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INDUSTRIAL BUILDINGS:

THE EVOLUTION OF INDUSTRIAL BUILDING FORM AS AFFECTED BY CHANGES IN TECHNOLOGY

WIKUS VAN HEERDEN

> "Cosmic evolution produced our solar system and this habitable planet; inorganic evolution put together the right ingredients to produce life; organic evolution shaped and moulded that life into its kaleidoscope of forms; cultural evolution took just one group and pushed them rapidly through intelligence and awareness to a position where they could manipulate the rest of evolution themselves."
>
> [Watson, 1950, 315]



A Dissertation submitted to the Faculty of Architecture, University of the Witwatersrand, Johannesburg, for the Degree of Master of Science in Building.

Cape Town 1995

ABSTRACT

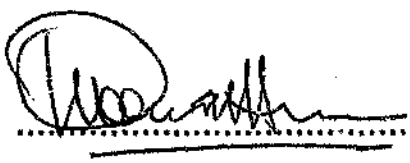
During the most recent period of man's transformation, the cultural evolution, man created many things. The latter part of this epoch was dominated by industry, when man created special structures solely for manufacturing purposes.

The first stage was the Handicrafts or Eotechnic phase and was characterised by the use of manpower and wind and water power. During the second stage, the Manufacturing or Paleotechnic phase, man made use of steam and electricity. This stage was regarded as functional in Europe and mechanised in the USA.

The changes in form in these stages follow the same patterns as the technological process, although the patterns are not unilinear, equal or similar in duration, the first stage evolutionary, the second stage more revolutionary. The changes were predominantly the result of technical pressures, but to a minor extent also of economical, aesthetical, philosophical and sociological pressures. Of late managerial pressures have contributed to the changes as well. A causality is thus revealed in that the changes in form are a consequence of holistic changes in these pressures.

However, the nature and essence of the industrial building as an enclosed space where something is produced remains constant, whatever the pressures.

DECLARATION: I declare that this dissertation is my own work.



.....Cape Town, November 1995.

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Dedicated to the women who have so willingly influenced my life:

Frieda Ursular (Kohler)
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Elfriede and Karen

CONTENTS

			PAGE:
		Introduction	1
Part One	Pre-industrial Manufacture Buildings		
	Chapter One	Man Power	6
	Chapter Two	Natural Energy	15
	Chapter Three	Factory Systems	30
Part Two	Manufacturing Buildings		
	Chapter Four	Industrial Revolution	40
	Chapter Five	Mill Buildings	54
	Chapter Six	Steam	62
	Chapter Seven	Factory Buildings	71
	Chapter Eight	Europe and the USA	85
	Chapter Nine	Mass Production	100
Part 3	Results and Conclusions		
		Conclusion	112
		Definitions	120
		Bibliography	123

INTRODUCTION

Everything is in a perpetual state of transformation, motion and change. However, we discover that nothing simply surges up out of nothing without having antecedents that existed before.

[Bohm, 1984:1]

Objectives

Much has been written about the evolution of the building form, but little coherent work has been done on the evolution of industrial buildings. Yet, it is a history no less important, since it parallels the industrialisation of the world. A desire to determine whether industrial design was guided solely by the requirements of the processes carried out inside such buildings or whether it could be related to developments in other fields of architectural design, prompted the author to investigate the subject.

Certain pertinent questions have provided the justification for exploring these concerns within an academic framework, since their answers may contribute to understanding the evolution of the industrial building form and its possible impact on future industrial design.

The first question concerns the main problem of designers, architects or engineers involved in planning and designing industrial structures, namely whether there is an aesthetics of functionalism [Richards, 1958:14] and whether it can be stated that aesthetics will be influenced by technology [Brockman, 1956:15] to such an extent that form [1] actually follows function [Greenough, 1947:xv and 85].

A major breakthrough occurred when the architects Sullivan [1856-1977], Wright [1867-1959] and Le Corbusier [1887-1965], who designed completely divergent buildings, could all write that form does follow

1. Horatio Greenough [1805-1852]. Neoclassical sculptor and art essayist, who was the first American to outline the functional relationship between architecture and decoration in 1852. The essays were reprinted in 1947.

function [2]. This dissertation attempts to explore this concept in the evolution of industrial building design.

The second question to be considered is the relationship between technology and form. What causes technological function to change and, as it changes, does the form of the industrial building also change? The changes may not be caused by a single innovation, but by an accumulation of many innovations. Is it possible that the source of change is not only technological, but that it may stem from various sources as there is a tendency in nature to produce wholes [3] from an ordered grouping of units? These units may not be immediately discernible nor are they key devices [4] that have to be identified. There may also be concepts which have not yet materialised at all due to a lack of technology.

Thirdly the author attempts to determine who the innovators were who demanded the changes in function and form and how they steered technology in an acceptable direction. The question is whether mechanical innovation was the consummation or continuation of earlier lines of development. Were there outstanding individuals who led the field or did the innovators work in series, parallel or groups and did the order perhaps change from time to time?

The fourth question is whether the process can be termed evolutionary, revolutionary or even devolutionary. Cause for concern, however, is that if an evolutionary process [5] can be identified, it may be unilinear or interrupted, multilinear or parallel. Also, will the patterns [6] be discernibly linked or will they be sequential [7] and come in waves that ebb and tide?

This dissertation seeks to answer these and other questions.

2. Industrialists in Europe and later in America followed this law since the erection of the first mill buildings in the early eighteenth century.

3. Holism - a theory espoused by Jan Smuts (1870-1950), a South African statesman, in 1926 to counter the hard and narrow concepts of nineteenth century causation [Smuts, 1926:87].

4. Key devices are basic developments that enable numerous inventions to follow [De Bono, 1974:216].

5. Pottery has a history of development rather than invention and this consists of aesthetic exploration, chemical and technical improvements [De Bono, 1974:69].

6. Paleotechnic and Neotechnic [Geddes, 1915:63]. Eotechnic [Mumford, 1946: 109].

7. Five stages of economic growth: Traditional society, preconditions for take-off, take-off, drive to maturity and high mass consumption [Rostow 1969:4-9] Three waves: Agricultural, Industrial and the future [Toffler, 1980:18].

Motivation

In a study of this nature one is necessarily concerned with the total process. One attempts to follow an holistic approach by including, if possible, all relevant influences such as economic, political, social, environmental, cultural, managerial and st ategic factors.

For the purpose of this dissertation the specific area of technology has been isolated, with the peripheral areas only referred to when important or for reasons of clarity and continuity. It is also chronological and thematic in nature. In spite of computing periods of time in series, the subject of chronology can be extremely complicated. Interfaces and interpenetrations of patterns are specific areas where the information must be treated with circumspection.

Documenting this vast subject - which covers industrial history in its entirety - in all its facets, nuances and depths would mean stretching far beyond the scope of this dissertation. The result would be too voluminous and general to have much value. The research course of action was to determine the nature of information available and then to attempt making the field manageable by a strict selection of critical texts.

Information published in the nineteenth century and earlier was readily available because of the excellent facilities in some research libraries. However, as a result of sanctions it was sometimes difficult to obtain information from offshore libraries.

The pre-war [1939-1945] technical and historical background consisted of a few sets of substantially illustrated volumes, but there was a post-war information explosion, a phenomenon which manifested itself in all spheres. This information covered everything from the now extremely popular industrial, archeological and

functional traditions - all well photographed - to research papers in journals on modern factories, many with explanatory plans. Journals, because of their nature, mostly probed single factories and their designers. Many of the authors, mainly architectural historians, presented books of prodigious research and others described new civilisations in great detail.

The author's interest in this subject started at an early age and was further encouraged when a book prize was won - Mumford's Technics and Civilisation - for designing the winning poster in a National Health Foundation under eighteen competition. I obtained my Diploma in Architecture thesis with distinction at the University of Cape Town in 1959 after designing a nuclear science building for Cape Town. I then worked in Britain for a year and for two years in Germany. I travelled to many of the Midland and other industrial archeology sites just when Richards' book The Functional Tradition was published. While studying and working in Germany I inspected many traditional structures in Europe and also a few of those turn-of-the-century buildings that were not located in East Germany or behind the Iron Curtain.

In 1972 I took part in the H H Robertson "Colour in Building" competition where I won the prize for submitting the best industrial design, a knitwear factory, as well as the overall prize for the best entry. The prize entailed an all-expenses paid trip to the USA where I visited many industrial building sites and spoke to many industrial architects and historians.

Since my university days I have maintained a laborious card system in which a variety of information was recorded. This card system [Corcoran, 1971:198], in spite of its primitive and low order in systems analysis, was not limited in terms of the amount of information that could be processed. The information was then refocused to bear upon the subject of this particular dissertation.

When faced by a complex puzzle of this nature there may be a tendency to seek a single solution rather than to recognise the overlapping units of a complex semi-lattice. Prejudice is overcome by reason and logic, based on a vast amount of information [Thouless, 1973:137 and 150] and acceptable judgements.

We attempt to learn from history by applying the lessons drawn from one set of events to another set of events [Carr, 1967:66]. The trick of reducing these arguments to their most basic form is the first step in lending sound support to a conclusion. The purpose of charting the rocks is to show where the channel lies.

PART ONE : PRE-INDUSTRIAL MANUFACTURE BUILDINGS

CHAPTER ONE : MAN POWER

Tools are an extension of man's physical attributes.
[De Bono, 1979:180].

When primitive man, our immediate forerunner, acquired the skill to walk upright habitually, his hands were freed. He used them initially to handle natural tools and then to make and manipulate tools [Oakley, 1963:1]. These activities, which depended on adequate mental power and bodily co-ordination and the ability to communicate, placed him above all creatures. Within this dynamic state, due to his materials and environment, man could change by adding or discarding as circumstances dictated.

Oakley also observed that the employment of tools appeared to be man's chief biological characteristic, but this statement is contradictory and poorly argued. Man's development is a process transmitted by social mechanics such as verbal and later written communication and an accumulation of technology, where each generation builds upon and adds to the tools [1] and techniques of his predecessors. Each step in the sequence is a necessary part of the process, each step taken in a given order. These steps, in form as well as content, are the very essence of history [Usher, 1954:5].

1. Man, a weak creature, could by means of tools extend his facilities, more specifically the arm and hand, to magnify the blow, lengthen the reach, increase precision of movement and enhance many other relevant manipulations [Spier, 1970:21].

This ability to develop has lifted man from the level of the brute and carried him through savagery and barbarism to civilisation [White, 1949:44]. The list of technological advancement proceeds almost without break from Homo Habilis c.2m BC, Homo Erectus c.1m BC, the crude man, Homo Faber the maker, right up to Homo Sapiens c.100 000 BC, the thinker, and Homo Sapiens Sapiens c.10 000 BC, the civilized man [Forbes, 1950:5]. Each generation acted in additive fashion, passing the torch to



Fig.1 When making a hand axe, a hunter uses a hammerstone to strike large flakes from one end of a chunk of quartzite, a rock that fractures to produce a fairly sharp cutting edge. With such implements, Homo Erectus gained increasing control over his environment [White, 1973:66-67]. These tools were made in the open, in caves and later in various shelters.

the next generation and every discovery and observation added to the existing knowledge [Spier, 1970:2].

Progress was painfully slow during the primitive and pre-industrial stages [2]. Man was a hunter-gatherer, compelled to rove in search of food. Already there was a division of labour and a certain co-operation, with important social implications. Man acted as hunter and the female was the gatherer [Kranzberg, Vol.I, 1967:8]. In the beginning, man only occasionally used an improvised tool.

Man was soon to discover the key to fire, which gave him control over caves, afforded protection and initiated cooking that changed his diet. Stones became tools when they were shaped deliberately for specific purposes [Fig.1], for example as weapons.

There is a subtle distinction between discovery and invention. When something is adapted from nature in various ways for various purposes for instance the powers of fire, water and wind and the methods applied to harness them, it is called discovery. As soon as man uses these powers to create something different, it is invention. There appears to be a natural limit to the number of discoveries, but there seems to be no limit to invention. Invention has become a combination of scientific research and reasoning and represents a far greater intellectual achievement than discovery [Forbes 1950:7].

The earliest group of tools made by man were the edge tools that were chipped and then later ground. Chipping took skill, but grinding took foresight. Chipping did not allow for standardisation, but grinding brought about marked standardisation. With the introduction of antler and bone as hammers and throwers, hafting encouraged the making of specialised tools and the first mechanised weapons.

2. Lower Paleolithic, or oldest period of Old Stone Age, c. 2m BC, when the oldest known tools were fashioned by man in Africa; Homo Erectus, 1m BC, emerges in the East Indies and Africa and populates the temperate zones. During the middle period of Old Stone Age, c.80 000 BC, Neanderthal man emerges in Europe. In the Upper Paleolithic or latest period of Old Stone Age, c. 35 000 BC, Cro-magnon man develops in Europe. Through the Mesolithic or Middle Stone Age period, c.10 000 BC, to the Neolithic or New Stone Age, c.9 000 BC, animals were being domesticated and settlements started to form [Spier, 1970:29].

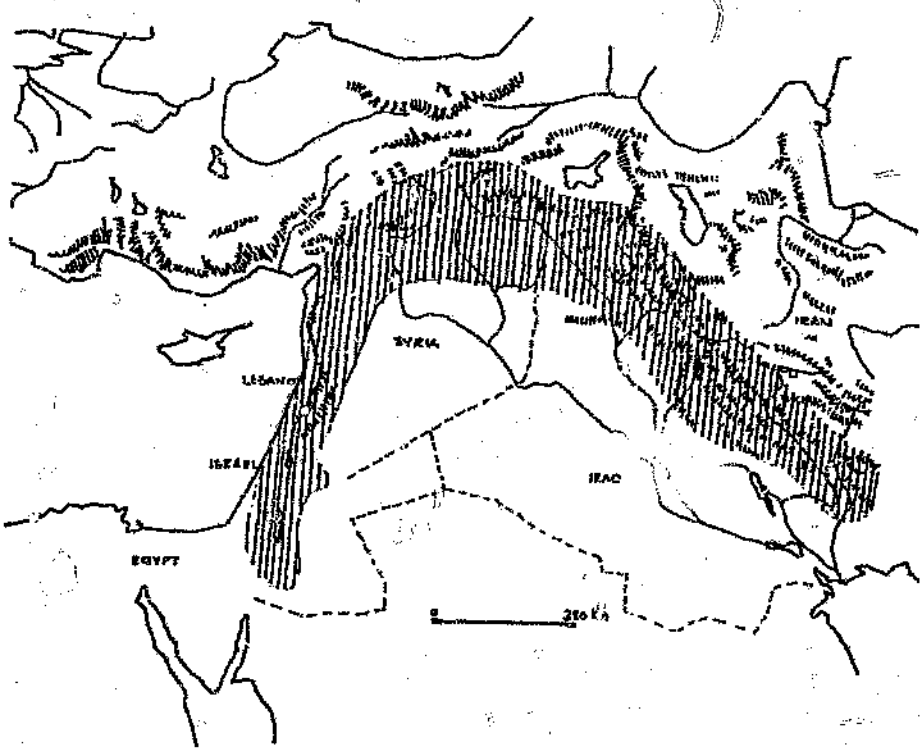


Fig.2 This topographical map of the Middle East shows the hilly flanks where agriculture began c.8000 BC in the foothills of the Zagros and Taurus mountains and the uplands of northern Israel. This fertile crescent curves from Iran around Iraq and Syria to the Valley of the Nile [Leonard, 1974:11]. *See shaded area.

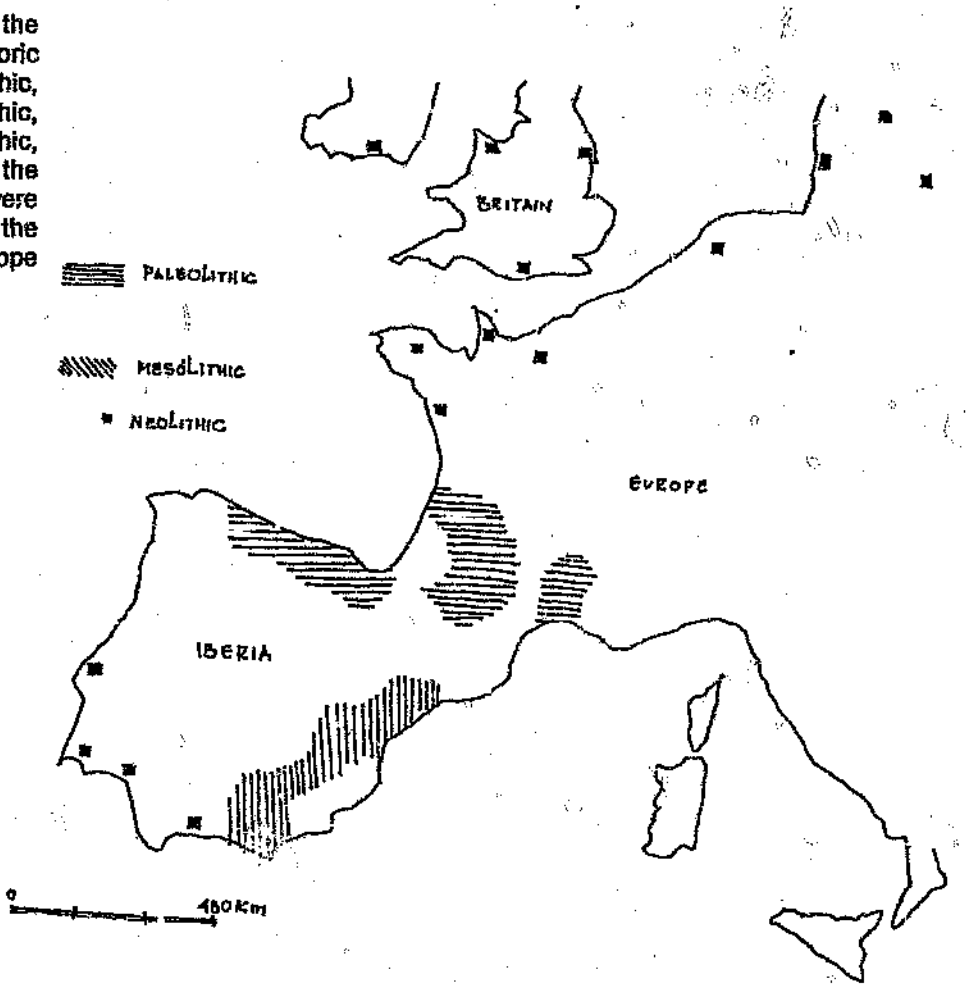


Fig.3 The map shows the area occupied in prehistoric Europe, by the Palaeolithic, c.32 000 BC, the Mesolithic, c.8000 BC, and the Neolithic, c.6000 - 1500 BC. By the Neolithic period there were permanent settlements over the whole of Western Europe [Gardner, 1975:24].

The second group of tools were the drills, at the outset used bi-directionally by hand and only very much later with a bow.

The third group were the tools used for making tools. This was a group of edged tools used as saws and scrapers for cutting wood and bone [Spier, 1970:29-37] and [Singer, Vol.I, 1965:22-23].

While man was perfecting these stone tools, his mental and physical energy were exceedingly low due to the haphazard eating pattern of transient peoples [White,1949: 375]. Over a period of many thousands of years [3], broad and major change took place in both the Middle East and Europe. Major settlements were established [Figs. 2 and 3] where both animals and cultivation were domesticated. Again there is the division of labour on sexual lines, with men clearing the lands and herding animals and women planting and reaping.

As a result of these changes, man was now able to increase his energy level by a more balanced and constant diet. He had more time to devote to the perfection of his tools, while developing animal power at the same time. This radical change took place during the agricultural revolution by harnessing plant and animal power [White. 1959:281].

Whatever its limitations, early farming permitted or required a stable society of farmhouses, villages and towns. Work was organised according to age and sex. The very young and the very old were given certain responsibilities, but their work was still divided along sexual lines. It also required crops that had to last from season to season and produce surpluses, which would then allow for leisure time or be available to support full-time specialists [4] for making tools [Singer, Vol.I, 1965:43].

3. Neolithic revolution transformed mankind from a scattered collection of savage bands of hunters into a collection of more or less interdependent agricultural societies [Kumar, 1985:47]. C.9 000 BC, sheep were domesticated in The Middle East; c.8 000 BC Jerico the oldest known city was settled; c.7 500 BC, man cultivates his first crops, wheat and barley, in The Middle East; c.7 000 BC the pattern of village life grows in The Middle East; c.6 200 BC, cattle are domesticated in The Middle East [Gardner, 1975:43].

4. To reach this point in man's history, c.7 000 BC, had taken nearly 2m. years, or 99% of man's existence on earth. This fact is as significant as it is remarkable.

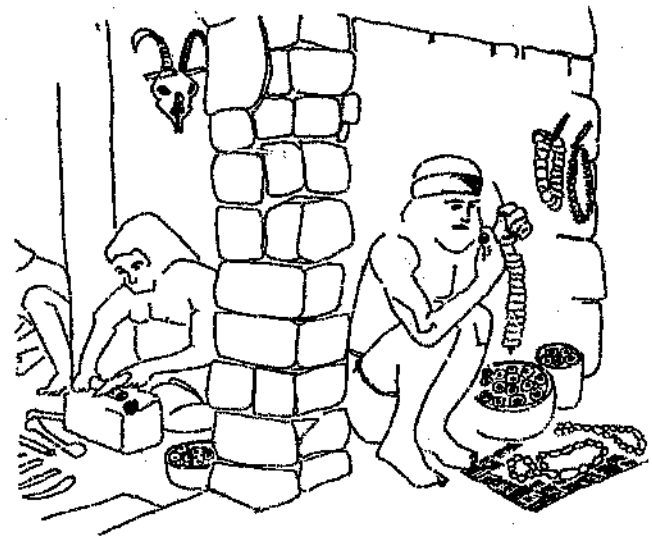
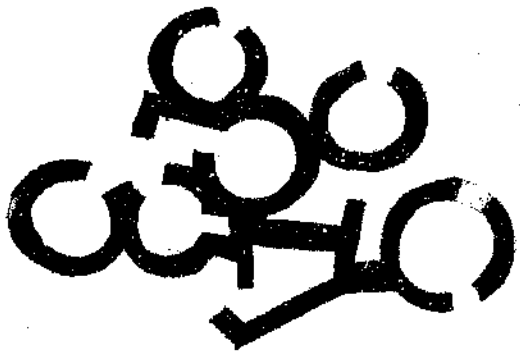


Fig.4 Typical workshops such as at Beida were clustered in and around a number of arcade-like buildings, consisting of a corridor and giving access to small workshops arranged in pairs facing each other. The shops apparently also supported a living area, usually above [Leonard, 1974:102].





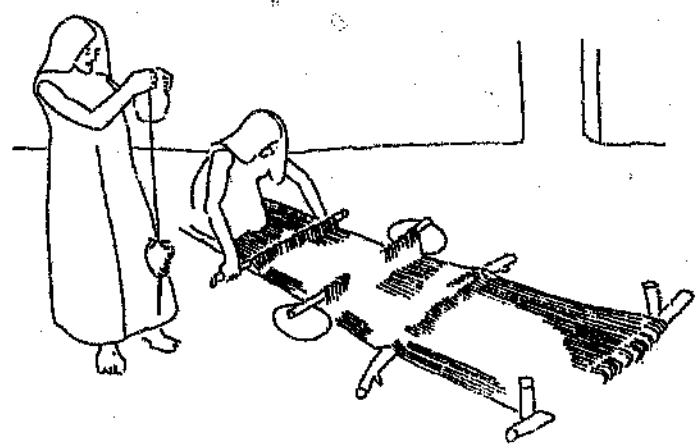


Fig.5 The first "weaving" took place possibly in 400 000 BC to form protective coverings. Later baskets and straw mats were woven. Neolithic peoples used wool and flax, Ancient Egyptians and Indians cotton, while silk was confined to the Far East [Spier, 1970:83].



Fig.6 Squatting by the stream bank from which she has dug her clay, a potter prepares to bake some pots in a fire fed with reeds [Hamblin, 1970:83].

The living standards rose slowly but steadily as the various crafts such as building, stone carving, weaving, pottery and woodwork contributed to the general comforts of body and home. The applied arts also flourished as never before in the early settlements [Leonard, 1974:69].

Since the stone age man has always made things for himself, but now the specialists and even ordinary farmers found that they could make part of their living [5] by practicing some craft [Hamblin, 1973:69]. The craftsmen made particular wares from different materials or general wares in a specific material. These applied arts did not appear all at once, at the same place or even at the same rate of proficiency, but did provide general comforts for man and his settlements [Fig.4].

Settlements, as the word indicates, permitted the use of larger or more permanent pieces of equipment. Weaving, for example, when it became more sophisticated, involved the use of a loom and pottery [6] required an oven [7]. To be able to weave, domesticated raw materials such as wool and flax were shorn and harvested. The next major operation was spinning yarn for weaving. The loom could be warp-weighted, set against a wall or fixed to the ground [Fig.5]. Few inventions have changed the quality of human life as pottery has. Much has changed since baked pots were first made in the Middle East [Fig.6]. The first principle of this process is understanding clay mixtures, mixing and grinding the materials to an acceptable consistency by adding water. The second principle concerns the dehydration of this water, an irreversible process caused by heating which subsequently stabilises the form created [Spier, 1970:101]. The next is the design of ovens for baking the pots. The fourth is the early discovery of controlled rotary motion, based on the principle of the wheel [8], which eventually led to later mechanical inventions [9].

5. In the village of Beida in Jordan craftsmen appeared as early as 6 500 BC [Leonard, 1974:102].

6. Later, in permanent settlements, ovens were constructed, which were built of clay and used for baking bread and pots.

7. The earliest evidence of fired ceramics goes back to 23 000 BC, when the hunter-gatherers baked figurines. Baked pots were made c.7 000 BC. The oven was the predecessor of the kiln and the smelting furnace [Hamblin, 1973:75].

8. The potter's wheel can be traced through three stages, namely the hand-rotated platform, c.7 000 BC; the potter's wheel based on the cartwheel, c.3 500 BC and the kick wheel, c.2 000 BC.

9. The cart wheel, c.3 500 BC; the windmill c.6[illegible] BC, and the water-wheel, c.65 BC.

As seen before, the oldest settled communities were founded on the grassy uplands of the fertile crescent. Later towns and cities were situated in topographically suitable locations on the ancient trade routes with constant food and water supplies [Hamblin, 1973:16]. Such a town was Catalhuyuk in today's Turkey which became rich because it lay in the region of the major prehistoric source of obsidian or natural volcanic glass. This prized material was used for the manufacture of ancient ceremonial knives, ritual bowls, mirrors and jewellery. Another example was biblical Jericho which lay on the trade routes and was important for commerce. As a result of its stable society, it came to dominate the whole area.

Simple irrigation was begun [10] in the delta of the Tigris and Euphrates [Gardner, 1975:291] and later in the valley of the Nile. These ancient civilizations were established because the food production was so regular due to irrigation that it became possible now for large portions of the population to be occupied with arts and crafts [White, 1959:291]. Irrigation also led to the use of mass labour and an organisational hierarchy to co-ordinate and direct its activities. This, together with the manufacturing experience of man over many millenium, allowed for the evolution of some very sophisticated implements.

10. Mesopotamia c.5 500 BC and Egypt c.5 000 BC.

When the malleable nature of metals [11], especially copper, was discovered and the methods of cold hammering applied, this led to the production of tools usually copied from the stone implements of the time [Singer, Vol.I, 1965:59]. It was, however, only when it was understood that metals could more readily be worked with heat that the heating of certain materials led to the smelting of ore [12]. Also, by mixing certain metals, stronger alloys [13] could be made. As a result of this the full change from agrarian to village culture was made [Gardner, 1975:46].

11 Gold, silver and copper in its native or metallic state had been known and used since 9 500 BC, and used mostly for its ornamental value [Leonard, 1974:111].

12. C.6 000 BC.

13. Bronze alloys and castings, c.3 500 BC. There was also the invention of writing and the Unification of Egypt during the Ancient period, c.3 100 - 2 650 BC.

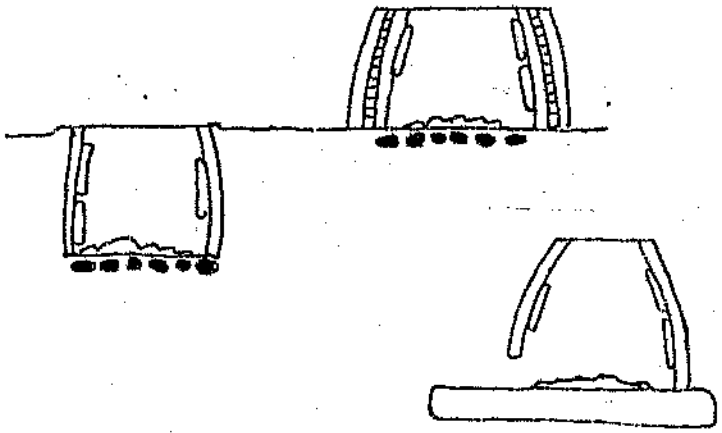


Fig.7 The kilns were invariably built of clay and later bricks, had hollow floors and flat or shaped domes with smoke outlets for wood and, later, charcoal burning [Singer, Vol.I, 1965:396].

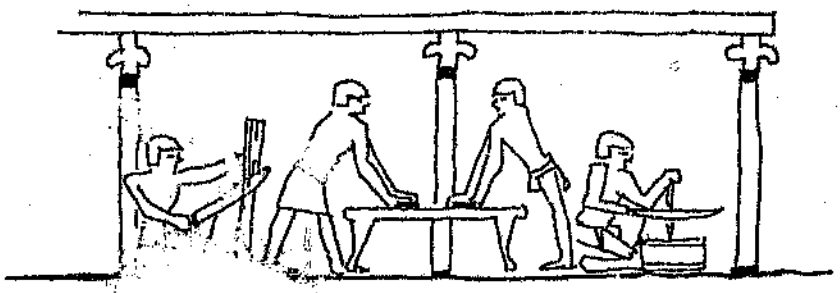


Fig.8 Joiners at work. On the left is a heavy pullsaw; rubbing on a finishing bed; and, far right, a bow drill. Taken from a tomb at Saggara, Egypt, c.2500 BC [Singer, Vol.I, 1965:689]

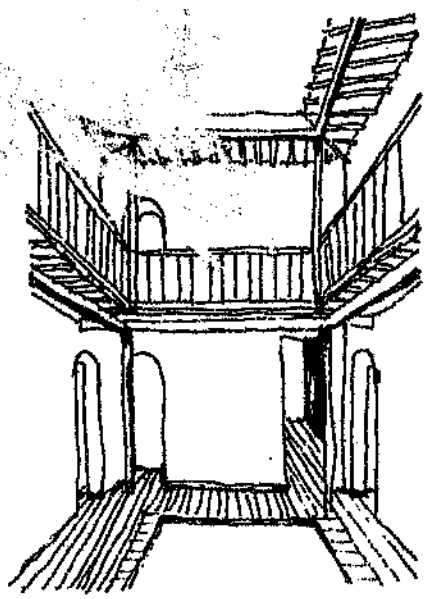
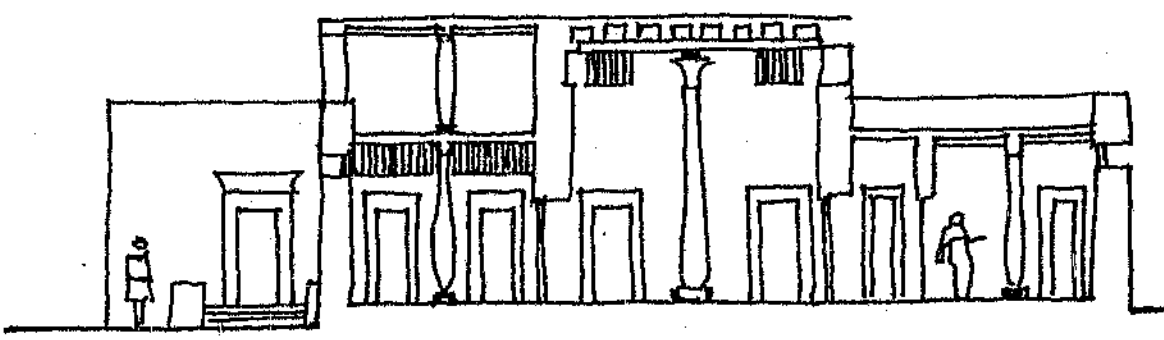


Fig.9 Two examples of double-storeyed private houses from c.1300 BC, which contained workshops below the living area. The upper sketch relating to Ur, Mesopotamia and lower to El-Amarna, Egypt [Singer, Vol.I, 1965:469].



The search now concentrated on materials that could be worked reasonably easily but which would create tools that were hard, remained sharp and were durable [14].

Metal workers were among the first full-time specialists in industrial production. The techniques of prospecting, mining, smelting, transporting, forging and casting were too exacting to be successfully combined with gathering, hunting or farming. Mineral deposits were usually rare and isolated from agricultural areas and the more settled towns and markets. The fact that large kilns had to be built which, by their nature, were permanent structures obviated a nomadic life [Fig.7].

In the Middle East [15] the economic revolution caused by irrigation and large scale food production supported a hierarchy of priests and officials [16] all requiring [17] records and accurate communication.

In the temple of Lagash in ancient Sumer, 1200 male and female workers, of whom about 300 were slaves [18], were employed as carders, spinners, weavers, bakers, millers, brewers, carpenters [Fig.8], blacksmiths and others. These temples represented great economic powers and were some of the cities' largest entrepreneurs [Hamblin, 1973:97]. At Memphis, south of the Nile delta [19] and traditional centre of handicrafts, priests were the patrons and the high priest bore the title "Greatest of Craftsmen". Priests were also the designers and all important works of art were executed under their supervision. In the city of Uruk [20] the rich merchants lived in two-storeyed houses facing the cool courtyards [21] where several rooms on the lower floor housed a variety of craftsmen [22] [Fig.9]. The manufacture of linen both coarse canvas and smooth cloth was an established art in Egypt.

14. The metal age evolved over many years, depending on heating agents and the design of kilns. Copper Age c.5 000 BC, Bronze Age c.3 000 BC and Iron Age c.1 400 BC.

15. Egypt c.3 500 - 500 BC.

16. Cities with populations up to 12 000.

17. Wooden furniture was rare before the copper period. When chisels for cutting mortices, dovetails and sockets could be used, this allowed for the making of stools, stands, tables and boxes [Singer, Vol.I, 1965:187]..

18. Slave labour, which was accepted in Egypt, provided a good and docile labour force which at times could have discouraged natural technical innovation. This may appear to be a sweeping statement, but there were local and regional variations [Singer, Vol.II, 1965:591].

19. City in Egypt during the Lower Old Kingdom, c.2 800 BC.

20. Erech in the Bible, c.2 800 BC. The population was 40 000 - 50 000 and all lived in brick houses.

21. In Egypt, column, lintel and stone was used [Gardner, 1975:82].

22. Sculptors, carpenters, metalsmiths, leather-workers, weavers and potters [Hamblin, 1973:89].

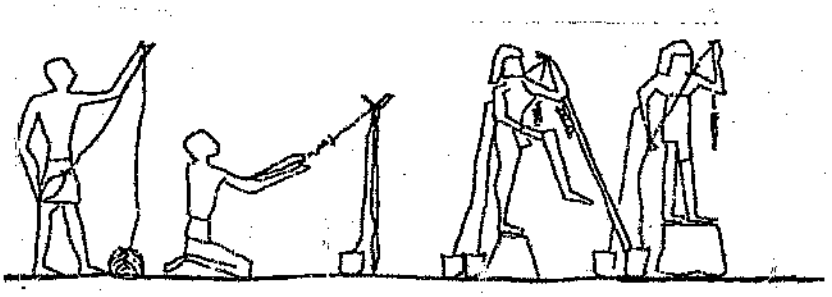


Fig.10 C.1900 BC. Men spinning with women doubling from the Tomb of Khety at Beni Hasan, Egypt [Singer, Vol.I, 1965:438].

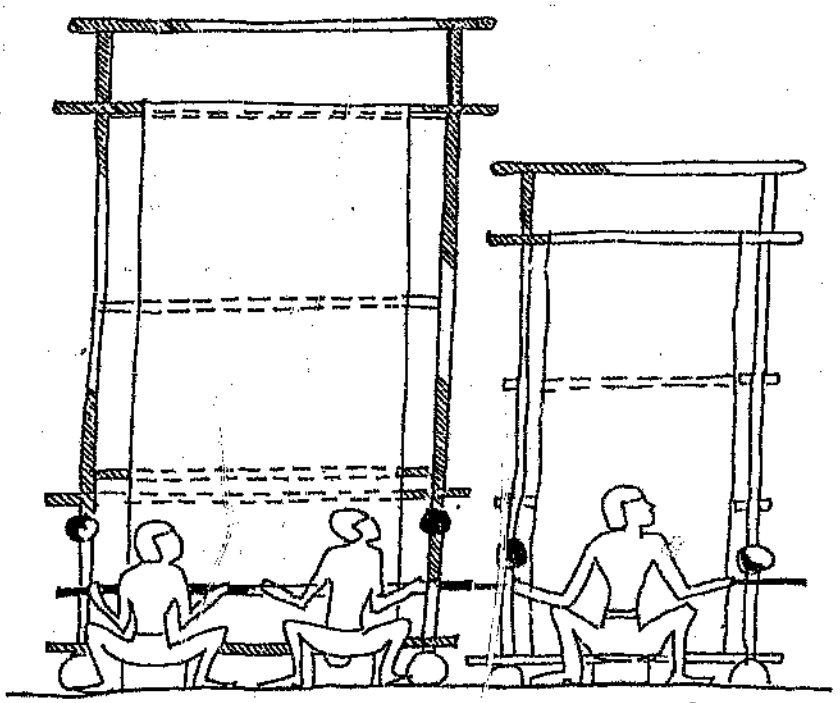


Fig.11 Vertical looms in the New Kingdom, c.1500 BC, showing warp and breast beams from the Tomb Thotnefer at Thebes, Egypt [Singer, Vol.I, 1965:439].

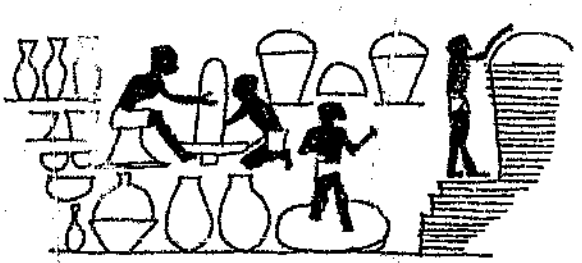


Fig.12 Potters in the New Kingdom c.1450 BC. The wheel was being turned by foot while another worker packed the kiln. Also from Thebes [Singer, Vol.I, 1965:389].

As the specialised crafts multiplied, guilds organised into groups. Labour became divided geographically, with the various crafts located in one or another part of the city or country. Pottery very soon specialised to such an extent that shaping, firing and decorating was done in separate establishments and sometimes the craft was divided even further into pots, jars, goblets or urns.

At the other end of the scale, achievements in large construction in Egypt projects during the first reign of the fourth dynasty shows in a striking manner how capable the administration was. The good years of the third dynasty had left the country in a very sound economic state. The Great Pyramid [23] could only have been built if national resources were concentrated, used with great efficiency and a good deal of arithmetric and geometric knowledge [Sarton, Vol.II, 1970:35].

23. The oldest of the Seven Wonders of the World - the pyramids of the Old Kingdom, c.2 686 - 2 160BC. Khufu is one of the largest structures ever erected, ancient or modern.

In many ways these achievements, of which the great monument is but one, provide the most obvious testimony. The moving and construction of large blocks of stone with an average weight of 2,5 tons by ordinary peasants, together with some superb workmanship and the artistic and refined taste expressed in the funerary furniture and ornaments found inside the tombs, mark a summit in the technological history of Egyptian achievement. For the most part, however, craftsmen still worked anonymously in the workshops of the temples or in private houses and received no personal recognition.

At the start of the Greek civilization [24], most of the early inventions that had secured mankind's supremacy over his environment are evident: the use of fire, domestication of animals and agriculture, use of metals and iron for weapons, tools, utensils, spinning [Fig.10] and weaving [Fig.11], the potter's wheel [Fig.12], glazing ovens, the use of wheels, the art of writing and buildings of wood, brick and stone. Agriculture was the basis of this

24. C.900 BC, in Ancient Greece.

economy, while the temple and home were centres of production and the source of power was still only man or beast [Kranzberg, Vol.I, 1967:48].

Ancient Greece was the parent culture of Europe. No other peoples of antiquity exhibited such a wide range of genius or left such a vigorous legacy. The Greeks, heirs to the Minoan civilization, who in turn had profited from their links with the cultures of the Fertile Crescent and Egypt [25] had a probing attitude of mind that enabled them to make major contributions primarily to philosophy [26] and the fine arts.

In spite of the Greeks spending virtually all their time on the design and construction of religious buildings during the classical period [27], the Greek philosophers [28] in this period - today called the "dawn of science" - explained the phenomena of the perceptual world rather than offering recipes for practice. These triumphs of science represent a cumulative process of increasing knowledge and a sequence of victories over ignorance and superstition.

From this science flowed a stream of abstract thought that extensively improved the lot of man. Here emerged a respect for reason, scientific enquiry, physical concepts of nature and humanistic views of man based on commerce, government, society and education, local religions and democracies in limited forms [Gardner, 1975:22]. It may appear that the Greeks spent their energies primarily on mental [29] and physical [30] activities and not so much on the development of technology, but this led up to it.

Also, mechanical innovation was not distinguished but more the consummation or continuation of the earlier lines of development. This is not quite true. Many inventions can be attributed to the Greeks: water and wind screws, pulleys, compressed air weapons, suction and force pumps, steam-powered toys and automata. They built

25. These great civilizations achieved highly developed technologies, religious, legal and administrative systems in complete absence of science as we understand it today [Kranzberg, Vol.I, 1967:49].

26. The Greeks had no word for scientists. They called them philosophers [Singer, Vol.II, 1965:603].

27. Classical period, c.500 BC.

28. The trio of ancient Greek philosophers, Socrates [470-399], Plato [428-348], and Aristotle [384-322]. Also Archyros of Tara [400-365] and Eudoxus [400-350]. Later there were also Archimedes of Syracuse [287-212] who became one of the world's greatest exponents of mathematics and mechanics of all time, Clesibus [270 BC] and Hero [62 AD]. During the later Roman period there were also the two Greek scientists, Galen of Pergamon [129-199] and Ptolemy of Alexandria, [180 AD] [Singer, Vol.II, 1965:630].

29. The Academy of Athens was founded by Plato in 387 BC. The Museum of Alexandria was started by Aristotle, c.350 BC.

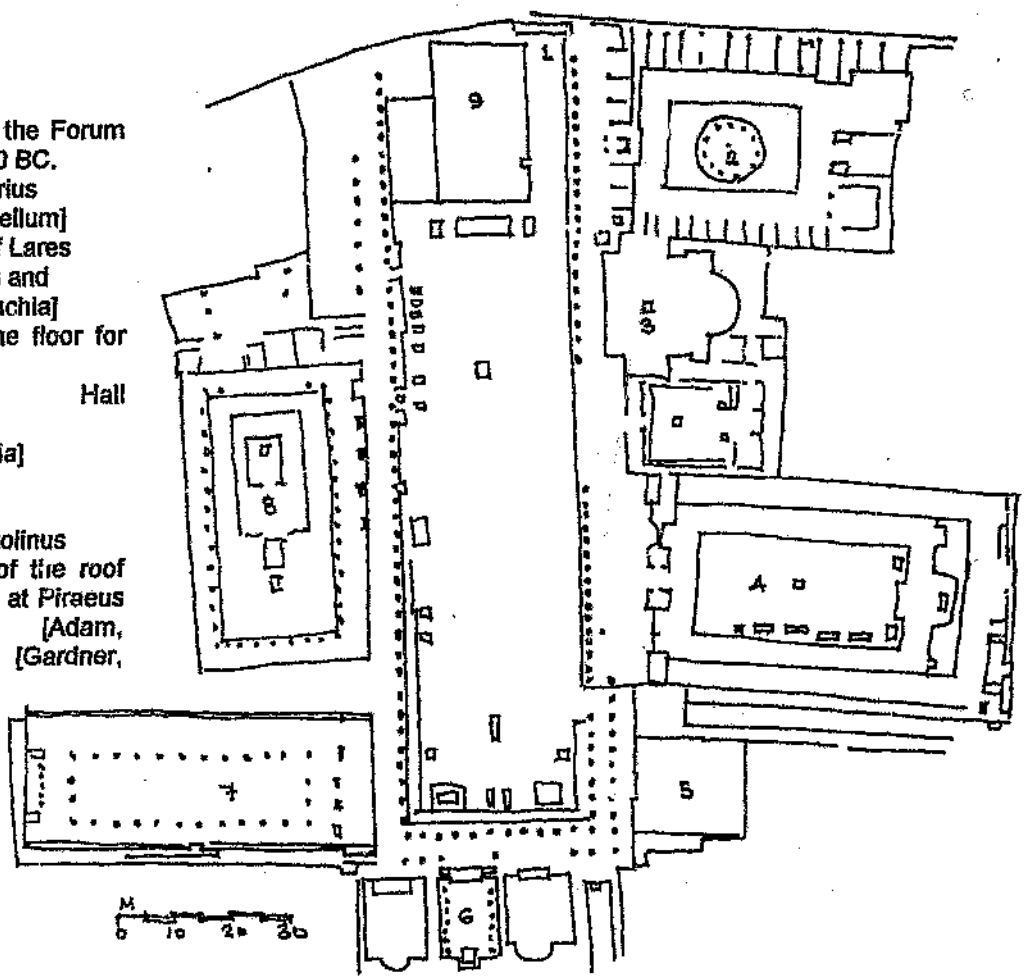
30. The Olympic Games [776 BC - 393 AD] were held at intervals for nearly 1 000 years.

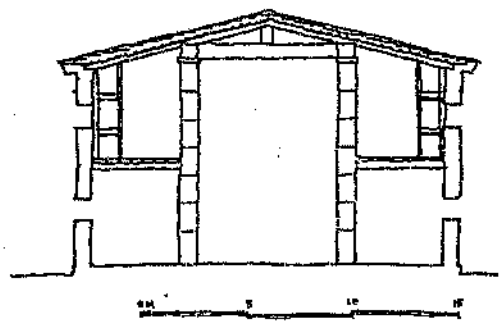
Fig.13 The plan of the Forum at Pompeii c.400-200 BC.
1. Arch of Tiberius
2. Market [Macellum]
3. Sanctuary of Lares
4. Clothmakers and Dyers [Eumachia]

Note the holes in the floor for dyeing vats.

5. Election Hall [Comitium]
6. Council [Curia]
7. Basilica
8. Apollo
9. Jupitor Capitolinus

The reconstruction of the roof of the Naval arsenal at Piraeus c.fourth century [Adam, 1984:23] and [Gardner, 1975:202].





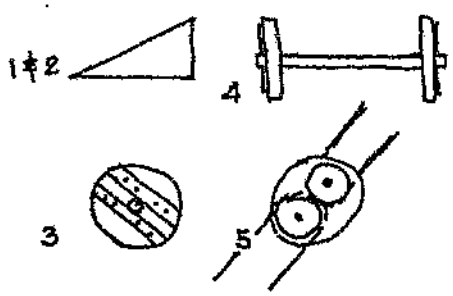
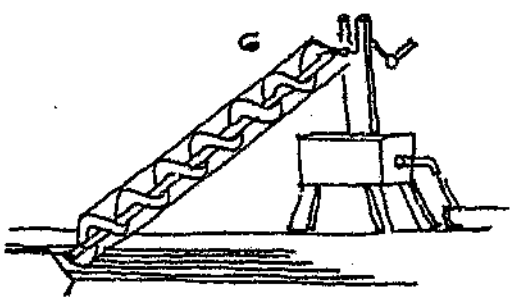


Fig.14 The six major Greek inventions, consisting of the wedge or lever, the wheel, axle and pulley, including the Archimedes screw to raise water [Singer, Vol.I, 1965:630 and 676].



