Models of change: the impact of ‘designerly thinking’ on people’s lives and the environment: seminar 3 ... modelling and the Industrial Revolution

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MODELS OF CHANGE

The impact of ‘designerly thinking’ on people’s lives and the environment

Seminar 3 … Modelling and the Industrial Revolution

Design: Occasional Paper No 5

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MODELS OF CHANGE
The impact of ‘designerly thinking’ on people’s lives and the environment
Seminar 3 … Modelling and the Industrial Revolution

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BACKGROUND

This is the third publication relating to a seminar series being led by Ken Baynes, who is a Visiting Professor in the Department of Design and Technology at Loughborough University. Consequently these seminars will be organised through Loughborough's Design Education Research Group (DERG). The titles of these seminars are:

- Modelling and Intelligence
- Modelling and the Industrial Revolution
- Modelling and Design
- Modelling and Society
- Modelling and the Future

The role of modelling in designing has been a key research interest of the DERG since its establishment, but it has never been more important as Ken Baynes's introduction to the seminar series makes clear. It is easy to say that designing is to do with creating preferred futures, but much harder to explain and understand how that can be achieved.

The first of these seminars took place at the Design and Technology Association's International Research Conference at Loughborough on Tuesday 30 June. The second will took place at the 1st International Visual Methods Conference at the University of Leeds in September, and this, the third, will take place in the Department of Design and Technology at Loughborough in association with the visit of the Quick on the Draw Exhibition. It is hoped that the fourth seminar will take place at Goldsmiths University, London in the Spring of 2010. An Orange Series publication will be available for free download about a month before each seminar via the DERG website, where details of venues and associated audio files and PowerPoint presentations will also be posted (http://www.lboro.ac.uk/departments/cd/research/groups/ed/index.htm)

There is no denying that current initiatives relating to STEM are important, but many commentators have noted the absence of 'design' in much of the emerging thinking, It is truly vital that the significance of such omissions is understood and that the role of modelling in designing, and hence in shaping the future is fully appreciated. Ken Baynes and his colleagues at the Design Education Unit at the Royal College of Art (eg Bruce Archer and Phil Roberts) took part in what can be viewed as parallel debates in the 1970s. Time and circumstances have moved on and it is not the same debate, but we need a similar outcome. Design and designing need to be recognised for what they are and the vital roles that they play. Some commentators trace the origins of design and technology to those debates in the 1970s, and it is time both to revisit and renew the fundamental ideas and concepts that provide its foundations.

It has been both a pleasure and privilege to help bring Ken's writing and ideas into the public domain.

Eddie Norman
Loughborough
August 2009

ACKNOWLEDGMENTS

It has been a pleasure to work on this book reflecting, as it does, a lifetime's interest in the nature of creative thought. I am particularly grateful to Loughborough University for giving me the opportunity to complete the project. I owe a special debt to my colleagues in the Department of Design and Technology. Professor Phil Roberts and I have many times debated the issues that are central to this book and I have to thank him for his continuing intellectual stimulus – also for his direct contributions and indispensable 'critical friend' response to my first drafts. Dr Eddie Norman has been instrumental in bringing the book to print and giving it life on the Internet and through a number of international seminars. This approach will create instant feedback and it is exciting to think that many other contributions will speedily be brought to bear on what I believe is a very important subject. Without Eddie's help it just would not have happened.

Over the years, Eileen Adams of the Campaign for Drawing and Roger Standen of the Design Dimension Educational Trust have helped me develop the ideas on which this book is based.

My greatest thanks go to my wife Krysia Brochocka. She is both intellectual colleague and practical supporter. She has encouraged me at every turn and whenever the going got rough insisted that the job needed to be finished! Her readings and suggestions have been invaluable.

Ken Baynes
Burley-on-the-Hill
April 2009

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ILLUSTRATIONS

Many of the illustrations intended for the eventual published version of Seminar 3 can be found in *The Art of the Engineer* by Ken Baynes and Francis Pugh, Lutterworth Press, Guildford, 1981

Seminar 3

MODELLING AND THE INDUSTRIAL REVOLUTION

The aim of this seminar is to demonstrate the importance of modelling as an instrument of cultural, social and economic change. In the case of the emergence of the Industrial Revolution, decisive factors were the dramatic development of science, technology and design driven forward by capitalism and the new market economy. The invention of new models to represent and handle revolutionary concepts and processes happened in all these fields but the emergence of design models was at the cutting edge of industrialisation in factories, technical institutions, drawing offices, surveyors camps, battlefields and naval dockyards.

Key figures in the Industrial Revolution – particularly inventors and engineers – are often depicted with rolls of maps and plans. Often they hold dividers or surveying instruments. Sometimes they are shown with scale models of a future device or structure. At the time, these were clearly recognised as the tools of their trade: innovative designers are shown along with the modelling tools that enabled them to carry out their work. How did these tools originate and why did they come to be so prominent in the iconography of the Industrial Revolution?

The Industrial Revolution was the result of a long period of gestation and change. Its beginnings can be found in the Renaissance. It was far from being a simple matter of technological innovation. Unprecedented means of production were central to it but these resulted from and were instrumental in new ways of thinking and new ways of behaving. The real revolution was not so much in machines as in men and women's concept of themselves and their role in the world. It was this change in the context of a market economy that allowed, perhaps compelled, them to create a new kind of society dependent on a new kind of technology.

