that assumption in order to interpret the image as a normal convex object.

The above examples show the difficulties involved in trying to represent three-dimensional information on a two-dimensional piece of paper using shading. A different type of visual illusion is shown in the tri-bar in Figure 1.4. Each of the three corners of the triangle, when considered separately, indicates a valid three-dimensional shape. However, when the tri-bar diagram is considered as an entirety, it becomes an impossible figure. This tri-bar visual illusion was first noted in 1934 by the Swedish artist Oscar Reutersvard. He produced many similar types of drawings of other impossible figures. It was the artist Escher who first brought the knowledge of impossible figures to a much wider audience. He will be particularly remembered for his 'waterfall lithograph' that he produced in 1961. Although channels of water is the subject of his drawing, it is essentially an impossible tri-bar in a different form.

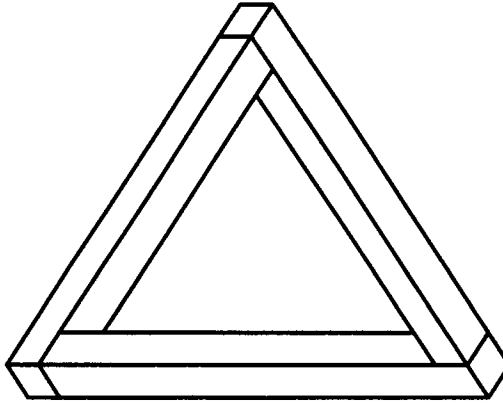


Figure 1.4 *An impossible tri-bar*

The above visual illusions are created because one is trying to represent a three-dimensional object in a two-dimensional space. However, it is still possible to confuse the eye/brain even when absorbing two-dimensional information because rules of perception are broken. The example in Figure 1.5 was actually handed to me on a street corner. The image was written on a credit card-size piece of paper. The accompanying text read, 'Can you find the answer?'. The problem is that the image breaks one of the pre-conceived rules of perception, which is that the eye normally looks for black information on a white background. In this case the eye sees a jumbled series of shapes and lines. The answer to the question should become obvious when the eye looks for white information on a black background.

Some two-dimensional drawings are termed 'geometrical' illusions because it is the geometric shape and layout that cause distortions. These geometric illusions were discovered in the second half of the 19th century. Three geometric illusions are shown in Figure 1.6. In the 'T' figure, a vertical line and a horizontal line look to be of different lengths yet, in reality, they are exactly the same length. In the figure with the arrows pointing in and out, the horizontal lines look to be of different lengths yet they are equal. In the final figure, the dot is at the mid-point of the horizontal line yet it appears to be off-centre. In all these figures, the eye/brain interprets some parts as different from others. Why this should be so does not seem to be fully understood by psychologists. Gillam (1980/1990) suggests that the effects appear to be related to clues in the size of objects in the three-dimensional world. Although the psychologists

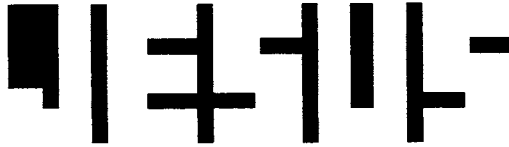


Figure 1.5 'Can you find the answer?' handout

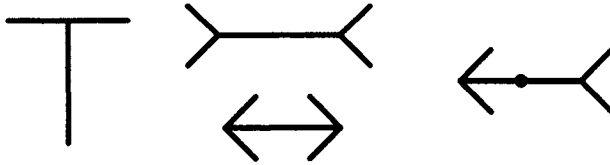


Figure 1.6 Geometrical optical illusions

may not understand the theories, the eye/brain sees lines of different length. This is another example of the fact that what the eye sees, even in two dimensions, is not necessarily reality.

All the examples of visual illusions in Figures 1.2 to 1.6 illustrate the complexities involved in firstly representing three-dimensional information in two-dimensional space and secondly making sure the interpretation of the two-dimensional space is correct. It is for these reasons that the fathers of engineering drawing decided that, in orthographic projection, only two-dimensional views would be taken which are projected from one another and things like perspective would be ignored. In this way the 'noise' which could creep into the communication sequence in Figure 1.1 would be reduced to a minimum. The two basic sets of rules of orthographic engineering drawing are based on what is called 'first angle' or 'third angle' projection. The word 'ortho' means right or correct.

1.5 Representation, visualization and specification

1.5.1 Representation and visualization

An artefact or system can be represented in a variety of ways. Engineering drawing is but one of the ways. Figure 1.7 shows some of the ways that products or systems can be represented.

Verbal or written instructions take the form of words describing something. If the words take the form of a set of instructions for doing something, they are ideal. If the words are used to tell a story, then they can paint beautiful pictures in the imagination. However,

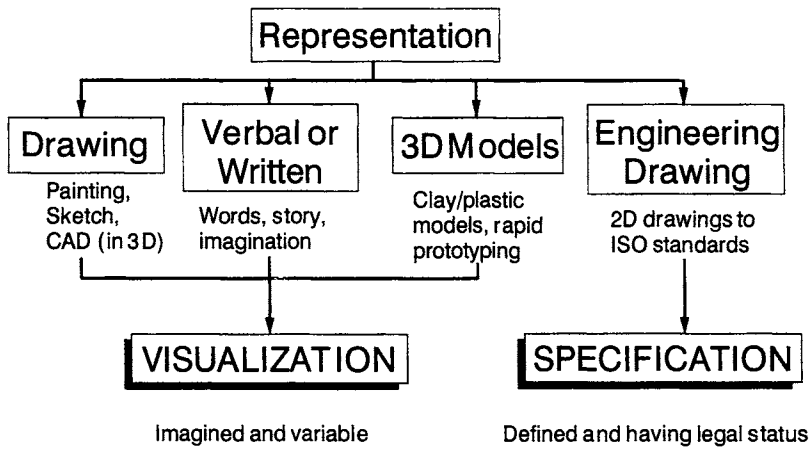


Figure 1.7 *Engineering drawing representation should be specification*

words are clumsy with respect to transmitting information about an engineering artefact. Perhaps a chair or a table could be described without too much difficulty but for anything very much more complex, words become inadequate. Hence, the expression, ‘a picture says a thousand words’! Painting or sketching can certainly convey visual information. However, it is also open to artistic interpretation and licence. Ancient pictures of kings and queens often did more credit to them than was justified! Several paintings by Constable of the Dedworth area show the church at different locations because it adds to the artistic balance. Three-dimensional models can certainly be made of engineering artefacts and structures. Indeed, the use of rapid prototyping for the construction of feasibility models is a fast-growing industry. Clay and plastic models have been around for years and mock-ups of new engineering designs for style-based design give the designer a new level of understanding and interpretation. However, three-dimensional models cannot be posted to somebody or sent via the Internet!

All the above techniques can certainly represent an artefact and enable it to be visualized. However, they all fall short of providing a specification that would allow something to be made accurately by a manufacturer speaking a different language to that of the designer. Specification of an artefact is of a higher order than visualization. Specification is needed for engineering artefacts because the instruction to manufacture something given to a subcontractor has financial as well as legal implications. Engineering drawing is a form of engineering representation along with all the others but it is

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