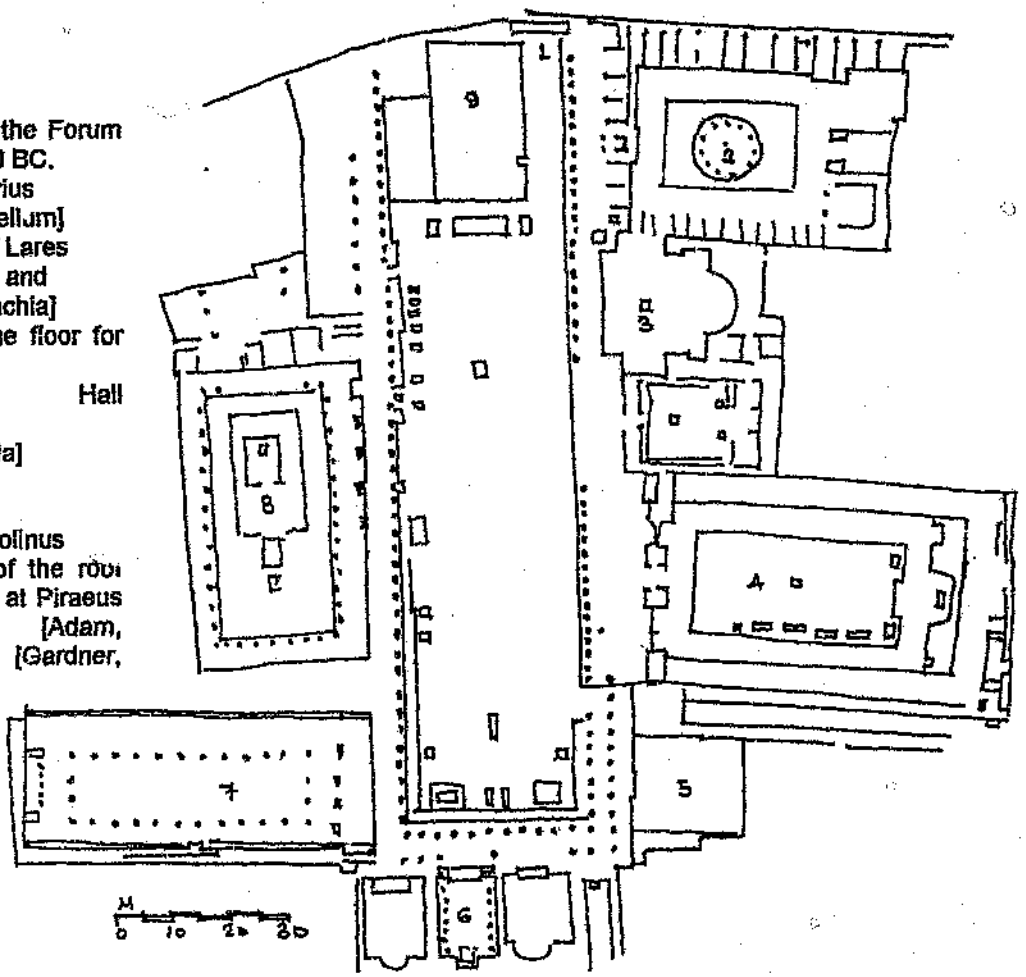


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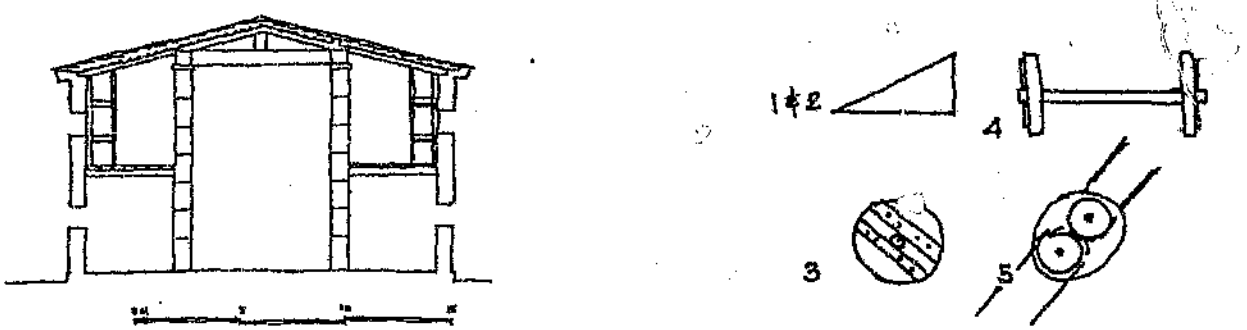
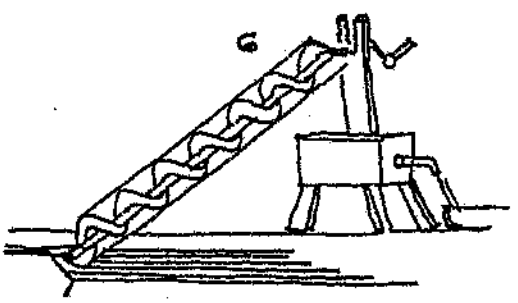


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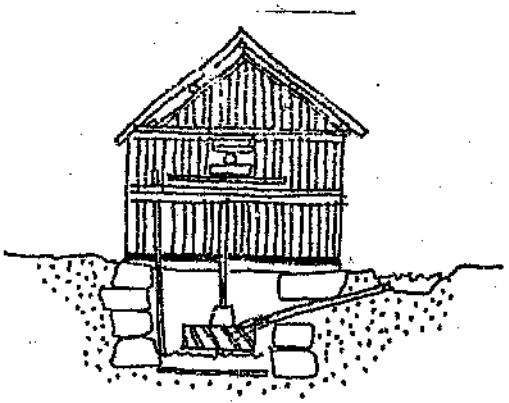
new and larger kilns with bellows and wood charcoal and had a lot of confidence in iron[31].

The Greeks' technology was transmitted to Persia and Indus through the empire of Alexander the Great, via the migration of the Barbarians to the Danubian basin and the Baltic, by the Roman Empire to Western Europe [Fig.13] and via Islam along the Mediterranean shores to the Iberian peninsula [Singer, Vol.II, 1965:111].

The word "machine" is derived from the Greek mechane and its Latin cognate machina, both loosely meaning "an ingenious device or invention". Hero of Alexandria seemed to summarise Greek inventive genius by stating that the machines of that time were [Fig.14] the lever, the wheel and axle, the pulley, the wedge and the screw [O'Brien, 1965:10]. In addition to the tools mentioned [32], prime-movers or machines that convert a natural form of energy into another form capable of producing power and motion, should now be included.

31. Also built during this period, the nursery of Western Civilization, the Colosseum 70 AD, Pantheon 120 AD and the Acropolis 161 AD.

32. Science belonged to the aristocratic philosophers and embodied all of knowledge, while technology remained the possession of the working craftsmen. [De Bono, 1974:70].



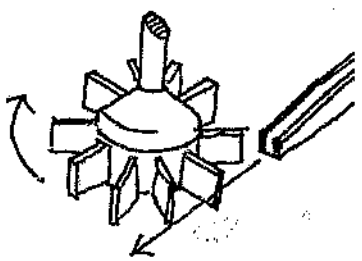


Fig.1 The horizontal Norse or Greek mill, driving the vertical shaft and top quern directly, fed the corn into a hopper. By pulling a beam upwards the paddles were removed from the stream [Singer, Vol.II, 1965:595].

CHAPTER TWO: NATURAL ENERGY

In the earliest days, those areas which did not have adequate water resources were at a serious disadvantage [Hills, 1970:93].

Up to now, during the period before mechanisation, man had been the energy that supplied the first power. This was followed by the domesticated beast [1]. Despite his weak physical strength and because of his superior intellect, man had already proved capable of applying limited technological expertise, coupled with a vast management capacity. Now natural energy was slowly to be harnessed and put to work, energy directed, concentrated and accomplished by technology.

1. Average man can only develop one seventh horse-power, or about one hundred watts. It was only by the eighth century with the oval horse collar and iron horse-shoes, that draught animals improved their energy output [Forbes, 1950:5].

From an examination of the water wheels and windmills, those wondrous, ancient and mediaeval natural energy structures, it would appear that the most appropriate place to begin would be with the water wheel [2]. However, on further reflection, the windmill [3] must be considered in parallel with the water wheel. The water wheel was the first natural energy machine. It went through many stages of development to become an extremely powerful prime mover with a variety of uses. The windmill on the other hand, once the idea had been established, became more refined by invention and in material. While universally used, both the water wheel and the windmill were limited in use because of the vagaries of the source of energy. It was only when water was controlled by the construction of weirs and dams that water wheel power could be developed to its maximum potential. This power was increased in two ways: by increasing the energy source, as was the case with dams, or by the efficiency of the instrument [Singer, Vol.II, 1965:589].

2. The oldest waterwheel recorded was in operation in Greece c.85 BC. It was used for grinding corn, while the noria had been in use in China and Egypt for raising water from rivers some 600 years before [Strandh, 1984:110].

3. The first windmill was constructed in Persia c.644 AD and was referred to by Arab writers of that period [De Bono, 1979:70].

The origins of the water wheel and its earliest forms [Fig.1] are not very clear, but they must have developed

Fig.2 The noria, with its jars, is considered to be the oldest type of water wheel. The first wheels raised water by human and animal effort. The more developed noria was attributed to Philo of Alexandria, c.15 BC [Daumas, Vol.I, 1969:106].

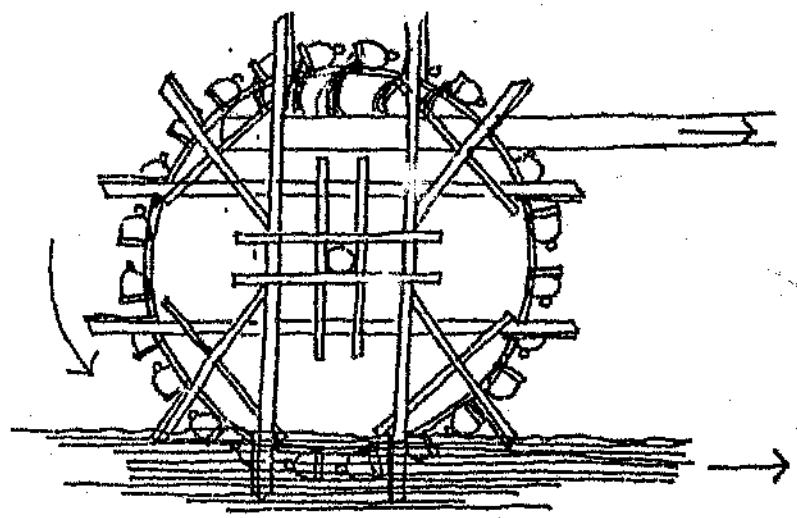
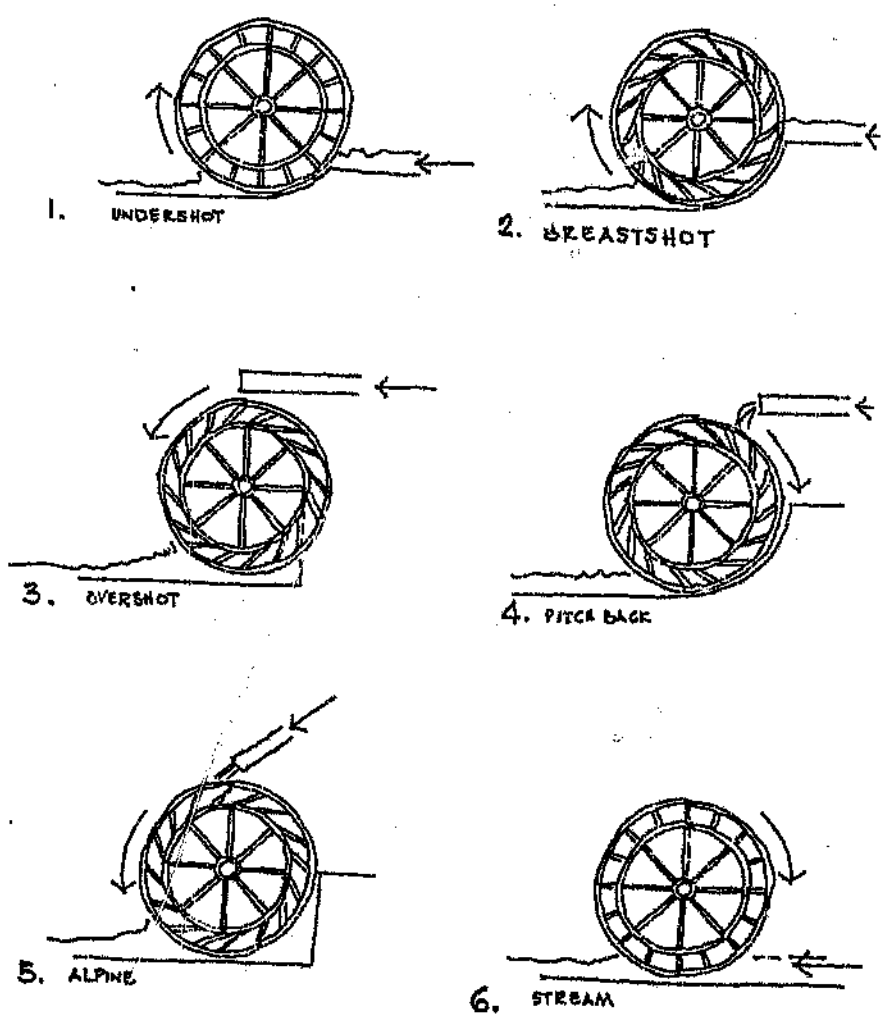


Fig.3 The various types and methods of construction are named according to the point at which the water supply reaches the circumference of the wheel [Winter, 1970:19].



from at least two sources - the horizontal mill, influenced by the potter's platform, and the wheel.

The horizontal wheel was small and fast. It required limited construction, a minimum of timber, and in the process of creating its limited power used very little water [De Bono, 1979:74]. The construction was no more than a very small hut built over or next to a stream. Local materials, such as mud and reeds were mostly used and were slightly sunken into the ground to add to the force of the water. Large numbers of such mills were found near small streams. It required no special skills to operate or maintain the mill stones, which were rarely larger than 60cm in diameter [Usher, 1954:123].

The vertical wheel was large and slow. The noria [4], as this device was called in the Mediterranean countries, could raise water up to five metres. Then it was noticed that, by adding paddles the stream could turn the water wheel and its energy not only increased, but it worked automatically. This obviously depended on the power the stream could create. The motion was developed by reverse transmission into the vertical water wheel [Fig.2].

The water supply and millpond also determined the method of construction of the wheel [Fig.3]. If the fall was low, the wheel was undershot or breastshot with slower revolutions and power. When the fall was high or the stream stronger, the wheel could be overshot or pitch-back and if the fall was high-velocity, the construction was alpine. The millpond could be watered by a well-regulated supply, an artificial stream, controlled sluice, weir or penstock, while the water wheel could be inside or outside the pond, below or even a short distance away [5].

Vitruvius [6], who was fully aware of the Greek mechanical skills of Aristotle and Hero and the latest Roman innovations, recorded the invention of the vertical

4. Up to five metres in diameter, they were spindly structures constructed of poles and planks [De Bono, 1979:70].

5. Early horizontal watermills delivered less than one horse power with 5% to 15% efficiency. Undershot wheels were 2-3 horsepower with 20% to 30% efficiency while overshot wheels where the weight of the water added to the pressure from 3-12 m height, delivered up to 50 hp and up to 70% efficiency [Reynolds, 1984:109].

6. Marcus Vitruvius Pollio, who lived in the first century BC, was a Roman architect, engineer and author of the celebrated treatise De Architectura - a handbook for Roman architects.

Fig.4 With the conversion of motion there was a conversion of power. The method of using gear ratios had been known since 310 AD [Singer, Vol.II, 1965:595].

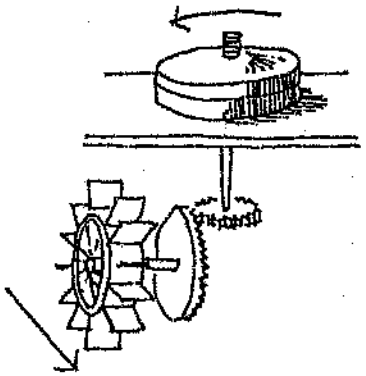
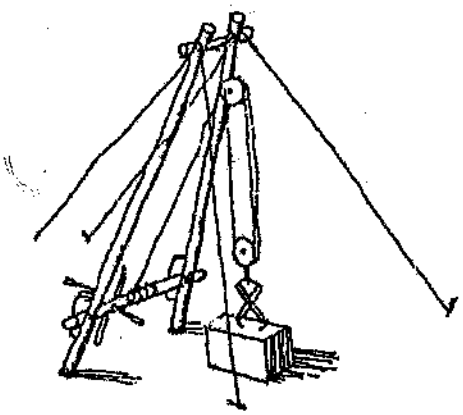


Fig.5 A reconstruction of the Vitruvius crane [Singer, Vol.II, 1965:655]. The other crane is part of a relief from a Roman sepulchral monument of c.100 AD. Five men inside the enormous treadmill lift the weight. The pulleys and stays are for moving the mast [Singer, Vol.I, 1965:660].



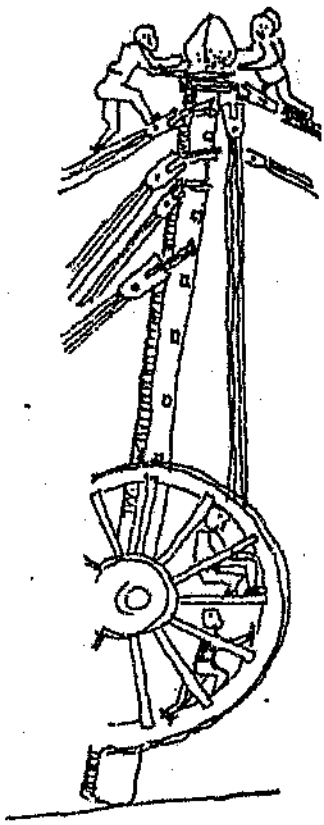
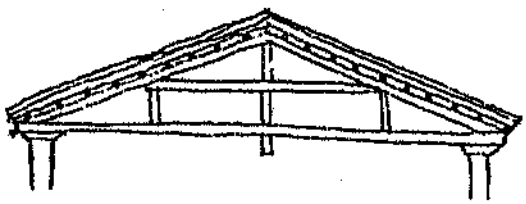


Fig.6 Roman timber roofs, very similar to those used in Greece many centuries ago [Singer, Vol.II, 1965:414].



water wheel, with a gearing of 1:5 revolutions [Singer, Vol.II, 1965:596]. This invention was a unique contribution not mentioned in any Greek treatise [Usher, 1954:124], which effectively converts the linear motion of flowing water into rotary motion. It transfers a portion of this motion into energy by means of the right-angle pin-gear drive [Fig.4] from the horizontal wheel shaft to the vertical shaft of the mill stock. It was important that the Romans could understand and build these machines. They had strong materials and understood construction. Until that time [7], bricks had generally been sun-dried, but were now being kiln-burnt. Cement was made from pulvis, a volcanic soil from the Alban Hills and Naples. When mixed with burnt lime, it could even be set under water, which was a great benefit when building water mills.

7. Gaius Octavius Augustus [63 BC - 14 AD] overhauled every aspect of Roman life, encouraged sculptors and created architectural master-pieces on both sides of the Alps [Sarton, Vol.II, 1970:158].

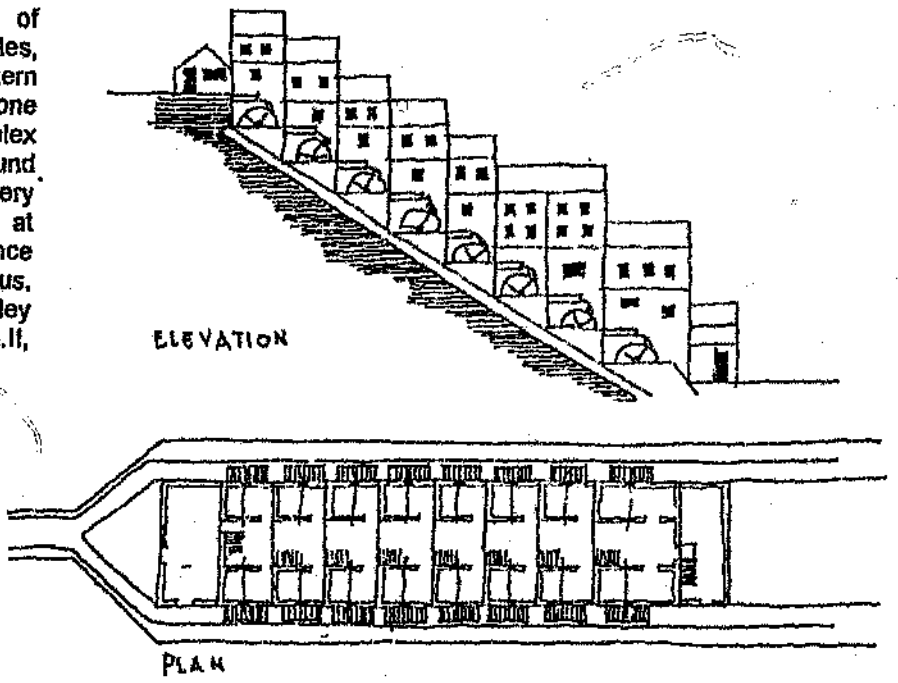
At this time [8] concrete was also one of the most common building materials in Italy. The mixture consisted of pozzolana cement, broken peperino, tufa or brick and was spread between layers of large stones and smaller aggregate. Vaults were also built using wedge-shaped blocks and timber shuttering [Singer, 1965, Vol.II:411]. When large heavy blocks of stone were required for construction, cranes made of simple straddled poles, triple pulleys, a windlass mounted on bearings and clamps for the stones were used. All were stayed [Fig.5] using guide ropes.

8. C.1 BC onwards. In his treatise, Vitruvius also discusses pile-driving [Singer, Vol.II, 1965:410]. Pozzolana a vocanic ash contains silica, alumina, lime, etc. which comes from the Naples district.

Vitruvius describes how to use timber post and lintel construction and mentions practical details of carpentry with dowels and mortices [Fig.6]. Terracotta-fired tiles that overlapped and were tapered were used on the roofs.

The largest known complex of Roman water wheels was situated at Barbegal near Arles. The water fell 23 metres and in the process drove 16 wheels, which were 2,2 metres in diameter x 700mm wide, and operated in

Fig.7 The plan and elevation showing the reconstruction of mills at Barbegal near Arles, the leading city of the western Roman Empire on the Rhone river in France. The complex produced 2.8 tons of ground corn [flour] per day for delivery to the Roman army at Narbonne. There is evidence of a similar mill near Tournus, Burgundy, in the Saone valley in northern Gaul [Singer, Vol.II, 1965:598-9].



pairs [Fig.7], each wheel propelling grinding stones one metre in diameter. All the wheels were overshot due to the fall created by an aquaduct [9]. The wheels were all constructed of wood, strengthened by nails and flat strips of metal to face the journals of the wheel, which ran on stone bearings. The construction of the foundations, walls and roof were, as before, of brick and concrete, with terracotta roof tiles on wooden trusses.

9. It was built by Quintus Candidius Benignus, 308 - 316 AD. The Romans utilised the force of the water, striking the paddles as well as the weight of the water [Daumas, Vol.I, 1969:109].

Science during the Roman Empire period was based mostly on practical techniques [Singer, Vol.II, 1965:124], while the Stoics and Epicurians [10] kept to ethical philosophies. Craftsmen were still considered a lower class socially and economically, but with the coming of Christianity there was a change of attitude toward the poor and slaves. Christianity attacked the classical views and extolled manual labour not as a beast of burden, but to make crafts honourable. There was also a growing conviction that nature should do the work, not man.

10. Schools of Philosophy in Greco-Roman antiquity that stressed duty, calm and order with a stern and tranquil mind. The Epicurians viewed man as a world citizen, obliged to play an active role in public affairs [Clagett, 1959:8].

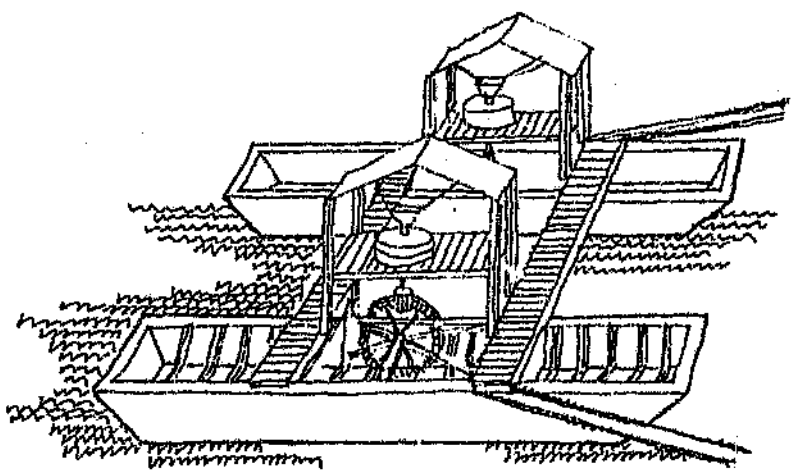
In spite of the vast Roman Empire and the obviously huge consumption of Rome, there was no industrial revolution. The period was paradoxical but it had a sophisticated and modern civilisation with regard to politics and law, and it had progressive military technology. The Romans had the ability to manage large projects, obviously well built, some of which are still standing today [Daumas, Vol.I, 1969:258]. The massive empire was administered very well and they built road networks, aquaducts, public buildings, public baths, harbours, docks and lighthouses, all of which demanded exceptional skill in the organisation of materials and workmen [11].

11. This included early Christian churches, such as the Holy Sepulchre 330, San Pietro 330 and Basilica Churches 432.

The Romans displayed limited inventiveness in mechanical matters, except to perfect the techniques they had inherited from the Greeks. In spite of producing few scientists [12], their practical knowledge of machinery was not surpassed until the early eighteenth century.

12. Galen [129-199] and Ptolemy [c.200 AD] were both Greeks who lived during the Roman period.

Fig.8 In 536 AD, when the Goths cut the Trajan aquaduct, the Roman general Belisarius constructed floating corn mills on the Tiber. Each consisted of a pair of anchored boats linked together with water wheels driving millstones mounted on the vessels [Singer, Vol.II, 1965:607].



Therefore, to cut marble with a water mill at Ausonius on the Mosel may have been possible [Usher,1954:144], but it was improbable [13].

13. It was too early, the watermill still worked only with a circular motion, the cam and crank had not yet made its appearance in Roman Europe. See later note p.30 no.5.

During the troubled disintegration of the western Roman Empire in 500 AD and the great migrations [Fig.8] of the Teutonic peoples who came from the north and east to settle in middle and southern Europe, there was little time for inventions and development, especially of heavier industry with high instrumentation.

What larger factories there may have been were destroyed or neglected. As the urban manufacture declined, industry moved to the rural districts, where the domesticated industry again advanced, and peasants created rudimentary installations just sufficient to provide for their own needs.

This period between the collapse of the Western Empire and the start of the colonial expansion of Western Europe in the late fifteenth century is traditionally known as the Middle Ages [14]. The first half of this period was known as the Dark Ages, when Greco-Roman life and learning remained dormant following the decline of those civilizations. The various crafts like pottery, glass, textiles, leather and fine metal work followed previous lines with development occurring mostly in style. Methods and materials were lost or forgotten and development was inhibited by inadequate material. The isolation led to hardened traditionalism, an unwillingness to accept technological improvements and a contempt for new products, machines and methods [Singer, Vol.II, 1965:649].

14. The Middle Ages 500 - 1 500 AD. This period lies between the classical Greek and Roman periods and the Renaissance.

On the positive side, the Middle Ages were still influenced by the inheritance of classical Mediterranean antiquity, Arabian and Christian traditions and by the Germanic and Scandinavian social patterns [Daumas, Vol.I, 1969:425].

Fig.9 The vertical shaft mill used in China, c.600 BC. It seems probable that the construction used was built of bamboo poles and matting sails [Standh, 1984:123].

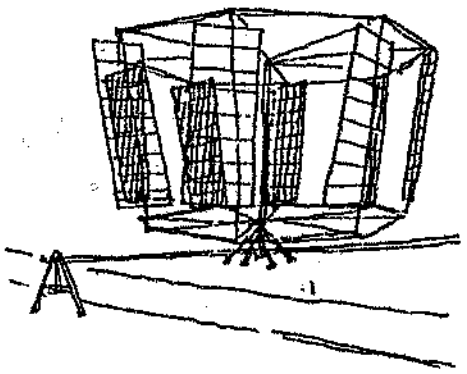
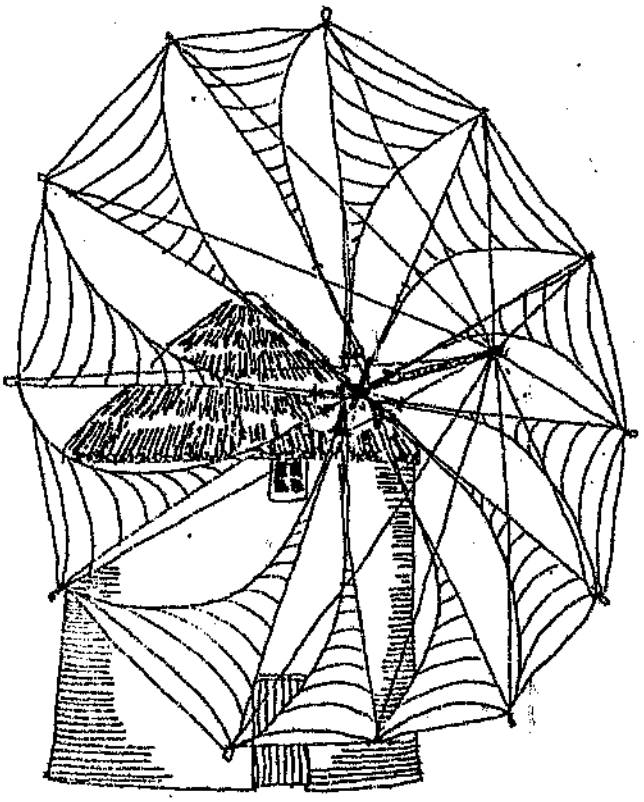


Fig.10 The sail blades were fixed into position in the direction of the prevailing wind [Standh, 1984:123].



The powerful Catholic Church played an essential role in preserving literacy and classical learning. They maintained limited public administration and created a role for themselves to fill the vacuum of the Roman collapse. The church, after being destroyed in so many towns and cities across Europe, moved to isolated rural areas away from the marauding tribes. Most large milling complexes had been destroyed in the continual fighting and workers were scattered. People could not gather in groups at the river side anymore, there was no financial means to build weirs, divert streams and create large, heavy mechanical structures as before. The monasteries were small, and there was very little progress with the water mill. It took many decades for new development to take place.

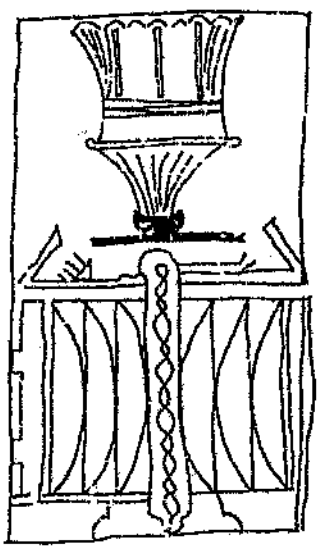
Approximately seven hundred years elapsed between the first recorded discovery of the water wheel in Greece [15] and the first recorded windmill constructed by a Persian builder, Abu Lu'lu'a [16]. Three hundred years later there were further references to windmills at Seistan on the border of Iran and Afghanistan. In both instances, the windmills appeared to be derived from the Chinese vertical shaft mill [Fig.9], its sails based on the shape of a junk [De Bono, 1979:70] and with a direct drive on to the millstones.

15. A water wheel was discovered in Greece C. 85 BC. See Fig.1.Chapter 2.

16. Windmill referred to by Arab writers c.644 AD.

The earliest development of the windmill progressed in the same manner as that of the water mill. It is not always clear when any of the important inventions evolved, and there is a large gap in the knowledge, the time of invention and its recording. There is also ample evidence of inadequate rendering of contemporary drawings and many have crude errors in perspective [Usher, 1954:125]. A windmill still found on Crete and in the Aegean [Fig.10] could have been the intermediate on which the western towermill was based [Derry, 1961:254], and not merely a primitive derivation of that mill [Singer, Vol.II, 1965:618]. This was a totally new type of mill with sails mounted

Fig.11 The windmill at Seistan 950 AD, was built as a two-storeyed structure. The upper part contained the mill, the lower, the sail without any gearing. A strange structure it should have been the other way round [Singer, Vol.II, 1965:615].



horizontally [Cipolla, 1979:88]. The main structure was constructed of soft local brick, painted white and had a thatched roof that could not be moved. The rate of rotation was controlled by unfurling the sails as required. There were usually eight to twelve sails. It is a reasonable but unproved assumption that it was inspired by the sails of a ship.

In general, the windmill was used away from the river settlements in the Middle East and in the waterless areas of the Mediterranean countries [Fig.11]. Later, as the idea spread to Europe, the windmill gravitated to the drier areas, sluggish streams, and the flat windy areas of northern Europe and Britain. The heart of the industrial area that was based on the use of water mills was, however, the drainage basins of rivers that flowed into the Bay of Biscay and the English Channel. In this region there were hundreds of small to middle-sized streams with a fairly regular flow that was convenient for water power.

Opinions differ about the manner in which knowledge of the wind and water mills reached Europe [17], but it is generally accepted that it travelled by at least three routes: one route followed the spread of Islam through Morocco to Spain and another comprised the trade routes from Persia through Byzantine [18], across the Caspian Sea and along the Russian rivers to the Baltic countries and northern Europe. The third route was by means of the Roman Empire which had been destroyed, but its routes remained fairly open.

Europe was starting to settle down by the year 1000 AD. Just about everything that could be had been destroyed, but the tide was turning and as the danger receded, territorial and intellectual expansion began again.

The Eotechnic phase [Mumford, 1946:109] [19]: The age of modern technics dawned when all or most of the key

17. The first water mill, 762 AD, was built in England at a monastery just east of Dover. By the year 1084, the existence of 5 624 water mills was recorded in the Doomsday Survey, situated in more than 3 000 locations [Reynolds, 1984:110].

18. The Byzantine period, fourth to fifth century AD, formed the bridge between Asia and Europe.

19. Mumford defined the eotechnic phase, 1000 - 1750, as the wood and water complex; the paleotechnic phase, 1750 - 1850, as the coal and iron complex; and the neotechnic phase, 1850 - 1900, as the electricity and alloy complex.

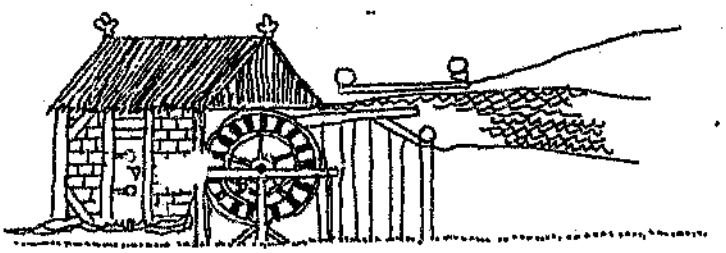
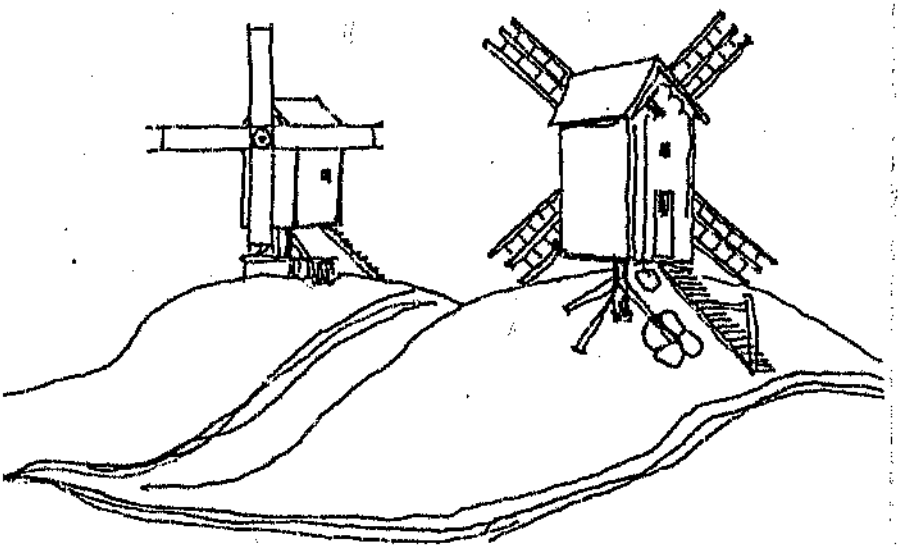


Fig.12 The water mill squats long and low over the stream, scooping its energy from the water while the windmill stretches its sails high into the breeze [Singer, Vol I, 1965:596].



inventions had either been invented or foreshadowed. This was defined as the first formal phase of the machine civilisation which is divided into three successive but overlapping and interpenetrating phases [20] and which preceded the paleotechnic and neotechnic phases [Geddes, 1915:63]. As conveniently as these phases may have been defined, first by Geddes and then Mumford, mechanisation started more than 1000 years before with the water mill. It was also possible that because of the constant upheavals in Europe, technological development had been seriously delayed and inhibited.

20. Geddes defined the paleotechnic phase, 1750 - 1850, as the coal and iron complex and the neotechnic phase, 1850 - 1900, as the electricity and alloy complex.

It has already been observed, even at this early stage of the dissertation, that water mills and windmills exhibit a totally different silhouette [Fig.12] despite both being driven by natural energy. Each is compatible with totally different environments, but is dependent on similar materials and methods of construction [21]. The mechanical technology, the conversion of motion by means of gears to speed and power, is the same in both cases, but to define the period as one of a water and wood complex [Mumford, 1946:110] is too narrow. It may be more suitable to define the period as one of power acquired from natural sources for water mills and windmills.

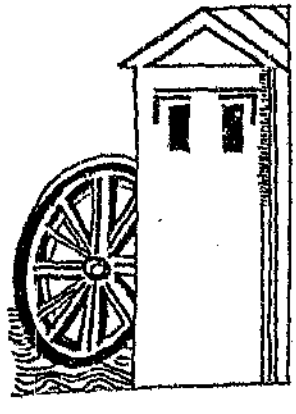
21. Brick or stone, but mainly wood, was used in the Middle Ages [Daumas, Vol.I, 1969:424],, as well as roofing tiles constructed by millwrights of that period.

The end of the Middle Ages was characterised less by a general progress towards mechanisation [22] than by the development of this small group of machines. The same problems were experienced namely that the use of wood for mechanical parts exhibited limited strength or resistance to frictional wear. The period also experienced, together with the many tools and techniques that had been lost or forgotten in the mediaeval conflagration a slow resurgence.

22. The progress was mostly related to existing mill design. Metallurgy progressed slowly from the use of semi-soft to semi-hard iron [Kranzberg, Vol.I, 1967:88].

The first water mill in England was built in a monastery east of Dover. Other large monasteries were also being

Fig.13 Small, Mediterranean water mill, as illustrated on a mosaic floor [Singer, Vol.II, 1965].



mechanised, mostly in France at Abbey Corbie [23], St. Riguier [24] and many others. This was also the period of translations [Forbes, 1958:93] and theoretical mechanics. Many books [25] were written about water mills [Singer, Vol.II, 1965:152], while there was a visible evolution in practically all areas of activity [Daumas, Vol.I, 1969:430].

23. 822 AD, with eight hundred persons.

24. 833 AD with four hundred monks.

25. By 840 AD about one hundred technical devices had been invented, of which twenty were practical, and the rest mechanical toys.

There is little evidence that water mills in these monasteries were applied for anything else but t grinding of corn for their own supply of bread [Kranzberg, Vol.I, 1967:78]. However, this changed with the establishment of the Cistercian order, a group of Benedictine monks [26]. The Middle Ages was an era of mysticism ruled by a blind faith in and obedience to the dogma that faith was superior to reason [Rand, 1971:83]. The Cistercians reintroduced manual labour, which included manufacturing everything themselves, and insisted that all monasteries be built near rivers that could supply power [Singer, Vol.II, 1965:650].

26. The Cistercians were started 1098 AD, but grew spectacularly when St. Bernard of Clairvaux joined the order in 1112 AD as a novice. By the thirteeth century it had grown to 742 monasteries and 761 nunneries [Braunfels, 1972:68]. Most of these monasteries were destroyed during the sixteenth century Reformation.

The water mills were often built only as simple rectangular buildings in local domestic style, consisting of a strong timber frame infilled with wattle and daub, the one wall pierced by a driving shaft. Other mills were clad in weather boarding and, when established on marsh land, were built on wooden piles [Guedes, 1979:94]. The use of brick and stonework appeared to have been lost during the early mediaeval period, but since the establishment of the large monastic factories, a perceptible change was noticed [Fig.13] in that water mills and windmills were now included in the monastery complex. The best description was found at the Abbey of Clairvaux, where the river entered the complex through controlled holes in the damwall, into the cornmills for grinding and sieving, filled the boilers for heating the beer, raised the mallets for the cloth fulling machines, served the tannery, rotated, crushed, washed and ground the minerals for the blacksmith works and finally carried away the refuse

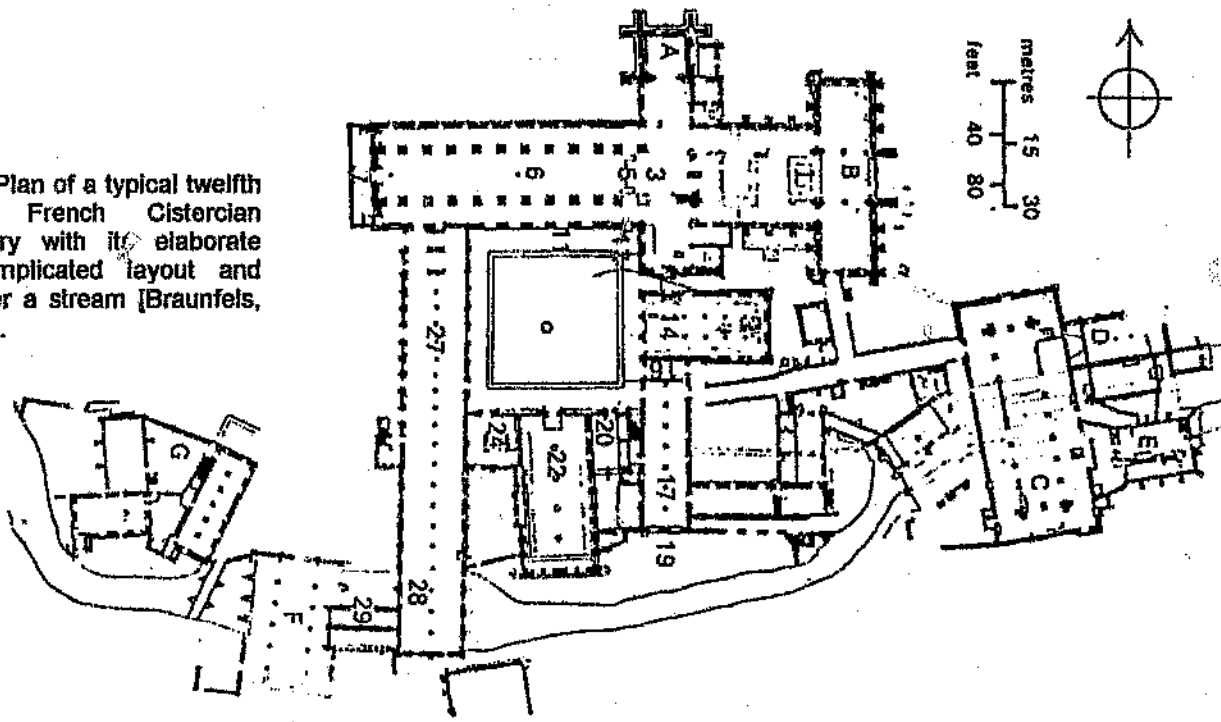


Fig.14 Plan of a typical twelfth century French Cistercian monastery with its elaborate and complicated layout and built over a stream [Braunfels, 1972:84].

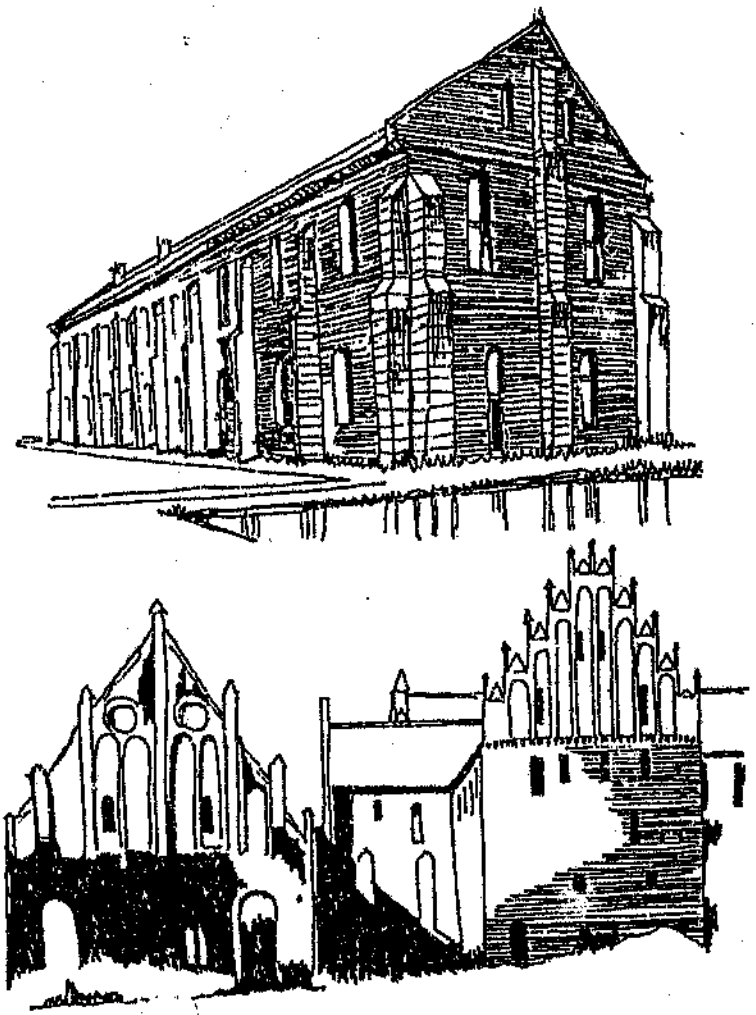


Fig.15 Romanesque elevations, c.1000 AD, of a Cistercian mill and early Gothic workshop, c.1200 AD, which were driven by water mills.

[Singer, Vol.II, 1965:650]. Note the clever sequence of use as the water became more foul after every use. Many similar monasteries were built as shown [Fig.14].