For the new ideas to emerge, new media of thought and communication were needed. It is significant that the first example of mechanised quantity production was in the field of information technology. Around 1455 Johannes Gutenburg made the first printed book at Mainz in Germany. It was a finely printed Bible in Latin. Latin was then the international language of an elite group of scholars, the Church, and the aristocracy. However, in 1466 Johan Mantling, working in Strasbourg, published the first printed book in a common European language. It was a Bible in German. Before the end of the century Bibles were circulating in Bohemian, Dutch, French and Italian. However, it was not until 1525 that the New Testament first appeared in the English language: this had to be printed clandestinely in Germany.

Making books in the vernacular languages of Europe proved profoundly revolutionary. The existence of accessible books created a demand for literacy, first in the emerging middle class and later amongst the common people. It was in the interest of printers and publishers to service this popular demand. Market forces and the new printing technology created a synergy which competed with state and Church censorship, to provide exactly the dynamic needed to disseminate a new culture of individualism, scientific enquiry and 'progress'.

NEW AND REVOLUTIONARY MODELS

We are used to thinking of books as essentially a medium of words. Printing made words available and encouraged writers to create more books. But this is far from the whole story. The books which drove the Renaissance forward and underpinned the later emergence of the Enlightenment did not only contain words. They were also a potent medium for the dissemination of other new and revolutionary models particularly various types of technical and explanatory diagrams, formulas and maps.

In 1963, two historical exhibitions were organised in London to mark an international trade fair for the printing industry. One was at the British Museum, the other at Earls Court. They dealt with the impact of printing on Western Civilisation. Called *Printing and the Mind of Man* (Bridges, 1963), they explored the interaction between printing technology and thought. The core of the exhibition was some five hundred books that changed the minds of men and women in significant ways.

Looking at the books on display, it became very clear that the era of the printed book saw not only a huge growth in the use of words to convey ideas, but also the use of images. What we should perhaps call 'visual exposition' was one of the key means by which the new humanist/scientific culture searched out, created and communicated new meanings.

Achieving this called for a revolution in the form as well as the content of visual exposition. The journey to be made at the start of the Renaissance was from medieval imagery designed to tell religious stories and reveal symbolic meanings to humanist imagery that would probe the physical reality of the natural and made worlds. What the new culture demanded was a new repertoire of models, models that would enable new thoughts to be thought and new actions to be taken.

MAPS AND MAPPING

The development of maps and mapping provides a good example of the emergence of new models and new uses for models. Medieval maps were an extraordinary combination of geography and theology. Showing the world as described in the Bible took precedence over any other purpose and, in this respect, they more resemble the story maps made by aboriginal Australians than modern maps.

The modern map sets out to represent the land in a code of signs and symbols. Its intention is to be an objective record though, of course, it is highly selective in what it represents and different mapping conventions have been developed to represent different aspects of reality.

Traders were always interested in trade routes and foreign goods but accurate and comprehensive explanations of distant lands were something new. Growth in trade and intellectual curiosity went hand in hand. An accurate survey became a very valuable property. Sailors and travellers kept their maps secret or sold them for a profit. Good maps were state secrets.

The earliest accurate maps emerged alongside the medieval ecclesiastical maps early in the Fourteenth century. They resulted from the increase in trade across the Mediterranean. Called 'portolano' or sailing charts they were hand drawn on skins or hides. The first printed maps appeared in 1477 and were produced from wood cuts with hand colouring. The quality of printed maps was transformed in the sixteenth century when engraved copper plates came into use.

The discovery of the 'New World' was a key factor in the development of maps and the skills needed to use them. Formal instruction in navigation began to be needed. In 1551 Martin Cortes' book, *Breve Compendio de la Sphera y de l'arte navegar* appeared in Seville. Cortes gave an authoritative account of the current state of navigational science. It included instructions for making charts and for plotting the courses of ships on them. Cortes seems to have been the first scholar to understand that the magnetic pole and the true pole of the earth were not the same.

Cortes' book was brought to England by Stephen Borough, the man behind Queen Elizabeth's measures to advance England's sea power. An English translation was published in 1561. It has been described as one of the most decisive books ever printed in English. It provided the English sailors with their key to mastery of the sea and so laid the foundations of the later British Empire.

Dr John Dee, the Elizabethan mathematician, understood the fascination and importance of maps to his era: 'Some to beautify the Halls….or Libraries with, some others for their own journeys directing in to far lands or to understand other men's travels ……liketh, loveth, getteth and useth maps, charts and geographical globes.' (Barron 1989)

The most obvious function for a map is to help travellers find their way. However, in cultural and political terms, this is only one use for maps. Just as the Doomsday Book was a quantitative summation of the content of the new Norman Kingdom, so too were objective maps a weapon of royal and state hegemony. Mapping was part of the development of a system of power based on the ownership of land. Accurate maps became an essential part of the legal title to land and elaborate county and estate maps emerged as a matter of pride in ownership and a visible demonstration of wealth.

Maps were important to the growth of imperial power and military and navel warfare. Charts of the ocean seaways and particularly fortified harbours, were treasured by admiralties in Europe and the collection and creation of such maps became state policy. Army officers were trained to read, understand and make maps. At a later period, the accurate mapping of a whole country often had a strategic and political inspiration. For example, the Military Survey of Scotland was begun in 1746 as a part of the Duke of Cumberland's military mission to subjugate the Highlands. Until the middle of the Eighteenth century, map making was dominated by a form of pictorial representation that tolerated many errors and inaccuracies. A triangulation of Britain was finally begun by William Roy after many delays in 1787. There were strong professional links between surveyors and engineers, particularly in the design of canals and railways. The formal relationship between large-scale maps and the drawings of civil engineers is a close one.

In addition to these socio-political applications, the existence of accurate maps had a profound psychological effect. They changed the way people thought about themselves and visualised their place in the world. Maps in the form of a globe showed the earth as a sphere. This model of the world, which eventually became commonplace in every school room and in every educated mind, was of course revolutionary in its day. The matching model of the earth's roundness turned into a flat sheet with lines of latitude and longitude crossing at appropriate angles, was first used in a world map by Gerardus Mercator in 1569. This projection, bearing Mercator's name, was fully developed by Edward Right (published in 1599) and remains in use today. The spherical globe and the earth as a flat sheet were only rivalled for their psychological power when the beautiful disc of rising Earth was photographed from the Moon.

For the Industrial Revolution, accurate maps were an essential pre-requisite. 'Capability' Brown, the Eighteenth century landscape architect, got his nickname because of his ability to perceive the 'capability' for the development of an estate's landscape. This way of looking at things to identify their potential for improvement and profit was fundamental to the entrepreneurial state of mind. Land and the natural resources it held, people living on the land and their skills and labour, all became commodities that could be turned into wealth. Maps helped first to reveal the capability or potential of the existing state of affairs. Next they served to show how that potential might be realised through building a new canal, railway, factory or industrial estate. The surveyor's map showing the new superimposed on the old, was a conceptual tool of remarkable power. Its use was not simply as a model to test the technical practicality of the engineering proposals; it was also a tool for obtaining capital, influential backers and popular support for the new development.

ARCHITECTURE, ANATOMY AND PERSPECTIVE

The Renaissance was partly about the rediscovery of the culture of Classical Greece and Rome. One of the most important works involved was Vitruvius' text book on architecture. This was the oldest original work on visual art and design to survive in its entirety from late Classical times. It transmitted the rules of classical architecture and aesthetics along with civil and military engineering to the Middle Ages and the Renaissance. It became the basis for the architectural work of Alberti, Bramante, Micaelangelo, Ghilberti, Palladio and many others. It powerfully influenced Eighteenth century design and its influences continues in post-modern architecture.

It was first published in Latin in Rome in 1486; a good Italian translation with fine illustrations was published in Como in 1521. The illustrations to *De Architectura* are now in part attributed to Leonardo da Vinci. They show the new 'design language' of the Renaissance at its most confident and powerful. Roman architects were professionals who used mathematical calculations, drawings and three-dimensional models. Alexander McKay (McKay 1985) discusses Vitruvius' attitude to his profession and the skills needed to be a member.

Vitruvius had no misgivings about the status of the profession and he was adamant about the necessity of a liberal education. The architect should also be a man of letters, an expert draughtsman, a mathematician familiar with scientific thought, a painstaking student of philosophy, acquainted with music, not ignorant of medicine, knowledgeable about the opinions of jurists and familiar with astronomy and the theory of the heavens.

The product of such an extensive and liberal curriculum was an architect in the true sense and as was implied by the title *architectus,* something more than 'master-builder'. The accumulation of such a vast range of subject matter required the aspiring architect to begin with service as apprentice to some master artist. Study of philosophy would provide a spur to high-minded modesty and honesty; musical training would enable him to tune *ballistae,* catapults and *scorpiones* with better success and ensure proper acoustics in theatres; study of medicine would direct the choice of hygienic town sites; legal training would help to ensure the drafting of fair contracts; and astronomy, rather unexpectedly, would assist the proper design of sun-dials!

Draughtsmanship was, naturally, a basic necessity. Vitruvius indicates that plans, elevations, perspective views and coloured renderings (on stone, terracotta tile, marble, mosaic or ephemeral papyrus) were basic to the exercise.

'Plans demand competent use of compass and rule, and with these the correct designs are made on the sites. Elevation is the vertical likeness of the façade, a slightly shaded drawing which outlines the finished appearance. Perspective also is the shading of the façade and of the retreating sides, with all of the lines converging at a point which is the centre of a circle.'

Other advantages attach to the curriculum:

'An architect must be literate so as to keep a lasting record of precedents. By his expertise in draughtsmanship he will find it easy by coloured drawings to illustrate the desired effect. Mathematics also offers many advantages for the architect. It teaches the use of ruler and compass, and so simplifies the layout of building on their locations by the use of set-squares, levels and alignments. By optics in the case of buildings light may be derived from certain quarters of the sky. By arithmetic one may assess the cost of a building; the methods of measurement are indicated; and the tricky problems of symmetry are solved by geometrical rules and methods.' (McKay, 1985)

Like Vitruvius, Renaissance 'architects' were really all-purpose designers and inventors. Their role as military engineers gave them a useful way in to the rulers of the time. They were able to satisfy the urge to build great monuments and palaces. We know, from a study of their notebooks, that Vitruvius' Curriculum became the common currency of these architects & engineers. It was their body of knowledge and if fed a spirit of enquiry, innovation and experimentation that continued to fire architects and engineers through into the Industrial Revolution.