The Cistercian monasteries [Fig.15] were mostly built in the Romanesque style. They were built as monasteries, which was their prime function, and not as industrial buildings. The use of water and wind power as prime movers did not affect their identity. The buildings were usually grouped to infer a monastic community form which had common stylistic features [Gardner, 1975:3]. The Romanesque building had round arched windows, massive piers and walls with few windows, an inspired sculptural form and was the first "international style" built of brick and stone with half-round tiles. The early Gothic building had pointed arch windows, a skeletal structure and screens of glass and stone. They used local stone, brick and timber which provided generously lit and well-ventilated work areas [Guedes, 1970:94].

The power created by water mills was now directed at fulling, oil and wine pressing, tanning, pigment stamping, sawing and later the production of iron and papermaking [27]. There was a correlation between the development of industry related to the water mill and the massive expansion [28] of the monastic orders. In spite of some extensive industrialisation at many Cistercian Abbeys like Foigny [29], it was not the only development that took place. Across the whole of Europe there was an awakening as a result of industrialisation [30]. The major inventions can be tied to the development of the water mill, the introduction of the windmill and the continuation of increased metal work [Singer, Vol.III, 1965:137].

The first windmills in Europe were built in Normandy [31]. Most of [32] those constructed were postmills. The housing was constructed of timber in the local domestic manner. Revolving on a central post was the platform

27. Fulling of cloth, 1050 AD in France and 1185 in England; pigment grinding at Peronne in 1257; crushing iron ore in 1135 at Styria, [Cipolla, 1979:89] and papermaking in Spain 1238 [Daumas, Vol.I, 1969:457].

28. The first iron mills mentioned in Germany, Denmark, England and southern Italy were all Cistercian establishments [Daumas, Vol.I, 1969:456].

29. The Abbey Foigny established in the twelth century consisted of 14 wheat mills, a fulling mill, 2 cable-twisting machines, 3 furnaces, 3 forges, a brewery, 3 wine-presses and a glass-works [Daumas, Vol.I, 1969:560].

30. Mechanically, the Dark Ages stopped in c.750, and the Mediaeval period during the eleventh century. By the fifteenth century, industry was in full swing [Mumford, 1946:113].

31. Built in 1180.

32. The oldest mills in the Netherlands were probably also fixed structures facing the prevailing south-west winds [Forbes, 1950:147].

Fig.16 A psaltermill, 1270 [Singer, Vol.II, 1965:623].

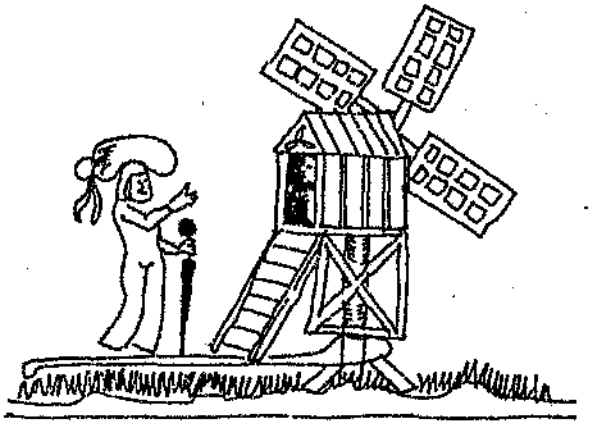


Fig.17 A postmill, with an auxilliary drive. Sometimes it was inside the housing and sometimes outside, as is indicated here [Singer, Vol.II, 1965:649].

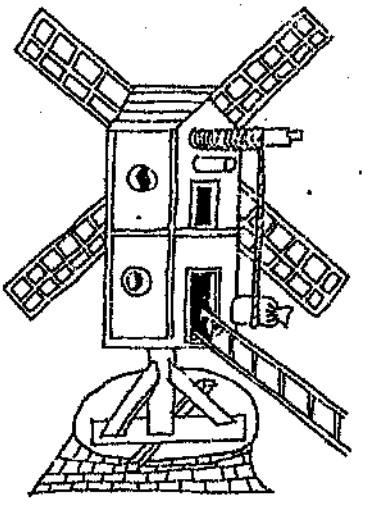
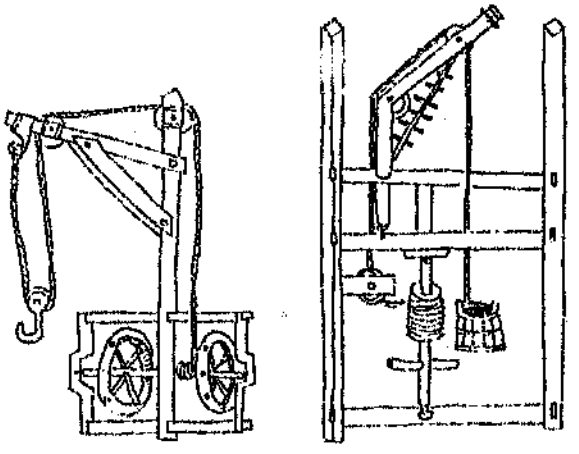


Fig.18 Simple forms of slewing cranes, which were activated by an auxilliary drive [Singer, Vol.II, 1965:656].



[Fig.16] supporting the stones and the gearing which was usually supported by a four-legged trestle [Fig.17] on a mound.

There were also sunken postmills, but these were never popular as the timber rotted and the sails were too low on the ground [Derry, 1961:255]. The whole body of the mill was turned to the wind by manually moving the tailpole [De Bono,1979:70]. The windshaft carrying the sails was inclined at an angle of about 15° from the horizontal, so as to throw the weight on the thrust bearing at the tail of the shaft and balance the weight about the neck or front bearing. This also enabled the sails to clear the housing of the mill [Walles,1975:22]. The mill was inclined to topple over because the centre of gravity was too high.

The auxiliary machines which were used to lift and lower bags of corn were usually taken off the spur wheel or skew gear and the raising or lowering of the bridge tree allowed for the grinding of fine or coarse grain meal [Fig.18]. There were still many limitations, as wind is generally less reliable than water. The weakness lay not so much in inefficiency of the power, but in the lack of it [Mumford, 1946:142].

Windmills were totally dependent on the elements. The only advantage was that the housing could be turned to use the full measure of whatever wind was available. The windmill was larger, lighter and turned faster, the speed controlled by furling the sails. The power was really limited and was used mostly for grinding the corn grown in the lowlands. The water mill, in contrast, was also dependent on the elements, but was generally more seasonal. The water in a stream could be controlled by building weirs, selecting the slope of the ground and adjusting the volume of the water with sluicegates. The speed of the wheel was generally slower but stronger. It

Fig.19 The advanced postmill with a roundhouse [Singer, Vol.III, 1965:94].

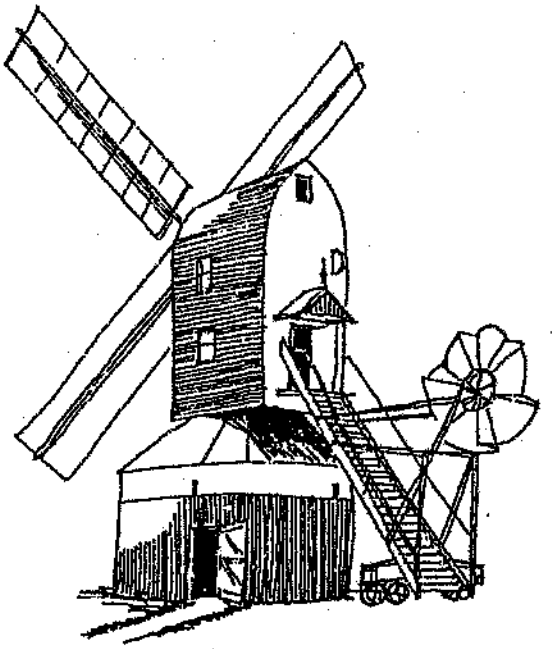
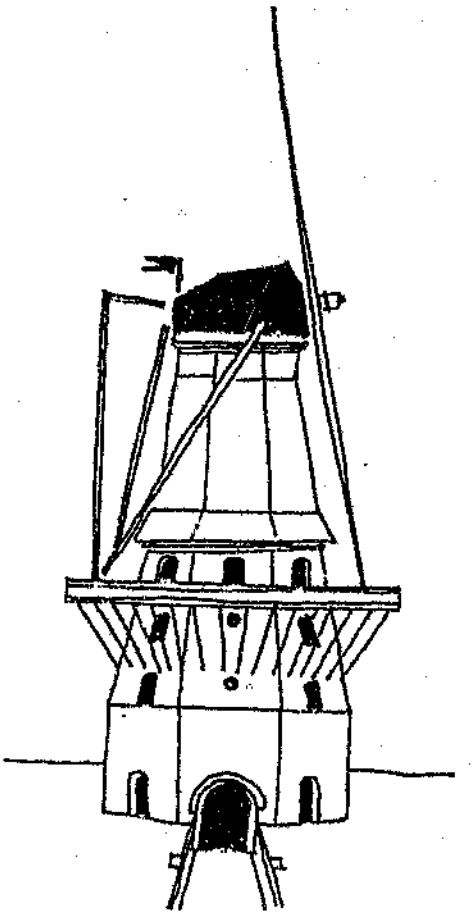


Fig.20 Towermill divided in two equal parts with the top section moving and the bottom section fixed [Strandh, 1984.112].



developed more power and was therefore more adaptable for use in industry.

These machines were both developed over the last thousand years or more. They were immobile, expensive to install and maintain, not economically designed and the timber was usually too weak for the great strains it had to bear [Kranzberg, Vol.I, 1967: 91]. However, develop they did.

As the mills grew larger in an attempt to make them more powerful, it was found that turning the postmill [Fig.19] physically, complete with sails, machinery and its heavy box-like super structure, demanded considerable effort. Round houses [33] were then built at the base of the postmill to protect the timber, store the corn to be milled as well as the flour and, it must be assumed, also to lower the centre of gravity. The next logical step was to increase the body and decrease the cap. With the increase of the body it was not necessary to place the mill on a mound anymore. This then brought into being the towermill [34].

33. First roundhouses were built of timber slats which became shabby. Later they used stone or brick [Singer, Vol.III,1965:94].

34. C.1300, the first tower mill is constructed in France [De Bono, 1979:70].

The body of the towermill, which was octagonal or tapering and often called a smockmill, was constructed of brick, stone or timber weather boarding and contained the corn, the gearing and milling stones. It remained in a fixed position, while the millhouse holding the sails and horizontal shaft turned in the wind [Fig.20], the tailpole attached on the outside. [Singer, Vol.II, 1965:623]. The taper or batter looked clean from the bottom to the top. It gave an undistorted proportion, with more space at the bottom for storage and working and weight where necessary. Some of these larger multi-storeyed mills had glazed windows added later.

Towards the end of the fourteenth century there was a major change in the structure of the windmill. It

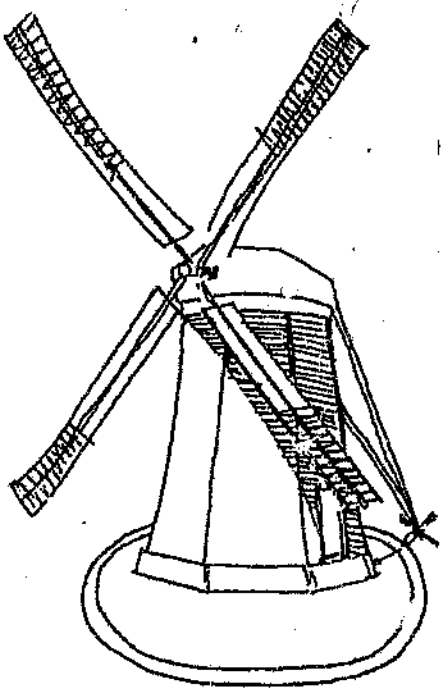


Fig.21 The modern mill where only the cap moves and the rest remains fixed [Singer, Vol.III, 1965:306].

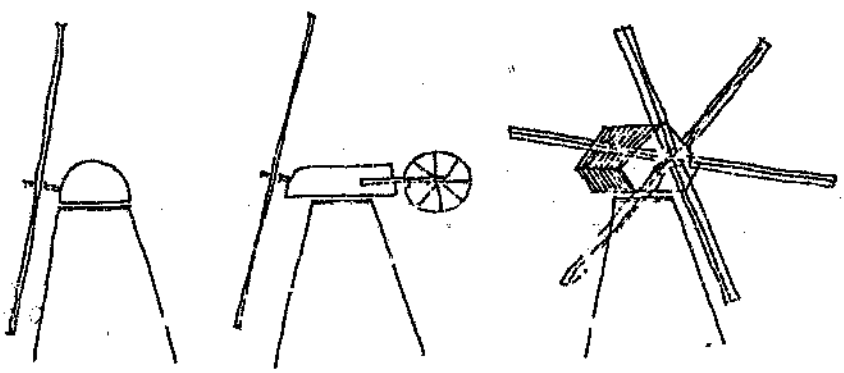


Fig.22 A round or boat-shaped mill [the fantail invented in 1745 by Edmund Lee] and the Kentish wagon cap [Wailes, 1975:11].

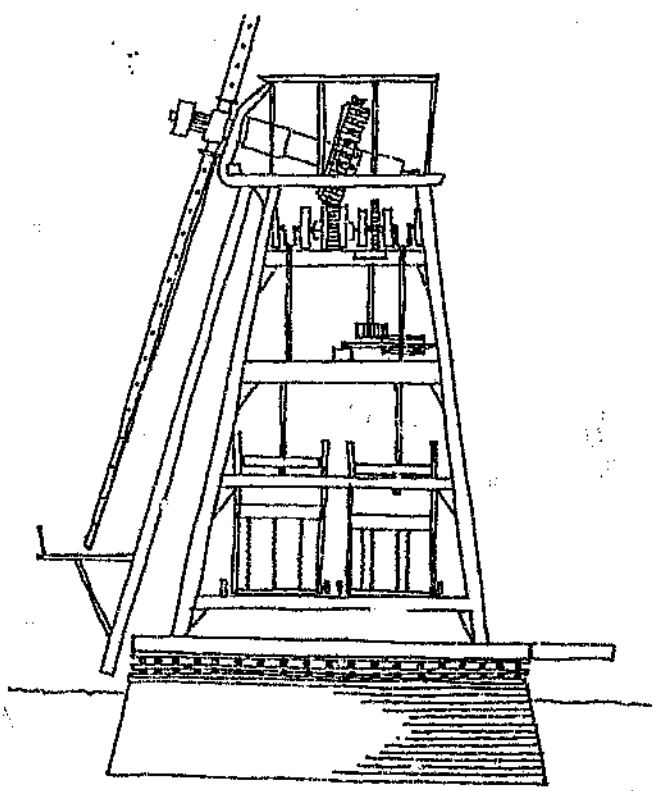


Fig.23 Paltrok sawing mill. Also called a smock in English [Singer, Vol.III, 1965:107].

demanded considerable effort to turn the whole body of the mill, which was becoming stronger and larger, complete with sails, stones and machinery to face the wind, especially with the primitive bearing available. This limited the size of the windmill sails and body with a commensurate restriction in power [35].

35. The smaller mills, with a 6m sail span, hardly developed 5 hp [Derry, 1960:258].

In order to increase the power of the mills, the size of the sails had to be increased. This meant additional weight that had to be moved and the overturning moment became critical. It was now discovered that only the cap needed to move, while the body of the mill provided stability [Fig. 21]. These larger mills [36] were tapered and had a low centre of gravity, while the sails, constructed of heavy timbers were held high off the ground. The housing was firmly fixed to the ground, and consisted of a number of levels with one or more sets of grinding stones covered with various materials. A substantial portion of power was, however, still being dissipated in clumsy transmission systems, even with iron-reinforced gearing and rollers to run on. [Walles, 1975:10].

36. The average mill developed 5-10 hp, while the very largest with a 30 m sail-span probably generated just over 10 hp in a 40 kph wind [Derry, 1961:258].

The cap running on the curb was a feature of the mill and had its own design, the most characteristic being round, the Kentish wagon or boat shaped [Fig.22]. The first [37] wind-driven sawmill was erected in the Netherlands. It was built of timber and mounted on a raft that could be turned into the wind [Fig.23]. This mill was called a paltrok and was used for every conceivable industrial purpose [38]. The millwrights designed and constructed these mills [39] with extremely simple tools and were the ancestors of the mechanical engineers of the future.

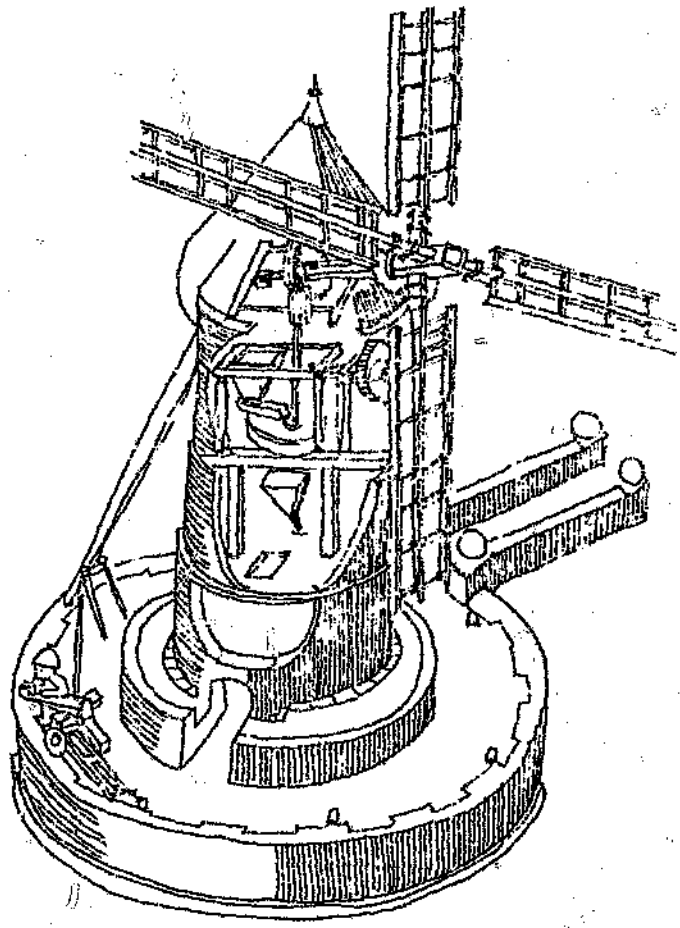
37. This mill was built by Cornelius Cornelitz in 1592. There were 900 in existence before the advent of steam [Kranzberg, Vol.I, 1967:79].

38. The Dutch economy was the most powerful of Europe, due to declaration of independence, clearing of marshes, windmills and industrial production, as well as the expansion of its colonial commerce. France, on the other hand, was dominated by religious wars and during the Reformation most of Cistercian monasteries were destroyed [Kranzberg, Vol.I, 1967:82].

39. They also built cathedrals, church spires, barns, etc., and had to be men of considerable talent to hoist the heavy windshafts and sails into position [Cipolla, 1979:88].

These wooden mills were vulnerable to the weather and ...tted at the corners. The mills using brick or stone could ...e round, with windows spiralling up the tower and not situated one above the other, which was structurally weak [Fig.24]. The towermill, which was a very complex

Fig.24 There were different floors in the tower mills. Starting from the top there was the dust floor, bin floor, stone floor [milling] and the meal floor [Walles, 1975:6].



mechanism [Usher, 1954:131] could now be defended or placed on walls, ramparts and towers. This was the last significant addition to the natural wind prime mover before the advent of the steam engine. The water wheel went from strength to strength until it was also superseded.

Most craftsmen were still equipped with simple hand tools and it was their skills that determined the quality of the product. Almost every sizeable village had its smiths, carpenters, tilers, millers, spinners, fullers and weavers [Postan, 1975:148]. The merchant guilds that had been so powerful during the twelfth century were now being complemented by craft guilds formed for the mutual protection and professional interest of master craftsmen, journeymen and apprentices with trade connections. Sometimes there were more than 100 different guilds in the large towns.

As wealth increased universally, the artisans became more important than the merchants. The guilds were formed to protect the producers and not the distributors [Brown, 1963:24], but the guilds started to break down when more capital outlay became necessary for elaborate machinery and equipment. On the one hand the guild gave the artisan or merchant protection, peace and serenity within an integrated society and raised the dignity of the individual. Guild socialism, however, also chained men into groups and dictated rules, standards and practices [Rand, 1971:45]. It was then that the merchants unified on a European basis through marriage, alliances and international contacts [Mumford,1940:68] and started capitalism.

The advance of material civilisation was not without its interruptions. Periods of great technological progress have often been followed by eras of stagnation [Kranzberg, Vol.I, 1967:4]. Towards the end of the mediaeval period, we see some of the first examples of capitalist enterprise

in industry [40]. The first universities which were the mainspring of technology and science [41], were established and put an end to the formal acceptance of alchemy [42]. We also witness, however, the start of the Hundred Years War [1337-1453], the great plagues [1300-1450] which swept across Europe and the collapse of the Italian banks. The end of this period must be seen as a total phase with the invention of inventions [43]. It provided the foundation of European technology [Kranzberg, Vol.I, 1967:79] and was like a dam about to burst.

40. In 1371, a weaving factory was started at Amiens, which employed 120 workers, while later, in 1450, printers in Germany were employing up to 150 workers [Brown, 1968:31].

41. The universities of Boulogne 1158, Paris 1170, Cambridge 1209 and Prague 1348. There was the great theologian, St. Thomas Aquinas [1224-1274], and the greatest of all experimenters and Franciscan philosopher, Roger Bacon [1220-1292]

42. The teaching of mathematics at Oxford and Paris was on the same level as other subjects [Daumas, Vol.II, 1969:17].

43. This period can be called the Commercial Revolution, a period from the eleventh century in Europe to the fourteenth century in Britain [Cipolla, 1979:31].

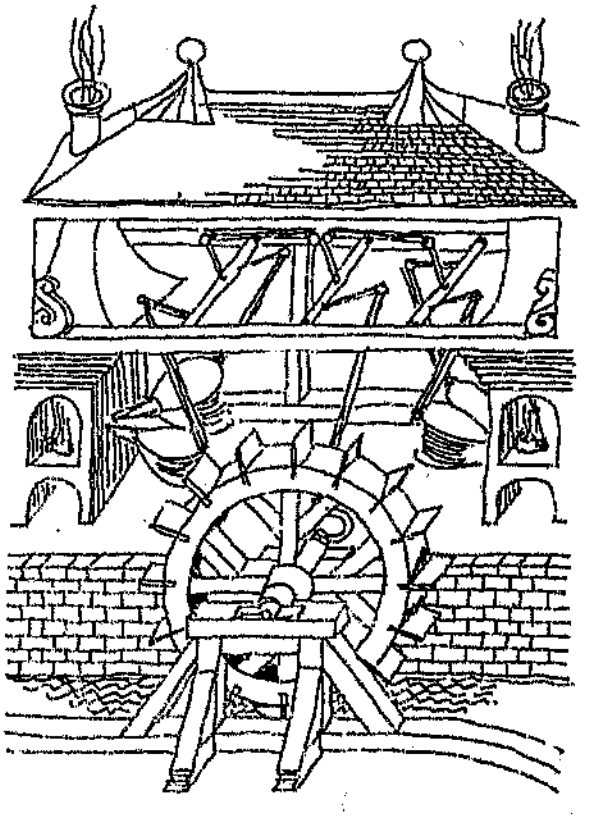


Fig.1 Internal view of a factory [Singer, Vol.II, 1965:613].

CHAPTER THREE: FACTORY SYSTEMS

In Birmingham, the Industrial Revolution of the nineteenth century, was based almost entirely on the water mill.
[Musson, 1969:68].

The end of the mediaeval period is sometimes referred to as the Proto-Renaissance [1] in Europe and which was also the start of early modern technology. The domination of restrictive religions was cast off, while wider fields with free ranges of endeavour were sought [Kranzberg, Vol.I, 1967:81]. The paths of fuel and machine development were still separate and natural energy was being exploited in many ways in order to reduce human effort and speed up production. There was also a period when great voyages of discovery were undertaken [2]. This enlarged the horizons of western Europe and was to create a stream of wealth from the new worlds [McNeill, 1963:565].

It was the dawn of the age of modern techniques, with an economy based on the use of constantly improved natural power in the form of wind and water and with wood as the principal material for construction [Mumford, 1946:495]. Perhaps the most important mechanical innovation [3] of the late fourteenth century and early fifteenth century was the transformation of the continuous circular movement, created by the increase in power of the water machines, into the straight-line, alternating back-and-forth [4] movement [Daumas, Vol.II, 1969:42].

The crankshaft which replaced the cam [5] for certain tasks combined well mechanically with the strength of the water wheel and also provided the advantage of double action on the horizontal plane [Reynolds, 1984:114]. This, to a large extent, pioneered the use of water-driven metallurgy. It was with bellows [Fig.1] that larger furnaces could be driven and large amounts of pig iron

1. A term used to describe the early revival, or rinascimento period of arts and literature in Italy [Gardner, 1975:403].

2. Bartolomeu Dias de Novais [fl.late fifteenth C] Portuguese, navigator rounded Cape of Good Hope in 1488. Cristoforo Colombo [1451-1506] from Spain's voyages opened the New World from1492 onwards.

3. See the last three paragraphs of Chapter 2.

4. This led to the mechanisation of sawing and pumping and the use of reverse treadle lathes for spinning, also in metal-working and later the chemical industry [Singer, Vol.II, 1965:iv].

5. The crank was known in China by the second century AD and was used in Europe in a mature form by the ninth century [Daumas, Vol.II, 1969:43].

Fig.2 The "mills of Babylon". A black and white timbered building on piles over a river, with three large water wheels under a bridge-like structure [Singer, Vol.II, 1967:628].

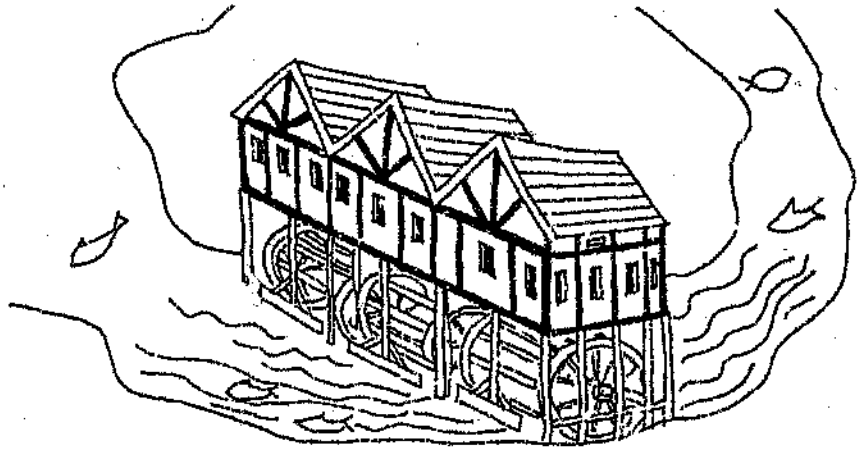


Fig.3 Hydraulic bellows for a furnace, operated by cams on the shaft, on an overshot wheel [Singer, Vol.II, 1967:613].

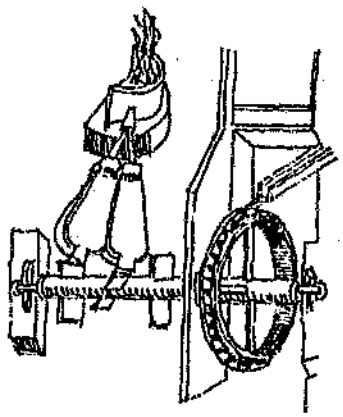


Fig.4 The water-driven stampmill with the stamp raised by cams on the horizontal shaft. The pedals on the vertical shaft operate the furnace bellows [Singer, Vol.II, 1965:642].

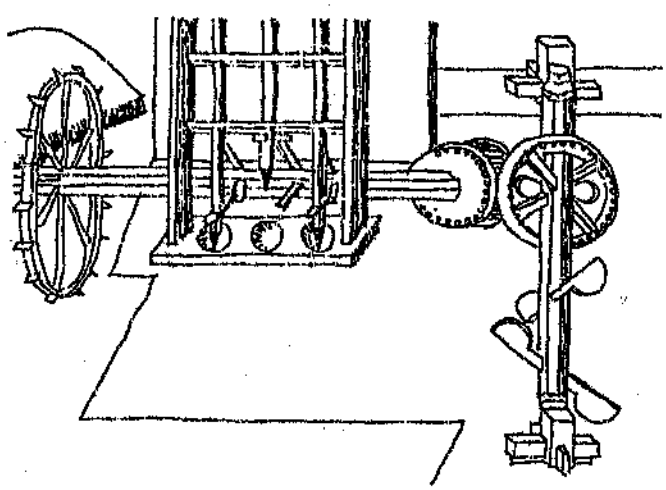
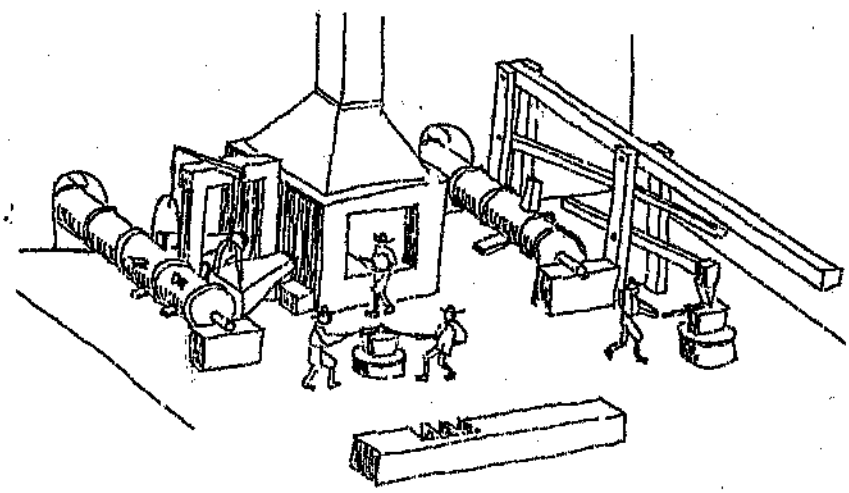


Fig.5 Manufacture of tin-plate. Showing here a forge with water-driven bellows heating the material which was then hand, or water-power hammered [Singer, Vol.III, 1965:690].



smelted and cast [6], while the saw [7] to cut wood and iron was invented by the French Cistercian architect/engineer De Honnecourt.

Three other extremely important events also occurred during this period. None of these directly influenced the form of the industrial buildings in this or later periods, but were indirectly responsible for tremendous progress. The first revolutionary change was the invention of mechanical printing. It is no coincidence that, as paper and books became more readily available, there was a scientific [8] and communication revolution. This is clearly revealed as the skill of draughtsmen and engravers is reflected in these manuscripts. The techniques of machine construction were, perhaps, not always capable of being realised, but were at least available in concept. At the same time, architects were preoccupied with spurious revivals [Gloag, 1958:322]. The engineers were generally just as short-sighted, but the work of the millwrights [Fig.2], and the progress achieved by these technicians during the second half of the century could have been of even greater importance than the discovery of the New World [Daumas, Vol.II, 1969:20].

The second major change that occurred was in the field of metallurgy [9], where the use of water-driven bellows [Fig.3] and coal produced temperatures so high [10] that good grade cast-iron resulted [Forbes, 1950:117]. The metal was actually liquefied and could be cast into forms. The process was extremely expensive, so that for a long period wood continued to be used for making toothed wheels and lantern pinions [11], while wrought iron was produced by beating iron into strips and often by welding. The advanced smelting works of the period consisted of a series of works [Fig.4]. It had special furnaces and hearths for each stage of the operation which were built along a thick central wall [Fig.5].

6. The first shaft and blast furnace was operated in the 1350s at Liege [Clarke, 1985:38].

7. Villard de Honnecourt [1225-1250] Sawmill at Augsburg, 1322, and a wire pulling machine at Nurnberg in 1350, the pipeborer evolved during the same period [Cipolla, 1979:91].

8. Johann Gutenberg [1390 - 1468] utilised type within an adjustable mould. The production of paper increased dramatically, manufactured mechanically by means of waterwheels and the Scientific Renaissance was in full swing by 1600 [Sevran-Schreiber, 1969:78].

9. The Chinese produced cast iron in the sixth century, and it has been produced in Europe since the the twelth century, but it was primitive, brittle and of inferior strength [Forbes, 1958:117].

10. The first furnaces with water-driven bellows were used in Liege on the Rhine early in the fifteenth century [Singer, Vol.II, 1965:656].

11. There were no metal cutting tools, and the ill-fitting metal parts jarred and shattered [Daumas, Vol.II, 1969:45].

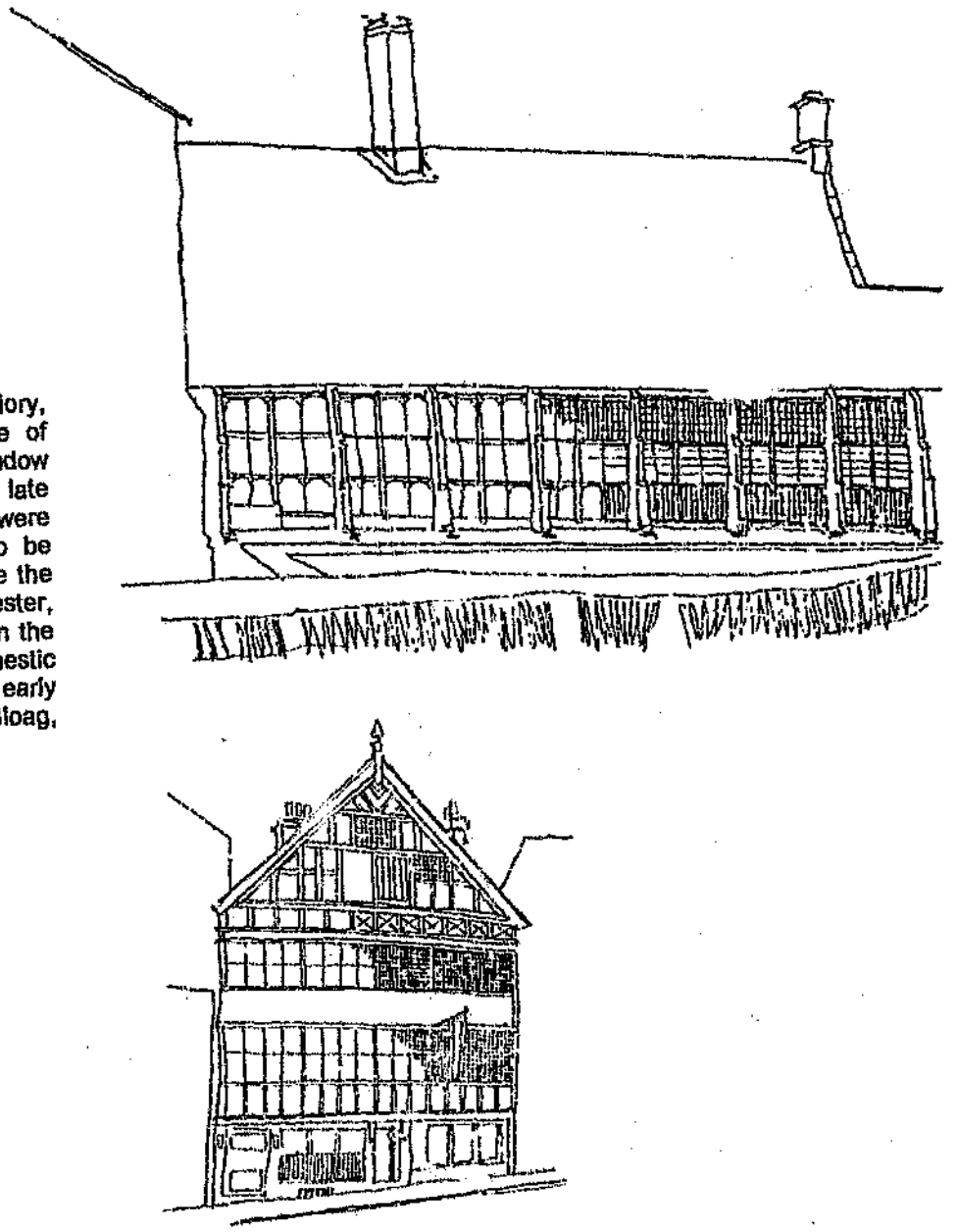


Fig.6 Much Wenlock Priory, Shropshire, is an example of continuous horizontal window development in the late fifteenth century. These were forerunners of windows to be used industrially later while the Bear and Billet Inn, Chester, shows bands of windows in the timber-framed domestic architecture of the early sixteenth century [Gloag, 1958:22 and 28].

The factories or workshops were still just large sheds constructed mostly with brick walls and wooden roofs. However, as the equipment became more sophisticated and larger it required heavy capital expenditure. With the help of bankers [12] the system became even more capitalistic.

The third development was the large number of fifteenth century manuscripts written about technology [13], the most famous by Leonardo da Vinci [1452-1510]. Again, these records did not change technology in the short term, but were the precursors of the seventeenth century revolution of pure and applied science. In his notebooks, which are now regarded as definitives [Daumas, Vol.I, 1969:3], Da Vinci laid the foundations for the new experimental sciences, breaking away from mere empiricism to the concept of an applied science of mechanics capable of general application. The machines illustrated were, however, far too advanced for the techniques of the period to be practically applied [Usher, 1954:125]. They were also too advanced for the available materials, or for the craftsmen who learned by apprenticeship and not from books [Kranzberg, Vol.I, 1967:103].

As law and order in Britain [14] was established in the South, the Midlands and East Anglia, the fortified manor became less grim, slit windows became larger [15] and early examples of continuous horizontal windows appeared [Fig.6]. Bay windows were thrust out ascending through two or more storeys, oriel windows projected from upper floors, mullions of both wood and stone became thinner and the techniques of glazing improved [Gloag, 1958:23].

Western building methods reveal comparative mobility and tempo [16], with an acceptance of change in contrast to the conservatism of non-Western cultures [17]. There seemed to be a willingness to experiment with forms,

12. Mining in the fourteenth century, and metallurgical plants in the fifteenth century, were the first industrial capitalist ventures [Brown, 1954:31].

13. At least seventeen manuscripts [Usher, 1954:294], including that by Georg Bauer as Agricola [1494-1555], who wrote De re Metallica and Vanoccio Biringuccio [1480 - 1538] on De la Pirotechnia [Kranzberg, Vol.I, 1967:102].

14. Wars of the Roses [1455 - 1485], a series of dynastic civil wars, which preceded the strong government of the Tudors.

15. The output of glass was limited. It was made only in small sizes and at high cost [Gloag, 1958:30].

16. The Late Gothic architecture of flying buttresses and large windows dominated church construction. With the help of mathematics, expanded building knowledge and financed by the aristocracy and merchant princes, soaring structures were erected at Wells Cathedral 1321 and Milan 1385 [Singer, Vol.II, 1965:441].

17. Romanesque were still building conservatively [Risebero, 1979:65].

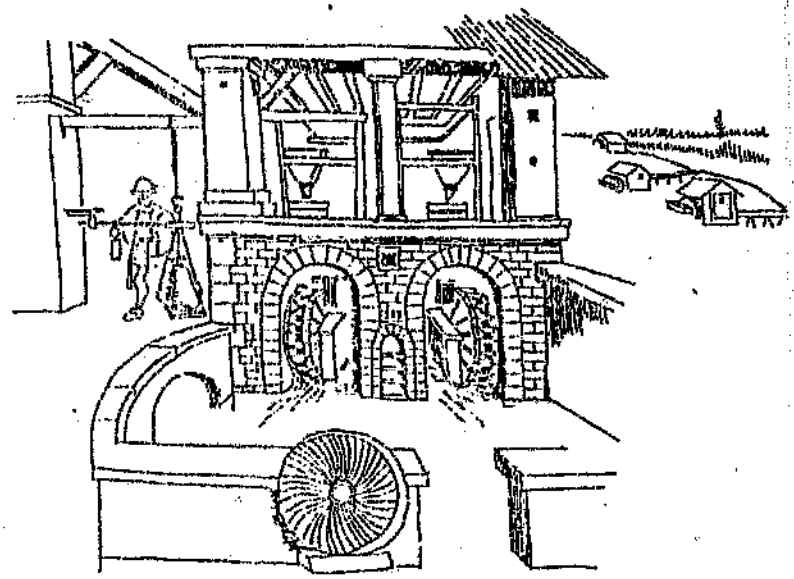


Fig.7 Water-driven wheat mill. Note an example of a sculpted millstone in the foreground [Forbes, 1950:145].

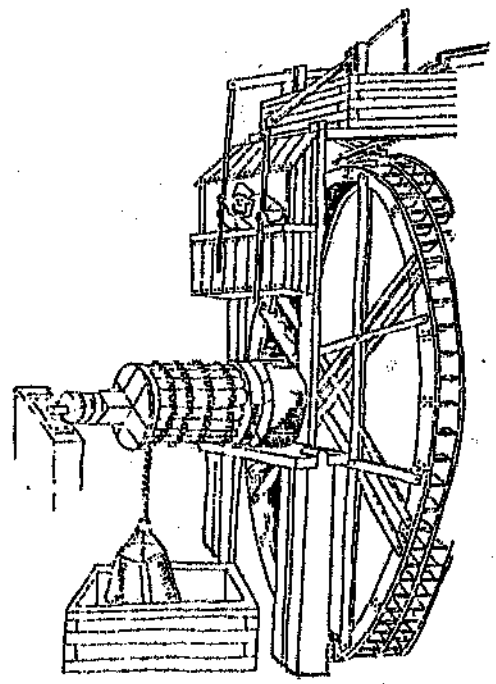


Fig.8 An overshot wheel used for raising heavy objects from mines. Note, the bi-directional wheel is operated by the man in the cabin [Derry, 1960:132].

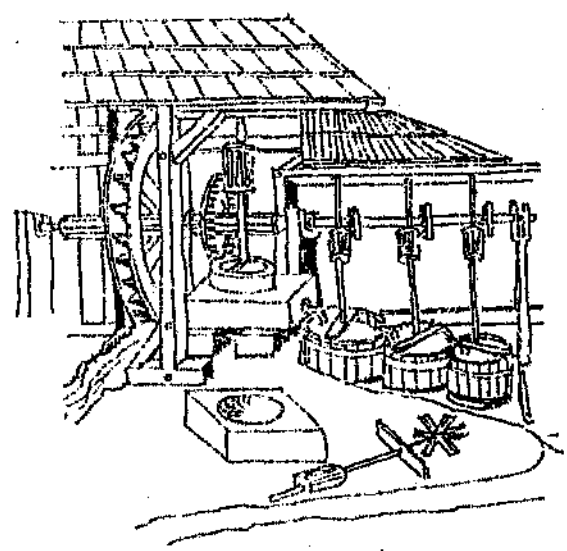


Fig.9 Circular orecrusher and mixers [Singer, Vol.III, 1965:327].

structural methods and a wide variety of building materials. The illustration [Fig.7] shows a substantial double-storeyed stone mill building, driven by a vertical shaft, the wheels at river level and the milling at street level. In the distance are two more conventional mills, the wheel and milling situated at water level. They were light temporary wooden structures that must have been susceptible to seasonal flooding. By this time, automation was applied to the grain hoppers. Grain was distributed over the mill stones by shaking the hopper off the vertical shaft which was controlled by the speed of the wheel [Daumas, Vol.II, 1969:53].

There was a general spread of industry during the early modern period preceding the Industrial Revolution. This was caused by the growth in demand [18], the introduction of new products and the development of new technology [19] and commerce [20]. In a factory belonging to Winchcome, also known as Jack of Newbury there were 500 operators who are described in over-rated terms by Delony [21]:

> Within one room being large and long
> there stood two hundred looms full strong ...
> And in another place hard by
> an hundred women merrily
> were carding hard with joyful cheer
> who singing sate with voices clear
> And in the chamber close beside
> Two hundred maidens did abide ...
> These pretty maids did never lin [cease]
> But in that place all day did spin
> [Singer, Vol.III, 1965:151]

By the mid sixteenth century, at least 40 different processes had come to depend on water power [22], with the largest growth in the metallurgical industry. It involved both mining [Fig.8] and manufacturing [Fig.9]. The mining

18. The period 1500-1750. Prior to that, the Middle Ages or Medium Aerum lasted from 395-1500. After the wars and plague there was a growth in population, general urbanisation and a rise in the standard of living [Singer, Vol.IV, 1965:99].

19. The application of the technology of power and organisation, while the cottage industries and the power of the guilds started to wane [Daumas, Vol.II, 1969:82].

20. The introduction of new ideas in banking, insurance and export/import markets [Brown, 1954:31].

21. John Winchcome and Thomas Delony. By 1550, there were similar factories in nine major towns in Britain.

22. Grain grinding and gun barrel boring, agitator mixers, raw material pulverisors for glass-making, snuff, cement, potter's clay, gunpowder, fertilizer and chalk for whitewash [Reynolds, 1984:114].

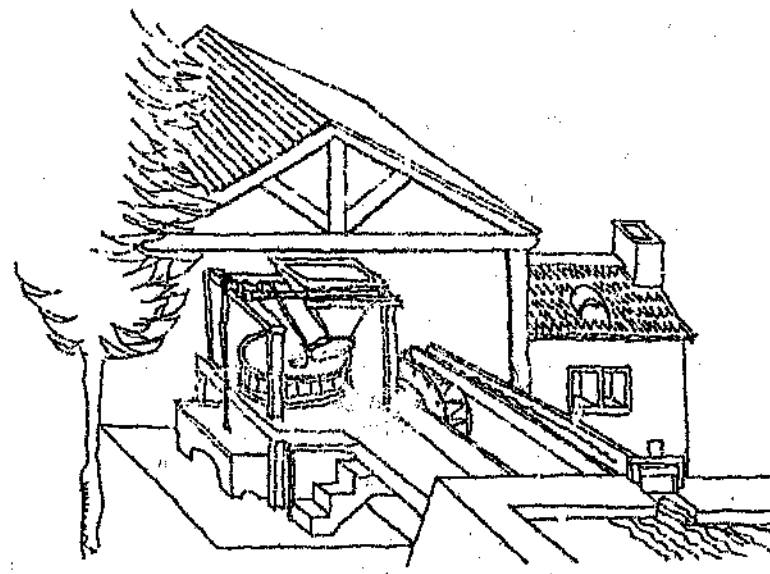


Fig.10 Water-driven corn mill with a mechanical bolting device, actuated by a lever from the main driving gear [Singer, Vol.III, 1965:19].

head gear was starting to take on an industrial form with its massive wheel and axle drum, strengthened with metal plates and spikes. The crusher plant was still no more than a heavy timbered open shed, weather-boarded and roofed with wooden shingles. In England and Europe there was a simultaneous development in industries which required traditional fuels, while the building of ships for exploration and defence also caused the widespread consumption of timber [23]. This led to a shortage as the forests were denuded.

While the water mills were being used primarily for the grinding [Fig.10] of corn, this agrarian function was confined to the platteland. The water mills were evenly spread, but when they were introduced in various other industries, particularly those producing iron and textiles, villages and towns grew and started crowding the valleys.

The most powerful agent was the overshot wheel [see p.16, Fig.3], where the weight and speed of the water produced the power [24], but this required the erection of dams. Many conflicting interests of ownership developed and the use of rivers and streams [25], especially when a new mill was constructed, affected those downstream [Singer, Vol.IV, 1965:201]. The water mills, which up to now had been very primitive and not nearly as sophisticated as the windmill, also developed methods of mechanical power transmission, especially concerning gears for driving machines of different types in various ways to increase speed and output [26].

Towards the end of the sixteenth century Flemish [27] weavers settled in the eastern counties of England where the knitting frame [28] had been designed by Lee. Earlier, silk workers had also emigrated from Italy to England. Whereas the early textile industry had been based mostly on linen [29] and wool, the future would depend on all textiles, including cotton.