Twenty-two years after *De Architectura* was published in Italian, there appeared in Basel a revolutionary work on medicine. This was Andreas Vesalius' *De humani corparis fabrica.* It broke with the traditional authorities on medical matters – Aristotle and Galen – and insisted that direct observation was the key to understanding the workings of the human body. Dissection gave him accurate knowledge of anatomy and this knowledge was communicated in revolutionary illustrations by Calcar. It opened the way for a new understanding of physiology but it was also a precursor of modern ergonomics where modelling the body (and its capacities) has become a major influence on designing.

In a broader sense it was Renaissance thinkers who conceived the idea of 'the measure of man' as a founding spiritual and philosophical principle in designing. Leonardo da Vinci's famous image of man related to the square and the circle presents this Vitruvian idea in its purest form. Man, as a work of the Creator, is related to the perfection of the two mathematical figures. The works of man should explore and express this relationship. This humanist vision had lost its force by the time of the Industrial Revolution but the fascination with pure forms as a basis for engineering design remained.

One intellectual development in Renaissance modelling techniques outstripped all others for its long-term effect on designing. This was the discovery – partly re-discovery – of perspective. It was significant in the arts, science, and design. It profoundly affected the way people saw the world. It remains instrumental in the way we see the world today.

It has often been noted that the Renaissance was a time when art and science were closely connected. Many of the great figures of the time combined the roles of artist, scientist, and engineer. This is because the distinctive culture of the period needed to be pursued by visual as well as literary means. The ability to draw and paint in the new way was highly valued. It made the humanist world view visible and tangible. The break with medieval art and architecture was as important as the rediscovery and revitalisation of Greek and Roman literature, philosophy and science.

Jacob Bronowski (Bronowski, 1973) notes that the development of perspective depended on a fundamental reappraisal of the mechanics of vision. The science of the ancient world had simply got this wrong. The

Greeks had thought that light goes from the eyes to the object. The opposite of course is the case. The first scientist to appreciate this was an eccentric Arab mathematician known in the west as Al Hazen. He was active round 1000 AD. Bronowski writes:

'The Greek view could not explain how an object, my hand say, seems to change in size when it moves. In Hazen's account it is clear that the cone of rays that come from the outline and shape of my hand grows narrower as I move my hand away from you. As I move it towards you, the cone of rays that enters your eye becomes larger and subtends at a large angle… The concept of the cone of rays from object to the eye becomes the foundation of perspective'.

Bronowski goes on to say that 'perspective is the new ideas that now revives mathematics.' It also could be said to have revived painting, sculpture and architecture. In addition, it gave designers of all kinds a powerful new medium in which to visualise and try out their ideas and proposals. Clearly perspective was particularly significant for architecture but it was also important for shipbuilding, engineering, fabrications, bridge building and the tools of warfare. It was because of the conceptual insights offered by perspective that architects were able to develop the conventions of plan, elevation and section and engineers orthographic projection.

It is important to recognise that these early types of drawings deriving from perspective did not only – or even mainly – serve design. It is rather that when later designers needed a 'language' or modelling medium in which to design, the elements of it were ready to hand, refined and defined by two hundred and fifty years of development. There were three main driving forces: philosophical attitudes; the growth of learning; professional pride. Often all three were inextricably linked together.

This can be seen clearly in Leon Batista Alberti's very early writing (in Latin and Italian) on art and architecture. He built on pioneering work by Brunelleschi who around 1425, made the first geometrically constructed perspective drawings. First written in 1435, the Latin version of Alberti's text contained much philosophical material as well as systems for perspective and human proportion and the first theory of painting that rooted this art in visual experience and its representation in geometrical terms. Although all subsequent authors were influenced by Alberti, the work was for fifty years only circulated privately between other artists and theorists. Its ideas were potentially dangerous and revolutionary; however, they were promptly adopted by many Italian 'artists', including Leonardo da Vinci. The first printed version appeared in 1485 in Florence. The design professions were then in the process of discovering their identities and it was the existence of published bodies of knowledge such as Alberti's that helped them define the intellectual content of their art.

Albrecht Dürer seems to have been responsible for spreading the techniques of perspectives north of the Alps. In 1525 he published a book in Nuremburg intended to explain the theoretical and practical problems of perspective to artists and craftspeople. Dürer introduced a way of representing the human figure that is akin to orthographic projection and made a detailed studies of human proportion.

THEORETICAL UNDERSTANDING OF PERSPECTIVE

The tradition which Alberti established was continued in a spate of theoretical publications over the following two hundred years. Typically, these contained both instruction about drawing systems and information on the principles of architecture, military engineering, hydraulics and fortifications. It was only slowly that the two diverged and books began to appear on drawing alone or on architectural, engineering or shipbuilding principles. It is worth briefly describing a number of these titles to demonstrate something of their character. They show how quickly interest in drawing as a way of modelling design principles and proposals spread through Europe.

Daniel Barbaro *La practica della perspittiva.* This was amongst the early treatises on perspective. It was first published in Venice in 1568. It deals with theatre scenery as well as perspective, Vitruvius and the use of the camera obscura. Barbaro was a scholar, translator of Vitruvius and patron of Palladio who built a villa for him.

Jacques Besson *Theatre des instruments mathematiques et machaniques.* Besson was a French mathematician who worked on this publication in the 1560s. With plates engraved by Jacques Androuet du Cerceau, it deals with drawing instruments, stone – cutting and woodworking machinery, dredging vessels, pontoon bridges, well-drilling and a water-driven mechanical clock.

Jan Vredeman de Vries *Perspective.* De Vries was an old man when this book was published in French at the Hague by Beuckel Nieulandt in 1604. The plates are by H Honduis and deal primarily with the application of perspective to architectural constructions such as staircases and city squares.

The Sixteenth and Seventeenth centuries saw a steady development in understanding of the link between mathematics and representation. French mathematicians contemporary with Descartes had already explored the fundamentals of projective geometry in the Seventeenth century. Girard Desargues, Philippe de la Hire and Blaise Pascall all contributed to the development. Desargues, who was a self-educated architect and engineer, saw clearly that his discoveries had potential for a variety of practical applications in engineering, painting and architecture when he wrote:

‘I freely confess that I never had taste for study or research either in physics or geometry except in so far as they could serve as a means of arriving at some sort of knowledge of the proximate causes…for the good and convenience of life, in maintaining health, in the practice of some art…having observed that a good part of the arts is based on geometry, among others and cutting of stones in architecture, that of sun-dials, that of perspective in particular.’

Desargues shared in the utilitarian spirit that was to triumph in the Nineteenth century. For the moment, however, Desargues' pamphlets had little effect on his contemporaries. It was not until the middle of the Eighteenth century that government patronage in France began officially to encourage research in perspective, solid geometry and applied drawing. Investigation in these areas was fostered for reasons of state at the military colleges and L'Ecole Polytechnique. The intellectual climate of the Enlightenment favoured the pursuit of knowledge for its own sake but, after the Revolution and during the Napoleonic Wars, the importance of commerce and the demands of fighting on a continental scale gave added urgency to official backing. Enlightenment, trade and the emergence of the nation state pushed the development of technical drawing forward.

All over Europe, but particularly in France, the Eighteenth century saw the rapid development of a wide range of objective drawing and modelling techniques. It was part of the attempt by men of reason in the age of reason to catalogue, quantify and thus understand the natural and made worlds. This work found the height of its expression in Diderot and D'Alembert's *Encyclopédie* published after enormous difficulties – Diderot and his publisher Le Breton were imprisoned more than once – between 1751 and 1756. Le Breton had originally planned a French translation of Chambers' *Cyclopaedia or Universal Dictionary of Arts and Sciences* which came out in 1728. He quickly changed to an original ten volume scheme that would celebrate the dignity and progress of man. This finally grew to a 28 volume work, 11 of them being volumes of plates.

The illustrations of *Encyclopédie* demonstrate a sophisticated graphic 'language' suitable for depicting and explaining machines and processes. They influence the style of technical publications even today. The *Encyclopédie* included sections on drawing and there is little doubt that these, together with the work as a whole, provided many of the elements to be found in the first true engineering drawings when they appeared in Britain at the end of the century.

It was the French military engineer, Gaspard Monge, who first codified the conventions of descriptive geometry. It is on his work that the theoretical aspects of modern engineering drawings have been based. Monge was born in 1746 and published his *Géométrie descriptive* in 1795. It was evident that Monge did not 'invent' descriptive geometry. What he did was to bring together and explain a variety of ad hoc techniques which masons and woodworkers had been using for perhaps two hundred years. Peter Booker, the English historian of engineering drawing, suggests that these craftsmen recognised clearly what Monge was doing and resented his invading their area. They saw that power of control lay in the new techniques of drawing. Booker describes the situation in this way:

'At Mezières there were schools of [military] stonecutting and carpentry…He [Monge] set about examining the drawing methods used…..and applied his first principles of descriptive geometry to them in order to replace many rote techniques with generalised methods…He came across stubborn opposition from the carpenters, however, who were relying on drawing techniques passed on from father to son for generations and who saw no reason for an academic person to butt in.' (Booker, 1963)

This incident was a rehearsal for a change in work relations that went on wherever industrialisation and bureaucratisation took command. What had before been the prerogative of the artisan or the craftsman was now transferred to the manager or the designer. Drawings became one of the ways in which the change could be brought about. They were portable shorthand models, the easily transmitted instructions through which designers and managers controlled the production process.

Monge's system of descriptive geometry quickly became an accepted part of the French system of technical education. From there it spread to most of continental Europe but it is doubtful if it had any immediate effect in Britain or the United States where state intervention in training was unusual. In these countries, but not Scotland, it was left to the new capitalist companies to organise their own apprenticeships and to teach trainee engineers the skills they would need in practice.

It is, however, to Britain that we have to look for the emergence of engineering drawing as a medium directly related to design for industrial means of production. Its origins here depend to some degree both on royal patronage and on military and naval interest but pre-eminently on the new class of forward looking manufacturers, mechanics and natural scientists. It is they who had both the commercial energy and the belief in 'progress' necessary to press ahead with the creation of novel products and new processes. With these momentous changes design-by-drawing was intimately concerned.

In London, King George III was interested in drawing. When still the Prince of Wales in 1760, he appointed Joshua Kirby as his personal tutor in 'perspective' and, in 1761, Kirby dedicated a splendid book on architectural perspective to him. William Hogarth drew the frontispiece. In addition to the fine illustrations *The Perspective of Architecture* included very careful instructions on the use of a new machine for making architectural drawings. Significantly this device was designed and made by George Adams, the King's instrument maker. These great London craftsmen held a key position in the practical development of Eighteenth century technology and their workshops provided a natural meeting place where cultural and technical ideas could come together.