23. The use of timber was forbidden, except in ships of the Realm. Coal was used to replace charcoal where the fumes had no deleterious effect, and bricks were manufactured again, a technique once lost in England.

24. Confirmed by John Smeaton in 1759 [1724-1792] nearly two hundred years later [Singer, Vol.IV, 1965:451]

25. It interfered with fishing rights and barge transport.

26. Water wheels were strong and slow with a seasonal supply of water. Windmills, which continually had to accommodate various speeds and directions, were fast but mostly weak [Daumas, Vol.II, 1969:439].

27. Wars of Religion in France from 1562-1598, and the massacre of St. Bartholomew's Day in 1572.

28. The weaving loom was invented in Danzig, 1579, and perfected by Rev. William Lee [-1610] [Usher, 1954:245]; while a frame was used mostly for machine-knit stockings in 1589. In 1581, due to umeployment, the guilds rioted [Jones, 1984:18].

29. Linen or flax had been woven in ancient times.

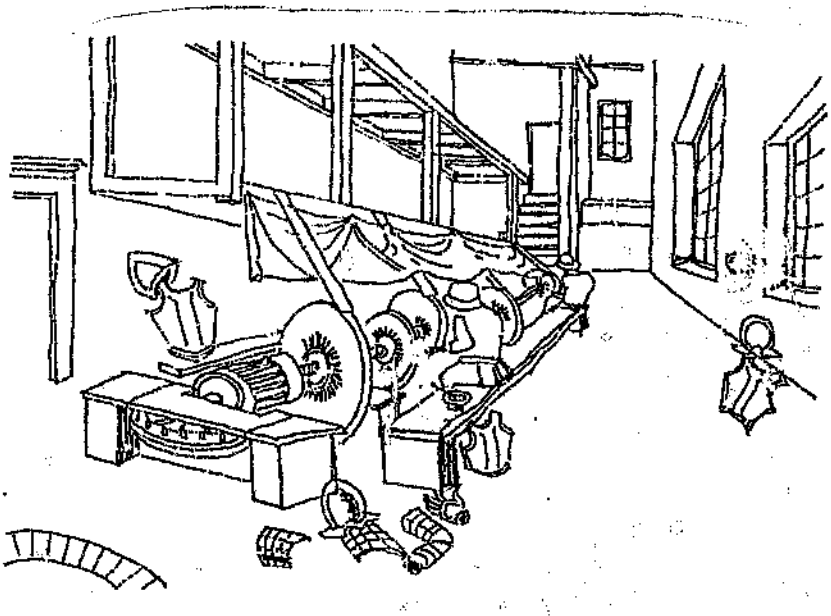


Fig.1 Armourer's workshop. The central horizontal shaft is powered by a water wheel propelling a number of polishing wheels. Note an attempt to prevent workers from inhaling metallic dust [Singer, Vol.III, 1965:351].

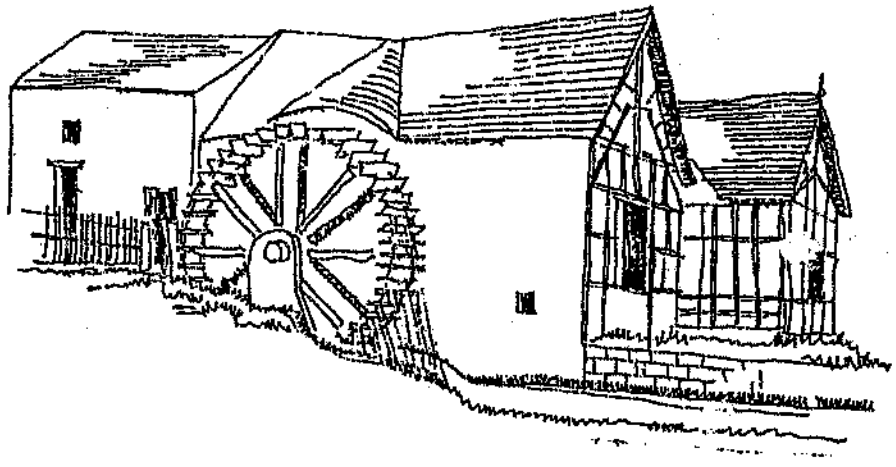


Fig.12 Half-timbered water mill at Rossit, Denbighshire, built in 1661 [Singer, Vol.IV, 1965:213].

As the power of the water wheel increased and the number of the industries using this power diversified, various complicated and expanded machines evolved [Fig.11]. There was, however, still a gulf between the scientist and the actual constructors [30]. In spite of systematic tests being done by practical scientists [31] on bars of metal, wood and glass sheets [32], there are no records indicating the early transfer of these results to the technicians [Singer, Vol.III, 1965:252].

The coal mines, because of the increasing demand [33], also became deeper and had to be pumped out by using water wheels. After 1600 the expansion of the iron industry in the British Isles became permanently interwoven with the replacement of wood by coal. The industrial hibernation of more than fifteen centuries, where the development of science had not only been halted but even reversed [Koestler, 1970:228] was now being overcome [34] in an attempt to establish a legitimate command over nature and a plan to reorganise the sciences.

During this period Britain was without rival in the exploitation of mining and the use of mineral fuel [35]. Up to now, there had been little demand for power beyond that provided by natural sources. The need for more power now was urgent and the money was available [36] to pay for these expensive contrivances [37]. It became time to consider harnessing the power of fire.

Few special industrial forms other than the windmill had as yet intruded on the eotechnic landscape. The water wheel buildings were largely still built on the scale of dwellings and large sheds in spite of the progress of big industry [Mumford, 1940:134]. The mass of industrial buildings was generally unobtrusive [Fig.12]. Many, especially in England, had open timber roofs and low beams on roof plates. The roof formed an integral part of the timber

30. At this stage, designers and constructors were mostly one and the same persons, or a team consisting of mastermasons, administrators and supervisors.

31. Galilei Galileo[1564-1642], considered the founder of the experimental method and modern scientific knowledge.

32. As early as 1693 plate glass was made in France [Gloag, 1958:30].

33. The countries that lacked coal did not progress industrially [Kranzberg, Vol.I, 1967:83].

34. Francis Bacon [1561-1626] wrote Novum Organum and Instauratio Magna between 1608 and 1620.

35. In 1628 and 1630, patents for the steam engine were taken out. In 1698 Thomas Savery [1650-1715] developed an engine for pumping out mines [Singer, Vol.IV, 1965:171].

36. From British trade routes; manufactured goods to Africa; slaves to the West Indies; sugar to the New World; and rum to Britain [Daumas, Vol.2, 1969:5].

37. The word technology was first used in 1658.

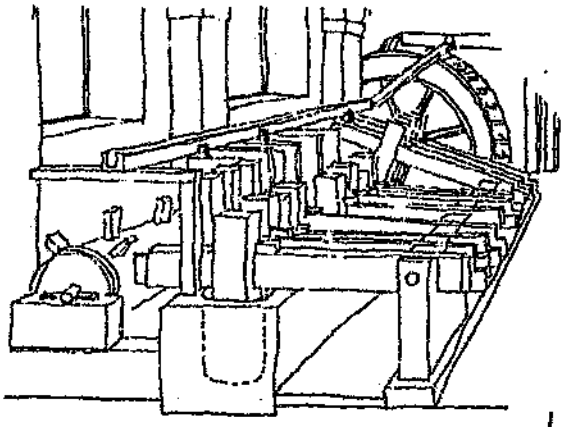
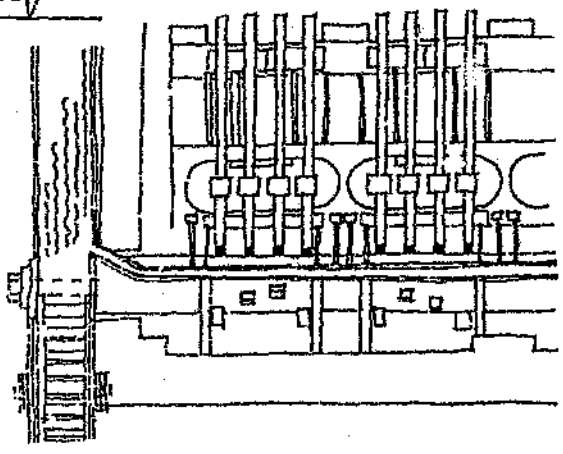


Fig.13 View of a paper mill and a plan of vats and a battery of mallets driven by a large shaft and cams [Daumas, Vol.I, 1969:209].



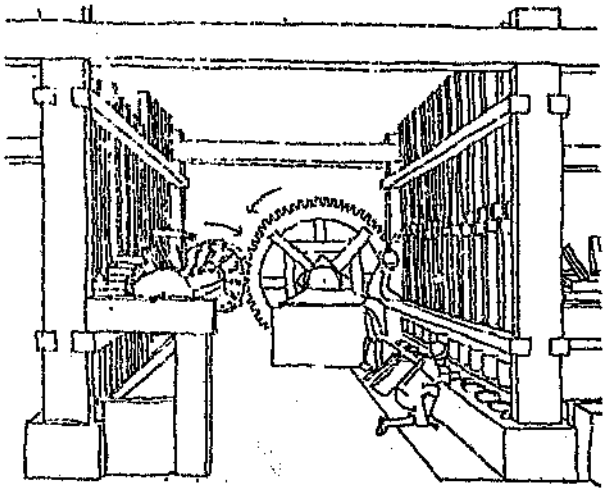


Fig.14 Pounding mills for making gunpowder [Daumas, Vol.I, 1969:181].

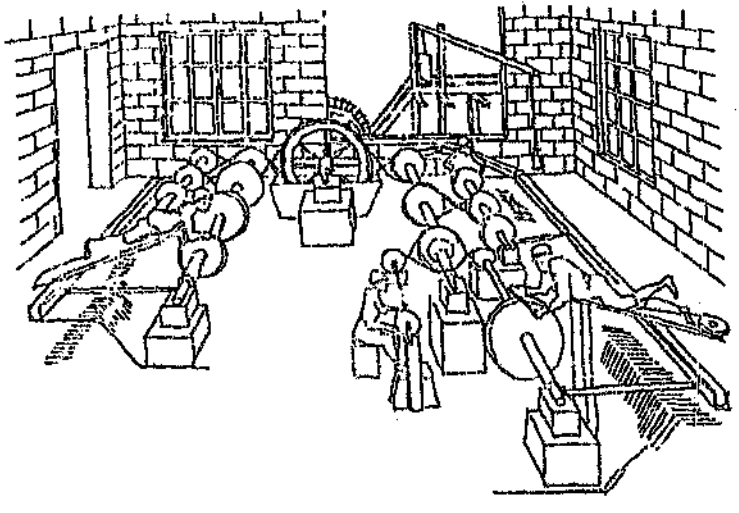


Fig.15 Sharpening and grinding machine shops. Note the water chanelling for keeping the axles cool [Daumas, Vol.I, 1969:259].

frame, with slopes ranging from 45°, depending on the frequency of snow. Iron was only employed in the form of nails, pegs, rods or strappings in masonry or reinforced timber [Kranzberg, Vol.I, 1967:93].

Long shafts and gearing were being developed, at first largely in wood which was strengthened with iron nails and straps. These machines would be extended along one wall of a factory so that many workers could use the power developed simultaneously [Fig.13], or they would be placed parallel to or in series with a number of water wheels [Fig.14]. There were exceptions, like a blast furnace or a brewery, which involved large sums of capital [38]. The development of the prototype factory centred mostly on textiles and ceramics.

38. The cost of a copper mill in Esher was R18 000 and that of a London brewery by Charles I [1600-1649] was R30 000 [£1 = R3] [Brown, 1954:31].

The start of the industrial society is usually associated with inventions and a breaking down of productive work into repetitive units in a factory system [39]. To a large extent these aspects predate the Industrial Revolution where, with the development of the natural prime movers over nearly two millenium, work was assisted by outside power [McHale, 1969:40]. These were the first hints of mass production. The increased power of the water wheel, together with the understanding of the strength of materials, allowed for the idea of powered factories [40].

39. Christopher Polheim [1661-1751], a foremost Swedish inventor, advanced this idea with a variety of special devices, including corrugated iron.

What became generally acceptable and was to be the forerunner in workshops for many centuries to come, was the parallel use of two shafts each placed against a wall with the workmen and materials in the centre aisle [Fig.15]. Pulleys were now to increase or decrease the speed of revolutions or to allow for the use of specialised equipment. The buildings thus became long and narrow [Fig.16], but still at a right angle to the motion of the water wheel. These were the first sure steps towards mass production.

40. The word "factory", first used in 1582, means gathering workers together under one roof to perform specialised tasks with the aid of machinery.

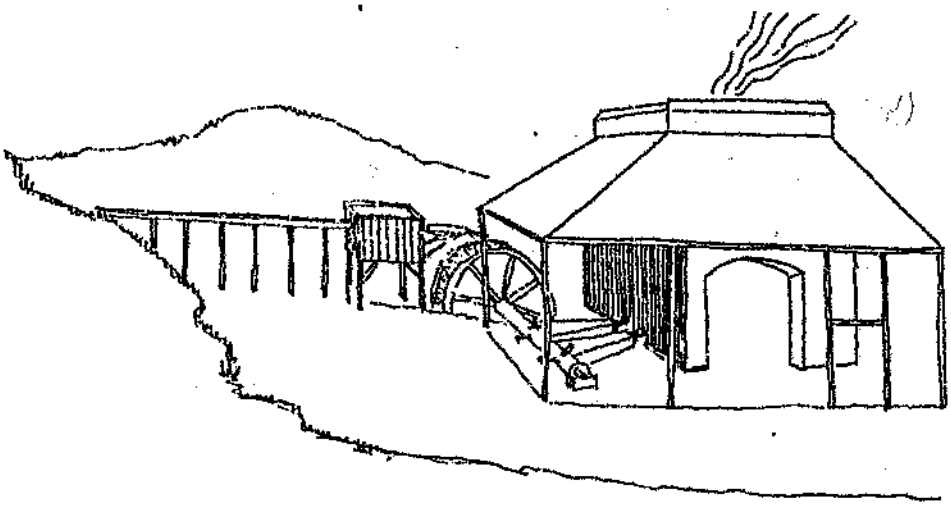


Fig.16 General view of a French ironworks in 1716 showing a water wheel driving the bellows and the building constructed around a furnace [Singer, Vol.III, 1965:71].

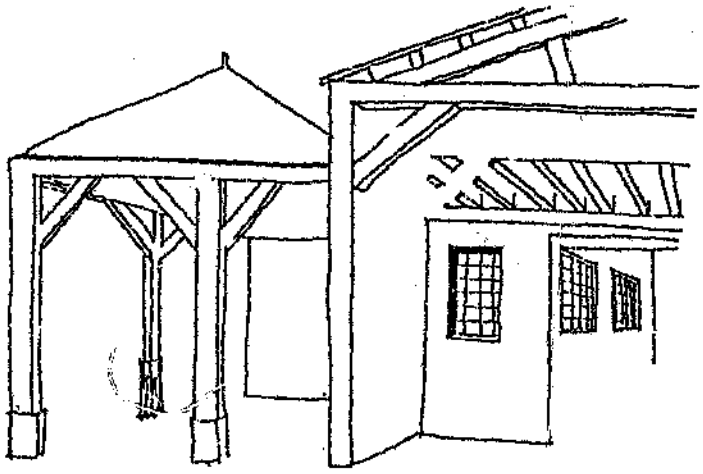


Fig.17 Structures were built of stone or brick with small glass panes set in wooden frames. It had a timber roof with hipped ends, covered with shingles or tiles [Singer, Vol.IV, 1965:347].

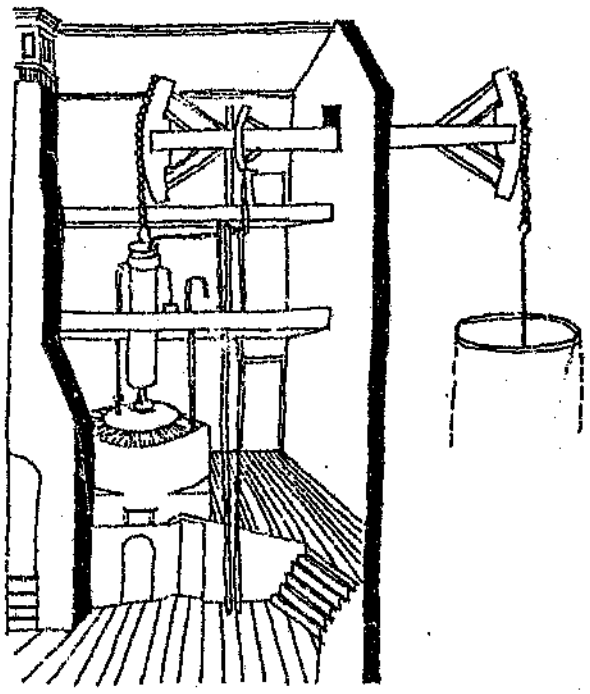


Fig.18 The steam-engine erected in 1712 by Savery and Newcomen at Staffordshire, next to Dudley Castle [Singer, Vol.IV, 1965:174].

There was a radical recasting of the objectives, methods and functions of natural knowledge. The objectives had to be devoid of magic and superstition, human or spiritual properties, the methods had to be disciplined and properly researched, while the functions had to be based on scholarly knowledge and industrial power. This was a revolution about science [41] rather than within science itself and by the year 1700 most of the elements of mechanics were practically completed [Singer, Vol.III, 1965:720].

The prime development in the new industrial era which, without a doubt, was responsible for the Industrial Revolution, was the development in the field of metallurgy [42], [Fig.17]. This made a wide spectrum of inventions possible of which the most important at the time was the manufacturing of textile machines and the steam engine [43], [Fig.18].

The British freely sailed the world trade routes and numerous export industries flourished [44], which were readily exploited by the English manufacturers. To state this is to simplify a very complex process, which can be attributed to many social, economic and political factors [Singer, Vol.III, 1965:712]. What is most important, however, is the influence it had on manufacture and specifically the newly established factory system.

The textile industry, while being a highly developed craft, remained a cottage industry, with some workers occasionally co-operating [45] under one roof. The growth in demand pushed this rural system to its limits [46] and even an advanced system of putting-out [47] could not meet the demand [48]. The frustrated manufacturers, with their vast developing markets, were forced to concentrate the work. The high cost of hiring independent workers from the platteland into a disciplined work situation proved so difficult that the invention of machines

41. Sir Isaac Newton [1642-1727] dominated science. In many ways, his Principia, 1687, culminated in the scientific revolution that lasted four centuries [Kuhn, 1970:168].

42. Abraham Darby [1678-1717] used coke which was sulphur- free, instead of wood or coal for smelting at Coalbrookdale in 1708 [Singer, Vol.III, 1965:80].

43. Savery used the "fire engine" to pump water out of the mines. Thomas Newcomen [1663-1720] invented the atmospheric steam engine with a piston and cylinder that did the actual pumping [Singer, Vol.IV, 1965:171].

44. The most popular exports to the colonies were textiles and crockery.

45. Derby, England, 1717. See side note No.21.

46. This demand was experienced especially in spinning, where it took four to five persons to supply one weaver with yarn.

47. Putting-out with wool-cloth weaving was started before 1400 by merchants, but land transport was expensive [Jones, 1984:18].

48. It was general practice to install a loom in the upstairs rooms which had long windows for light. Women did the spinning, hence the word spinster, and men weaving [Jones, 1984:18].

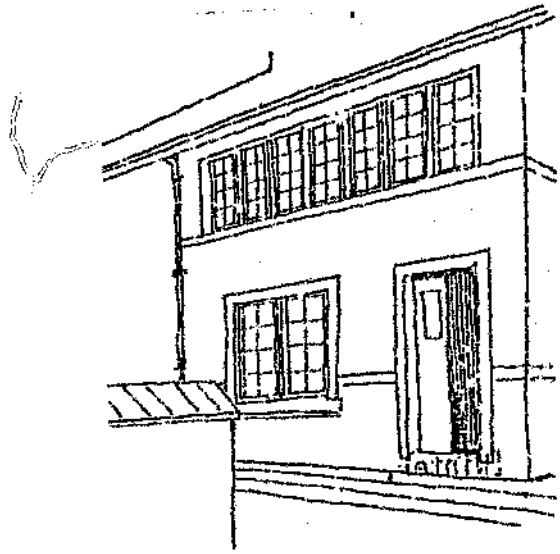


Fig.19 There were cottage windows upstairs where the weavers would work [Richards, 1958:77].

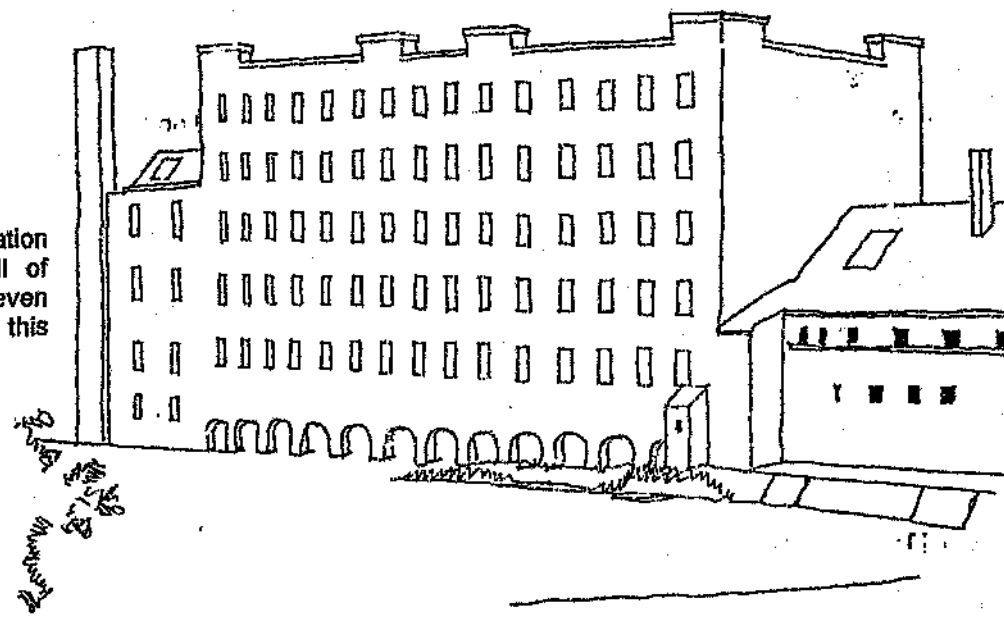


Fig.20 Conjectural restoration of John Lombe's silk mill of 1718. A strange building, even for one as non-uniform as this [Winter, 1970:24].

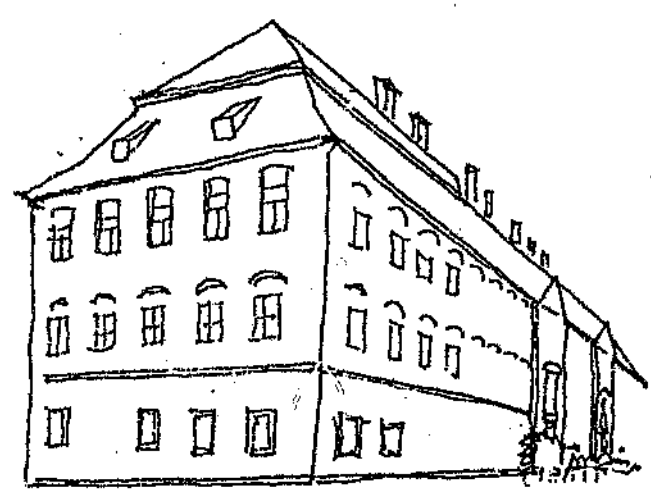


Fig.21 Linz wool mill, 1722-1726 [Pevsner, 1976:274].

became an economic alternative. In the process, these machines became so large that they could only be driven by inanimate power and could not be accommodated in small rural rooms any more [Fig.19].

Therefore, the start of the Industrial Revolution [49] in the 1750s depended firstly on the mass markets of the colonies; secondly, on the simultaneous advances in metallurgy at home [50] and, thirdly, on the development of mass-production machinery in the textile industry. These factors, coupled with the eagerness of manufacturers to exploit the situation to its maximum and abetted by the engineers who invented the textile machines and the buildings to accommodate these machines [51], were the spark.

In what appears to be a radical departure from any industrial building previously built, a silk mill [52] was constructed by the river Derwent in Derby by the Lombe brothers [53]. This mill, constructed in 1718, is a bit of a puzzle. Only conjectural drawings of it exist and nearly 70 years were to pass before the next multi-storeyed mill was erected. No photographs exist despite it only being demolished this century [Winter, 1970:24]. It was to become the pioneer for industrial structures, described by some as satanic mills [54], and by others as some of the more beautiful industrial buildings ever built [55]. The building [Fig.20] was 13 m wide, 36 m long, with regularly spaced wooden pillars down the centre of every floor and was five storeys high. The outer wall was constructed in masonry and was reported to have 468 windows. The mill had a 6 m undershot water wheel, which drove no fewer than 26 000 machine wheels [56] and employed 300 persons by 1730 [Guedes, 1979:94].

European industry was also expanding and was not that far behind. At Linz in Austria, a wool mill [Fig.21] was built, designed [57] in typical Austro-Hungarian fashion.

49. The term "Industrial Revolution" is an historical concept, more convenient than precise, used to describe the progress from handicrafts to an economy dominated by machine manufacture [White, 1959:283].

50. 1738, cast-iron rails; 1740, cast steel; 1746, Huntsman's crucible process; 1775, Wilkenson's boring mill; 1781, Watt's steam boiler.

51. The accent is on the textile machines and the radical buildings for these machines [Singer, Vol.III, 1969:152].

52. The word "mill" comes from molere meaning to grind.

53. John Lombe [1685-1739] who learnt about silk throwing in Italy [Hills, 1970:30].

54. Surely the building is not at fault, but is a superb example to ways to overcome the foul northern England weather where lighting and heating were non-existent, especially in winter.

55. Georgian period buildings of late eighteenth century.

56. The undershot waterwheel developed no more than 10 hp.

57. Johann Michael Prunner was an architect.

Standing on a stone plinth are two storeys of production floors and a dachkammer. Industry as a whole was expanding [58], many techniques were rediscovered and many new ones developed [59], especially with regard to agricultural products. There were also inventions in metallurgy, where machine-rolled tinplate or rolled hot iron was used in several stages to create various thicknesses [60].

Steam was still in its infancy. Technology could not increase the power of the water wheel much more, but what was significant was the utilisation of transmission elements which increased significantly as power increased.

58. True hard pottery was rediscovered by Johann Friedrich Böttger [1682-1719] of Meisner near Dresden.

59. Sugar and flax mills.

60. Roof sheeting rolled by Christopher Polheim, 1751.

PART TWO : MANUFACTURING BUILDINGS

CHAPTER FOUR : INDUSTRIAL REVOLUTION

The Industrial Revolution was a process not a distinct period of time.

[Kranzberg, Vol.I, 1973:217].

The term Industrial Revolution, defining the period 1750-1830, is both convenient and conventional, but it can be misleading. Writers at the beginning of the nineteenth century who were impressed with the changes in politics brought about by the French Revolution [1789-1815] wanted to characterise the changes they saw in industry and economy. In Britain the term was popularized by Toynbee [1], who used it to describe the rapid economic development from 1780-1840. Previously it has been understood as an economical event, a term to describe a rapid, ongoing shift from agrarian society to machine manufacture, from home workshops to factory and from rural villages to urban concentration [Kranzberg, Vol.I, 1967:107]. It is now seen as a historical concept restricted to no precise period, with no clearly defined beginning and no predictable end.

1. Arnold Toynbee [1815-1883] uncle of the more famous historian of the same name [1889-1975] [Kranzberg, Vol.I, 1967:217].

Five basic technical achievements were required to start and maintain the Industrial Revolution, namely the replacement of hand tools by machines [2], the introduction of new, large and powerful prime movers [3], mobile prime movers [4], a factory system as a new form of organising production [5] and people of an inventive nature from all strata of society [Giedion, 1959:163]. Within a century they transformed the whole life of western man and the nature of our society that, as seen before, started in 1000 AD.

2. More than man's physical strength.

3. Power to move the machines. The more the power increased, the larger the factories could be.

4. Transportation to move the items produced. As roads were bad, canals were developed to carry heavy-bulk commodities. Later steam locomotives on permanent rails [Rolt, 1975:21].

5. The methods to organise the machines - a new form of management [Shephard, 1987:16].

In each epoch of history we now see many factors interacting to determine the nature of technology. We

must also start to distinguish between empirical and planned technology and between the direct actors and the activators [Singer, Vol.II, 1965:589].

Machine tools are the key to early industrialisation. They are the tools used to make tools. They are also the tools used to make the machinery for mass production, and prime movers [McHale, 1969:40]. Precision mechanics [6] could not come into being until certain conditions had been reached, the most important being the use of advanced metals [7]. The use of coal as fuel in metallurgy was recognised at the beginning of the seventeenth century. The slow growth in the output of cast and wrought iron in Britain must be attributed to a considerable degree to the stubborn technological difficulties that had to be overcome before coal could replace wood [Singer, Vol.III, 1965:78], the new methods of transforming matter, and the system of the transmission of movement [8].

The traditional beginning of the Industrial Revolution is seated in the late eighteenth century and is linked to the advent of the early English waterpowered cotton-textile mills [9]. The production of power was certainly not new. Windmills had reached their peak and water mills grew in size and strength not because of any fundamental new inventions but because of the improved methods used to harness the water. There was also the construction of the wheels, the utilisation of the elements of transmission of movement and the development of metals [Daumas, Vol.II, 1969:2]. The steam engine was still in its infancy and would only become powerful later [10].

Some enormous plants were constructed in these forerunner factories, using water power and later steam power as that source developed [11]. All these power sources were overlapping and interpenetrating phases [Mumford, 1946:109].

6. Precision mechanics arose from the clock making and so did the scientific instruments of the early eighteenth century. Kays fly-shuttle, 1733, and Arkwright's spinning machine, 1769, stimulated the search for higher production [Shephard, 1987:8].

7. Pig iron 1709 by Abraham Darby [1677-1717] of Coalbrook, cast steel, 1750, by Benjamin Huntsman [1704-1776], refined bar iron, 1784 by Henry Cort [1740-1800] and the blast furnace 1820 by James Beaumont Nielson [1792-1865] [Mumford, 1946:164].

8. Lathes, drills and boring machines, including the perfectly adapted drop hammer. Also using the shaft and various diameter pulleys to control rotation speeds [see previous Chap. Figs.14 & 16]. During the second half of eighteenth century [Daumas, Vol.II, 1969:247], this had hardly advanced beyond the middle ages, but by 1850 the majority of modern machine-tools had been invented [Singer, Vol.IV, 1965:417]

9. Hemp industries were mechanised in the twelfth century, silk 1300-1600 and in Ulster alone more than 200 linen plants established between 1700-1760 [Reynolds, 1984:114].

10. Thomas Savery [1650-1715] used steam to pump out deep mines and thereby replaced horses. Thomas Newcomen [1663-1729] improved on Savery by using an atmospheric pump, the vacuum created by con-densing steam. John Smeaton [1724-1792] further improved the Newcomen with cast-iron shafts and gearing while James Watt [1736-1819] invented the separate condenser in 1769 to cut fuel consumption by 75% [Giedion, 1948:245].

11. The Paleotecnic period 1750-1850/70 as defined by Sir Patrick Geddes [1854-1937] and explained by Lewis Mumford [Mumford, 1946:109].

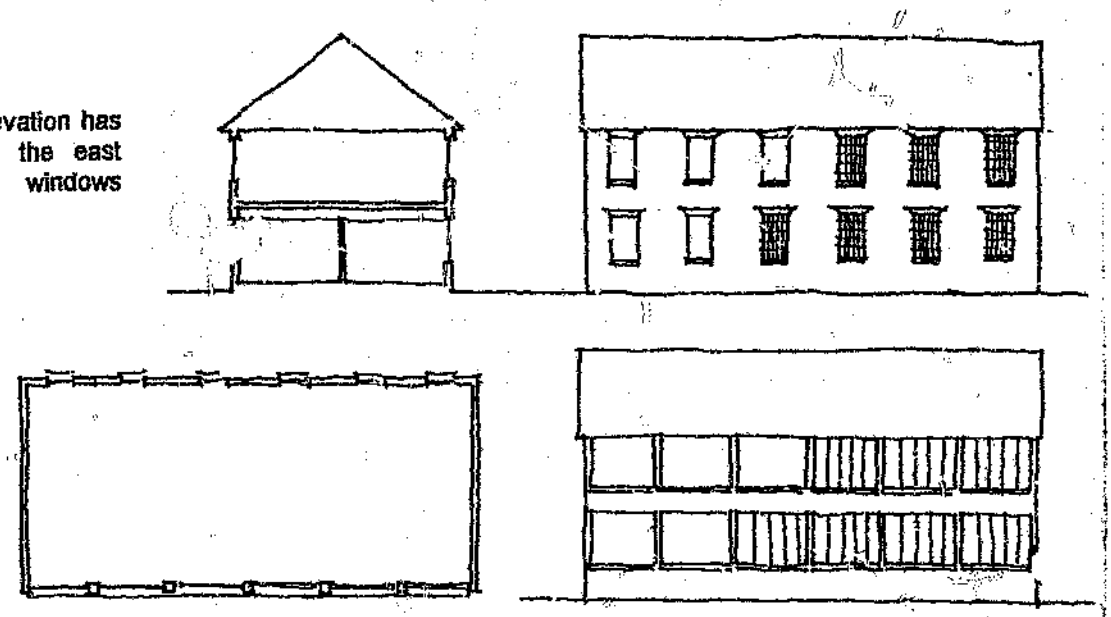


Fig.1 The west elevation has small windows and the east elevation large windows [Shephard, 1987:11].

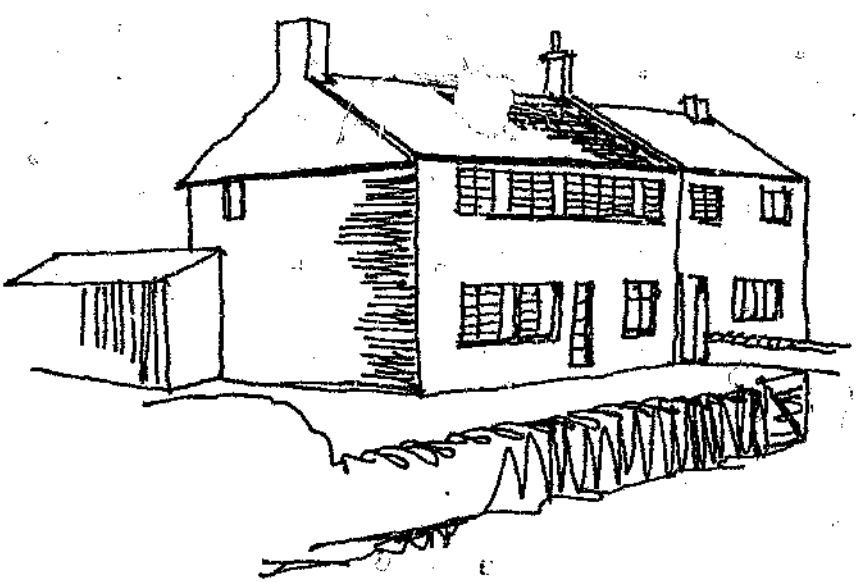


Fig.2 Weaver's cottage in Lamb Lane, Almondbury was built of local stone, the upstairs workshop is apparent from the closely grouped windows [Jones, 1984:19].

The early [12] industrial buildings in England and later in Europe and America, built in traditional stone, brick and timber, were developing their own spaces. The power was usually supplied by water wheel and transmitted by long horizontal shafts, the length limited by the shaft material and the efficiency of the bearing. Machines were now accommodated on floors on top of each other and not alongside or in line with each other. It was discovered that the vertical drive was more efficient [Shepherd, 1987:16] and took less space along the stream.

The width of the building was determined by the limitations of the materials used in the floors and the general need for natural light. The tallow candles used for artificial light represented a great fire risk. One of the first factories built [13] according to the above-mentioned philosophy was Cotchett's Silk Mill in Derby [14], consisting of two floors for spinning, throwing and doubling. There were four double Dutch mills on each floor at the west wall which were driven by a 29 ladle water wheel, 4,5 m diameter. The doubler [15] sat on the opposite side facing the windows in the east wall. The western side, where the heavy equipment was placed with the driving shaft, was thick and stable and had relatively small windows, while the east side had studs with wide windows [Fig.1].

Weavers who were working on contracted-out material [16] required no mechanical power for their hand-operated looms in their terraced houses or cottages at first and devoted the upper floor to weaving while they lived below. Often the upper floor had long mullioned [Fig.2] windows facing north [17] to provide ample daylight. These domestic features clearly indicated a debt to local building traditions and were later [18] revealed in America during the early New England, Rhode Island and Pawtucket pioneering phases.

12. From about the turn of the Century 1700 AD.

13. Designed and constructed in 1702 by George Sorocold [-1720], local engineer and millwright. The structure was 20 m long 14 m wide and 12 m high.

14. Illustrations show the John Lombe mill erected in 1717 as being situated next to Cotchetts Silk Mill.

15. The doubler was the machine operator feeding in the material that was to be thickened.

16. In spite of logistics, it was still cheaper to provide wool or silk to homebased weavers in the platteland than to provide housing for the workers in the villages.

17. In Europe read north and in southern hemisphere south. This prevents direct sunlight and dangerous contrasting shadows.

18. From c 1790s.

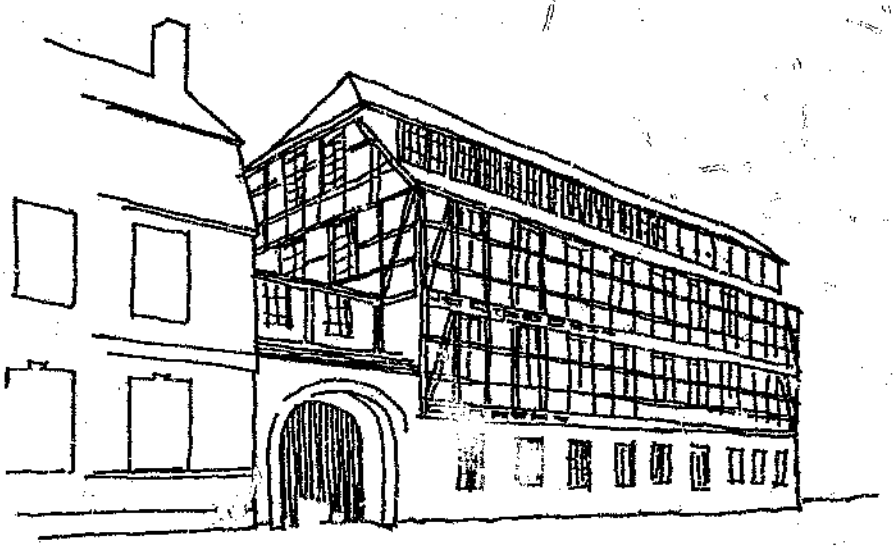


Fig.3 A textile factory built in 1756 at Luckenwalde in the district of Potsdam, Berlin which was famous for its cloth and hat fa . ies. Note the set-back fourth floor with continuous window in the timber-framed building. It was a combination of ship-and-millwright construction common in many localities in Europe and Britain [Henn, Vol.I, 1955:21].

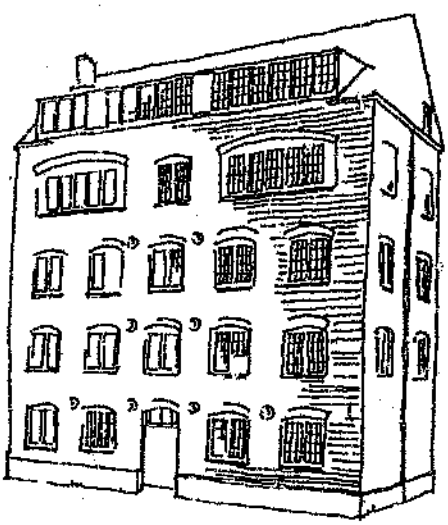


Fig.4 A tall stone woollen mill at Nailsworth near Stroud in Gloucestershire built in the 1760's. The long attic window resembles the "weavers" window [Richards, 1958:81].

Silk weavers were placed within dormer windows [19]. In some small Georgian factories the looms placed in the garrets with windows in twos and threes between piers of brick, wood or iron. Later [20] in the villages and towns the cottages were planned in small squares, with an engine sited in the enclosur . The shafting ran the length of the lane and each weaver paid a weekly rent. Small mills were spread across the country [21]. All were constructed in similar fashion by local millwrights, using traditional materials and neighbours learnt from each other. The only problem was fitting the new technology into compact traditional boxes [Jones, 1984:46]. The method of "contracting or putting out" was adequate when the workers dealt with owners and agents of whom they had personal knowledge. The agent provided the workers with raw material and paid them for the finished product. The agent could therefore handle and contract orders and control it while the family could divide the labour amongst themselves. However, there were also independent weavers who produced for agents as well as for themselves, which led to a lack of control in the materials given and received [George, 1968:48]. As a result of the small capital investment and decentralisation of the population there was still very little incentive to develop managerial techniques in domestic weaving.

As the factories grew it became clear that organisms displayed the same characteristics as societies [Durkheim, 1949:41]. The more specialised the functions of the organism were, the greater the development [Fig.3] was. The greater the productive power, the more the ability of the workman was analysed [22]. Adam Smith [23] recognised the steady advance towards powerful machines. There was a greater concentration of forces and capital and machine processes were broken down into simple operations, each performed by semi-skilled or unskilled individuals. He also stated that productivity depended more on organisation than on skill and that in

19. In 1722 Spitalfields and in 1723 Wilkens Street and Elder Street [Jones, 1984:34].

20. C. 1769, James Watt's vastly improved engine [Singer, Vol.IV, 1965:187].

21. The Peel family of Lancashire owned 23 such mills in the area. Sir Robert Peel [1788-1850] British Prime Minister was from this family.

22. Christiaan Freiherr Von Wolff, [1679-1754] philosopher, mathematician and scientist was the spokesman for eighteenth century Rationalism.

23. Adam Smith [1723-1790] social philosopher and political economist, who wrote "Wealth of Nations" in 1775-76.

Fig.5 In 1764 the Soho manufactury was erected by William [1734-80] and Benjamin Wyatt [1744-1818] who were 30 and 20 years old respectively. The building cost £9000 and was the largest of its kind in Europe based on Palladian Villa. It was symmetrically ordered, three-storeyed, had gabled wings and a central entrance. Workers lived in the upper-floor wings, while the forges, furnaces and the huge waterwheels were located at the back [Jones, 1984:35]. In the weaver's cottages lightweight equipment could be kept upstairs but now the machines became too heavy [Jones, 1984:36].

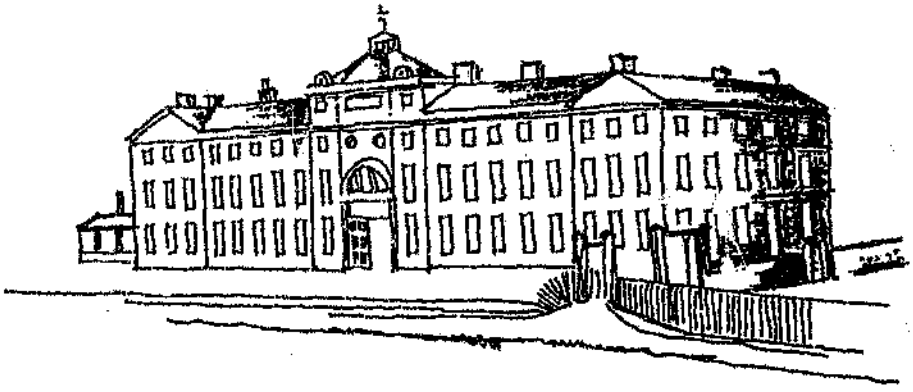
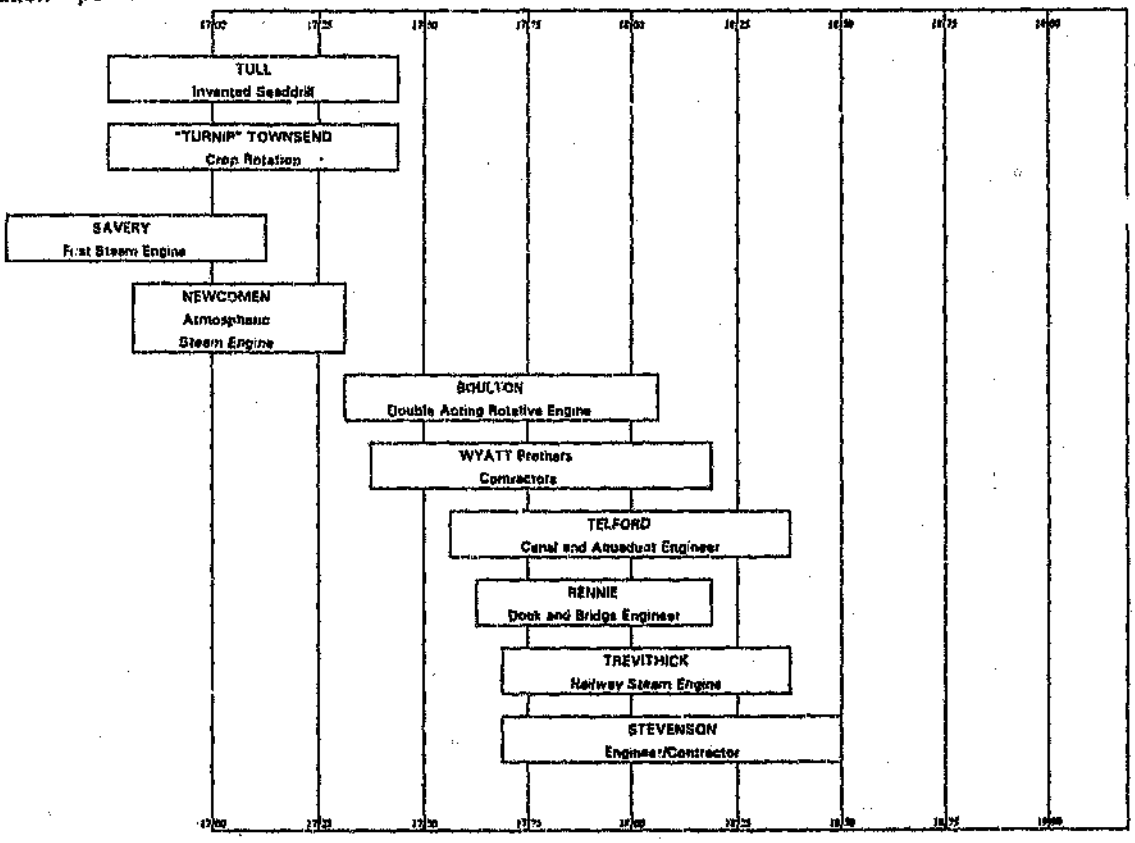


Fig.6 There were a number of persons responsible for the major inventions that made the industrial revolution possible [Author].



the textile industry manual dexterity and alert response was more valuable than experience, hence the employment of women and children. In spite of the spectacular and widespread growth of textile technology in England it was also realised that the transformation of the organisation of factories [Fig.4], commercial diffusion and social structures played as important a role in the Industrial Revolution of the eighteenth century as the methods of production [Daumas, Vol.II, 1969:7]. The diffusion of innovations as a process was as important as the invention [Jeremy, 1981:3], but from a managerial standpoint it focussed attention on the practical control and co-ordination of men [24], materials and machinery.

24. It was only much later in 1811 when the Luddites, a band of handicraftsmen who were being displaced by machinery, rioted [Jones, 1984:12].