The Royal Navy was a key player in these momentous changes. The Marxist historian Eric Hobsbawm has characterised it as 'that very commercially minded and middle class organisation'. It certainly was one of the first really effective bureaucracies in Britain. Ever since the early years of the Eighteenth century, the Navy Board had required that a model and plan for each of its ships should be prepared for the records. The standardised layout and simple conventions of these ships' draughts remained unaltered until the advent of steam on a large scale in the 1830s.

What was needed to make perspective and projective drawing a part of the everyday work of engineers was a greater closure between the worlds of manufacture and learning. The first development of steam power happened in an isolated setting where mine owners worked with metal workers of practical genius. Thomas Newcomen, who had designed and built the first viable steam-powered atmospheric pumping engine as long ago as 1712, was not in the mainstream of Eighteenth century intellectual life. What Newcomen relied on was his carefully acquired tacit knowledge of metalworking and ephemeral forms of setting out. He used templates, jigs and models just as he used construction techniques that were well established to the point of being almost medieval in their rugged simplicity. The only drawings we have of the resulting engines were made by scholars or travellers after they had been built. Their drawings are inaccurate in many technical details.

THE FIRST ENGINEERING DRAWINGS

By the end of the Eighteenth century the situation had changed. The scene was set by three things:

1. The emergence of an intellectual climate that valued and sought after utilitarian application of theoretical knowledge;
2. Improvements to steam engine design and manufacture which decisively extended its commercial application and so hugely increased investment and demand;
3. The specific abilities and background experience of James Watt, the Scottish engineer, who contributed most to early atmospheric steam engine design and who was responsible for the first recognisably modern engineering drawings to be used as models for manufacture and to convey information to clients.

The appearance of engineering drawings as a fully-fledged medium for communication in the engineering industry coincides appropriately with the establishment by Matthew Boulton and James Watt of the first specialist factory in the world for the construction of stationary steam engines. This happened in 1773 when the partners founded the Soho Manufactory in Birmingham and revolutionised the original Newcomen design by the application of a separate condenser. This was the technical development that made steam power commercially viable.

James Watt's personality, education and historical situation meant that he was well fitted to codify drawing practice. His background was unusual in that it combined a practical training and apprenticeship to an instrument-maker with involvement in natural philosophy (as science was then known) at Glasgow University. Thorough, methodical and dour, he drew together the threads of architectural, technical, scientific and military and naval draughtsmanship to turn them into an effective means for design, development and production control.

These personal characteristics found a congenial setting in Birmingham. The English West Midlands in which Watt worked was at the end of the Eighteenth century no provincial backwater. It was, on the contrary, a dynamic centre for intellectual as well as commercial speculation. Under the auspices of Josiah Wedgwood and Erasmus Darwin, Charles' grandfather, it was the meeting point of science and industry. In the famous Lunar Society – to which Watt and Boulton both belonged – it had one of the leading philosophical clubs – or 'think-tanks' – of the time. At its meetings, famous men met one another in small groups, exchanged ideas and hotly debated techniques for progress in society, natural philosophy and manufacture.

Why did Boulton and Watt need these design drawings and how did they use them? At this early stage, the Boulton and Watt Manufactory was not like a modern engineering works, turning out complete and finished pieces of equipment. Their stationary pumping engines for mines and blowing engines for iron smelting depended on the construction of an engine house to hold the working parts in the correct relationship with one another. Many of these parts were 'bought-in'. For example, George Wilkinson the ironmaster and his rivals, the Darbys at Coalbrookdale, competed for Boulton and Watt contracts for the production of cylinders. Many of these parts would go straight to the site – sometimes as far away as the United States - without ever coming to Birmingham. In this situation drawings were essential modelling devices. Watt used them for three different purposes:

1. As project drawings to model the particular form of each new engine and to be the basis of a contract with the client;
2. As outline production drawings for ordering the necessary parts and raw materials from outside the works, eventually to be combined with fittings made inside;
3. As means of controlling the work on site where bricklayers and carpenters would be required alongside specialist fitters from Boulton & Watt.

Before 1781 Watt executed all the necessary drawings himself. Between then and 1790, when a drawing office was at last established in the factory, he worked in his own house with only one assistant, an ex-surgeon called John Southern.

THE DRAWING OFFICE

Although Watt and Southern had established basic principles that were to hold good for many years, there were great differences of style and technique separating them from the work that would be done in the 1830s and 1840s. By this time, in Britain, drawing offices had become the main institutions in which engineering design was carried out and engineering drawings had become the normal means of modelling ideas and controlling production. These later drawings are far more sophisticated than those produced by Boulton and Watt. Often coloured, they also display formalised conventions.

The projections used are more uniform and the approach is based on better theoretical knowledge. How did this happen?

It is not possible to ascribe these changes to any single event. Rather they are to do with the continuing ferment of ideas in engineering, to the hugely increased scale of industry and to the emergence of characteristic forms of industrial organisation and administration. Step by step there evolved from Watt's work alone, through his joint work at home with Southern, first small groups of draughtsmen and, finally, well organised, recognisably modern drawing offices.