The Industrial Revolution also profoundly affected the topology as well as the techniques of architecture. It moved away from the domestic environment into an area dominated by devices and processes rather than by individuals, which created the need for more specialised and more numerous buildings than previously in history.

The architecture of warehouses, mills and foundries was rated after that of royal palaces, cathedrals, mansions and churches [Jones, 1984:12]. The textile mill broke with tradition and promoted a style all of its own. They were designed by millwrights and engineers of no great academic training and were determined less by aesthetic consideration than by the evolving needs of manufacture. The only style that was used was to be governed by the reason [25] inherent in certain geometrical forms and proportions. The style was dignified, but lacking in variety and originality [Fig.5].

25. The Vincenza Renaissance architect Andrea Palladio [1508-1580]. Later called the Palladian style, it was very popular in England in the seventeenth and eighteenth centuries [Jones, 1984:14].

During the first part of the Industrial Revolution [Fig.6] knowledge was mostly acquired as a result of practical experience and informed empiricism. Skills were still arduously learned by craftsmen in hundreds of trades and crafts, but with the knowledge gained from pure science

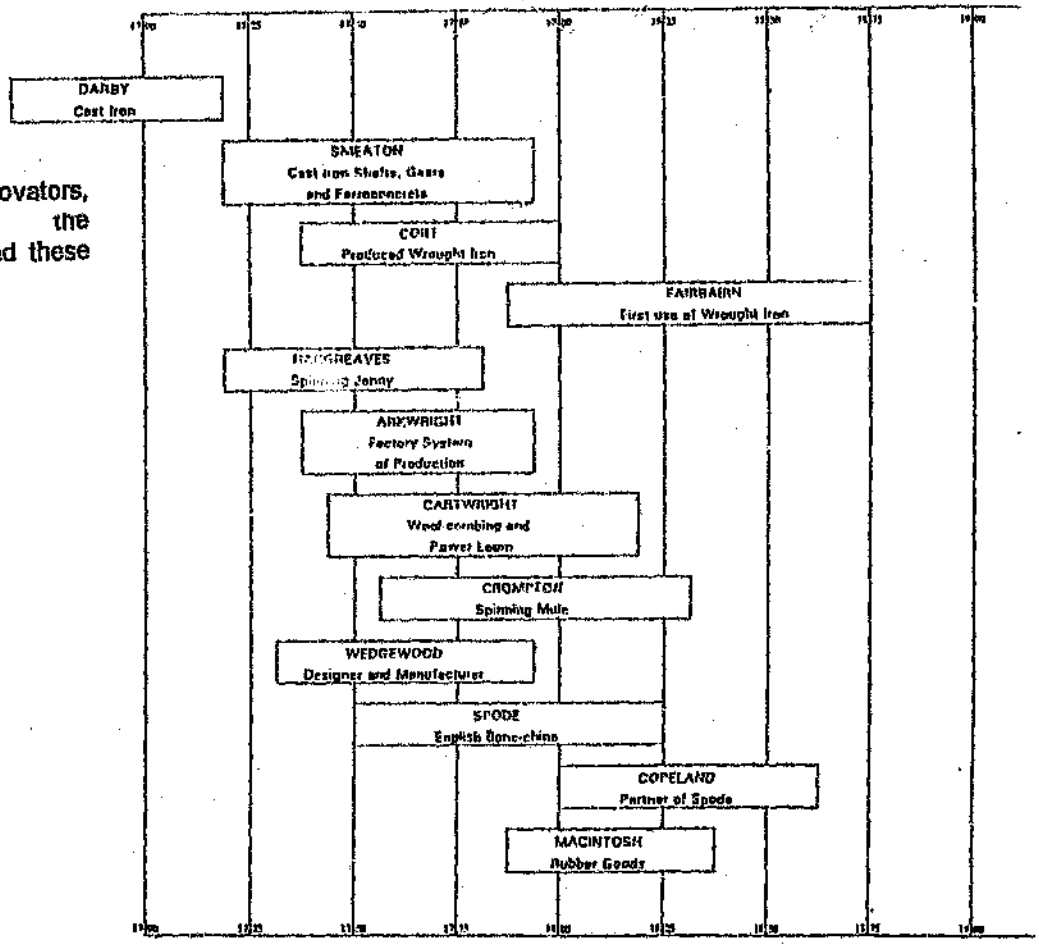


Fig.7 Many innovators, together with the manufacturers, exploited these inventions [Author].

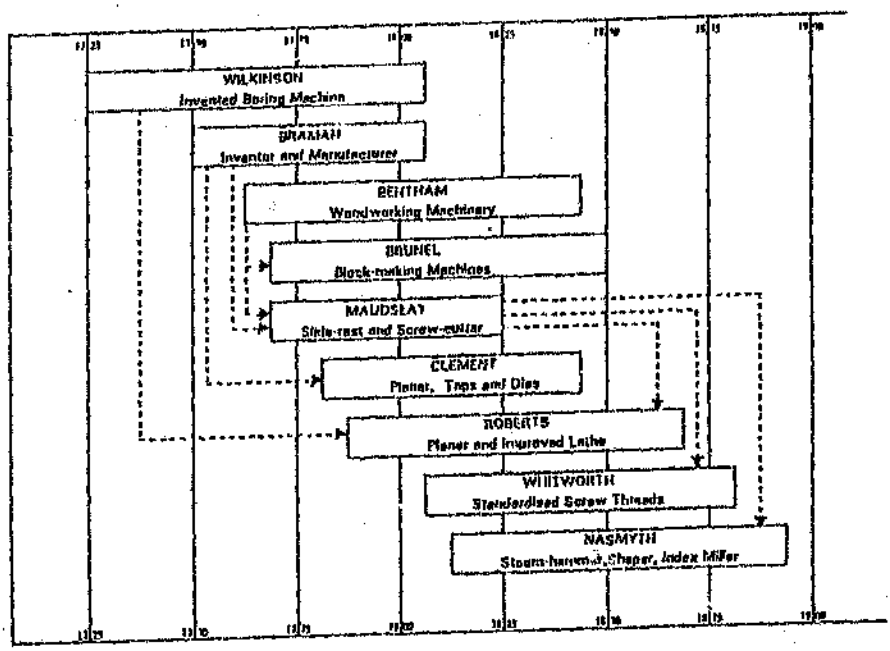


Fig.8 Some important machine-tool builders and inventors of the eighteenth and nineteenth centuries. The dotted lines represent employer-employee relationships [Singer, Vol.IV, 1965:418].

this relationship was changed. In many fields theory had moved ahead of practice, with many inventors tapping the pool of scientific knowledge for ideas and information. These were the true heroes [Usher, 1954:5]

The movement of history cannot be attributed to the efforts of a small number of uniquely gifted leaders [26] in strategic positions [Fig.7]. Many obscure and unrecognised innovators played important roles in this dynamic development as all sections of the community became inflamed by the pursuit of patents [Munce, 1961:5]. Human accomplishment can be a continuous activity. It is not an intermittent manifestation of mysterious trancendental powers exhibited by men of genius [Usher, 1954:6]. It can also hardly be coincidence that the inventors of 1750-1875, the entrepreneurs and the contractor engineers tended to appear at the same time [Fig.8] with the new associations [27] and gatherings for a mutual [illegible] especially in the construction industry.

The Industrial Revolution, however faltering and though limited mainly to Britain, was concerned principally with the textile, metal and chemical industries and was confined to cotton, wool and silk mills, iron and engineering works, chemical plants, gasworks, and warehousing. Technical progress had been fairly continuous for at least two centuries and had reached an advanced state of development. The groundwork for the age of the machine tool had been laid [Daumas, Vol.II, 1969:247].

There must have been some important reasons why Britain took the lead, slowly drew away from the other developing countries and forged ahead. The Netherlands was deliberately conservative and possessed no coal [Cipolla, 1979:158]. Germany, in spite of the Hanseatic League [29], became so involved in internal strife [30] that it floundered in the backwaters of European politics. Only

26. As Thomas Carlyle [1795-1881] did writing nearly a century later about his personal heroes. Many biographers were inclined to recognise only a few [Rolt, 1957:Preface], but this is a crude fairytale [Mumford, 1946:109].

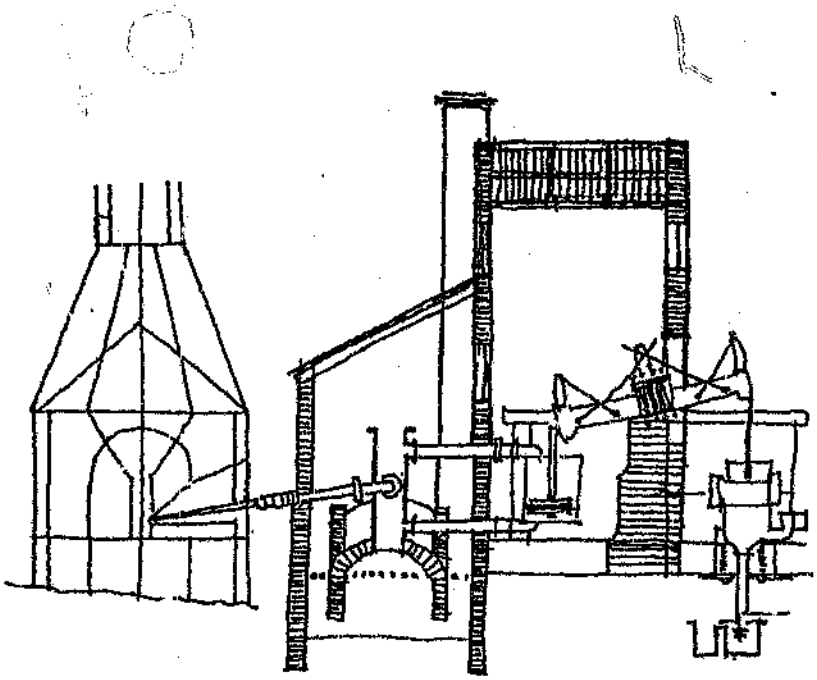
27. In 1768 Architects joined the Royal Academy, in 1771 the Society of Engineers was formed, in 1818 the Institute of Civil Engineers, in 1834 the British Institute of Architects and in 1866 the R.I.B.A.. The Lunar Society of Birmingham was formed with members like Watt, Boulton, Murdock, Priestley and Baskerville.

28. 1763 saw the first exhibition of industrial arts in Paris.

29. Founded by the North German commercial harbour cities from 1280-1670.

30. War of Spanish Succession 1701-14, Great Northern war, 1700-21 and the Polish Succession, 1733.

Fig.9 The arrangement of the blowing-engine | water-blast regulator, tuyeres and furnace was first run with the water wheel and in 1762 it was introduced by Smeaton and in 1765 by Watt [Singer, Vol.IV, 1965:103].



Austria remained powerful until the middle of the eighteenth century. The only powers that possessed a solid foundation [31] were France, England and Spain. Unlike Austria, Spain was little more than an appendage of France after the war of succession [32].

Both France and Britain had the same opportunities, inventiveness, qualifications and ability. Both experienced land reform [33] but France was to exhaust itself [34] and only much later regain some of its former power. The stage was set for British domination in the industrial revolution. Communication was advanced by building canals [35] to carry heavy bulk commodities and their naval domination of the seas made Britain [36] the greatest colonial power [37] of its time. France wasted its capital and had a large bureaucracy. Roads radiating from Paris were built for show and machines were built as toys for a wasteful royal court [Kranzberg, Vol.I, 1967:220].

In Britain massive capital was generated by trade [38] and this was invested in machinery [Fig.9] for further manufacture and agriculture. Interest was kept low and there was no sterile hoarding or luxury consumption. The quality of the workers was good. They were mobile and adaptable, causing rapid urbanisation. However, both Britain and France had a chronic shortage of skilled labour. Britain was blessed with many natural resources such as iron [39] and coal, other minerals like salt and china clay and a humid climate for high finish textiles. Many of the late starters managed to catch up later by leapfrogging over some of the difficult stages Britain had to work through. See p.46 [31].

There was an awareness and interest in the new building development [40] taking place, namely the use of iron as a structural material. The celebrated Iron Bridge, designed by Thomas Pritchard [1723-1777], a Shrewsbury architect, was erected by the third generation Abraham

31. In the future we see some late starters leapfrog some of the stages with borrowed technology e.g. Germany, France and the U.S.A.

32. Austrian Succession, 1740-48 and the Seven Years War, 1756-63.

33. The inauguration of political stability in Britain in 1725 and the Proclamation de la Liberte du Travail in 1791.

34. The French Revolution, 1789-1815, and the Napoleonic Wars 1795-1814.

35. Canals in Britain can be traced from eighteenth century, namely the Mersey to St. Helens canal 1757 and the Worsley to Manchester, 1761. By 1815 2200 canals had been built and 2000 rivers improved for navigation [Jones, 1984:11].

36. As an island Britain was free from invasion and the consequent disruptive warfare. It was relatively small with many small harbours which gave access to the whole country.

37. In spite of losing its American colonies in 1783.

38. Britain had a well ordered Atlantic trade route based on the the tradewinds and currents. Cotton goods were exported to Africa's west coast, slaves to British and American colonies, sugar from the plantations and mollases to New England for rum. All this was reinvested in new cotton mills [Daumas, Vol.II, 1969:247].

39. Many of the minerals were soon depleted and then imported from the various colonies.

40. The new factories for spinning and weaving, originally powered by water, borrowed the term "mill" from corn grinding [Richards, 1958:75].

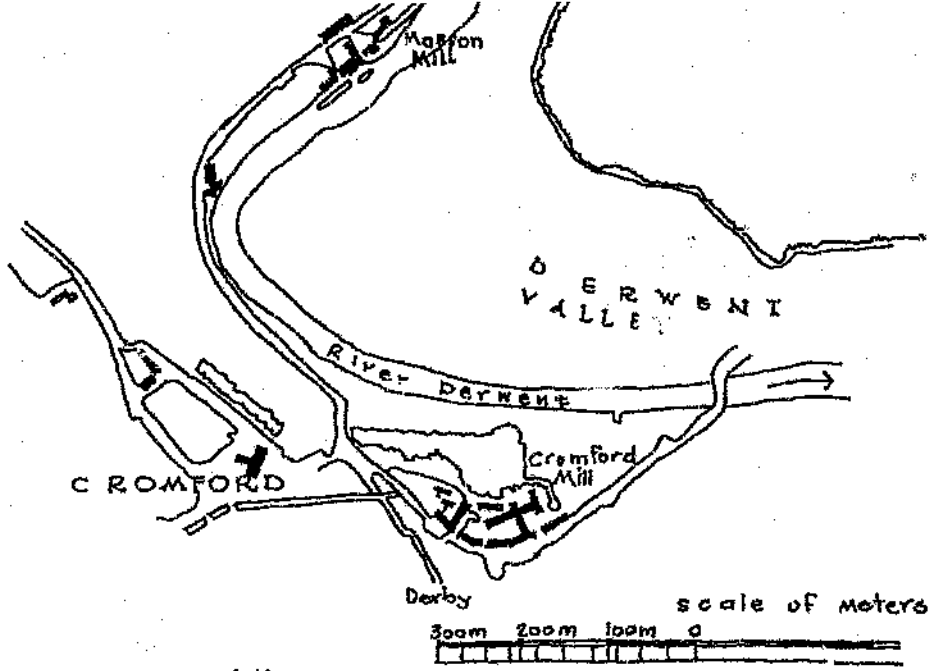


Fig.10 The water for the wheel came from a number of reservoirs draining the lead mines where the water was slightly hotter and less likely to freeze in winter [Shephard, 1987:3].

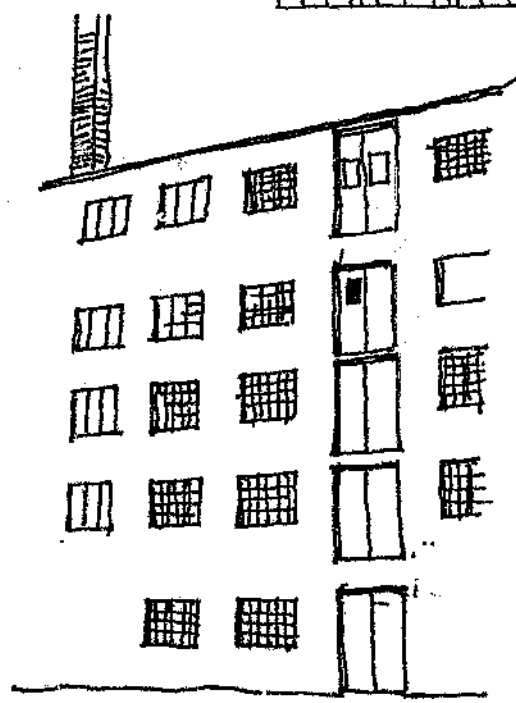


Fig.11 Mullioned windows lit the weaving rooms at the Carlton mill, revealing a link with earlier domestic architecture [Jones, 1984:20].

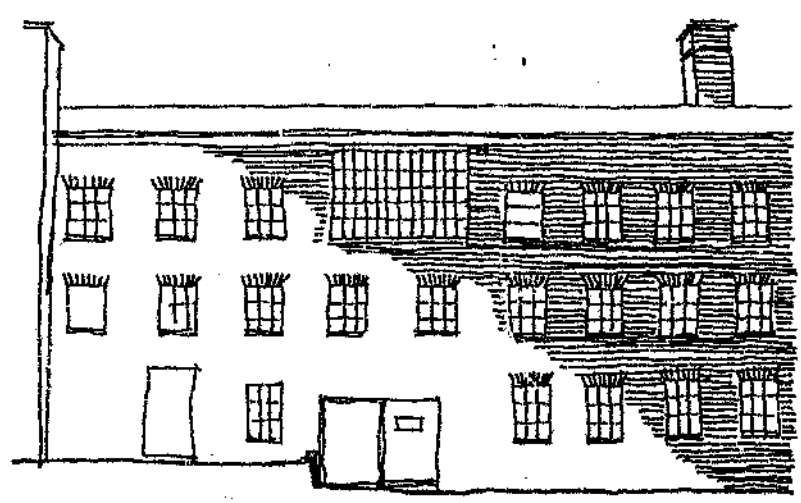


Fig.12 A building undergoing extensive restoration by the Arkwright Society [Jones, 1984:25].

Darby [1750-91] in 1777-81. Only twelve miles away in Coalbrookdale, his grandfather, also Abraham Darby [1677-1717], had smelted and cast iron for half a century [Fig.10]. At the same time Smeaton was using cast-iron shafts and gears.

The Hockley mill which was built in 1769, had four storeys. It was 30 m long, 8,5 m wide and 13 m high, was still driven by horse capstan [Shephard, 1987:5] and facilitated the transition [Fig.11] between domestic and factory production [Jones, 1984:18] [41]. The walls were constructed of brickwork. The ground floor walls were 600 mm wide, those on the first floor 500 mm and the walls on the top floor 400 mm wide. The roof was timber framed, which provided an attic for light spinning machinery, and was covered by slate. The mill was lit by naked flames using an inflammable lubricant and this was a great fire hazard. Patents had been taken out by Watt in 1769, the year that Hargreaves and Arkwright set up some mills in Nottingham [42] where the cotton industry led the way. This was partly because of all the textile fibres cotton proved the easiest to spin by mechanical means [Singer, Vol.IV, 1965:277]. Nevertheless, many non-textile industries and several processes other than spinning cotton, such as the fulling of wool, spinning silk and several stages of linen production, had been mechanised [Jones, 1984:24].

41. The mill was destroyed by fire in 1781 and was restored by Boulton and Watt, who installed a steam engine. It was destroyed again in the 1890s restored and still stands today [Jones, 1984:52].

42. The steam engine as prime-mover was still subject to mechanical breakdowns and erratic motion. In 1772 Smeaton, with the new machine tools, and very little change, improved the engine sufficiently to be quite acceptable.

In 1771 Arkwright, Strutt and Need erected a new cotton mill powered by a water wheel at Cromford [Fig.12]. The construction had masonry walls, a heavy timber floor and a slated roof. The floor was laid with 160 mm x 50 mm boards notched into 400 mm x 250 mm timber beams and approximately 2 600 mm apart.

The main building was 31 m long, 12 m wide, 15 m high and consisted of 5 storeys [43]. The rooms were well lit by 12 wooden sashes, each 1,5 m high and 1,15 m wide

43. 4th Floor 2.4m high
3rd Floor 2.8m high
2nd Floor 2.8m high
1st Floor 3m high
Ground Floor 4m high
[Shepard, 1987:5]

Austria remained powerful until the middle of the eighteenth century. The only powers that possessed a solid foundation [31] were France, England and Spain. Unlike Austria, Spain was little more than an appendage of France after the war of succession [32].

Both France and Britain had the same opportunities, inventiveness, qualifications and ability. Both experienced land reform [33] but France was to exhaust itself [34] and only much later regain some of its former power. The stage was set for British domination in the industrial revolution. Communication was advanced by building canals [35] to carry heavy bulk commodities and their naval domination of the seas made Britain [36] the greatest colonial power [37] of its time. France wasted its capital and had a large bureaucracy. Roads radiating from Paris were built for show and machines were built as toys for a wasteful royal court [Kranzberg, Vol.I, 1967:220].

In Britain massive capital was generated by trade [38] and this was invested in machinery [Fig.9] for further manufacture and agriculture. Interest was kept low and there was no sterile hoarding or luxury consumption. The quality of the workers was good. They were mobile and adaptable, causing rapid urbanisation. However, both Britain and France had a chronic shortage of skilled labour. Britain was blessed with many natural resources such as iron [39] and coal, other minerals like salt and china clay and a humid climate for high finish textiles. Many of the late starters managed to catch up later by leapfrogging over some of the difficult stages Britain had to work through. See p.46 [31].

There was an awareness and interest in the new building development [40] taking place, namely the use of iron as a structural material. The celebrated Iron Bridge, designed by Thomas Pritchard [1723-1777], a Shrewsbury architect, was erected by the third generation Abraham

31. In the future we see some late starters leapfrog some of the stages with borrowed technology e.g. Germany, France and the U.S.A.

32. Austrian Succession, 1740-48 and the Seven Years War, 1756-63.

33. The inauguration of political stability in Britain in 1725 and the Proclamation de la Liberte du Travail in 1791.

34. The French Revolution, 1789-1815, and the Napoleonic Wars 1795-1814.

35. Canals in Britain can be traced from eighteenth century, namely the Mersey to St. Helens canal 1757 and the Worsley to Manchester, 1761. By 1815 2200 canals had been built and 2000 rivers improved for navigation [Jones, 1984:11].

36. As an island Britain was free from invasion and the consequent disruptive warfare. It was relatively small with many small harbours which gave access to the whole country.

37. In spite of losing its American colonies in 1783.

38. Britain had a well ordered Atlantic trade route based on the the tradewinds and currents. Cotton goods were exported to Africa's west coast, slaves to British and American colonies, sugar from the plantations and mollases to New England for rum. All this was reinvested in new cotton mills [Daumas, Vol.II, 1969:247].

39. Many of the minerals were soon depleted and then imported from the various colonies.

40. The new factories for spinning and weaving, originally powered by water, borrowed the term "mill" from corn grinding [Richards, 1958:75].

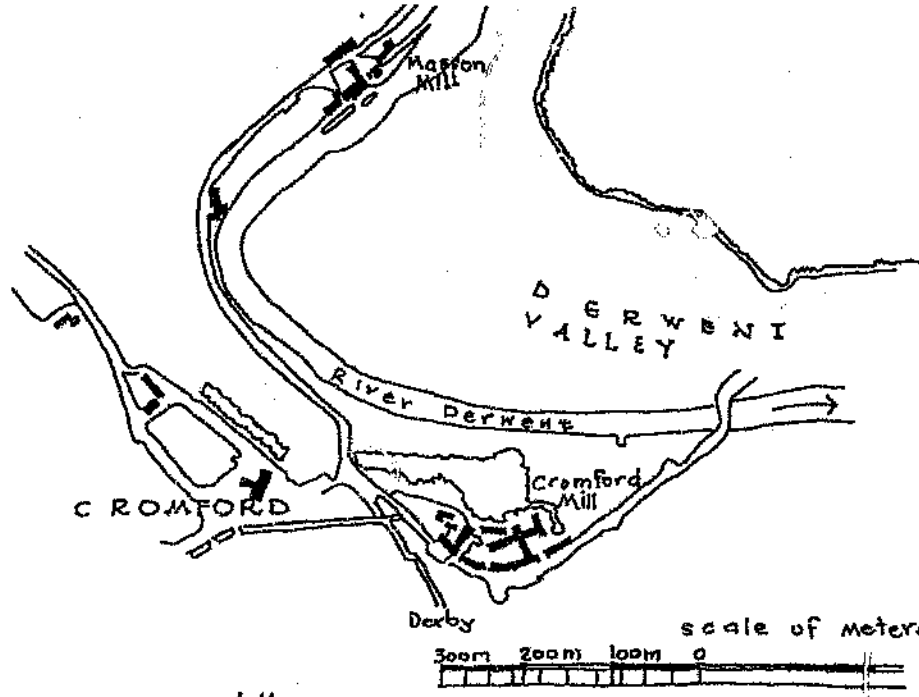


Fig.10 The water for the wheel came from a number of reservoirs draining the lead mines where the water was slightly hotter and less likely to freeze in winter [Shephard, 1987:3].

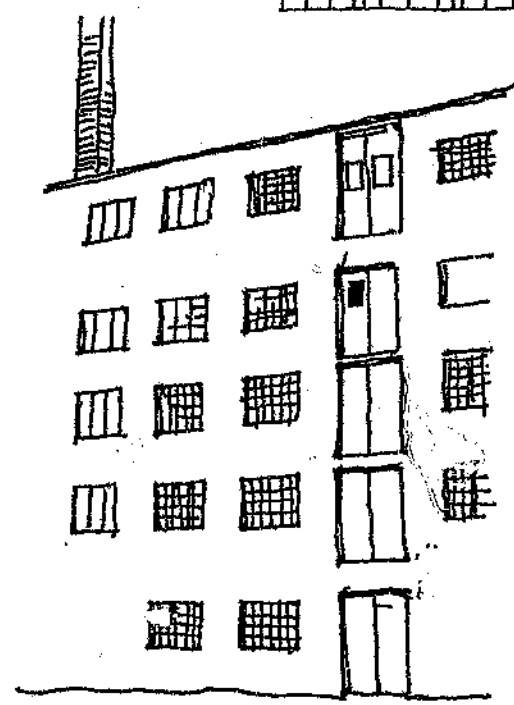


Fig.11 Mullioned windows lit the weaving rooms at the Carlton mill, revealing a link with earlier domestic architecture [Jones, 1984:20].

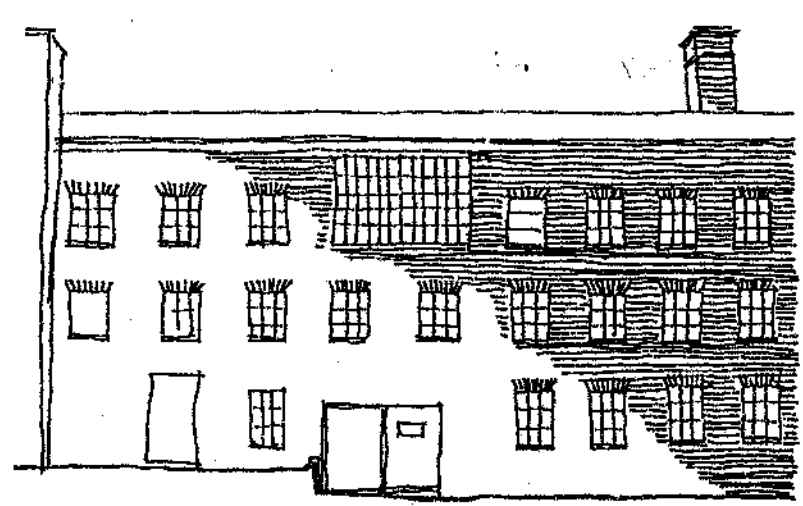


Fig.12 A building undergoing extensive restoration by the Arkwright Society [Jones, 1984:25].

Darby [1750-91] in 1777-81. Only twelve miles away in Coalbrookdale, his grandfather, also Abraham Darby [1677-1717], had smelted and cast iron for half a century [Fig.10]. At the same time Smeaton was using cast-iron shafts and gears.

The Hockley mill which was built in 1769, had four storeys. It was 30 m long, 8,5 m wide and 13 m high, was still driven by horse capstan [Shephard, 1987:5] and facilitated the transition [Fig.11] between domestic and factory production [Jones, 1984:18] [41]. The walls were constructed of brickwork. The ground floor walls were 600 mm wide, those on the first floor 500 mm and the walls on the top floor 400 mm wide. The roof was timber framed, which provided an attic for light spinning machinery, and was covered by slate. The mill was lit by naked flames using an inflammable lubricant and this was a great fire hazard. Patents had been taken out by Watt in 1769, the year that Hargreaves and Arkwright set up some mills in Nottingham [42] where the cotton industry led the way. This was partly because of all the textile fibres cotton proved the easiest to spin by mechanical means [Singer, Vol.IV, 1965:277]. Nevertheless, many non-textile industries and several processes other than spinning cotton, such as the fulling of wool, spinning silk and several stages of linen production, had been mechanised [Jones, 1984:24].

41. The mill was destroyed by fire in 1781 and was restored by Boulton and Watt, who installed a steam engine. It was destroyed again in the 1890s restored and still stands today [Jones, 1984:52].

42. The steam engine as prime-mover was still subject to mechanical breakdowns and erratic motion. In 1772 Smeaton, with the new machine tools, and very little change, improved the engine sufficiently to be quite acceptable.

In 1771 Arkwright, Strutt and Need erected a new cotton mill powered by a water wheel at Cromford [Fig.12]. The construction had masonry walls, a heavy timber floor and a slated roof. The floor was laid with 160 mm x 50 mm boards notched into 400 mm x 250 mm timber beams and approximately 2 600 mm apart.

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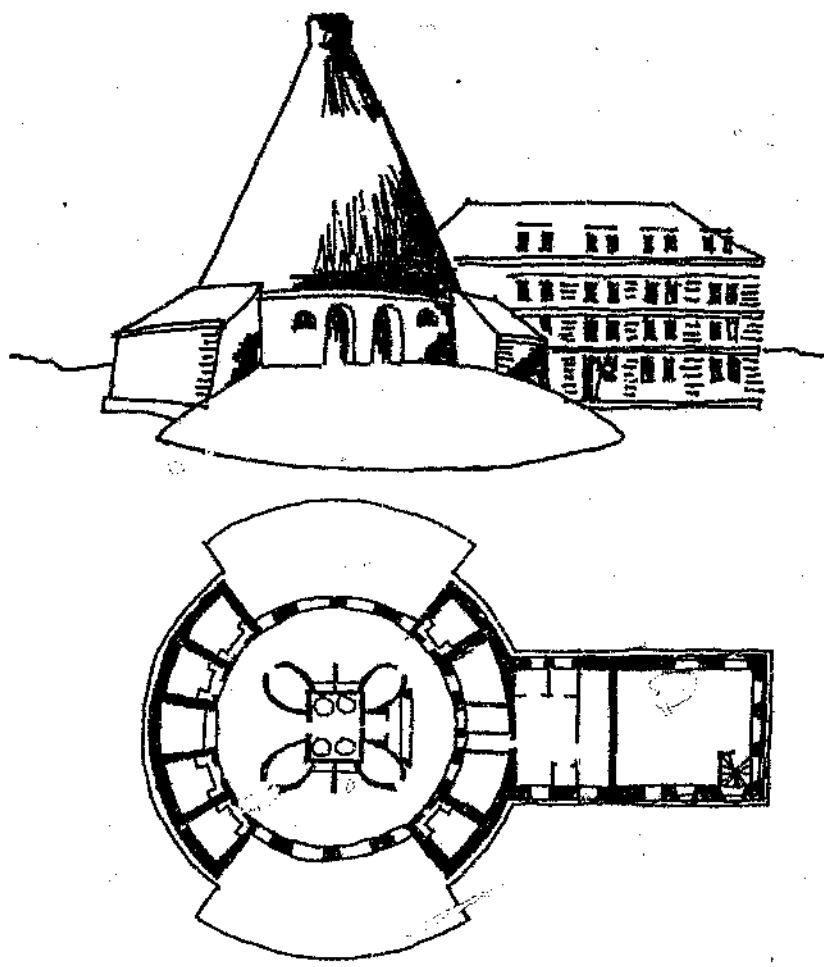


Fig.13 English type glass-house which was constructed in 1772 and based on a patent granted in 1734 to Humphrey Perrot of Bristol. It was a cone-shaped glass-house where the concentration of air currents was introduced in one single movement [Singer, Vol.III, 1965:227].

with splayed reveals and segmented arched heads. Local stone and brick were used functionally and traditionally. The buildings were essentially utility buildings in which the expenditure was concentrated on strength and wide floorspans. The fabric was protected against the rough treatment by means of hard material plinths and doorframes and granite bollards against the corners. There was a tone and colour contrast between the white-washed walls, the painted constructions and heavily battened woodwork which contributed to its robust but lively quality. There was a generic architectural character reflected in the powerful rectangular outlines and gable ends which ofter supported cranes and hoists [Richards, 1958:25].

Three basic types of cotton factory emerged in Britain between 1770 and 1790. In the small factory a horse capstan was still used to drive carding machines and it contained hand-operated jennies and mules [44] while the medium sized spinning mill, which was 3 to 4 storeys high, 25 m long and 8 m wide, was powered solely by water [45] and modelled on the Arkwright water frame mill. Finally the steam powered spinning mill, which contained up to 3 000 spindles [46], was developed. The various construction dimensions were determined more by the requirements of operation than by architectural or structural considerations [Jones, 1984:34]. The width of building was for example determined by the need to provide window light in a northern English climate. Mills were not the only factories to be erected. The manufacture of glass had been radically transformed [47] in England. English [48] lead glass was favoured by the Dutch engravers, but more important was the manufacture of cut glass [Fig.13]. The first cast glass was produced in France in 1688 and in 1776 the Huguenots introduced cast plateglass [49] to England.

44. These factories cost approximately £1000.00 at the time. They were situated mostly in the English Midlands where 55 factories had been erected [Jones, 1984:24].

45. Approximate cost £3000.00 and mostly situated north of England. By 1795, 75 were erected.

46. Approximate cost £10 000.00, 50 were erected mostly in Scotland's Clyde Valley where coal was available [Jeremy, 1981:15].

47. In 1615 the use of wood for firing glass-furnaces was prohibited and coal had to be used.

48. Glass had been produced from 2500 BC in the Near East and Egypt, in Greece from 1200 BC and Rome from 300 BC. The revival of glass-making skills in Europe came by way of Venice during the seventh century.

49. Cylinder blown by compressed air, split, and lain on an iron table and allowed to flatten under its own weight.

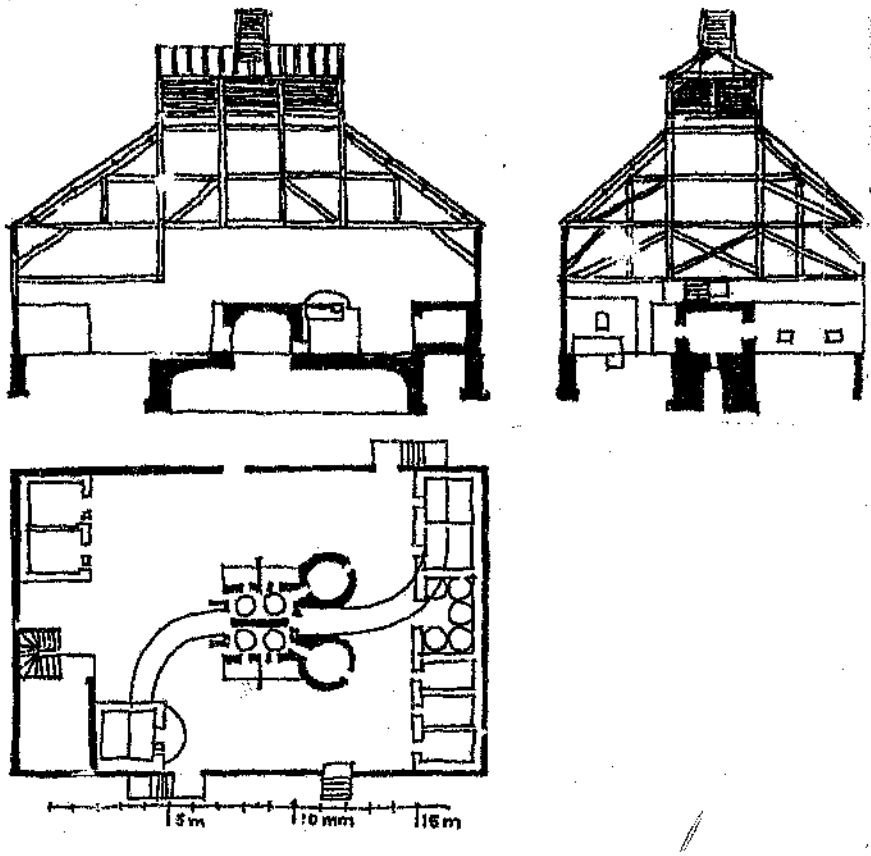


Fig.14 A London bottle-glassworks designed by Swedish Architect C W Carlberg in 1777-8 with an appealing and innovative lantern-light type of roof for smoke extraction [Singer, Vol.III, 1965:222].

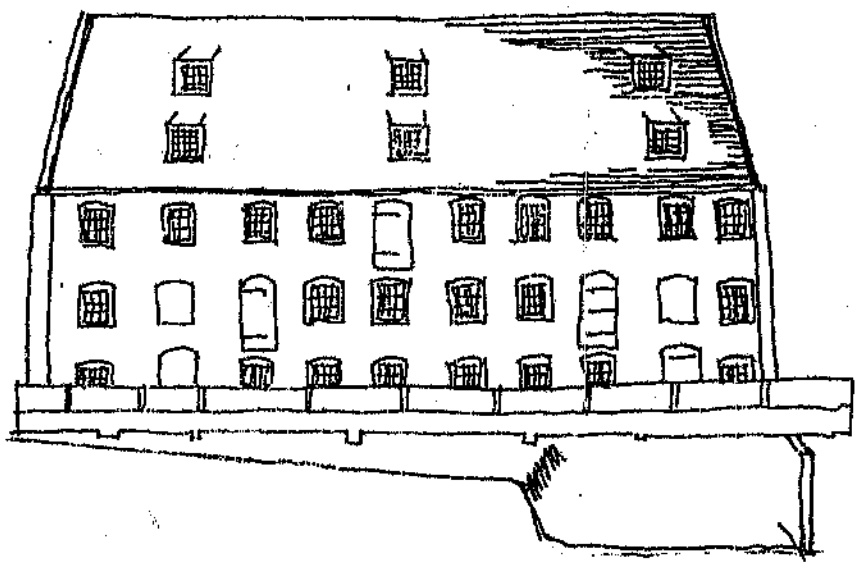


Fig.15 Bromley-by-Bow astride the River Lea, House mill was built in 1776 and used for malt distilling. It had brick in front, was weather-boarded at the back with a slate roof and was fed by four undershot waterwheels [Jones, 1984:16].

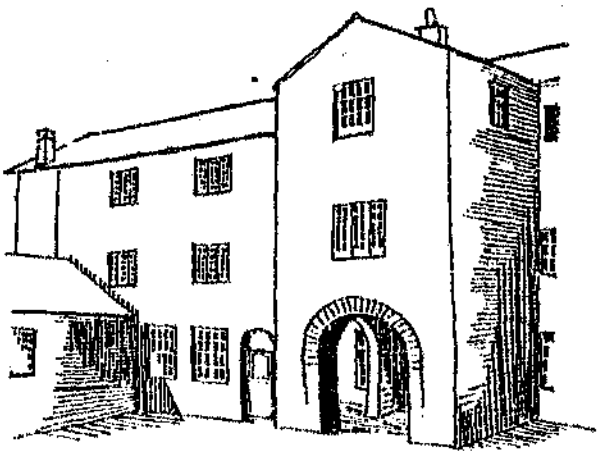


Fig.16 Higher mill, 1778, at Helmshore south of Haslington, was a water-powered fulling mill [Jones, 1984:15].

The manufacture of crown window glass entailed an elaborate process of heating and reheating, blowing, blowing after rolling and rapid rotation which caused a flash into a flat dish. The sheets were always small and the crowns could only be used domestically [Fig.14].

As machines were being used more frequently, the manufacturers [50] began to think about layouts to obtain their maximum use. In a continuous production line of cotton textile, various activities became centralised under one factory roof. Great attention was paid to the co-ordination and control of inter-related activities. With the use of centralised, heavy power-driven machinery it became paramount that an holistic view had to be taken of site planning, co-ordination of machines, materials, men [51] and capital. Men also had to be disciplined and there had to be a greater division of labour under central supervision [George, 1968:52].

50. Sir Richard Arkwright was neither engineer nor merchant, but an organiser of production [Jones, 1984:24].

51. Adam Smith [1729-1790], who wrote "An Inquiry into the Nature and Causes of the Wealth of Nations" [1776].

To illustrate the transition of the water mill, two examples from the second half of the eighteenth century can be used. Their external design was not affected by architectural theory and reflected a relatively small-scale traditional style, namely solid brick [Fig.15] and stone [Fig.16] walls and minimal architectural embellishments pierced by small-paned mullioned windows [52]. They were presumably designed by the local millwrights and could even pass as restrained residences [Jones, 1984:16]. In terms of practical operation and external appearance, these local millwrights [53] could only call upon their regional or domestic vocabulary.

52. The maximum dimensions were determined by the strength of the waterwheel or engine. This, in turn, limited the operation. Fear of weak walls controlled the sizes of windows and the whole was based on the domestic scale.

53. Having an empirical training without the means to undertake a grand tour or obtain classical learning.

These mills did not attract attention or pioneer innovations in external appearance, but were seminal in their structural advances. The placing of a palladian gable, often brought forward slightly, a few venetian-type rounded or segmented windows and the provision of a simple bell cupola, sometimes with a clock that rang the shifts, could

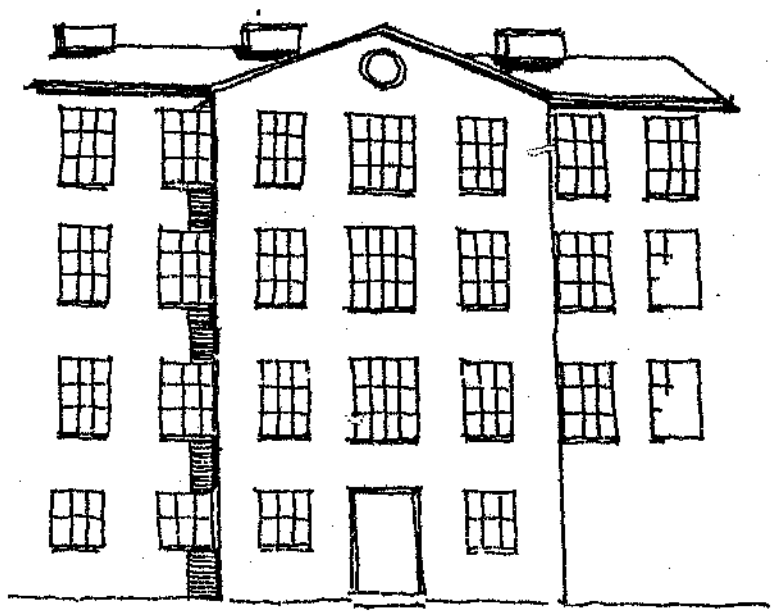


Fig.17 Carlton mill was erected in 1780 and consisted of four floors, a three-bay pediment with lunette and regular windows except in the middle to accentuate the details [Jones, 1984:26].

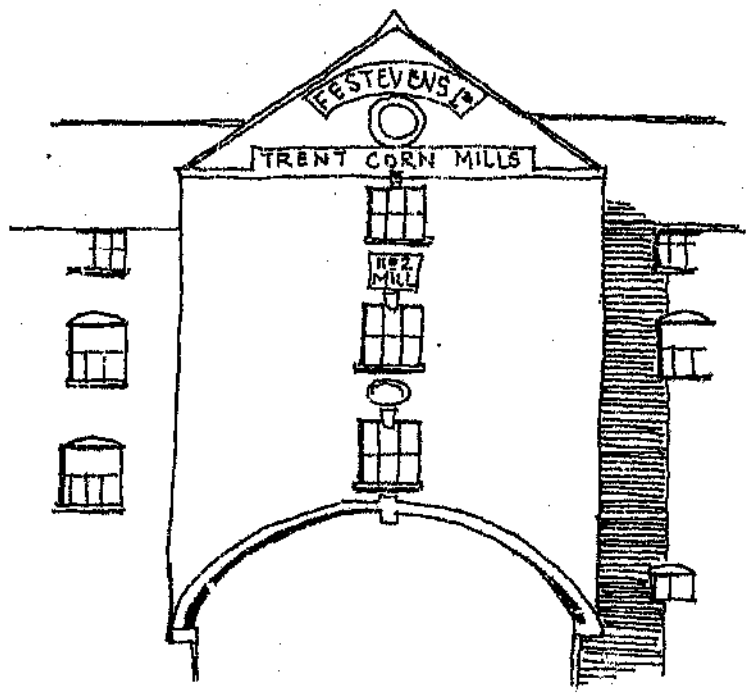


Fig.18 A red brick corn mill at Sherdlow, Burton-on-Trent built in 1780. It may, however, originally have been a warehouse. The wide arched opening resembles the covered loading docks common in canal warehousing [Richards, 1958:124].

hardly be called major architectural features. In a sense the owners [54] were the pioneers in the venture and with broad practical skills they often built the mills for themselves. The architect, if employed at all, nearly always occupied a subsidiary role and was commissioned merely to design a suitable facade [Fig.17] or advise on decorative detail. This did not seem to disturb the architects, because they generally considered it beneath their dignity and most felt that they should not even be associated with such work [Jones, 1984:34]. It is pleasing to note that a sane and level-headed tendency prevailed in most instances and that factory buildings remained relatively unadorned [55] even as they became larger and increasingly prominent.

54. Arkwright at Cromford, the Strutts at Belper and Gutt at Beauling [Jones, 1984:45].

55. Monumentality only later evolved into a pluralism of styles which became the obsession of the Revivalists of the ninteenth century, and it took a century for the desire for a truly modern style to emerge in the 1880s [Jones, 1984:28].

These water mills were the prototypes of warehouses with massive timber construction and clear spanning storage lofts often serviced by hoists cantilevered [Fig.18] directly over the canal [Guedes, 1979:101].

Industrialists found themselves able to handle large masses of energy to an extent not conceived of in the preceding age. With the development of large water wheels [56], mitre gears and heavy cast-iron vertical and horizontal shafts, rectangular buildings of 4 to 5 storeys high [57] and sometimes as low as 2,4 m were erected. Because of the frugal nature of the northern Englanders, no space was wasted by using excessive building material [58].

56. Up to 5 m in diameter and made of iron.

57. The ceilings were low as the machinery required no great headroom.

58. It was cheaper to heat smaller rooms.

These rectangular masses were piled one above the other and followed the river slopes of the grey northern countryside. It was a triumphant achievement and gave confidence to the Industrial Revolution. Designs displayed the forthright but highly adaptable spirit of the functional tradition [Richards, 1958:21]. It was an era which produced some of the most beautifully proportioned buildings ever designed. The emphasis was on basic geometry rather than on the ritual of historical styles and

Fig.19 The buildings clustered along the Serpent in North England. The workers experienced fairly good living and working conditions, but because of long hours had little personal freedom [Risebero, 1979:184].

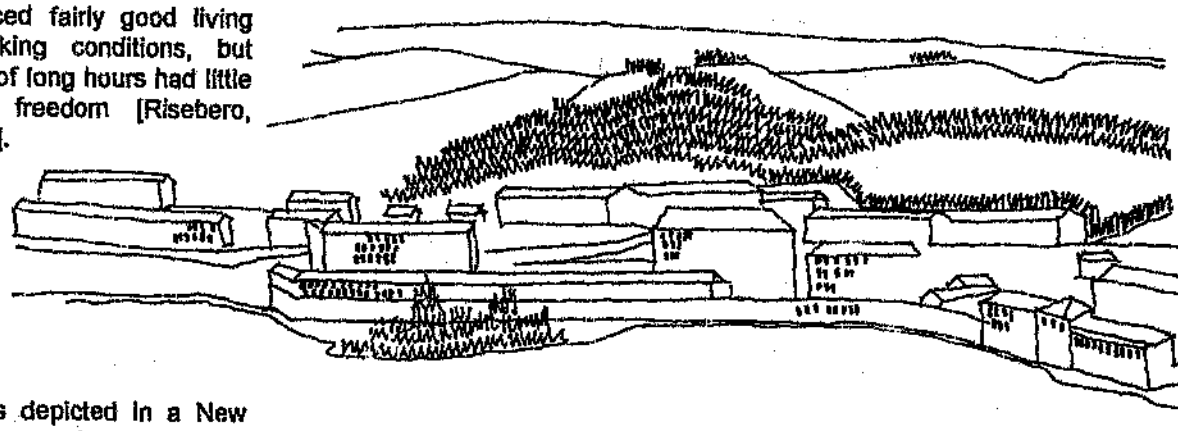


Fig.20 As depicted in a New London magazine in June 1790. Note the barge about to enter the central shipping channel from the Thames [Jones, 1984:24].

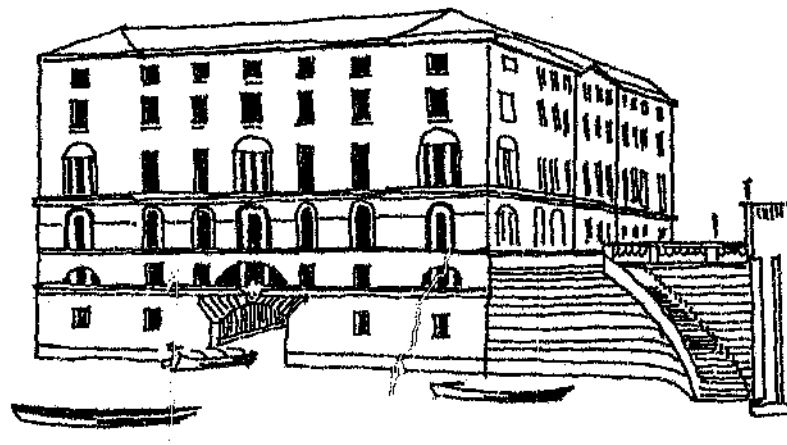
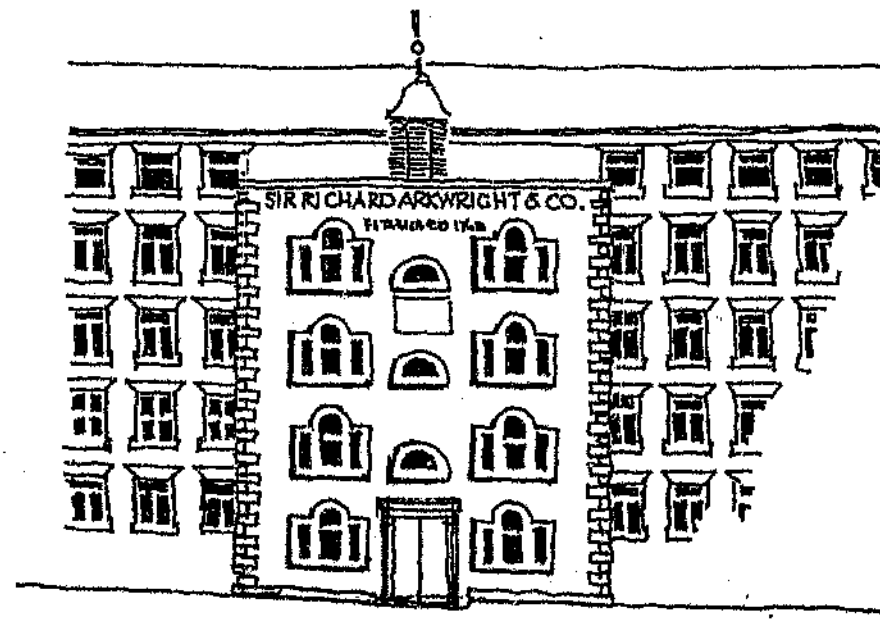


Fig.21 Note the attention paid to the detailing [Richards, 1956:75].



materials were used mostly for their strong intrinsic value [Fig.19].

The first all-steam powered corn mill erected [59] and demonstrated [60] by Watt at Blackfriars, London, meant that in future the mill or factory could be located close to the raw material, transportation, markets or coal, rather than be tied to water flows. These engines could not be developed until [61] sheet and rod iron was available. To the modern eye they appear as pitiful, clumsy bits of ironmongery [62].

The Albion Mill [Fig.20], which was designed and managed by Samual Wyatt [1737-1807], illustrates the palladian principles which were applied to a working building. It was a well-proportioned structure of some architectural merit. It had a rusticated stone basement with a central entrance off the river for the delivery of grain and coal by barge. The ordered facade of five storeys featured a variety of symmetrical windows. The exterior did not betray the purpose or structure of the building and it could have passed for the substantial town house it mimicked.

Behind this conventional Georgian facade the mill was a particularly large [63] example of an internal-framed timber building [64]. The concept foreshadowed a load-bearing skeleton framework for which the walls provided little more than protective cladding.

One of the more ornate and elaborate of the earliest textile mills [65] was the Masson mill [66], constructed in 1783. Situated in the picturesque valley of the Derwent south of Matlock [Fig.21], its design was a naive version of Georgian architecture. This concern for appearances manifested itself more on the outer surfaces through simplified venetian and semi-circular windows in a regular pattern beneath a bell cupola. The workers lived across the road in three-storeyed cottages [67].

59. The Albion mill in 1786 and, at the same time, the first steam spinning mill [Jones, 1984:52].

60. A huge 50 hp double-acting rotative engine with parallel motion was developed in 1786. The waterwheel had been doing this for close on 400 years [Shephard, 1987:8].

61. Sheet iron in 1728 and rolled rods and bars in 1783 [Wells, 1972:801].

62. Furnaces in Britain were built as follows:
1760 x 17 coker-furnaces
1775 x 31 coker-furnaces
1790 x 81 coker-furnaces
and of the 106 blast furnaces, at least half were in the Midlands [Singer, Vol.IV, 1965:103].

63. The mill constructed in 1783 was 52 m long and 39 m wide [wider than normal due to use of the Argand oil lamp invented in 1784] and the parapet was 20 m high [Jones, 1984:24].

64. The mill was destroyed by fire in 1791 [Shepard, 1987:8].

65. By this time Richard Arkwright, inventor industrialist had a capital of £200 000.00 and employed 5000 persons. He was knighted 1786.

66. Boulton and Watt rotary motion engine - one of 500 produced on Watt's patents.

67. This mill employed 150 men, 300 women and 700 children. The younger children were kept in daycare by the older women.

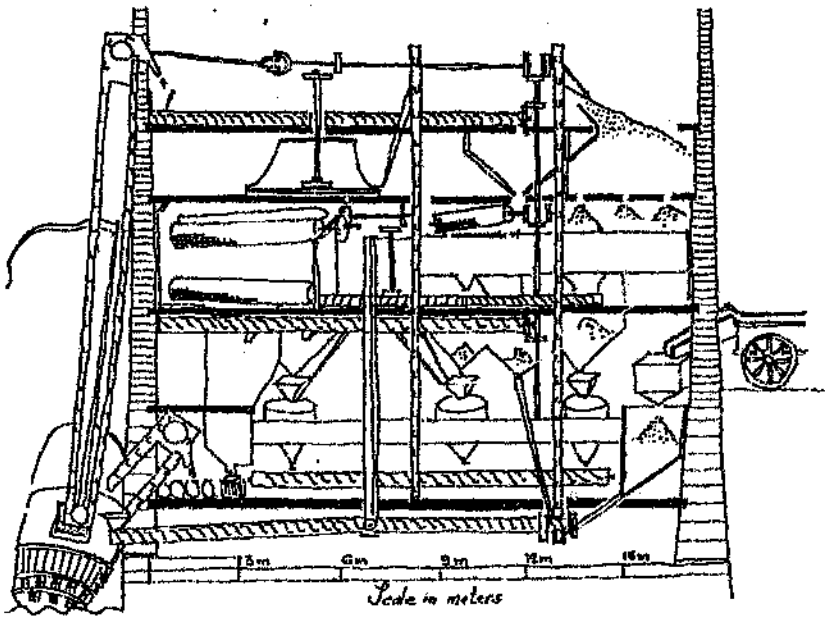


Fig.22 Shortage of labour stimulated early attempts at automation in the USA. Corn was lifted with bucket elevators and processed by gravitation and transverse screw conveyors [Drury, 1980:5].

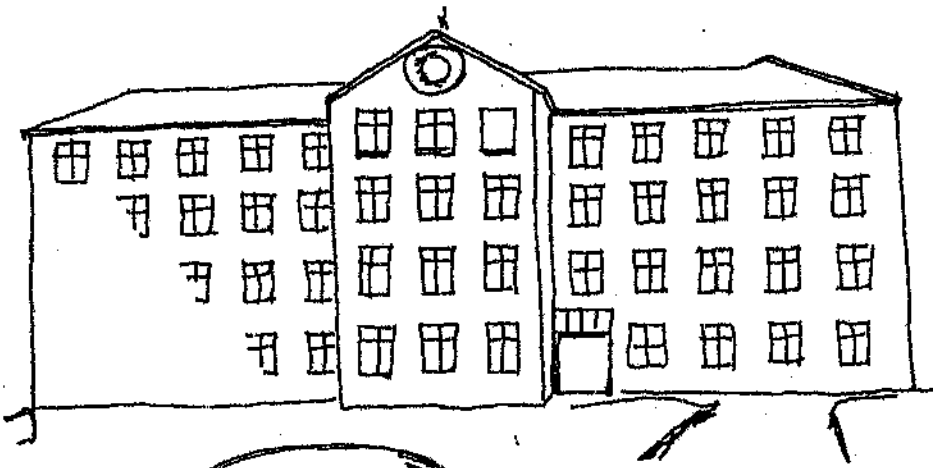


Fig.23 Frost's mill, 1785 at Park Green, Macclesfield, was originally powered by a water wheel From 1811 it was steam driven and electrified in 1914 [Jones,1984:34].

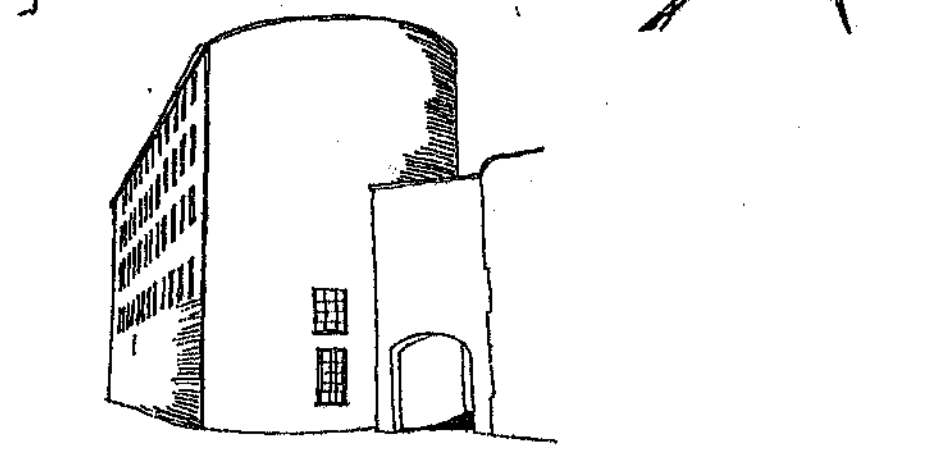


Fig.24 The Arkwright mill at Cromford, erected in 1785, was designed to resist attack by unemployed handloom operators, who became desperate as more and more mills were constructed [Jones,1984:44].

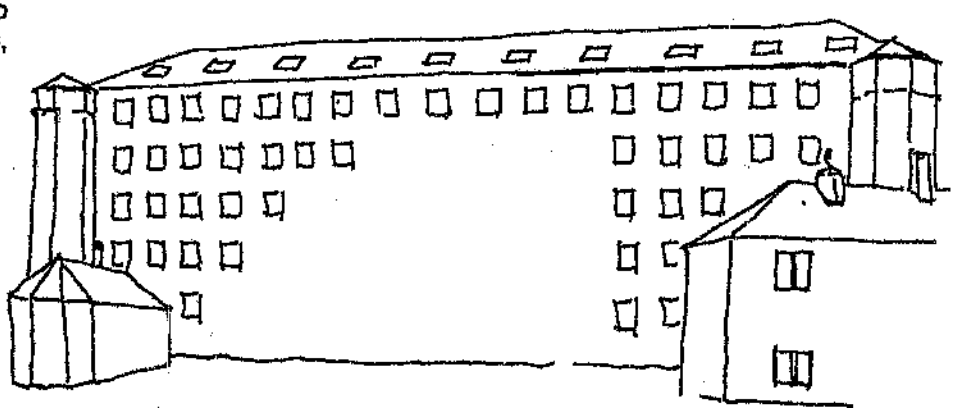


Fig.25 The Calver mill was six storeys high. The turrets at each corner of the main building were probably designed for bales of cotton to be dropped down [Richards, 1958:90].

There were not many mills erected in the United States of America [68] and Europe at this time. One of the most advanced factories in the USA, where labour-saving techniques were already a common concern, was a totally mechanised grain mill [Fig.22] at Redley Creek, Philadelphia. All the products were handled by mechanical power [69], from the unloading of barges off the canal through the flour-making mill to the filling of the bags at the end [Guedes, 1979:98]. All the products were handled by a system [70] of chain bucket conveyors, chutes, screws and other devices.

Large profits arose from cotton manufacture which enabled proprietors to build mills, some of them considered to be of colossal industrial [71] dimension. Most of these mills were still square brick buildings without any pretensions to architectural form or character [Fig.23]. The elevations were of regular fenestration, relieved only by a projecting bay topped with a clock pediment [Jones, 1984:34]. As the mills increased in size, the handloom weavers objected to these mills. Riots took place and attempts were made to destroy the mills. Not to be outdone, Arkwright constructed a mill at Cromford [72] in the shape of a fortress square, [Fig.24] with lower floors that had no external windows [73].

The puddling process had been developed [75], but wrought iron was still too expensive to use in industrial buildings. The earliest buildings to employ wrought iron were markets and glass-houses.

The first cast-iron columns were used in a factory at Calvermill [76] where timber beams and flooring with load-bearing brick walls were still used. This was an attempt to reduce the fire risk so inherent in the cotton industry. The columns were part of the interior construction and the exterior [Fig.25] remained the same, namely built of stone. Even though cast-iron became more frequently used on the

68. The War of Independence 1775-83, was over and trade with the former colony accelerated.

69. Designed by Oliver Evans [1755-1819] and driven by a waterwheel. From 1790 it was driven by high-pressure steam engine based on the Trevithick engine.

70. Evans published "Young Millwright and Millers Guide" which was used by Thomas Telford [1757-1834] as an example.

71. Compare this with St Paul's Cathedral, London which was more 120 m high and built nearly a century earlier from 1675 to 1710.

72. At Ratigen Dusseldorf Johann Gottfried Brügelmann [1750-1802] designed a four storeyed five bay mill based on Arkwrights plant and called it Cromford [Pevsner 1976:284].

73. There were about 5000 cotton weavers in Manchester and a power loom could do the work of three. Later Jerediah Strutt [1726-97], former partner of Arkwright, inspired the building of non-combustible factories [Jones, 1984:45].

75. Henry Cort [1740-1800] was called the Father of the Iron Trade for processing pig iron to wrought iron. Smelting iron ore at Le Creusot in France was only successful in the 1790's [Singer, Vol.IV, 1965:104].

76. In Derbyshire, 1785, the columns were slender and now machines were placed on all floors not only in the attic as before [Giedion 1959:120].

Fig.26 The New Lanarkwas constructed by Arkwright and then Robert Owen, who turned it into a model industrial community [Drury, 1980:1].

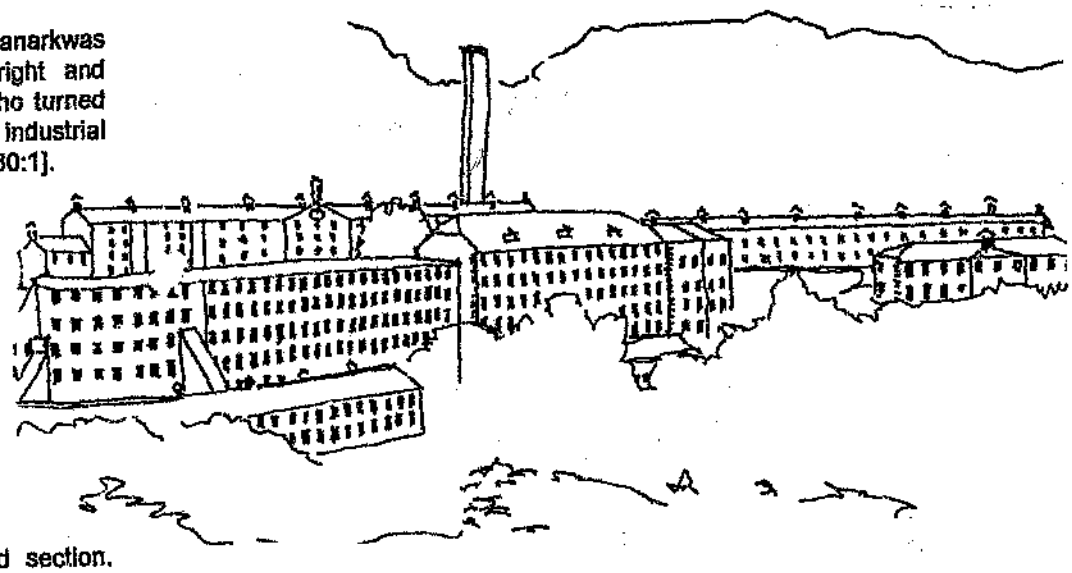
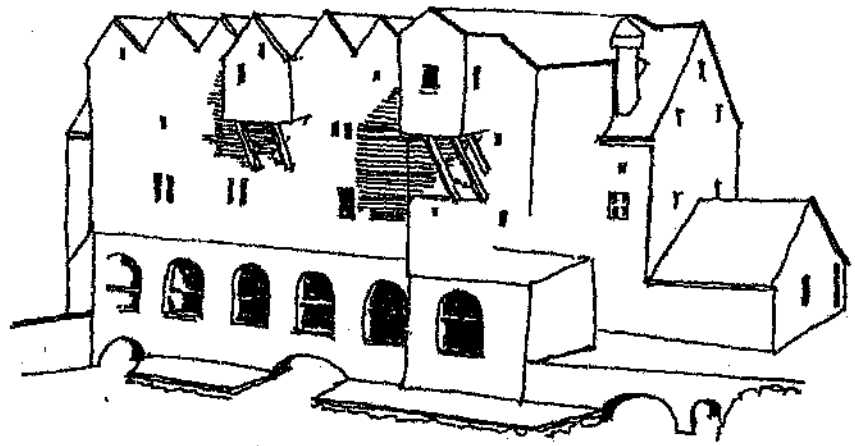
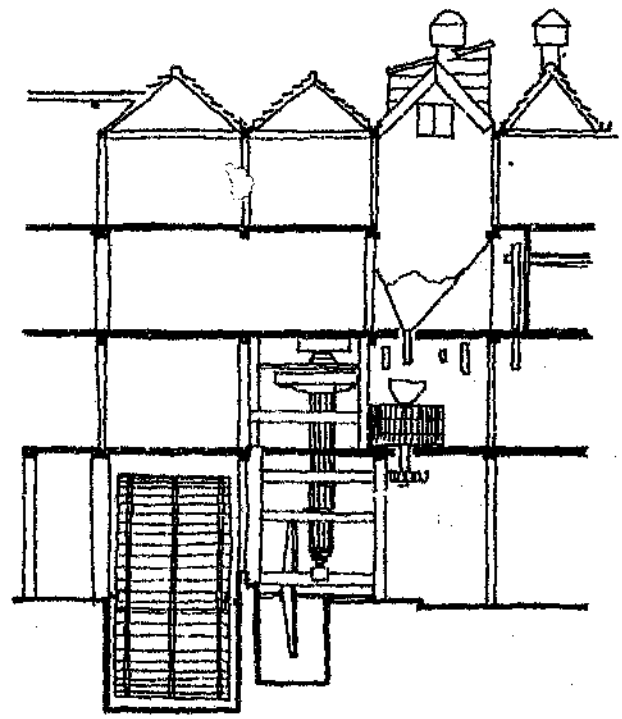


Fig.27 Elevation and section. It had weatherboarded upper floors and on groundfloor a solid structure. In this section, note how the water flowing under the mill turns the 5 m breast wheel, which in turn drives the vertical timber shaft and the mill stones [Winter, 1970:13 and 20].





interior, it did not change the exterior [77], where a splendid scale evolved. When placed in perspective an almost savage grandeur developed [Fig.26]. The spaces between buildings were hardly ever landscaped in an attempt to humanise them. Space was valuable and circulation complicated.

77. The mature and common sense of Gothic Architecture now reached the end of the eighteenth century. To be overcome by the rigid and codified discipline of the classical style and the formulas of Neoclassicism was even more inhibiting. The Gothic Revival swept all this away.

It was thought that the aesthetic answer lay in the layout namely attaining a semblance of order and unity using generic forms for specific uses.

[illegible] all mills were constructed of stone. Regional building styles combined with the use of local material in this case timber framing and weatherboarding, produced a pleasing structure at Horstead, Norfolk [78], in 1789. This was a practical building with charm and distinctiveness [Fig.27] that owed much to the accumulated abilities of local craftsman and the fortunate provision of appropriate materials.

78. A similar structure was erected at Old Mill, Essex.

The Industrial Revolution was now irreversibly underway, with technological advancement relentlessly creating a tradition of functionalism [79]. The evolution of successive styles was sometimes dominant and sometimes recessive [Jones, 1984:222] and buildings became quite large. The handweavers in their cottages were being drawn into the industrial environment and were being concentrated, with water wheels providing power which was sufficiently strong to drive the new weaving, fulling and carding machines. Steam was in its infancy and engines were not reliable in any way. There was some attention paid to the layouts [80] and the mov[illegible]ont of material, while Wedgewood [81] assigned workers to a post where they worked at one task only.

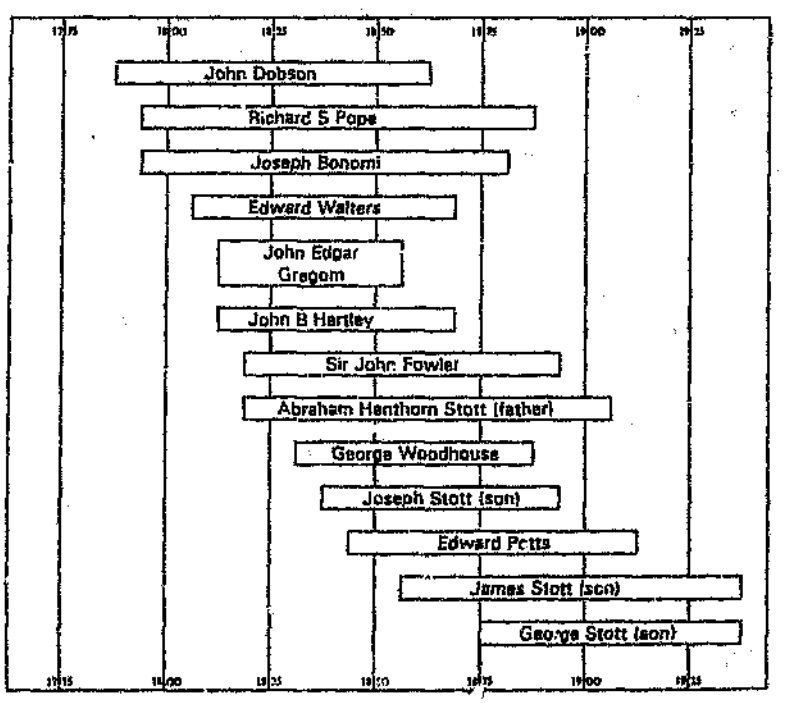
79. Severely practical structures as functional as peleolithic caves, Roman Forts and aquaducts and medieval castles [Blake, 1958:98-103].

80. Thomas Jefferson [1743-1826] called attention to the concept of interchangeable parts in 1785.

81. Josiah [1] Wedgewood [1730-1795] introduced specialisation and work divided into departments.

The stimulating atmosphere created principally in Britain is reflected in the inventiveness of its entrepreneurs.

Fig.1 The earliest recorded modern industrial architects appear to be those practicing in the Midlands [Author].



CHAPTER FIVE : MILL BUILDINGS

Man found himself able to handle great masses of energy to an extent inconceivable in the preceding bucolic age.
[Cipola, 1979:156].

There had never been a single evolutionary modern movement until the emergence of the Industrial Revolution and its industrial buildings. There had been several movements [1] since man first settled into hamlets and towns [2] and the whole of the architectural scene had been and was to be dominated by a pluralism based on these previous styles.

As architecture evolved in the eighteenth and nineteenth centuries, this eclecticism became an obsession of the revivalists [3] and nearly a century elapsed before the desire for a truly modern style emerged and prefaced the architecture of the early twentieth century. The leading architects [4], even of the later period, avoided industrial work and it is quite possible that the standard of design of industrial structures may in some way have suffered as a result [Jones, 1984:220]. Commentators like Ruskin and Pugin [5] argued that buildings should reflect the developing archaeological and religious interest of the early nineteenth century which had manifested itself in a spate of Gothic churches. They gave the movement a moral and intellectual purpose. At the same time Goethe and Schelling [6] were examining Newton's theory of colours and proposing a philosophy of nature in which the hand, eye, mind and spirit would all be united [7].

Generally the Victorian architects believed that ornaments and fine materials should be reserved for churches, palaces and buildings of state. There were however, a number of architects [8] who accepted commissions for mills and other industrial buildings [Fig.1].

1. Greek, Roman and Islamic movements and styles, together with their Renaissance, were principally sectarian. The modern movement had an unadorned technological style [Mumford, 1940:405].

2. Some 8000 years ago.

3. Mimetic ornamentation is decoration merely applied with no reference to the use of the building or structure [Jones, 1984:35].

4. Sir John Soane [1753-1837], The Bank of England 1778; Sir Charles Barry [1795-1860], Houses of Parliament [1840-1860]; William Butterfield [1814-1900] over 100 churches; Sir George Scott [1811-1878]; George Edmund Street [1824-1881] and even Sir Edwin Lanseer Lutyens [1869-1944]. Between them they did not design one factory or warehouse.

5. John Ruskin [1819-1900], and Augustus W N Pugin [1812-1852] were champions of the Gothic Revivalists [Pevsner, 1960:626].

6. The poet Johann Wolfgang von Goethe [1749-1832] and the philosopher Friedrich W. J. von Schelling [1775-1854] [Gardner, 1967:15].

7. Once the conviction of intellectual honesty and moral rectitude of the Gothic revival lapsed, the movement degenerated into a simple stylistic revival.

8. The Stott family of architects, their predecessors and contemporaries [Jones, 1984:219].

Fig.2 Broadclough Mill at Bacup which was designed in 1791. Although small in scale, it showed a concern for appearance and reflected Palladian principles [Jones, 1984:31].

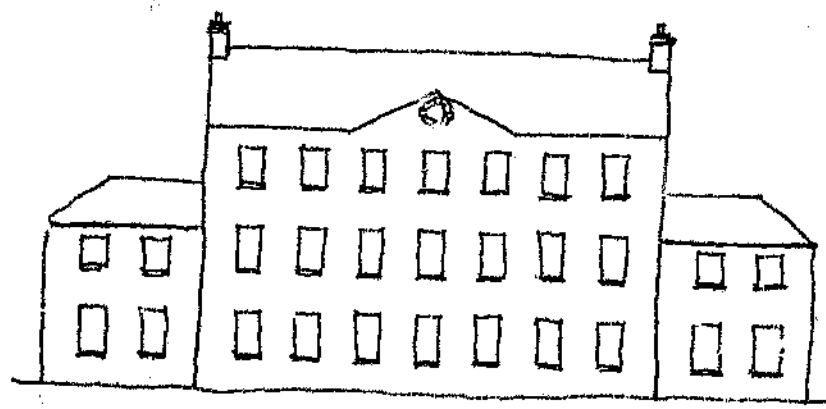
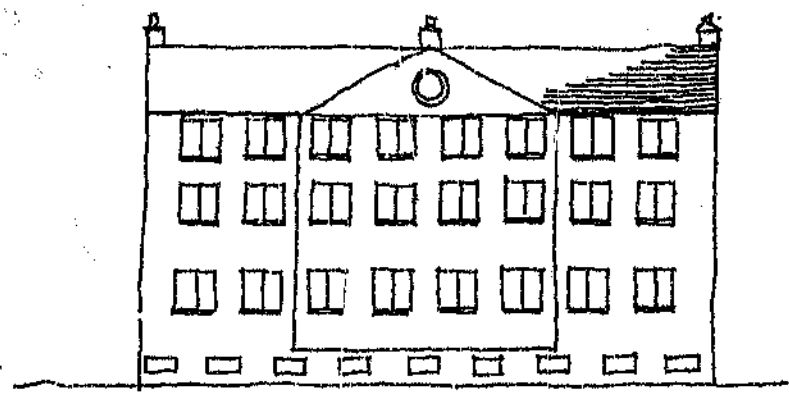


Fig.3 Smithies Mill 1796 at Birstall - the east elevation [Jones, 1984:31].



Few, if any, of the contractors and engineers designing and building the utilitarian industrial buildings would have bothered to argue the point. They were desperately concerned with the regular demolition [9] and loss of life suffered when these mills all too frequently were destroyed by fire. The fire risk was enormous. Naked candles and lamps and cotton fibre were a horrific combination. There was no stopping the fire before the whole mill was gutted (Shepherd, 1987:7]. With the improved iron manufacture and a growing understanding of civil engineering of a practical rather than scientific nature [10], major innovations in structural design resulted. Steam power was not to replace the water mill until well into the nineteenth century [11]. Factories were generally still quite small [Fig.2], for example Broadclough which was constructed by Sutcliffe [12] for Messrs Ormrod and Whitaker.

9. In the weaving process dust, which was highly volatile, settled everywhere [Shephard, 1987:7].

10. There were only two universities, Edinburgh and Leiden, which provided effective instruction in science.

11. The average power was 20 hp. Even as late as 1835 it was only 35 hp.

12. John Sutcliffe a Halifax millwright. Ormrod employed James Whitaker as engineer/architect [Jones, 1984:26].

The mill was a seven-bay, three storey structure with palladian features, ordered and symmetrical with fenestration, central pediment and wings. These wings accommodated the joiners, blacksmith shops, cottages and turning rooms. It was similar in size and appearance to Smithies Mill [Fig.3] erected by Nussey and Co., [13] demonstrating the constrained capital requirements entrepreneurs felt compelled to adhere to. These features were added to the eastern elevation of this steam-powered scribbling and fulling mill. To date there had been no design difference between a water or steam-driven mill, but for practical considerations the boilers and chimney were placed beside the two right-hand bays which then partly obscured that wing.

13. Constructed for Boulton and Watt [Fairbairn, 1857:2].

Cast-iron columns had been used at Culver Mill in Derbyshire since 1785, but in spite of the load-bearing brick walls it was not fireproof. The beams and floors were still timber. In 1792/3 Jerediah Strutt and his son William [14] designed a six-storeyed calico mill which was

14. Jerediah Strutt [1726-97] and his son William [1756-1830], who was then 36 years old [Jones, 1984:45].

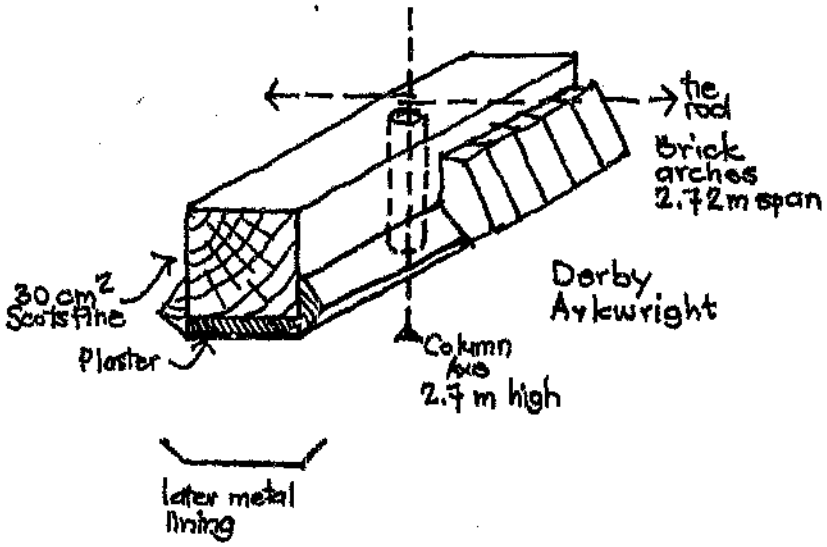


Fig.4 Milford, Derby built in 1792-93 [Singer, Vol.IV, 1965:477].

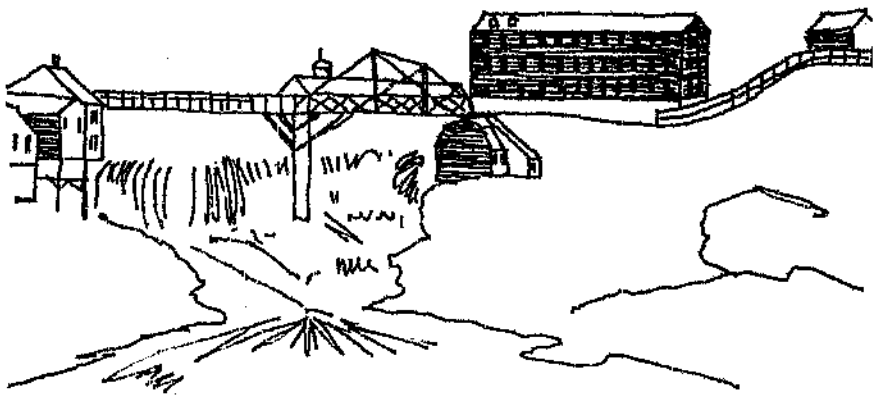


Fig.5 It was onstructed on a stone pediment. The rest of the construction had a timber frame and timbe weatherboarding [Jeremy, 1981:85].

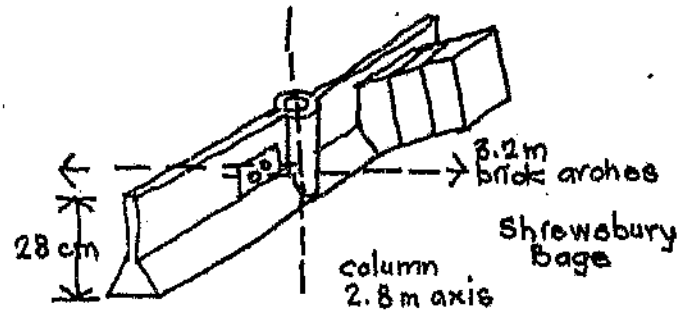


Fig.6 Shrewsbury displayed the first use of flanged beams [Singer, Vol.IV, 1965:477].

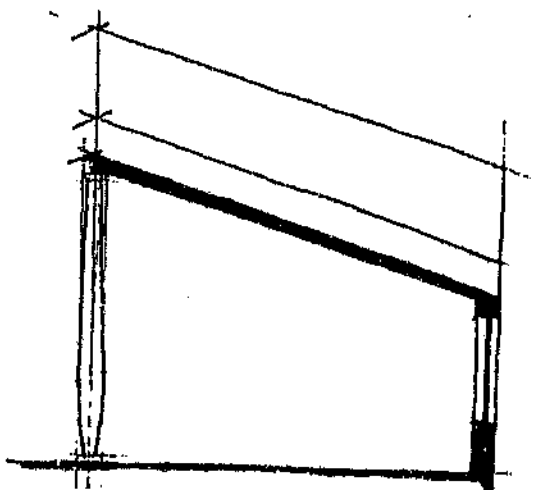


Fig.7 This shows the same construction as the floors but, without the same load to carry, it required only one column in the centre [Winter, 1970:49].

constructed by Arkwright. It was made of fire-resistant cruciform cast-iron columns which supported lathed and plastered timber beams. It had low brick arches [15] and was overlaid with sand and tiles [Fig.4]. Later sheet iron was used to protect the timber beams and hollow pots [16] for the sake of lightness. The early beams were nearly rectangular in section [17] but tests soon proved that the extra metal provided at the lower edge, especially when shaped to help support the brickwork, also increased the strength of the beam. The building was 31 m long and 10 m wide. The brick walls were 56 cm thick up to the second floor, 45 cm thick to the fourth and 39 cm thick for the rest. It was powered by three large water wheels.

15. It was based on the Palais Royal or Palais Cardinal built by Jacques Lemercier [1585-1654] in 1637. He used plaster to cover the timber structure [Shephard 1987:7].

16. Paris architect St Fart designed hollow clay pots [Singer, Vol.IV, 1965:475].

17. Heavy square wooden beams charred deeply, remained stead-fast during fires [Shephard, 1987:7].

At the same time, Slater [18] founded the United States cotton textile industry. When he learned of the bounties offered for the introduction of cotton-manufacturing equipment and financed by a Rhode Island firm [19], he set up the first successful cotton mill at Pawtucket [Fig.5]. The mill on the Blackstone river was based on the construction of large local farm houses in the area and had a small bell cupola [Hitchcock 1939:37]. Slater also built several other plants in New England and founded the town Slatersville [Guedes 1979:98].

18. Samuel Slater [1768-1835] was an apprentice to Strutt and Arkwright. He memorised the details of machines made by Arkwright, Hargreaves and Crompton [Jeremy, 1981:85].

19. The emigration and/or export of drawings of textile machinery was forbidden [Hitchcock, 1939:37].

Four years later 1796-97, Bage [20] started work at Shrewsbury on the first mill with a complete internal iron frame [Fig.6]. Bage was a wine merchant with a passion for engineering [21]. He was a friend of William Strutt and when the opportunity arose he designed this flax spinning mill for Thomas and Benjamin Benyon at Shrewsbury. The cast-iron columns and beams [22] also supported low brick arches which made for a strong and comparatively fireproof structure. Bage was also determined not to have a timber roof. He adopted a system of brick arches carried on iron beams, spanning 5,50 m from the walls to a central pillar, and with the slating almost immediately above the arches [Fig.7].

20. Charles Bage [1752-1822] wrote the first theory for the strength of cast-iron columns, [Skempton 1962:186] based on tests done by Telford for a cast-iron aquaduct.

21. He must have been a considerably talented amateur.

22. The first building in the world to have columns and beams of iron and therefore the progenitor of all our modern steel buildings [Guedes, 1979:95].

Fig.8 The interior of the Shrewsbury Mill. The centre columns have a cap that accommodates the shafting to drive the machines [Winter 1970:48].

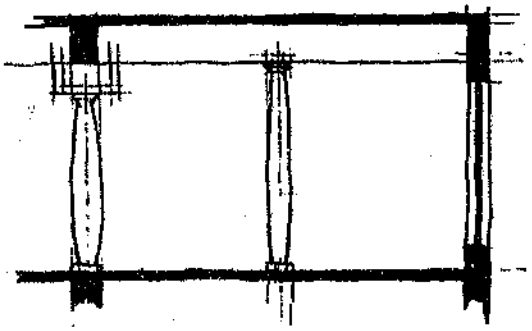


Fig.9 Windows 1 - wood and cast iron at Milford. Window 2 - cast iron at Shrewsbury [Shephard, 1987:16].

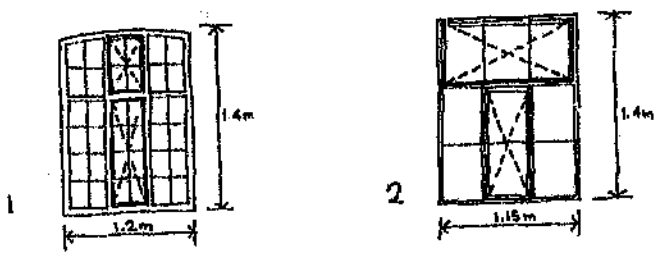


Fig.10 The sloping, vaulted brick roof created this characteristic external appearance. Each vault was covered with its own little roof, creating gables on the long elevation [Winter, 1970:48].

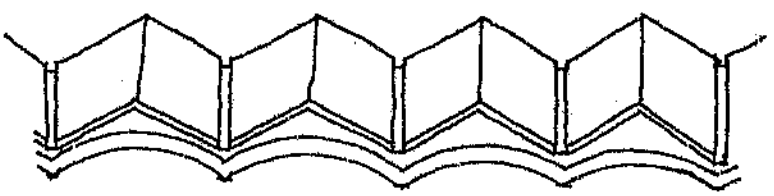
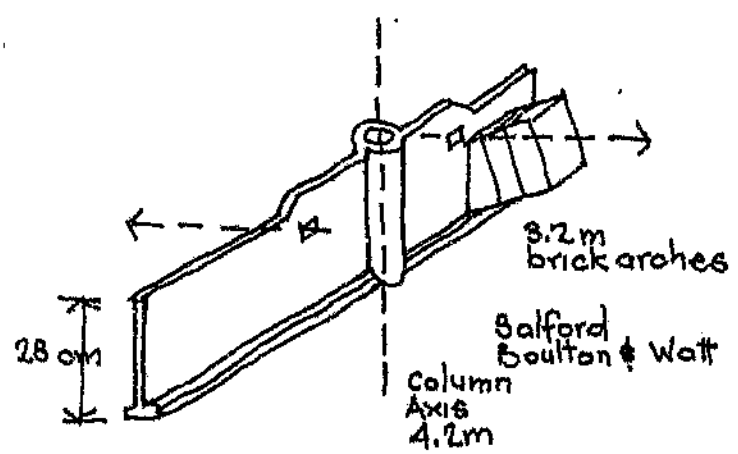
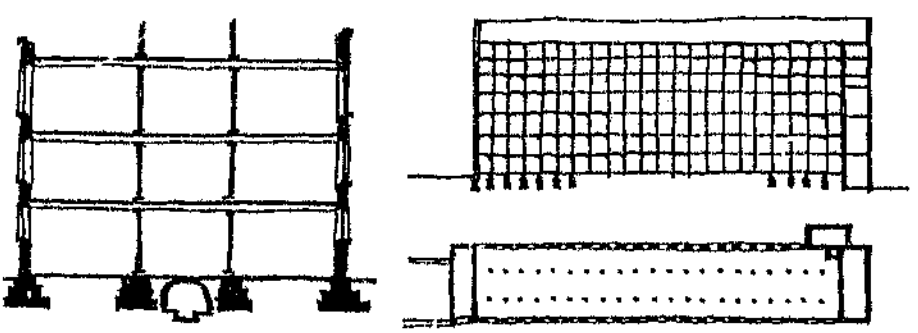


Fig.11 Salford Twist Mill with hollow cast-iron columns for the steam heat. The columns on the two lowest floors were 16,5 cm diameter while on upper floors they were all 14 cm diameter. The beams were 34,2 cm deep, 8,2 cm wide and 3,1 cm thick. The beams were cast in two lengths and bolted in the middle [Shephard, 1987:8].

Fig.12 Typical floor plan and section of the Phillips, Wood and Lee mill which was built in Salford, Manchester in 1801. The Watt steam-engine had a cast-iron working beam [Munce, 1961:3].





This mill was a strictly utilitarian structure [23] with no concession even to the simple elegance [Fig.8] attained in many industrial buildings of the period. The visual effect of the interior must have been remarkable with three rows of columns in the high and long rooms [24]. The rooms were flooded with light from the great windows [Fig.9] which reached up to the soffit of the arched floors above [Fig.10].

The columns were bell-shaped, the maximum depth of section situated at mid-height where the tendency for bending was greatest. The star sections in the lowest storey were 15 cm deep at the belly and 42 cm^2 in area, had a load of 32 tons and were 3 m long. These sections were manufactured by Hazeldine [25].

As a technical achievement, the mill was altogether outstanding [26] and Bage fully acknowledged the debt to Strutt's design of Derby [Skempton, 1962:183] and the Boulton and Watt steam engine that was installed.

The inventiveness of Bage did not stop here [27]. In 1799 he designed the Salford Twist Mill with the owner Lee [28] using for the first time hollow cast-iron columns [Fig.11]. It was the second of its kind and the fourth important fireproof building [29]. It was 78 m long, 15 m wide and seven storeys high. All the floors were divided into 23 bays 3 m apart, with two columns to each bay of 4,6 m [Fig.12]. Chimneys became an element to be reckoned with, but with a typical no-nonsense attitude, the early designers built them of brickwork. They were attached at the boilers on the one side of the main structure.

More mills [30] were being constructed on the banks of Brandywine Creek [31] at Wilmington in Delaware. The river which flowed in from Pennsylvania falls 39 m over a course of 6,5 km. Since Du Pont, who had moved there in 1802, had been driving his power mill with water power,

23. There were many adverse aspects. In spite of Robert Owen praising the system as benevolent, Dr Aiken, Wordsworth, Blake and Sir George Head claimed that it was cruel to use child labour, that the children were slaves and that the mills stank [Pevsner 1976:276].

24. The building was 35,5 m long and 11,5 m wide and including the roof area, there was 2850 sq m working space [Shephard, 1987:16].

William Hazeldine [1763-1840] became one of the great ironmasters of Britain. He maintained a foundry in Shrewsbury and cast columns for Bage in 1796 [Skempton, 1962:182].

26. Based on rigorously practical experiments which resulted in major innovations in the structural designs of industrial buildings [Jones, 1984:44].

27. Bage was now 47 years old.

28. George A Lee [1761-1826], who wanted to heat his factory with steam [Jones, 1984:45].

29. Boulton and Watt did not only build the mill, they also supplied the steam-engine and, more importantly they installed gaslighting. Their chief engineer, William Murdock [1754-1839], perfected the thermolampe developed earlier by Phillippe Lebon [1767-1804] in Belguim [Jones, 1984:45].

30. Eli Witney's [1765-1825] new cotton gin lowered the price in the USA to such an extent that it became the model for textile production, but he was plagued by patent infringement [Singer, Vol.IV, 1965:438].

31. Bancroft plant [Hitchcock, 1939:37].

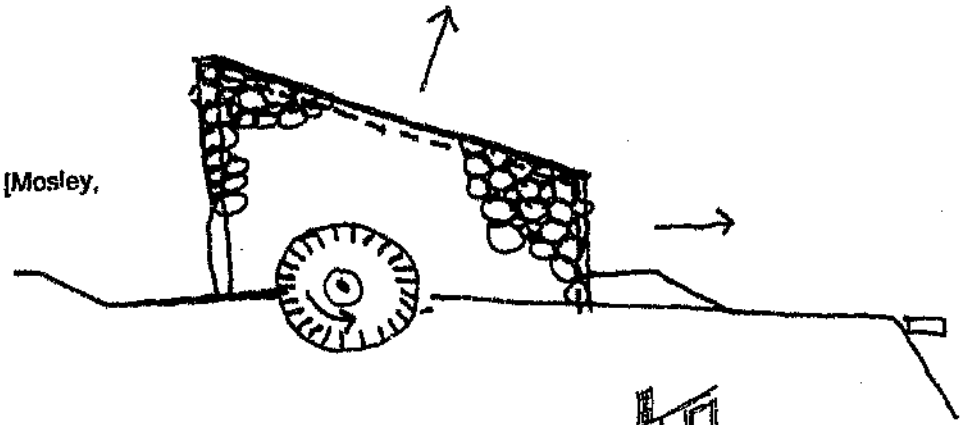


Fig.13 Du Pont Mills [Mosley, 1980:24].