The drawing office that emerged during the Nineteenth century was far more than a place for draughtsmen to work. It was in fact the intellectual centre of every manufacturing or construction company. It was the powerhouse that drove innovation forward. It was here that new ideas were explored and schemed out and where detailed designs were produced. Drawing office staff would carry out field trials and tests, quantifying the performance and viability of the company's products. Young men came here to serve their apprenticeship, combining a practical 'shop' training with learning scientific, technical, design and drafting skills. A training in this setting resulted in engineers with deep practical knowledge and experience to back up any innovations they proposed.

The early drawing offices played a specific role in producing the cadres of young engineers needed for the Industrial Revolution. They were also influential in determining the form and content of engineering drawing. Henry Maudslay's workshop was a prototype for many others. It was Maudslay who made the block-making machinery designed by I K Brunel's father Marc. Maudslay rapidly became Britain's leading toolmaker. Among the engineers he trained were Joseph Clement, engine-builder and maker of precision tools; James Seawood, marine engineer and inventor; Richard Roberts, locomotive engineer and inventor of the self-acting spinning mule; Joseph Whitworth, the greatest British tool manufacturer of the Nineteenth century; and James Nasmyth, inventor of the steam hammer.

It is an extraordinary roll-call. This one small workshop trained a body of engineers that might do justice to a university department. It is clear that these men inherited much of their love for an orderly and precise approach to design from the early experience of working for Maudslay. His high regard for the art of drawing as a way of modelling design ideas was widely disseminated by their work throughout British engineering.

Marc Brunel himself believed training in draughting to be essential for an engineer and encouraged his son to master mathematics and drawing. The young Brunel showed drawing talent when he was only four years old and he had mastered Euclid by the time he was six! Later his father encouraged him to make a survey of the English seaside town of Hove, sketching the buildings there just as he had done years before in his own youth in Rouen. Marc insisted that this habit of drawing was as important to an engineer as a knowledge of the alphabet.

The Maudslay influence was repeated in the railway field by Robert Stephenson & Co. When Robert joined with his father George, Edward Pease and Michael Longridge to found the first specialist locomotive factory in the world at Newcastle they inevitably took on also the role of pioneer teachers. The post of head draughtsmen already existed in 1829 and the drawing office was organised on efficient hierarchical lines. Apprentices and their fees are specifically mentioned in the Memorandum of Agreement which founded the company. JGH Warren, the company's historian, records correspondence dating from 1836 where Robert Stephenson complains of the thankless task of training these apprentices. They have no sooner come into the office and 'become acquainted in every detail with our plans than they leave and carry away what has cost us a great deal of money and more thought'.

Surviving work from the Stephenson office differs both from the early Boulton and Watt drawings and also from the more flamboyant coloured locomotive drawings dating from the 1840s onwards. They are sober and workmanlike, using tinted washes in grey and sepia but no other colours. It looks as though this style was, in its own turn, influential in the United States for a number of very similar railway drawings are preserved in the Smithsonian Institution. By the time of the Great Exhibition in 1851 the engineering industry and with it engineering drawing was well established in Europe and America. The hectic days of technical invention and industrial innovation had been transformed into an orderly, institutionalised process.

THE SIGNIFICANCE OF ENGINEERING DRAWING

At this point it is useful to step back and attempt to answer two questions. First, is it possible to say why engineering drawings took the form they did? And second, did the Nineteenth century engineers themselves recognise the crucial importance of draughtsmanship as a modelling medium?

The body of work that can properly be described an 'engineering drawing' as distinct from 'technical illustration' such as that found in the *Encyclopedie* is far from homogeneous. It ranges from the slightest sketches to elaborate and carefully coloured sets of presentation drawings. This variety is essentially functional. It relates to the differing demands of, for example, initial design, where ideas are not yet resolved, to production where exact and complete instructions are required. A basic 'typology' of drawings appears to have emerged early in the development of the engineering industry and by the 1840s it was well established. The same typology is, in fact, still evident today even in digitally produced drawings.

At least six distinct categories have emerged clearly.

Initial or Concept Drawings

These relate to the stage in development when the engineer is considering broad alternatives and putting forward outline schemes. They are frequently found in notebooks kept by senior engineers and are often very individual in style. It is usually this kind of drawing that people have in mind when they say that something was 'designed on the back of an envelope'. A characteristic of these drawings is that they leave vague those parts of the design which the designer is not concerned with at the time. They normally highlight those aspects of the design which are particularly difficult or novel.

Project Drawings

Like designers' drawings these show proposals in broad outline. However, they are not personalised; instead they are produced according to accepted rules and conventions, usually by the drawing offices of established companies. They are often drawn to a relatively small scale.

Discussion Drawings

This is a category identified by Eugene S Ferguson(1993) in *Engineering in the Mind's Eye*. Called 'talking sketches' by him, they are drawings done as an aid to discussions during the development of a design. Often sketchy, they try to capture the essence of ideas or proposals. By their nature they are ephemeral and so infrequently preserved. However, they are often remembered by designers and played an important role in communications between engineers.

Production Drawings

These are perhaps what most people think of as engineering drawings. Typically, they conform to a sequence starting with a general arrangement drawing and covering every detail of the product to be manufactured. In the earliest days the sequence was frequently very incomplete and concentrated on those parts that were unusual in some way. As industrial organisation increased in sophistication so did the number of drawings needed to control production. By the 1950s a sophisticated product – a military aircraft for example - might need 50,000 drawings to cover every aspect of its construction.