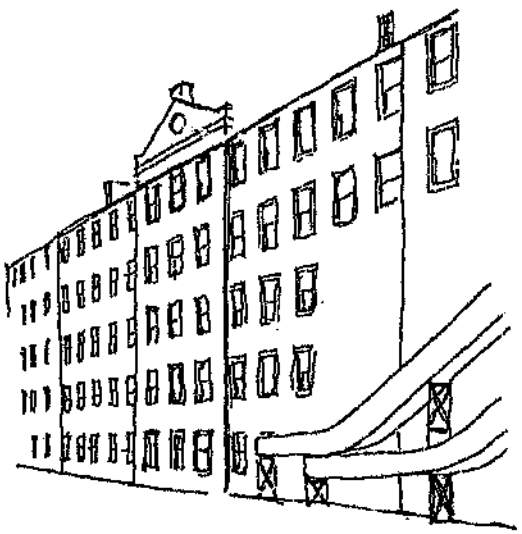


Fig.14 No 3 Mill with fireproof interior, erected at New Lanark for Robert Owen [Jones, 1984:28].

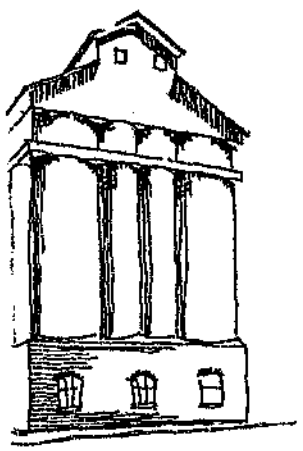
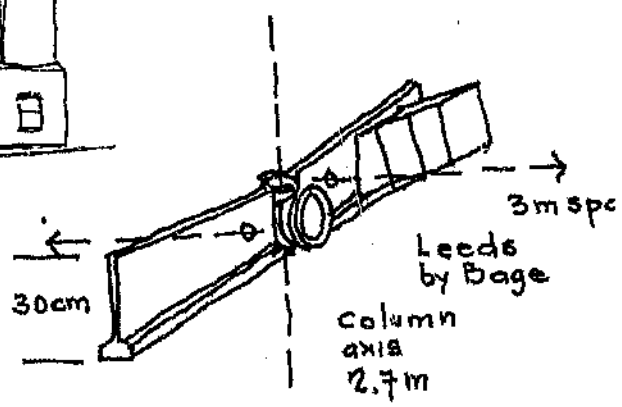


Fig.15 Grain elevator at Worms, Germany erected by Wayss and Freytag in 1908 [Banham, 1986:212].



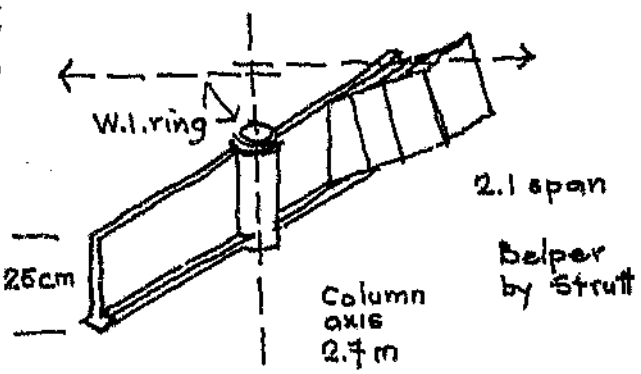


Fig.16 The tubular columns came into general use in most mills, the beams changing only in section [Singer, Vol.IV, 1965:477].

they could hardly have hoped to find a more suitable location. There were several small [32] factories with wide spaces of unused land between them. Because of the danger, three sides of the factories were thickly walled while the wall to the river was thin [Fig.13]. The roof had to be thin too in spite of the snow and sloped steeply towards the river [Mosley, 1980:24]. The Du Ponts were a pragmatic family who installed steam engines at a later stage, but used them only when the water was too low or too high.

32. The Du Ponts were chemists who emigrated from France during the Revolution and concentrated on manufacturing explosive powders and textiles [Hitchcock, 1939:37].

The flour mills, sawmills, gristmills and papermills were some of the largest in the United States of America. Witney was given a contract by the United States Government for the manufacture of muskets [33]. Within two years he designed and built the factory and the equipment based on the principle of interchangeable parts [34].

33. In France Le Blanc, a gunsmith who was the director of an ironworks, suggested the method of interchangeable parts in 1785. Thomas Jefferson [1743-1826], third President of USA after a visit to him, described it to Congress [Singer, Vol.IV, 1965:240].

The influence of the British immigrant showed in some of the mills where palladian detail was present. As most of these mills were still water powered, they were situated mostly in isolated valleys. It was not surprising therefore that they lacked the finery and splendour of their late nineteenth century counterparts. These mills were constructed mostly in timber, but when steam engines became prevalent and the mills moved into the towns and villages where they were considered more permanent, they became larger and were constructed of masonry [Fig.14]. They exhibited a range of architectural styles and an individuality of their own [Fig.15].

34. The theory of mass production came from cotton and was later to extend to sewing machines, typewriters, bicycles and motorcars [Guedes, 1979:98].

In Britain the evolution of the fireproof mill buildings continued. Two mills were being constructed at the same time [35] at Leeds and Belper [Fig.16]. The Meadow Lane mill in Leeds was of evolutionary importance in that the cast-iron beams were designed with flexible connections at each end. The beams were in simple bending with tension

35. 1803-1804.

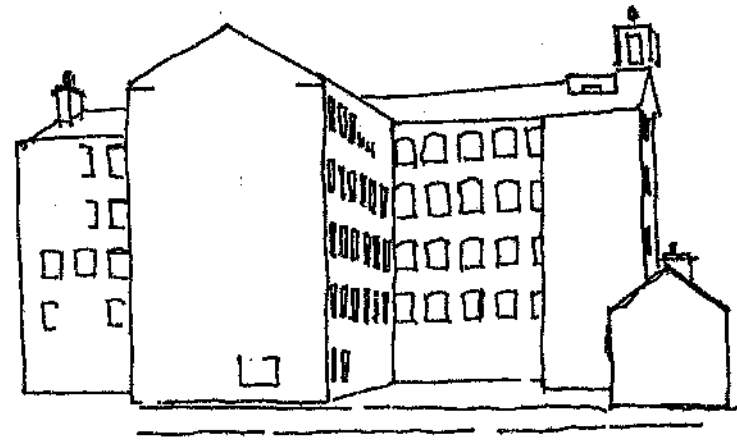


Fig.17 The North Mill at Belper was the fourth iron framed building built and had an elaborate heating system. It worked by hot air that was ducted from a central heating plant [Winter, 1970:37].

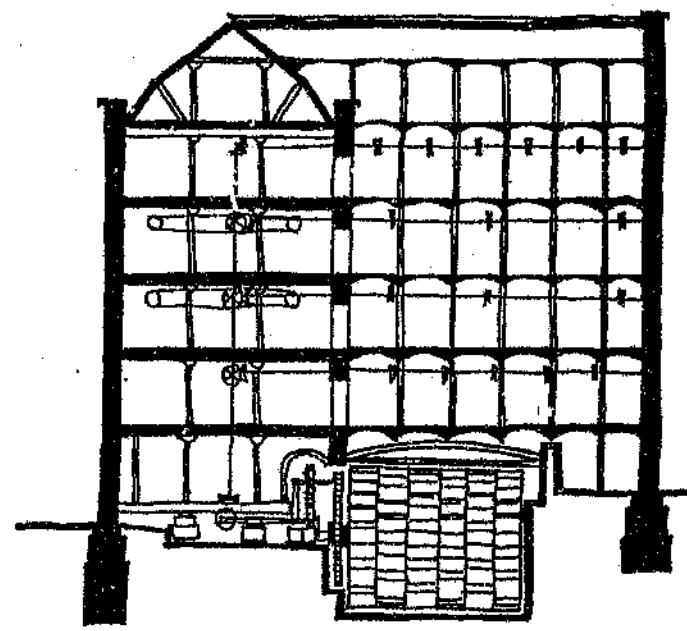


Fig.18 The structural frame carried all the floors. The supports for shafting transmitted power to all the looms and other machines from a central water wheel. The columns had brackets and supports cast into them to hold the shafting in place [Winter, 1970:21].

in the lower portion only. In addition a flange was provided at the bottom serving to support the arches. Bage had therefore obtained a solution suitable to the new material and moved away from the use of continuous timber beams, which had been suitable at Derby but were not well adapted to cast-iron. In a letter to Strutt, Bage discusses his beam theory and then further describes his somewhat primitive triangulated cast-iron trusses with spans up to 11,50 m and spaced up to 3 m apart. This agrees with the construction of Leeds and suggests the iron trusses may have been used here. We know that this was the case at Belper.

The William Strutt Mill at Belper on the east bank of the Derwent river, which had been destroyed by fire, was now rebuilt in a highly restrained cruciform brick structure [Fig.17] on a stone ground floor. The columns and beams as well as the roof trusses [36] were cast-iron and the spans were very much smaller [37] but great care had been paid to every detail. It was a fitting culmination to nearly a decade of experimentation and development. The huge 5,5 m diameter and 8 m wide water wheel developing 20 hp. [38] drove the overhead iron gearing and shafts [Fig.18] to power all the frames. The attic was used as a Sunday School on Sundays.

In just more than a few decades at the turn of the century small workshops and water powered mills had grown into substantial factories. The speed of these changes should not be exaggerated nor the continuity ignored. The mills had attracted much comment in view of the seminal structural advances. The external appearance would not justify any attention in an architectural study [39], nor were the mills large or daring in construction when compared with churches and other similar structures, but they were novel structural frameworks [40] of some genius and enthusiasm.

36. The experiments were done for Leeds, but whether they were used there, has not been proven [Pevsner, 1976:276].

37. Only 2,1 m. The reason for the short spans is not apparent and is contrary to development [Jones, 1984:45].

38. The fourteen famous water wheels at Versailles which worked all the fountains, delivered 75 hp [Usher, 1954:297].

39. They were unadorned brick boxes pierced at regular intervals by identical windows [Pevsner, 1976:276].

40. The internal framework failed to produce fundamental change in the outward appearance [Jones, 1984:46].

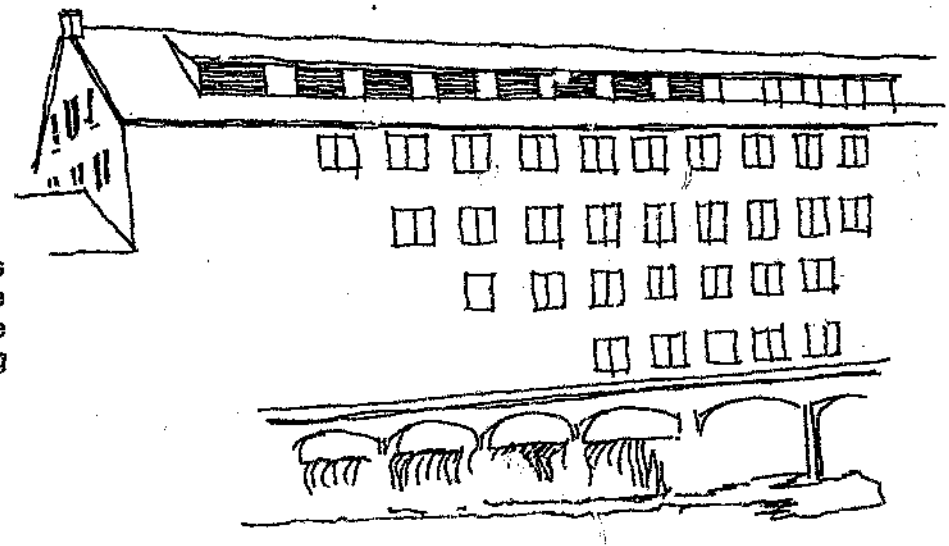


Fig.19 Note the large windows giving excellent light in the factory and the rooflights in the roof. See also the matching windows [Richards, 1958:78].

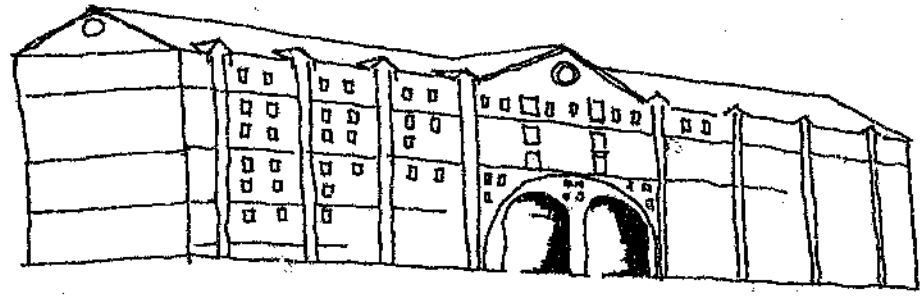


Fig.20 The six-storey brick building is characterised by two centrally-situated shipping holes framed by a blind arch [Jones, 1984:41].

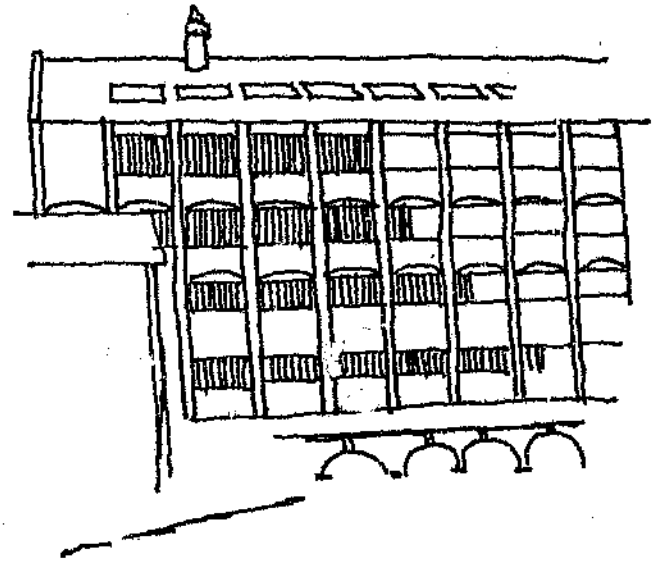


Fig.21 Strong vertical structural element and continuous horizontal windows [Drury, 1980:4].

As the efficiency of the steam engine increased [41] cotton machinery got larger with the result that the column positions became critical.

Within a decade [42] there were some highlights, such as at Ebley Mill near Stroud (Fig.19), a well-proportioned structure with its magnificent stone work [43]. The windows are paired with a sculpted, bowed stone lintel on the front elevation. The lower storey shows the delicate outlines of the beautiful masonry and the wooden frames echo the shape of the upper stone heads and mullions. The mill was run by a water wheel, the stream coming from the Cotswold hills east of Stroud [44].

At Liverpool the first warehouses were [45] being constructed with elements of internal iron frames [46] and consisting of cast-iron columns and T-section beams. Externally it incorporated subdued palladian details in a way that did not interfere with the building's practical operation [Fig.20]. The rectangular windows were simpler. There was a rusticated stone ground floor and dressings with an angled pediment represented stylistic flourishes, while the projecting gables [47] for hoisting the grain accentuated the vertical elements.

There are occasions in history when some structure stands out. The Stanley Mill [48] with its marvellous [Winter, 1970:38] exterior of brick and stone [Fig.21], very simply used, has an equally splendid cast-iron interior which is not at all that simple, but extremely sophisticated. This was erected during a period which had failed to produce much fundamental change to the outward appearance since that major breakthrough on the River Derwent at Derby nearly one hundred years previously. Again we have an exception where strong vertical elements constructed of stone, are also duplicated in the roof clear storeys. The lighting was a continuous band of horizontal glazing with brick infill panels which gave the exterior a

41. There was a finite power to water wheels, even when they were supplemented by beam engines [Jones, 1984:46].

42. In 1813.

43. Typical of this Cotswold area.

44. This was still a woollen mill owned by Marking and Evans, who also owned the Stanley Mill [Hitchcock, 1939:41].

45. In 1811 the Duke's grain warehouse over the Bridgewater Canal [Jones, 1984:41].

46. Until then it was thought to be too expensive for warehouses.

47. Sometimes called "locums" [Winter, 1970:13].

48. In Stonehouse, England. It was built in 1813 on the river Frome.

Fig.22 By now cast iron windows were already well estebiished and being used in various mills [Richards, 1958:85].

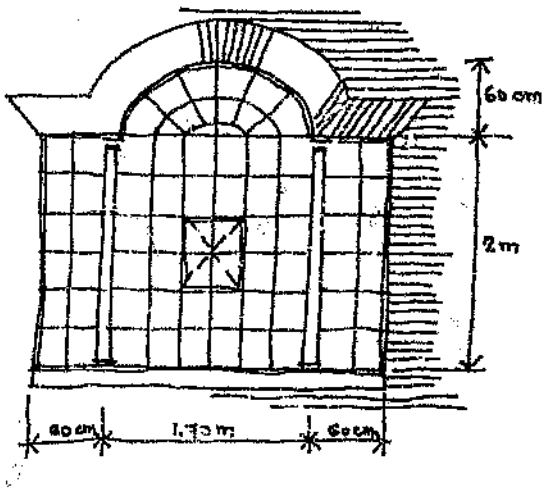
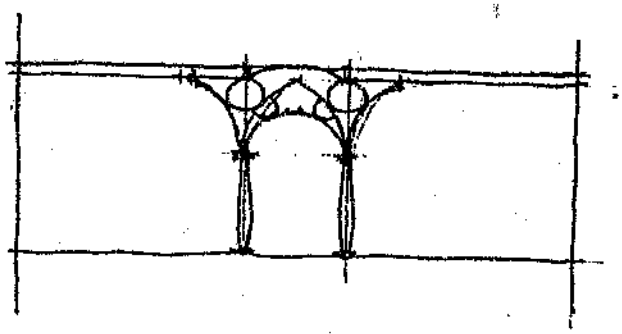


Fig.23 The machines were 5,6 m wide and the building 13,2 m wide [Shepard, 1987:10]



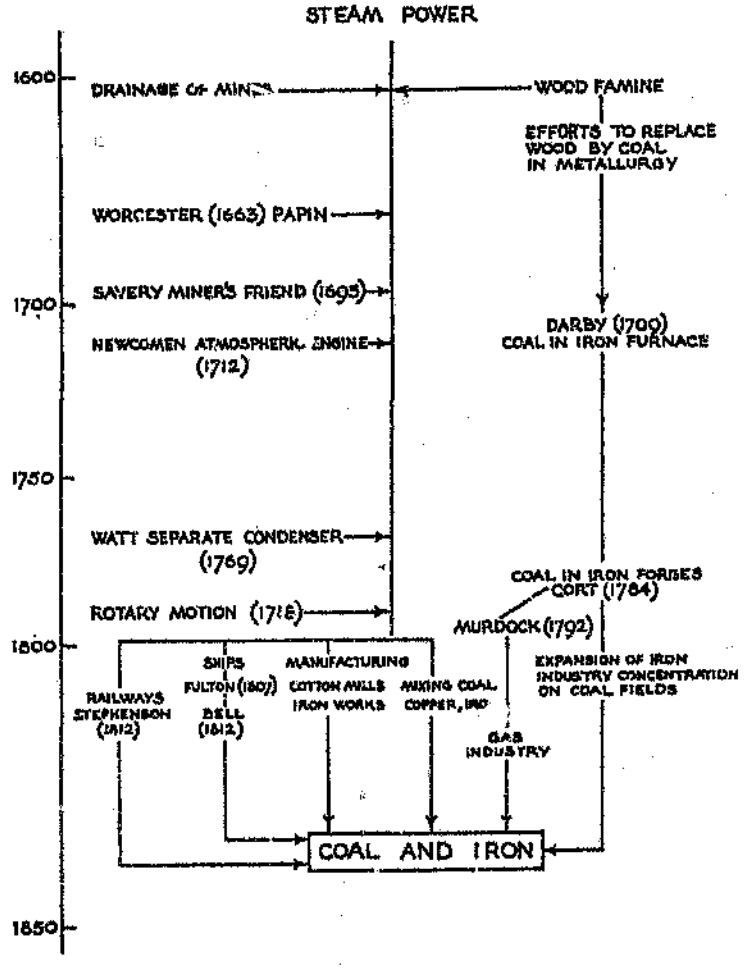
"modern look". It was not used again for at least two decades [49].

49. Thomas Lombe's water-powered silk mill in 1718.

For some reason the fenestration was not continued to the gable ends. Here the character changed [Fig.22], showing well-proportioned venetian-pattern windows [50]. The mill's interior structure was even more remarkable, with arches and columns designed to appear delicate. The tracery [Fig.23] of the beams, which consisted of spring brick arches for the floor above, incorporated supports for shafting and machinery.

50. The windows, like those on the main elevation, and the columns were cast iron.

Fig.1 Chronological chart of the introduction of steam for the period 1600-1850 [Singer, Vol.IV, 1965:165].



CHAPTER SIX : STEAM

The extensive use of cast-iron shows how far the Industrial Revolution had progressed from its medieval ancestry.

[Hills, 1970:246].

In spite of being relatively inefficient, the inorganic steam-engine was a machine which performed mechanical work through the agency of heat instead of through the organic power of wind and water. After manpower the horse wheel [1] was cheaper than the water wheel [2] and the latter certainly remained cheaper and more reliable than the first Boulton and Watt engines. Before 1780 the only source of reliable strong power [3] for driving textile mills was water augmented by steam engines to pump water back to the upper pond [4]. It was only when the steam-engine was converted from a pump to rotary motion that industrialists thought that sufficient even motion to the spinning machinery could be maintained [Fig.1]. Up to then the steam-engine had been subject to sudden stoppages and breakdowns.

The best available river sites that could deliver [5] more power than the early steam engine [6] had been developed, but the triumph of the steam-engine had begun [7], despite water being considered cheaper than co [Hills, 1970:93]. To date no scientific comparable costs between water and steam power have been discovered.

At the turn of the century water power was still preferred and the steam-engine was held in reserve [8]. With water power it was reasonably certain that a steady rate of production could be maintained. As the mill owners could not afford to have expensive workers and equipment standing idle because of a lack of power, they took no chances. In the construction of steam-engines wood was finally being replaced by cast-iron [9] and two designs of

1. The greatest advantage of horse power was its ready availability.

2. There was no expenditure in earthworks.

3. The single-action steam engine could not impart such even motion to run spinning machinery [Singer, Vol.IV, 1965:196].

4. Windmills were also used, but were seasonally unreliable.

5. The main cotton textile areas were Lancashire, Nottingham and Derby. Bolton was already suffering due to a water shortage [Munce, 1961:3].

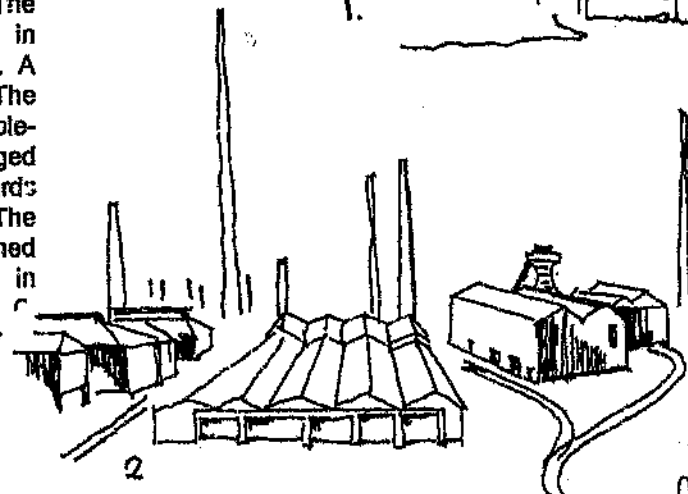
6. 1780 to 1830.

7. 1800.

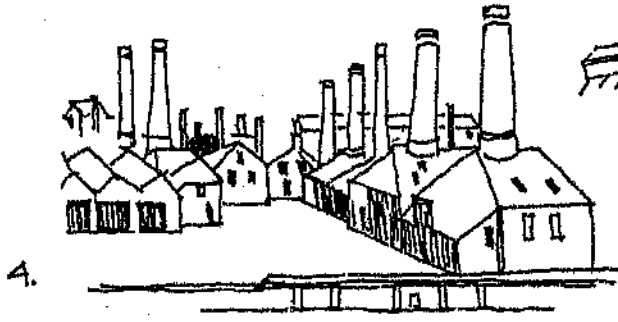
8. To retain two separate power sources must have been very expensive. It shows how carefully running costs were being studied [Jones, 1984:52].

9. 1800, Boulton and Watt.









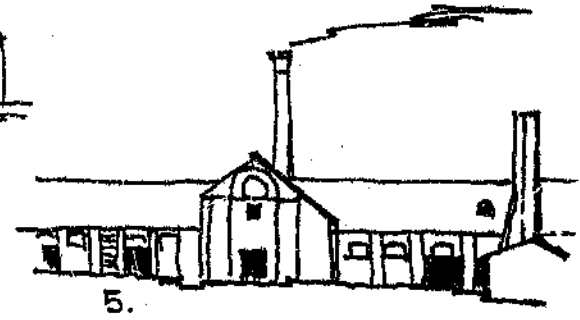




Fig.2 1. The Old Forest iron works at Swansea c.1800. 2. The St Rollox chemical works in Glasgow [Derry, 1960:534]. 3. A coal mine at Northumberland. The buildings were single and double-storeyed volumes, mostly arranged formally around courtyards [Guedes, 1979:97]. 4. The Fishergate glass-works established in 1794. 5. A foundry in Eberswalde, Germany, in 1806. 6. A brewery at Langley, Worcs [Richards, 1958:135].

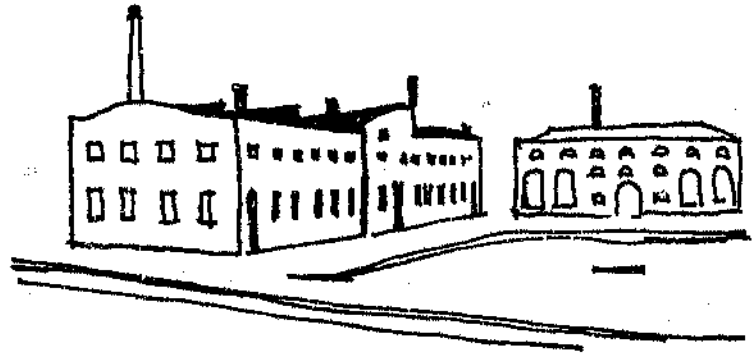


Fig.3 The building on the left was built in 1802 and contained the foundry, pattern and turner shop and, on the right, the boring mill [Jones, 1984:61].

iron beams were erected for the Salford Twist Company [10]. These advanced machines now enabled the industrialists to weave cheaply cotton cloth, of a superior fineness, smoothness and a quality never witnessed before.

10. 1801. These may not have been the first iron beams used, but accurate records were not readily available.

Watt had grave doubts concerning the overmanning and overbuilding of cotton mills [11] which relied solely on the natural power available in the valleys of the North, but the gradual development of the steam-engine brought about a freedom in the choice of sites. The new industries were now freed from the rivers and streams and attracted to the traditional and existing sources of labour [12] and coal. This transition came about during [13] the first decade of the nineteenth century [14] and the landscape changed as coal mines, steel and glassworks were established, factories and mills built [Fig.2] and coal mines sunk to supply all these industries. Most were smoke-stack [15] industries.

11. Watt's patents expired in 1800 when there were 496 steam engines at work in Britain, 308 rotative engines, 164 pumping engines and 24 blast furnaces [Singer, Vol.IV, 1965:163]. There were not more than 6 steam-engines at most in the USA.

12. By using the poor as machine minders they put parish craftsmen out of work.

13. From 1786-1806 when approximately 50 mills were erected in Manchester alone [Munce, 1961:3].

in Britain, where these new industrial processes and techniques were the first to be coal-driven, the use of steam as source of power had a strong impact on design. The most conspicuous design elements to be employed after pyramidical roof forms were capped ventilators and the chimneys, which broke the skyline over the as yet low brick buildings.

14. The cloth output increased to 81 million pounds or 40 000 tons by 1815 [Jeremy, 1981:92].

15. The Paleotechnic period or the coal and iron complex [Mumford, 1946:110].

The expansion of the textile industry and its demand for machinery and engines provided a stimulus to engineering firms. One of the largest, the Soho Foundry [16], was erected in Manchester [17] by Boulton and Watt [18]. The factory - its two principal buildings [Fig.3] - exhibited certain limited Palladian principles in their symmetry and detail, the foundry having an unusual curved central bay.

16. Built for David Whitehead. When he died, it was sold to Peel, Williams & Co. in 1810 [Jones, 1984:61].

17. See item 13 above.

18. By this time the sons of the founders had taken over.

The buildings consisted of a smith and finishing shop and well-lit [19] pattern-maker and turner shop. On the left

19. See the tall and wide windows on the ground floor.

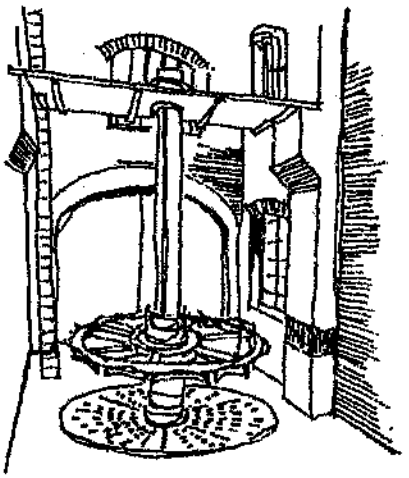


Fig.4 Typically hard and uncompromising interior, showing the early boring machine within a well lit area [Singer, Vol.V, 1965:649].

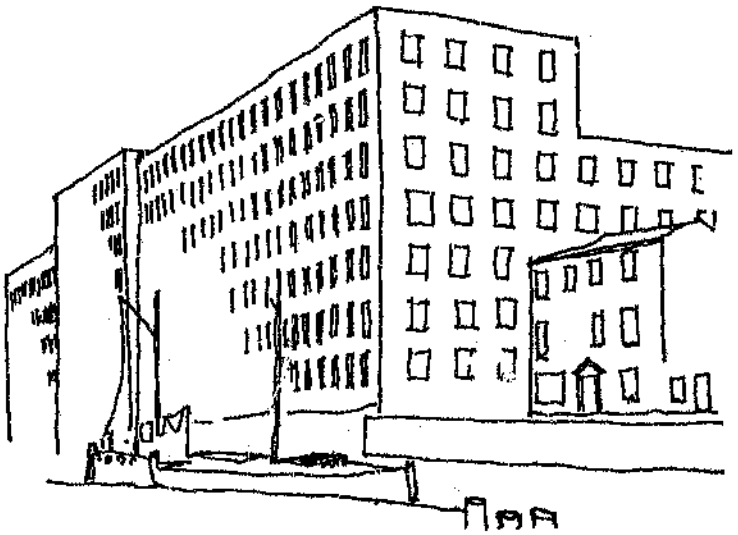


Fig. 5 Sedgewick Mill built in 1818-20 for McConnel and Kennedy beside the Rochdale Canal in Ancoats, Manchester [Jones, 1984:55].

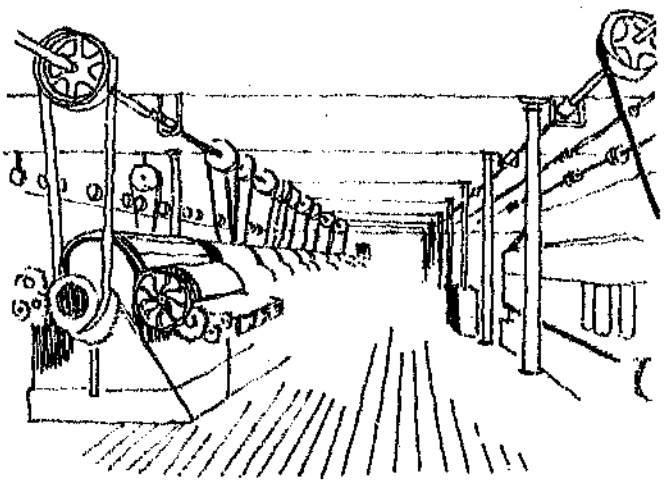


Fig.6 Steam power driving the shaft and pulley system [Clark, 1985:79].

was the foundry's boring [Fig.4] and forming shop. The whole works was run by an excellent steam engine of 18 horsepower which also worked the blast for the cupola furnaces. The foundry was not only one of the leading engineering works in the city, but was also one of the most well-managed [20], while it was architecturally distinguished [Jones, 1984:62]. All the buildings, including the offices, were arranged around the four sides of a rectangular yard with the wharf on the Manchester-Ashton-Stockport Canal.

Mechanical engineering, initially using wood and later reinforced with metal, now became closely linked with the iron and steel industries. This not only brought about foundries for manufacture, but created greater demands for steam-engines and large machine tools in these engineering workshops [21]. There were enormous gains in power conversion, based on the high pressures and improved methods of transmission of energy from engine to machinery [22]. At the same time there was an upsurge in the training of an army of engineers many of them from elsewhere in the British Isles.

The mill owners experienced a demand for their improved cloth products [23] and foresaw sound financial reasons to increase the size of their factories [24]. Some of the mills [Fig.5] became many storeys high and of great length, pierced by regular rows of rectangular windows. The mill remained a visual block whose shape and fenestration were determined only by the practical considerations of manufacture and cost. These large brick, fireproof buildings exhibited dimensions which were derived from its vastness and lack of ornamentation or variation. The strength came from the height and must have intimidated the hundreds of persons employed in them.

Such was the scale of these buildings [Fig.6] and the more units there were within a given area the more efficient the

20. There were standard operating procedures, incentive wages, standard times, employee Christmas parties, bonuses and employee insurance societies [George, 1968:56].

21. In Britain manufacturers seemed to concentrate on textiles, steam locomotives, sugar, paper and coal; in Belgium on mining and also metallurgy, in France and Switzerland on textiles and light industries; in Russia on coal and metallurgy; in Germany on early electrical theories while in the USA standardised and mass production was made possible by the manufacture of machinery accurately and indefinitely. The conveyor belt was also invented in the USA by Oliver Evans [1755-1819] [Singer, Vol.IV, 1965:189].

22. The Luddites was a movement of English handicraft workers who rioted for the destruction of the textile machinery. In 1812 many were shot and in 1813 there were hangings and transportations [Clark, 1985:79].

23. This was being established in major towns where communications were better, wealth concentrated and labour pools at hand.

24. This was the Third Stage or take-off period in Britain, 1819-1848, when industry experienced rapid overall growth and large-scale industry matured [Rostow, 1969:40].

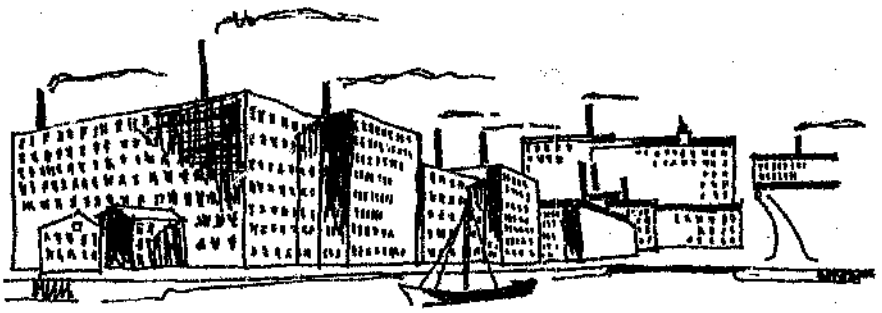


Fig.7 Some factory buildings grouped together in Britain in 1828 [Munce, 1961:5].

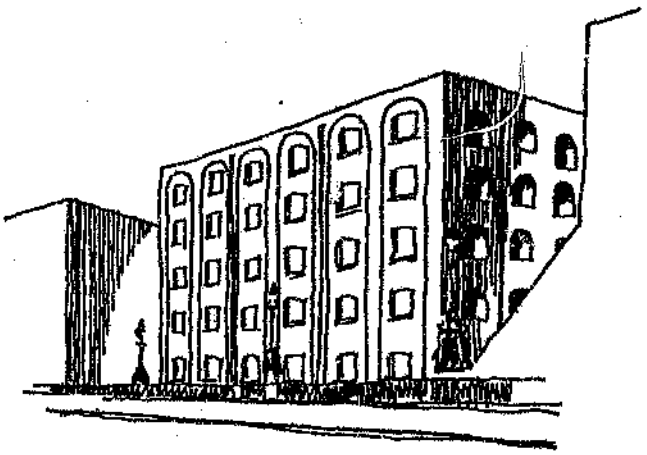


Fig.8 Warehouse constructed 1824-28 by Thomas Telford [1757-1834]. He started work as a mason and educated himself as Architect. Telford was the first President of the Institute of Civil Engineers founded in 1828 [Munce, 1861:6].

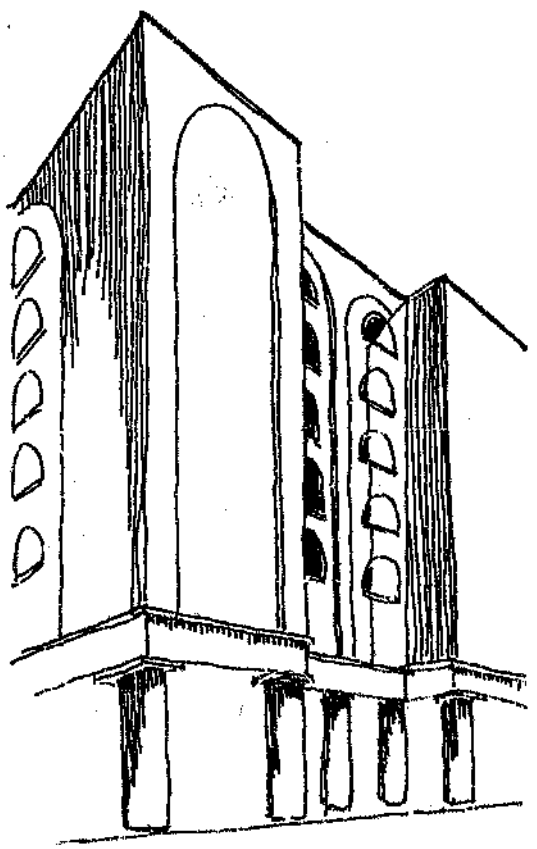


Fig.9 St Katherines Dock designed by Telford 1825-28 and built by Phillip Hardwick [1792-1870]. Telford was also responsible for canals, aquaducts and bridges. St. Katherines Dock has a yellow brick superstructure standing on sturdy Doric columns of cast-iron [Richards, 1958:49].

source of power [25] was. A single factory might have employed up to 250 hands. A number of these factories [Fig.7] operating together could constitute the nucleus of a considerable town and they were [Mumford, 1946:158] situated mostly on the major canals.

25. The system of shaft, pulley and belt was economical to within 250 m [Clark, 1985:80].

There were some grave evils which followed the almost haphazard centralisation of industries during this period as the housing of the workers [26] who urbanised while looking for work, was as bad as the working conditions in the factories. They came from rural homes, with relative independence and operating in small workshops, to these giant mills where the owners economised with low ceilings, windows [27] reduced to a minimum, hardly any ventilation and inadequate lighting [28]. They used mostly women and children for their labour.

26. Living conditions were sometimes worse, unsanitary and back-to-back, huddled amid the mill buildings and exposed to filth and smoke [Mumford, 1940:164].

27. William Murdock [1754-1839] used coal gas lights in the Boulton & Watt mill in Birmingham 1802-3 [Shephard, 1987:14].

Many visitors came from USA and Europe to study these industrial buildings. Schinkel [29], who was a forerunner of the modern movement in Germany, visited the area in 1825. He had come to see the miracles of the new age, the machines and the buildings called factories [Winter, 1970:42]. Schinkel visited Britain officially on behalf of the Prussian Government [Guedes, 1979:95]. He went to Ancoats, saw the Sedgewick Mill and recalled that he was most impressed by the size of the buildings and the strength of the economy [Jones, 1984:55]. He remarked that because the building was made from red brick for the sake of bare necessity it created a rather gloomy impression. It stood as big as the Royal Palace in Berlin and the chimney, like so many obelisks was 24 - 54 m tall [Pevsner, 1976:277].

28. In 1802 a Bill was introduced in the British Parliament which determined that all internal walls and ceilings had to be whitewashed twice a year and that window area had to be adequate for ventilation [Jones, 1984:52].

29. Karl Friedrick Schinkel [1781-1841], the greatest architect of Germany and a pupil of Friedrich Gilly, [1772-1800] was impressed by the simplicity of the mill designs [Pevsner, 1976:277].

Industrial buildings did not occupy a place in the forefront of architectural change [30]. Instead, they [Fig.8] followed behind, picking up developments in style and adapting or modifying them to suit their own [Fig.9]

30. Based on the fashionable styles.

Fig.10 Shows the various beams in use by 1825. 1. That of Sir William Fairbairn [1789-1874] with the single flange. 2. That of Eaton Hodgkinson [1789-1861] with flange to depth ratio was 6:1. 3. That of architect Thomas Tredgold [1788-1829] with unequal flanges. The longest cast-iron beam of the period was 25 m long and was used by John Dixon and Co. of Amsterdam for the Haarlem railways [Tredgold, 1842:59].

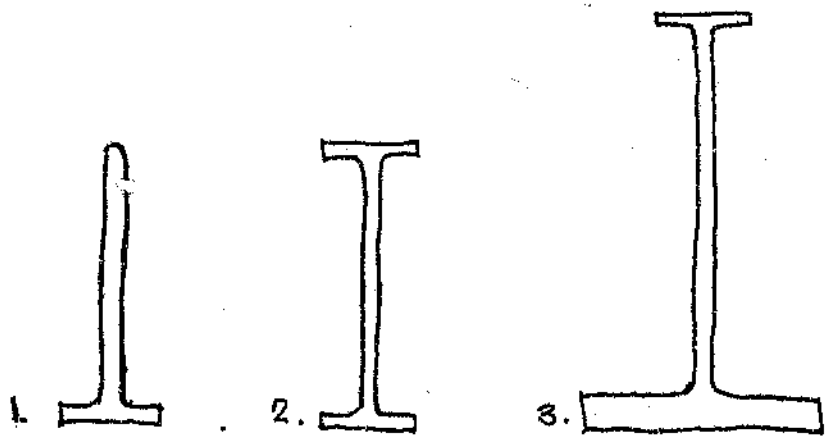
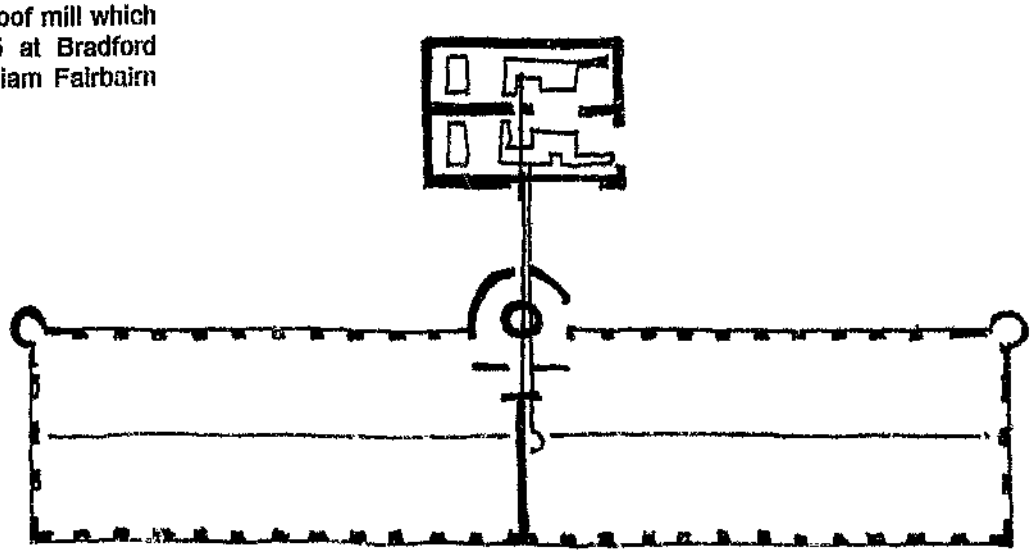


Fig.11 Plan prepared for Boulton and Watt's new fireproof mill which was erected in 1825 at Bradford and designed by William Fairbairn [Jones, 1984:58].



circumstances. Only St Katherines Dock [31], designed by Telford, could rank near the forefront.

The pattern of concentration was also followed in America [32] which allowed for co-ordinated production and resulted in economy of scale. Some mill owners added gloss to their factories to advertise or raise the status of their businesses. Externally the factory design followed the British pattern, with diluted Palladian features. Labour-saving machinery driven by steam power encouraged the construction of masonry mills [33]. There was, however, an increasing tendency for the simplicity and restraint of Palladian detail to be replaced by monumental buildings that reflected the various architectural movements sweeping through Europe [34]. During the early nineteenth century the fancy-dress [Pevsner, 1960:626] ball of architecture was in full swing [35] and by 1840 pattern books of builders and clients included the reigning fashions [36]. Shortly before that, Pugin [37] theorised that to construct in the forms of the Middle Ages was a moral duty [38].

From approximately 1825 onwards the urban factory system was fully operational in several European countries, the units increasing in size [39]. There were many innovations [40] and the older form of beams [Fig.10] were being superseded, allowing the construction modules to increase to 6,5 m x 4,25 m. Now buildings of six to seven storeys high and up to 17 m wide with one column in the centre of the hall [Fig.11] could be constructed.

The transportation of goods played an extremely important role in factory production and was increasing [41]. Coal had to be carried to the steam engines and raw materials to the factory, while the finished product had to be shipped to customers' warehouses. Canals had made a major contribution [42] towards transportation especially when the mills were water powered and situated next to

31. Cast-iron columns and beams, and brick arches modelled on those of the textile mills [Richards, 1958:48].

32. F C Lowell [1775-1817] had surreptitiously toured England to discover the secrets of the power loom [Jones, 1984:53].

33. Most rural mills had consisted of wooden framing and clapboarding.

34. The rise of neo-classicism - the Greek Revival had partly reached its zenith around 1829 - in fashionable building [Jones, 1984:67].

35. Classical, Gothic, Italianate and Olde English.

36. Tudor, French Renaissance Venetian [Hitchcock, 1939:42].

37. Augustus Welby Pugin [1812-52] equated Christianity with Gothic [Jones, 1984:113].

38. Did this mean that the industrial buildings of the period were ungodly or was the justification that the new progressive industrial building had no need for art [Mumford, 1940:405]?

39. Average of 85 workers and an engine of 19 hp [Jones, 1984:53].

40. Robert Owen [1771-1858] claimed in 1820 that workers should be well-trained and housed, while James Mill [1773-1836] analysed and synthesized human motions. DelaRue [1815-1889] invented the incandescent lamp 1820, Michael Faraday [1791-1867] the electric motor in 1821, Charles Babbage [1792-1871] the elaborate calculating machine in 1823, Joseph Aspdin [1799-1855] portland cement in 1824 and canned goods in the same year by Peter Durand.