Presentation and Maintenance Drawings

Many of the finest drawings which now survive are presentation drawings, that is, drawings made of the product after it had been finished. Frequently they are the work of skilled draughtsmen, based on measurements taken by apprentices as part of their training. In shipyards, the drawings record changes in design made while the ship was being built.

In the case of the great private locomotive builders in Britain, the term 'contract drawings' was used. These were complete sets of drawings that formed the basis of the final contract with the customer. In many of these marvellously finished drawings there is clearly an element of industrial pride and public relations, but they also served a practical purpose. They were used as reference when a machine needed maintenance or modification and many have later additions recording the changes that were made.

Technical Illustrations

These are illustrations for instruction manuals, technical or popularising books that use the conventions of engineering drawing. In the Nineteenth century, they reached a very high level of skill and presentation.

AN ENGINEERING LANGUAGE

The first engineers, like all designers, needed a modelling system or 'language' in which to conceive their schemes and to command the subsequent work of production. For this purpose they frequently used written specifications and descriptions but any such literary or verbal form is inadequate when faced with the problem of defining a three-dimensional reality that is highly specific. The only possible way to do that is to use a visual form of communication incorporating signs and symbols that are as 'readable' as the words in a sentence.

For engineers this is precisely what the conventions of the engineering drawing eventually became. By 1902, when Hawkins published his text book on *Mechanical Drawing* in New York, he was able to write that 'drawing constitutes a universal language, to acquire which is a matter of importance, for by its use one is able to illustrate the form and dimensions of an object, device or utility, in very much less time, and far more clearly, than by a verbal description'.

The ability to do this is at the root of engineering, and without its existence the technological revolution of the Nineteenth and Twentieth centuries could have taken place.

The vital importance of engineering drawing and its role in management, was well recognised by Nineteenth century designers and manufacturers. Writing in 1835 *On the Economy of Machinery and Manufactures* Charles Babbage, the British mathematician and inventor of the calculator, made its significance explicit:

'When each process has been reduced to the use of some simple tool, the union of all these tools, actuated by one moving power, constitutes a machine. In contriving tools and simplifying processes, the operative workmen are, perhaps, most successful; but it requires for other habits to combine into the machine these scattered parts. A previous education as a workman in a peculiar trade, is undoubtedly a valuable preliminary; but in order to make such contributions with any reasonable expectation of success, an extensive knowledge of machinery, and the power of making mechanical drawings are essentially requisite. These accomplishments are now much more common that they were formerly; and their absence was, perhaps, one of the causes of the multitude of failures in the early history of many of our manufacturers'.

Babbage gives what are basically utilitarian reasons for the importance of drawing. But their interest and meaning go beyond this. There is in them an excitement and intensity that comes from their function as a medium of creation. They are about what might be. They are wrestling with future possibilities. They are attempting to give form to uncertainties. Again this is something that was well understood in the nineteenth century. Men like Watt and Maudslay were interested in drawing for this reason and, as a result, believed that it should be of high quality. The linkage between clarity of concept and clarity of depiction was recognised as was the connection between 'fluency' of drawing and 'fluency' of invention. By the middle of the Nineteenth century, the pioneering companies had already developed a sense of history and took steps to preserve their early drawings. Scott Russell, in his book on ship design, published in 1864, looked back to Hendrick Chapman's Eighteenth century drawings in *Architectural Navalis Mercatoria* and recognised them as exemplary pioneering work in his own field, not only for their content but for the quality of their draughtsmanship. By the 1860s, engineers were beginning to recognise and value of their own particular modelling system.

It is evident that engineering drawing was a particularly exact expression of the ideals, interests and aesthetic sensibility of the late Eighteenth and early Nineteenth centuries, not only for engineering but for a more elusive 'spirit of the times'. It is this close cultural involvement that goes to explain both the excellence of mechanical design between 1829 and 1850 and the obsessional perfection of many of the drawings that the age produced. When James Nasmyth, Maudslay's pupil who invented the steam hammer, gave evidence to a British Parliamentary committee in 1836 he stressed 'the entire reconcilability of elegance of form with bare utility' and in his *Autobiography* defined engineering as 'the application of common sense to the use of materials'.

For Nasmyth there was an almost magical significance in geometry and in the perfecting of a small range of geometrical forms. This same passion is also something which comes through in engineering drawings from the first half of the Nineteenth century and, as we have seen, has its cultural roots in the Renaissance. It shows how the drawings reflected ideology as well as utility. In a striking passage Nasmyth (1841) set out the basic elements of machine design:

'Viewing abstractedly the forms of the various details of which every machine is composed, we shall find that they consist of certain combinations of six primitive or elementary geometrical figures, namely the *line,* the *plane*, the *circle*, the *cylinder*, the *cone* and the *sphere*; and that, however complex the arrangement, and the vast number of parts of which a machine consists, we shall find that all may be as it were decomposed and classed under these *six* forms; and that, in short, every machine, whatever be its purpose, more or less complex, for the attainment of certain objects and performance of required duties'.

This brief statement by Nasmyth contains the whole programme for engineering drawing as a modelling medium for design and production control in the Nineteenth century. His clarity of purpose and his almost puritan insistence on simplicity and common-sense may not have been the attitude of all engineers but they continued to be most at home with the line, the plane, the circle, the cylinder, the cone and the sphere and to devote their skill to representing them in the classic drawn viewpoints of orthographic projections and sections. It was practical, it worked. And its aesthetic perfectly matched the passionate rationalism of their utilitarian philosophy.

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