41. Canals developed in France and Flanders in the late seventeenth century, in Germany in the seventeenth and eighteenth centuries and England right up to the mid-nineteenth century when the Grand Trunk Canal was built across England [Mumford, 1946:122]

Fig.12 The mill gave the appearance of a strictly practical design [Jones, 1984:56].

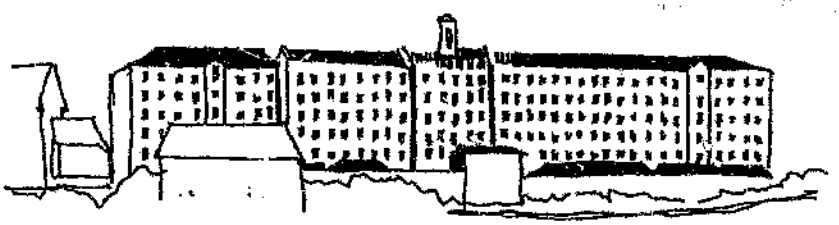
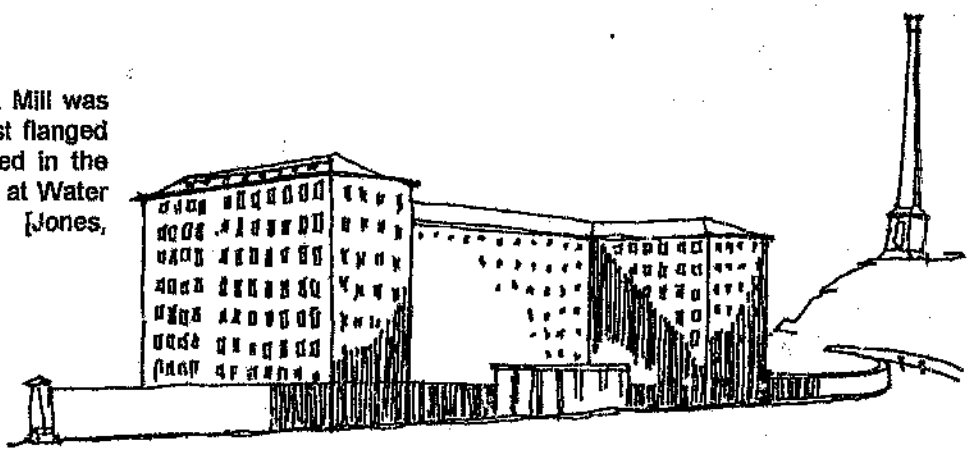


Fig.13 The Travis Brook Mill was constructed in 1834. First flanged cast-iron beams were used in the mill. The application was at Water Street B), 1829 [Jones, 1984:57].



rivers, along which most of the transport during the early Industrial Revolution took place. The development of the modern industrial society, particularly with relation to bulk commodities [43], was made possible by canal transport. The railway as it is known today originated [44] in Britain during the first part of the nineteenth century [45]. Almost from its inception, the railway became the all-purpose land carrier of both freight and passengers. The development of railways is considered one of the great landmarks in the progress of civilisation [46]. Its most impressive and significant technological innovation [47] and massive economical volumes and loads stimulated other industries.

The Fishwick Mill [48] in Preston, built for the cotton spinners Swanson, Birley, Tuston and Co., was a large structure consisting of a building 144 m long with some 44 bays and was seven storeys high [Fig.12]. The windows were regular with some play on the facade, casting shallow shadows and battlements on the central projections. This imposing and dominating building depicted the Palladian tradition and a measure of contemporary industrial opinion.

The Orrell's Travis Brook Mill [49] was also a mammoth mill. Its engine house was attached at the right side of the plant and the chimney constructed on a classical base, detached on a nearby knoll to increase draught and reduce pollution at low level. The mill [Fig.13] had projecting wings for storerooms, winding of yarn and minor tasks. The power looms were installed on the ground floor of the main block [50]. The frames used for spinning the warp were placed on the first and second floors and the mules for the weft on the fourth and fifth floors, whereas the preparation rooms were located centrally on the third floor. The attic was used for warming the yarns for the power looms. The mill was noted for its structural innovation. Flanged beams of cast-iron [51] were being used and with

42. The mitre lock with double leaf gate developed in seventeenth century, allowed for changing levels.

43. Coal, ore and grain.

44. Railways were introduced in Germany in the coal mines in the early seventeenth century, by end of the eighteenth century nearly all the mines in Europe had railways [Mumford, 1946:158].

45. In 1813 Puffing Billy was built by William Hedley [1779-1843] to haul coal from the mine to the wharf. George Stephenson [1781-1848] opened the Stockton and Darlington line in 1825, and the Liverpool Manchester line in 1830 and the London to Birmingham in 1836.

46. The second half of the nineteenth century saw railways reach maturity world-wide.

47. Electric motors, 1821; corrugated iron, 1829; dynamo and transformer, 1831, sheets of glass 1832, and the water turbine, 1833.

48. Constructed in 1830.

49. Constructed in 1834 and designed by Sir William Fairbairn [1789-1874], the millwright [Jones, 1984:57].

50. The looms were later moved to single-storeyed sheds with better light.

51. That of Eaton Hodgkinson [1789-1861].

Fig.14 In the 1830's houses were often, as illustrated here, placed between gas-works and plague-pits [Risebero, 1979:184].

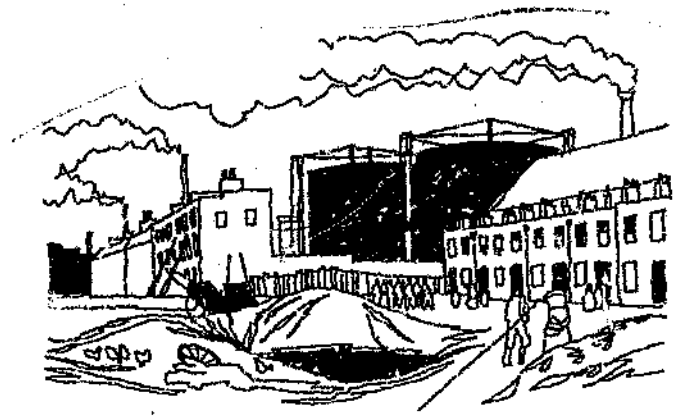
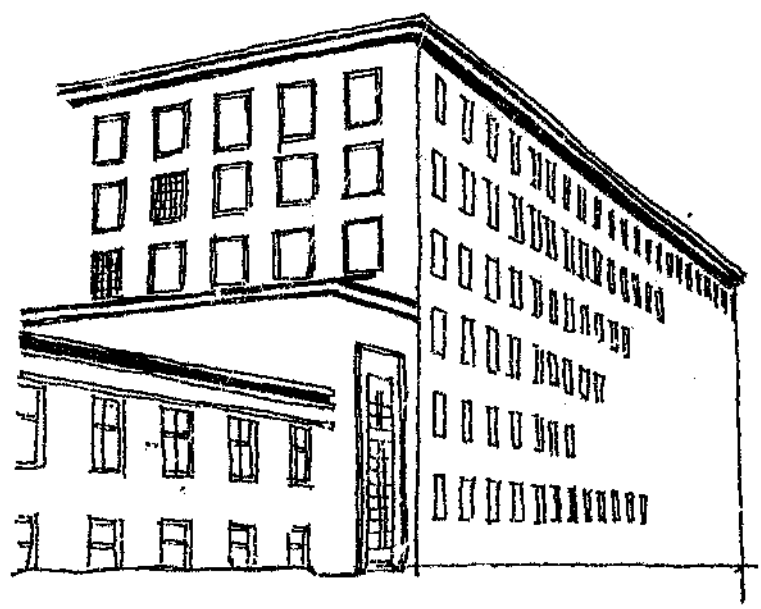


Fig.15 Shaddon mill, built in 1835 was of local red sandstone found in Manchester [Jones, 1984:59].



the column spaces increased to 6,6 m instead of 4,6 m as was common practice [Jones, 1984:84].

The technical and management innovation of the scientific approach of Babbage [52] who emphasised specialisation, division of labour, time and motion study and general employee efficiency, was questioned. At the same time as these developments took place and because of the generally poor urban housing [Fig.14], the workers started a Chartist [53] agitation in the textile and other industries. The movement drew support from unemployed block printers, wool combers, hand-knitters and weavers [54]. There was also rural unrest when the mechanical thresher was developed and riots broke out to stop automation [De Bono, 1979:111]. The horrors resulting from the use of child labour to save wages were largely responsible for the Factory Act [55], while it was thought that the joining of scientific and technological knowledge in industry inaugurated the rule of experts and was not egalitarian [56]. Various political and social movements based on the writings of Fourier and Saint-Simon [57] were established. Both these authors were anti-capitalist and loathed competition, claiming that it was a wasteful method, unjust and unequal. They argued for the complete nationalisation of the means of production within a strong central state and guided by socialist planners.

In the United States of America the situation was parallel to that of Britain, except that the time span was somewhat delayed [58]. The mills which converted to steam were released from the streamsides and established in the old ports and commercial towns where the transportation facilities had their termini [Hitchcock, 1939:38].

One of the largest cotton mills in England, Shaddon Mill [1835-6], was designed by Tattershall [59] and was 68 m long, 17 m wide and 25 m high. This red sandstone, seven-storeyed block [Fig.15] with minimum decoration,

52. Charles Babbage [1792-1871], mathematician and inventor, had in 1823 invented an elaborate calculating machine.

53. British working class movement for Parliamentary reform, called the People's Charter, to protest against the social injustices of the new industrial order in Britain [Burns, 1968:25].

54. They were put out of work by the technical innovation, the increased speed of mechanical spinning and increased capital investment which required reduced wage bills [Singer, Vol.IV, 1965:274].

55. In 1833 and later in 1842 by Lord Shaftsbury [1801-1885] who was one of the most effective social and industrial reformers in nineteenth century England.

56. Socialism can be traced back to Plato's Republic [428-348 BC] and Sir Thomas Moore [1477-1535] who wrote Utopia.

57. François-Marie Charles Fourier [1772-1837] and Comte Henri de Saint-Simon [1760-1825] [Guedes, 1979:95].

58. After visiting Murray's Hill, a British Mill, in 1830 an American industrialist Zachariah Allen wrote about the eight-storey brick mill [Jones, 1984:55].

59. Richard Tattershall [1804-44] had articled in Manchester and was one of the earliest architects in general practice to seek industrial work.

Fig.16 A fine simple structure in the functional tradition is concealed behind this naïve neo-classical frontispiece in Howard Street, Shrewsbury. The warehouse is lofty with brick walls, iron columns and heavy timbered roof. It was built by Fallowes and Hart Birmingham in 1835 with a vaulted brick basement and still preserves part of its original slate-slab floor [Richards, 1958:37].

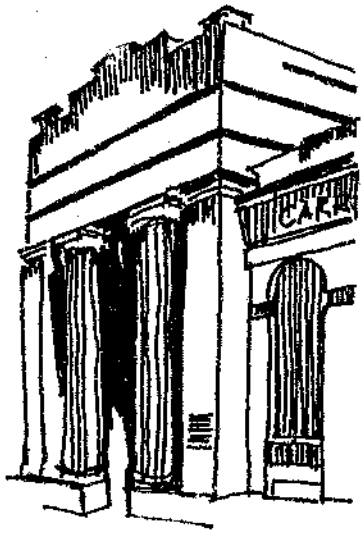
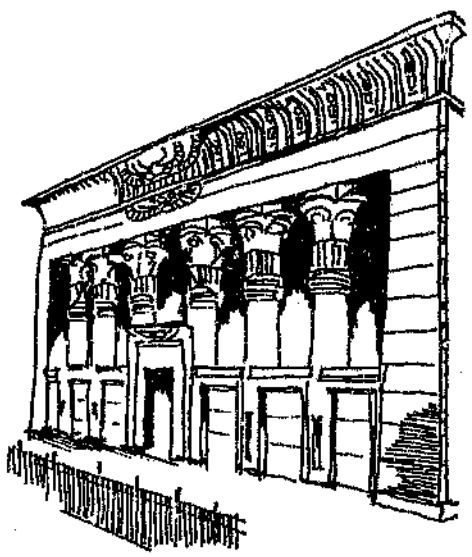


Fig.17 Totally absurd Egyptian facade, consisting of massive columns with papyrus capitals; the Nubian theme continued in an obilisk-shaped chimney. Behind it was one of the most innovative factories of its period [Winter, 1970:84].



flat frame windows, unmoulded architraves and a fireproof interior was built by Fairbairn [Jones, 1984:59] south of Old Carlisle in Denton Holm, a rising industrial suburb. It was recognised by its plain brick-tapered chimney nearly 100 m high. Steel [60], glass and corrugated iron [61] were being employed in many structures not directly related to industrial building but which did have an influence. The influence of iron [62] was largely a technical one. At the same time there was a dichotomy in the nature of twin movements. Engineers and embryonic scientists were involved in a gradual evolution of building methods and the other leg was dominated by the academically educated architects and the rise of neo-classical architecture [Fig.16]. Marshall's [63] Temple Mill [Fig.17] was a single-storeyed spinning factory with iron columns, shallow brick arches and circular glass skylights in each bay to allow in natural light [Pevsner, 1976:286]. The factory described as one of the marvels of the district [64] consisted of a one-room waterproofed shed which was drained through hollow columns covered with earth and grass and with sheep grazing abo[illegible] [Guedes, 1979:96]. This elaborate roof served to maintain the correct level of heat and the humidity was controlled by ventilation from beneath the floor [Jones, 1984:103].

Mercifully the Egyptian movement [65] acquired only a limited following and the functional tradition, which can be traced as an unbroken line through to the modern period, did not reflect or respond to fashion and popular taste as strongly as most of the other buildings of that period.

The growth in the scale of industry, commerce and advancing technology necessitated larger mills and factories [66], more powerful steam-engines and more sophisticated equipment and services. This in turn led to considerable development in banking and financial institutions. After the Napoleonic Wars [67] banking, which had been centred in London, spread to the market

60. The smelting of iron had not been successful, but from the 1830s large quantities were being produced in Britain and the USA.

61. Roof sheeting was rolled in 1747 by water power Christopher Polhem [1661-1751].

62. Market Hall, Madeleine is one of the earliest examples in steel 1824. Hungerford fish-market 1835 built of cast-iron spanning 10 m. Paxtons Conservatory at Watsworth in Derbyshire, 1836. Camille Polonceau [1813-59] invented a simple trussed rafter in 1837 and Albert Fink [1827-1897] a truss from railway bridges and sheds of moderate span.

63. John Marshall built Temple Mill, 1838-40. It was designed by Joseph Bononni [1796-1878] who had spent ten years in Egypt on archaeological sites [Pevsner, 1976:286].

64. Inspired by a weaving shed constructed at nearby Deanstone.

65. Striking proof of the disregard paid by contemporary architects to the purpose of the industrial buildings they were called upon to design [Guedes, 1979:96].

66. First legal use of the word "factory" is in the Textile Factory Act of 1844 [Singer, Vol.IV, 1965:150].

67. In 1814 France was defeated by the Allied coalition and again at Waterloo in 1815 this ended 23 years of constant war between France and other European powers.

towns and rising industrial areas. As a result of the power of the steam-engine industry was not exposed to seasonal risk anymore.

The growth of foreign lending to new countries, especially during the height of speculation in Britain and abroad, for railway booms [68] accumulated large funds in the hands of the landlords and merchants and led to the rapid growth of the middle classes [69]. Generally the standard of living increased [70], the population urbanised and, without augmenting the agricultural land, mechanisation could feed the whole population.

68. 1836-37 and 1844-47.

69. The population of Europe, in spite of emigration, had doubled from 1750-1900 [Giedion, 1959:468].

70. In the USA the par capita income increased from $385 to $1022 while the population grew from 4M in 1790 to 75M in 1900 [Singer, Vol.V, 1965:1].

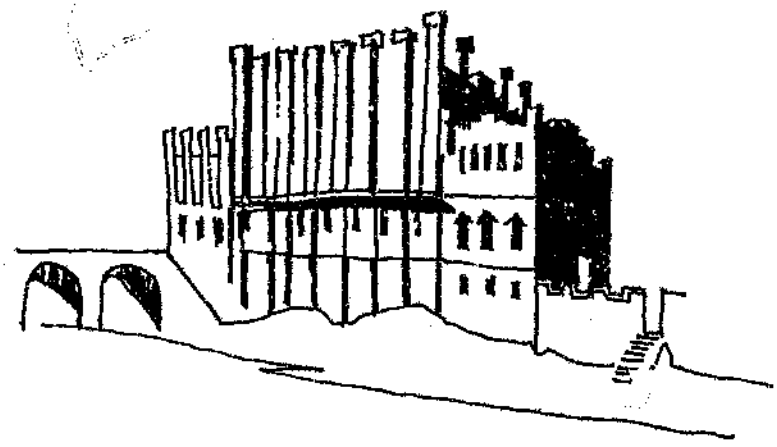


Fig.1 The Castle Grinding Mill at Sheffield c.1840, is striking proof of the utter disregard paid by architects to the purpose of the building they were called on to design [Jones, 1984:111].

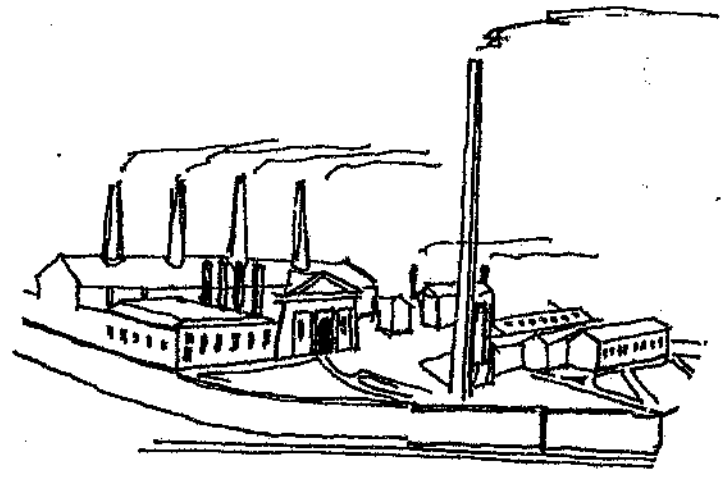


Fig.2 Engineers on the other hand paid scant attention to the external design features as shown in this illustration of the Union Plate Glass Company's works at Pocket Nook c.1843 [Singer, Vol.IV, 1965:374].

CHAPTER SEVEN : FACTORY BUILDINGS

A building, or buildings, with plant for the manufacture of goods; a manufactory; works.

[Onions, 1970:667].

The middle of the nineteenth century witnessed a number of schisms and also an association. The split between architect and engineer made itself felt not only in the industrial field [Fig.1], but in every sphere of building. It became obvious that the techniques of thought and feeling were widely separated, which was contrary to previous lessons taught in the history of architecture. Science now became associated with technology [1] and was to follow a completely different path as the arts [2]. At this early stage of the new scientific development, whose structural innovations were reflecting the spirit of the age, the architect was looking back [3] for his inspiration while the engineer was discovering the potential of new materials and frameworks. The engineer was not trained to develop the theme. It is now felt [Munce, 1961:8] that perhaps the meanness and squalor of the Industrial Revolution could have been lessened had there been a questioning and vigorous architectural profession [4]. This left the field open to the engineers, who coped as best [5] they could by solving the problems [6] with practical solutions [Fig.2] often of exceptional quality.

There also seemed to be a split between the various directions in Britain, which had taken the lead in the industrial revolution and now seemed to hold that direction relentlessly, and the less dogmatic approach of the USA and later Europe. The British seemed to be locked into the mould of guilds of skilled workers, whereas the Americans after being flooded with unskilled peasants from Europe [7], turned to mechanisation as a method of industrialisation.

1. Scientific methods were used to establish the strength and design of building elements and the empirical methods were abandoned [Singer, Vol.V, 1965:466].

2. One man, Renaissance man, had been able to comprehend the whole and overcome the technical as well as the artistic problems [Wells, 1972:799].

3. The eclectic medley of inherited forms that overlaid architecture [Giedion, 1959: 212].

4. The architect generally worked at the offices of older firms until they set up on their own. The in-breeding allowed few new thoughts [Jones, 1984:114].

5. The cast-iron beams at Oldham cotton mill failed in 1844, killing 20 persons [Fairbain, 1857:27].

6. Also philosophers like John Stuart Mill [1806-1873] who wrote his System of Logic in 1843 and The Principles of Political Economy on the division of labour in 1848 [Durkheim, 1949:39].

7. Potato blight caused famine in Europe in 1845. Ireland was worst affected

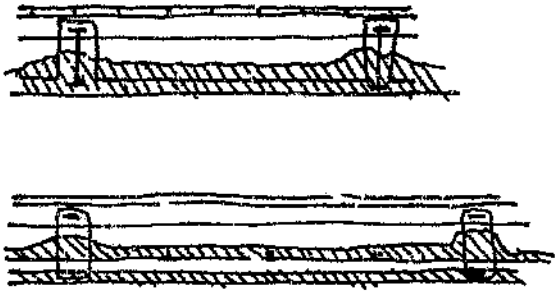


Fig.3 Method developed in 1840 in France using iron beam floors [Singer, Vol.IV, 1965:450].

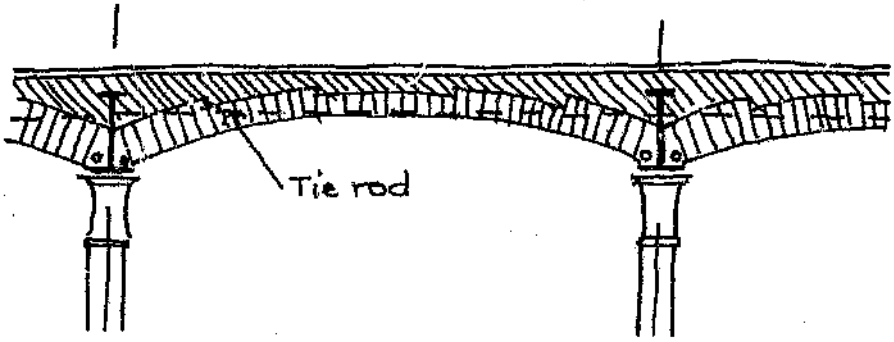


Fig.4 Good strong bricks laid in an arch, the haunches filled and levelled with concrete of lime and ashes plastered smooth [Fairbairn, 1857:148].

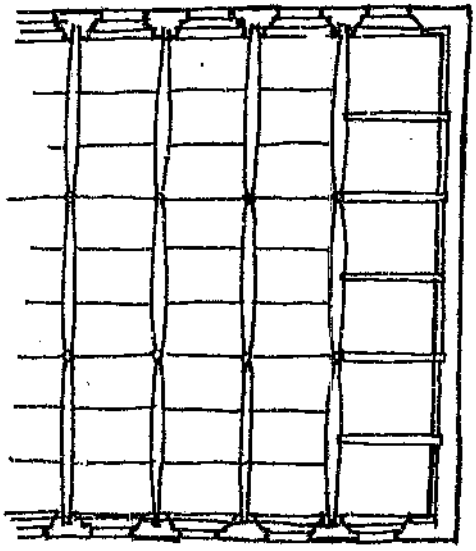


Fig.5 The rods are cottered into the ends of each beam. They form a bond when built into the wall and tie the floor beams, the side walls as well as the gables into one solid and compact mass [Munce, 1961:4].

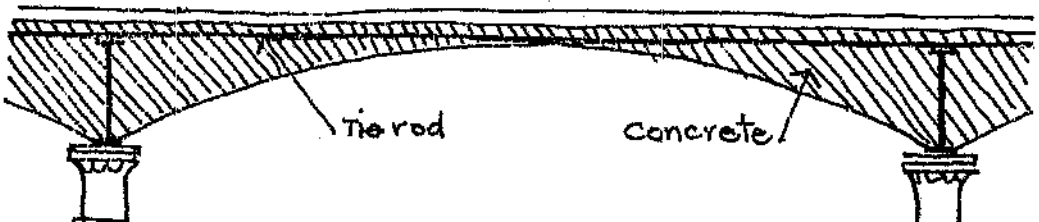


Fig.6 The construction used for a cotton mill by architect John Whittaker near Ashton-under-line [Fairbairn, 1857:158].

In Britain the structure of the mills was advanced by engineers across a wide spectrum using the latest methods of employing iron [8], concrete [9], glass [10] and finance [11]. Fairbairn [12] was very impressed by the advanced structures developed in France [Fig.3]. He then created two different methods of his own [Fig.4] using similar techniques. One consisted of a brick arch which was supported by wrought-iron beams on cast-iron columns. In mills used for the manufacture of cotton, silk, flax and wool, the span of the arches varied from 2,9 m to as much as 3,6 m, with spans of 6 m in the opposite direction [Fig.5]. In some cases hollow bricks were used to reduce the weight so that there was a great sense of lightness and security in the factory.

When a warehouse construction was considered, the weight factor was increased appropriately. Fairbairn proposed and then constructed a building 16 m wide with one column down the middle. The wrought-iron beams were 8 m long from the centre of the column to the walls at each end. The supports between the beams were wrought-iron plates 5 mm thick and riveted to T-bars spanning 3,3 m from beam to beam. The plates were approximately 3 m wide and riveted to each other. Here again the haunches were now much deeper at the column, but shallow at the apex and were held together by means of a tie rod [Fig.6]. The main building was 100 m long 20 m wide and six storeys high. Together with the weaving-shed and warehouse it covered 2600 m^2 and had 1 800 looms and 40 000 spindles [13]. The transmission machinery consisted of two engines of 300 hp each, but with an actual force upwards of 800 hp, 1580 m of shafting and 1 250 pulleys driving the different machines [14].

The very large steam-engines required chimneys that created a good draught. They were visible and obvious landmarks and, like the buildings [Fig.7] themselves,

8. William Kelly [1811-1888] invented the blast furnace in USA. Robert Wilhelm Bunsen [1811-1899] experimented with the loss of heat in blast furnaces in Germany while Sir Henry Bessemer [1813-1898] invented the converter in Britain [Singer, Vol.V, 1965:54].

9. Fox, Henderson and Co. developed the method of using concrete as filling between iron girders [Giedion, 1948:322].

10. Sir James Chance [1814-1902] invented the method of grinding and polishing sheet glass [Singer, Vol.IV, 1965:368].

11. In 1825 it was rare to have joint-stock companies, but by 1840 a few corporations and limited liabilities had been established and by 1844 the Acts of Public Companies was passed [Singer, Vol.V, 1965:805].

12. Sir William Fairbairn [1789-1874], civil engineer and inventor [Fairbairn, 1857:5].

13. Manufacturing 48 km of calico per day.

14. A total weight of 460 tons.

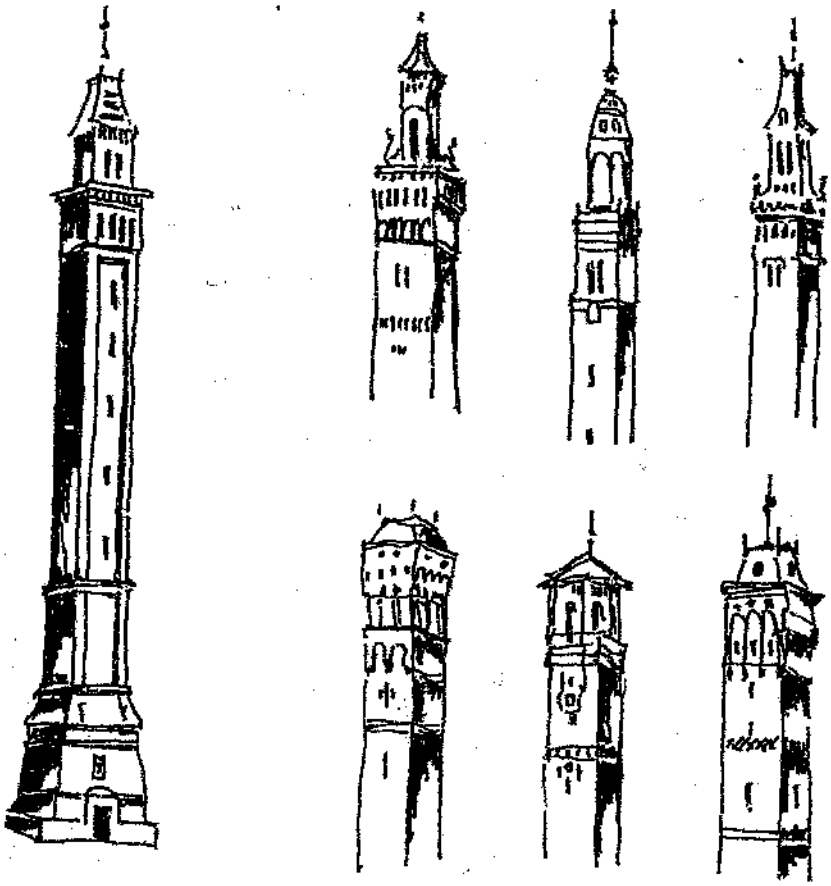


Fig.7 In 1859 Sir Robert Rawlinson [1810-1898] produced a pattern book of chimneys based on campaniles, watch towers and minarets and resulting in some bizarre designs [Jones, 1984:143].

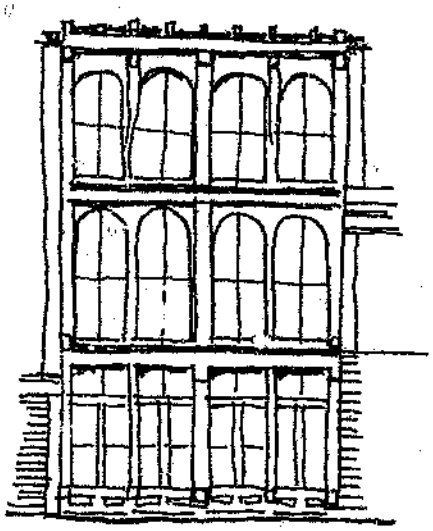


Fig.8 These flat surfaces are reminiscent of the shape of the simplified Romanesque style [Giedion, 1859:200] with its great casement windows. This development coincided with the invention of the safety elevator by Elisha Graves Otis [1811-61] [Munce, 1961:6].

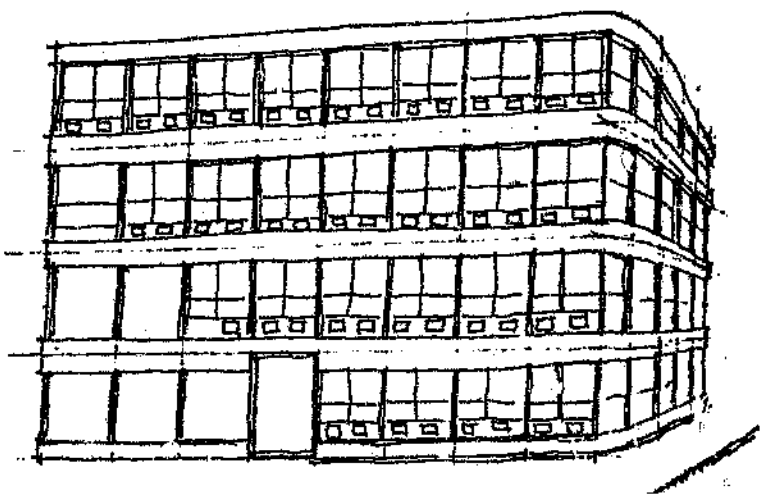


Fig.9 One of many lower but wide cast-iron facades in New York, 1851 [Munce, 1961:7].

generally reflected popular taste. During the early part of the eighteenth century they were short and square, but as power and pollution [15] increased they became taller and more circular to decrease resistance.

Among the many export items were prefabricated factories constructed by Hodgkinson and Fairbairn for the numerous projects in the various colonies such as India and America and this often included all the equipment [16]. During this period Bogardus [17] visited England to study the work of Hodgkinson and Fairbairn and on his return decided to apply his own technical knowledge to a multi- torey factory erected in 1848-50 in Central Street, New York. The cast-iron sections [18] not only formed the internal framework of his five-storey works, but also determined its external appearance [Fig.8]. The design did not win universal approval. In New York a few examples of the iron-and-glass building followed [19], but elsewhere in America it spurred the most exciting architectural development [20].

The ironmaster, in most cases anonymous and as a rule self-made and only of empirical education, erected these buildings for various storage purposes and made a notable contribution to architecture [21]. Most of these men were convinced individualists and their buildings, because of their utilitarian purposes, were not thought to require the artistic treatment that architects [22] were accustomed to applying to buildings. The result was again that the direct relationship of form to function remained unencumbered by the irrelevant styling that we see as a cause and effect of the Industrial Revolution, based on the robustness and simplicity displayed by engineers and buildings [Fig.9].

The Industrial Revolution evolved into the Neotechnic [23] or take off period [24] where so much was changing. Sharply opposing stances were taken by Bentham, Smith [25] and others [26] who supported the laisser-faire, the

15. As the industrial areas became more populated and sophisticated, pollution became more dense and noxious [Jones, 1984:141].

16. Hodgkinson and Fairbairn, makers of textile machinery, steam engines, bridges and ships had already in 1839 delivered a prefabricated cotton mill consisting of three storeys, 8 m x 16 m to Istanbul [Shephard, 1987:12].

17. James Bogardus [1800-1874] inventor and contractor from New York. He was one of many ironmasters who based their designs on those of Boulton and Watt [Jones, 1984:173].

18. Generally accepted that the Lippett Mill in Rhode Island, USA, used the first iron columns in 1846-47 [Pevsner, 1976:280].

19. In St Louis, after the great fire of 1848 and the civil war of 1861, nearly 500 fur and china warehouses, and other commercial buildings were erected [Giedion, 1959:198].

20. 1850-1880 was the so-called cast-iron age.

21. Not only utilitarian, but also interchangeable parts were manufactured. Standardisation by the 1850s was so accurate that different parts made in different cities could be perfectly assembled [Singer, Vol.V, 1965:638].

22. In 1849 John Ruskin [1819-1900] wrote the Seven Lamps of Architecture, showing himself an ardent critic of modern civilization and the prophet of a spirit of regeneration [Jones, 1984:123].

23. The electricity and alloy complex; the third definite development in machines [Mumford, 1946:212].

24. The third stage of economic growth [Rostow, 1969:31] was the period of new commodities and institutions of credit and commerce.

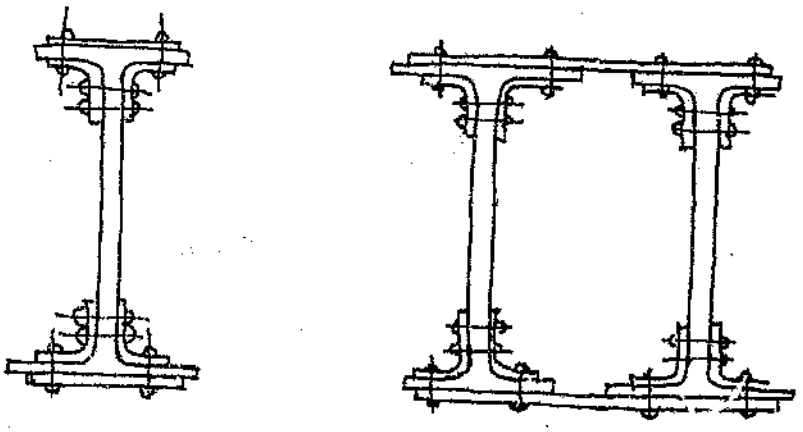


Fig.10 The strengthening of cast-iron plate and the use of box beams with wrought-iron plates could now span up to 10 m. In 1855 Dorman Long were rolling double T-beams at Middlesborough [Fairbairn, 1857:83].

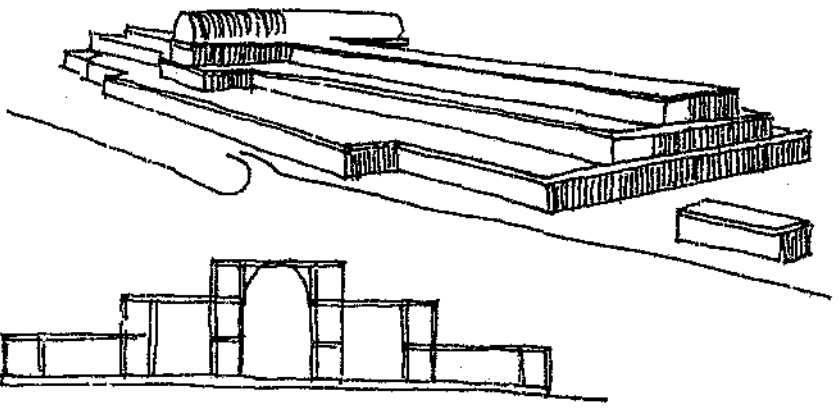
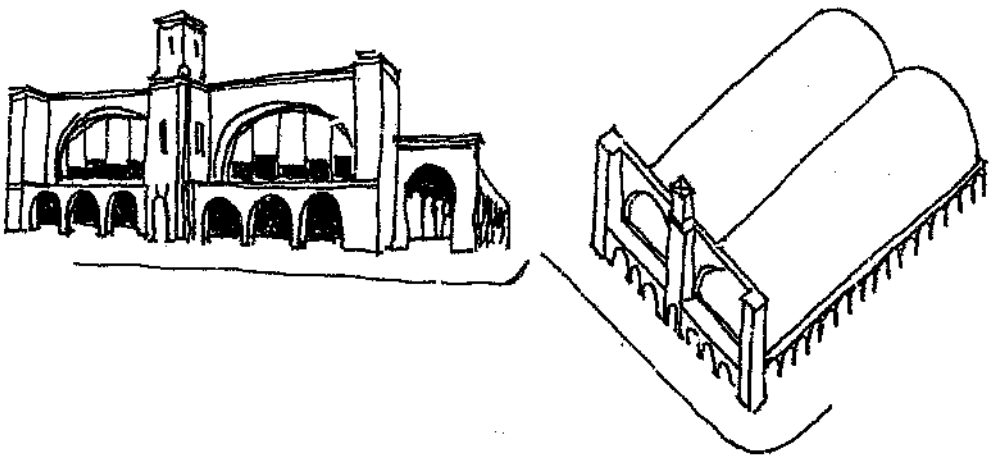


Fig.11 Paxton's Crystal Palace of 1851 was elegant, economical and structurally simple while the Cubitts' Kings Cross Station of 1850 had a frivolous Italianate tower and facade, but the arches did reflect the train-shed structure behind [Risebero, 1979:193].



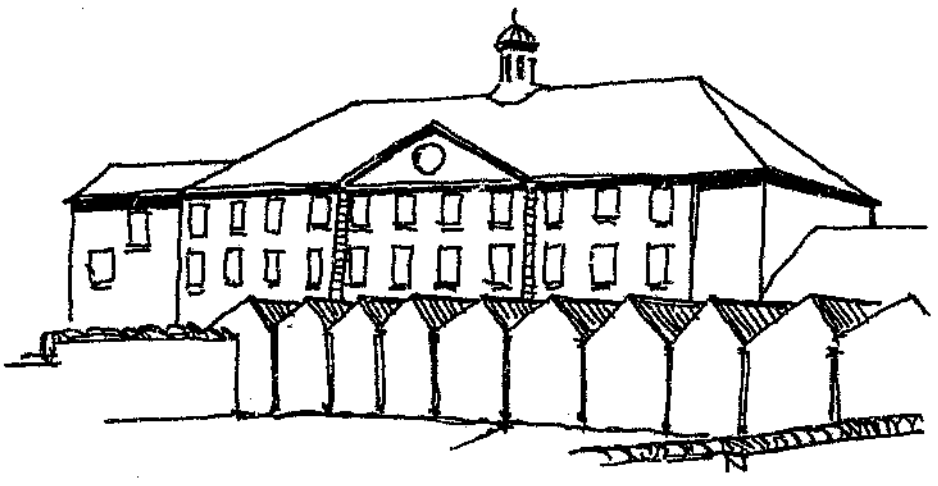


Fig.12 The main building was dressed stone with large windows, a Palladian gable and cupola. The northlight was built in random-rubble [Richards, 1958:87].

competition and a free market system where maximum benefit would accrue to mankind [Brown 1954:33] and later also by Marx and Engels [27] who assumed that with a particular productive facility there must be a corresponding social constitution [Burns, 1968:19].

During the last half of the century of manufacturing buildings materials like steel and concrete, with determinable strengths and coefficients of expansion, radically altered the problem of building. There was a decrease in solid members that built up into great sculptural masses. The aim was to use the least possible amount of materials compatible with safety measures by means of fine calculation and scientific insight [Fig.10]. From guesswork it was probably overloaded with absurd margins of safety.

The development continued from the supporting wall, enclosing mass or crustacean, to the age of vertebrates with a thin protective skin [Fig.11]. These ideas were also exploited by Paxton and Brunel [28], Cubitt and Eiffel [29] and had a direct influence on the design of factories, in spite of the functions being totally different.

The first use of the northlight roof [30] appears to be an extension to the Wye Mill [31] in the mid-nineteenth century. The internal construction constituted a timber roof and trusses resting on iron columns [Winter, 1970:62]. The main building, when completed, represented the skilful incorporation of Palladian principles [Fig.12], while the northlights over the weaving shed were purely utilitarian.

Saltaire, which was designed [32] by Lockwood and Manson [33] and constructed near Leeds, consisted of a spinning mill six storeys high, running east-west 180 m long and 20 m wide, with a single column placed just off centre of the room [Fig.13] [34]. The columns were cast-

25. Jeremy Bentham [1748-1831], who attempted to solve social problems scientifically, Adam Smith [1723-1790] who wrote Wealth of Nations [Brown, 1954:33].

26. Utilitarianism a normative ethic.

27. Karl Heinrich Marx [1818-1883], revolutionary sociologist and Friedrich Engels [1820-1895], socialist philosopher, who wrote the Communist Manifesto together in 1848 [Barber, 1972:131].

23. Sir Joseph Paxton [1801-1865] landscape gardener and designer of hothouses turned architect in 1851 for the Great Exhibition in Hyde Park and Isambard Kingdom Brunel [1806-1859], civil and mechanical engineer of outstanding originality [Guedes, 1979:47].

29. Sir William Cubitt [1785-1861], engineer and railway man and Alexandre-Gustave Eiffel [1832-1923], engineer, bridge builder and designer of the Galerie des Machines Paris Exhibition 1867 and the Eiffel Tower, 1887-89 [Giedion, 1959:631].

30. The Saltaire mill by Fairbairn wrongly claims the honour of the north-light invention for itself [Jones, 1984:96].

31. Built by Arkwright in 1783 destroyed by fire, rebuilt in 1787 and increased in size in 1814-18 [Jones, 1984:24].

32. For Sir Titus Salt [Guedes, 1979:95].

33. Henry F Lockwood [1811-78] and William Manson [1828-89] who employed Fairbairn as the consulting engineer responsible for fireproofing the interior [Jones, 1984:95].

34. To allow for unobstructed passage down the middle.

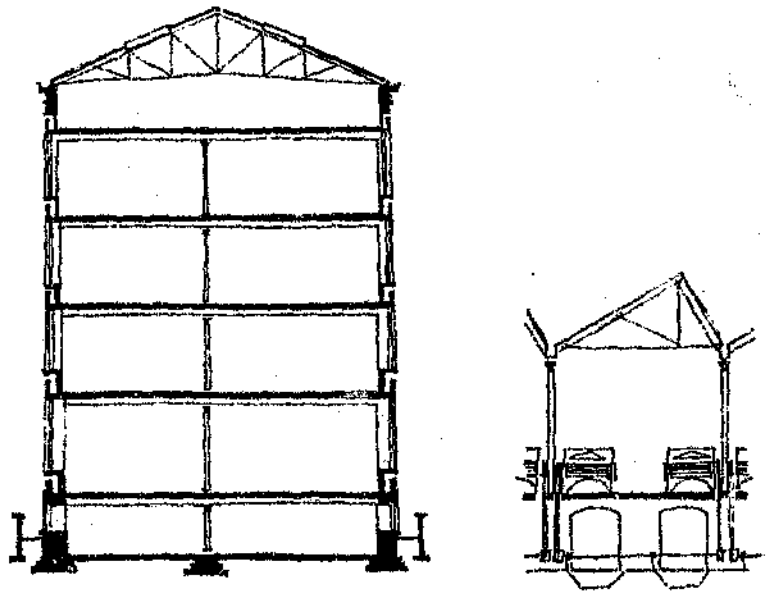


Fig.13 The section through the mill indicates the cast-iron roof members, columns and wrought-iron beams. The floors are concrete on hollow bricks. On the same scale is a section through the weaving shed showing the wooden beamed roof supported by the wrought-iron tie rods with glass on the northside and hidden gutters also of cast-iron. The rain water drained into hollow cast-iron columns [Fairbairn, 1857:Plate II and p 173].

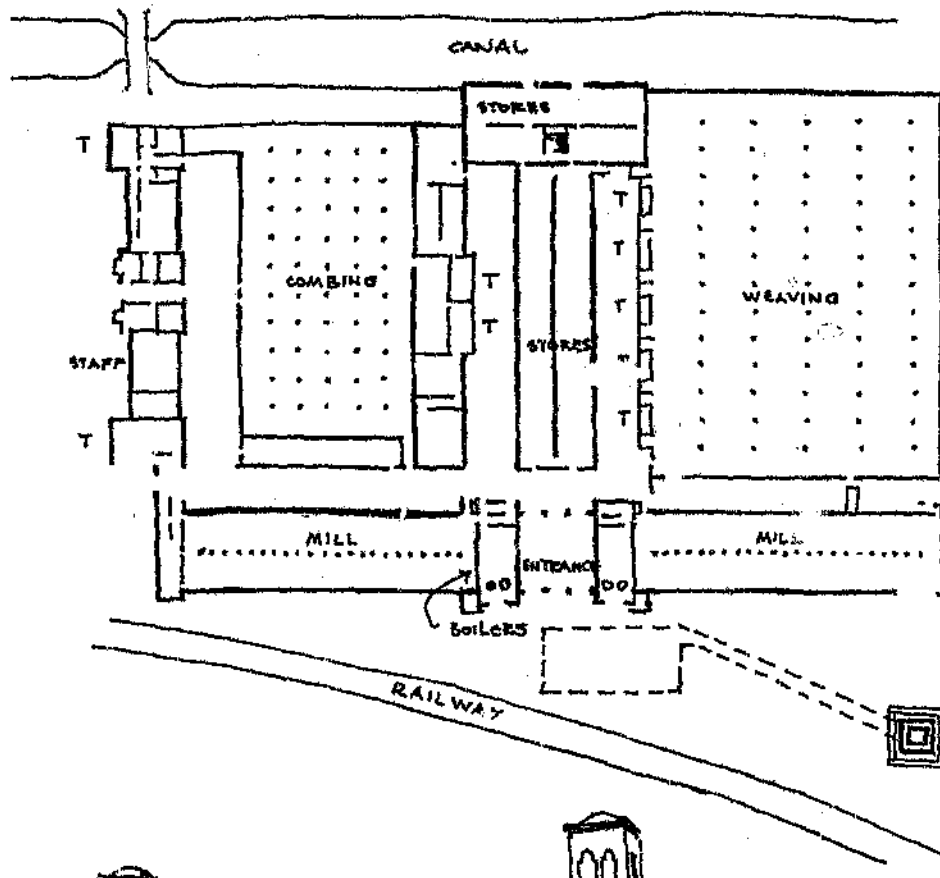


Fig.14 Ground floor plan of the mill showing the layout which includes the six-storey mill and single-storey weaving and combing sheds. Note the decentralised toilet facilities and the despatch directly on the Leeds and Liverpool canal. On the other end of the factory there is the Leeds and Bradford Extension railway [Fairbairn, 1857:Plate I].



Fig.15 Central entrance flanked by the boilers and towers [Guedes, 1979:16].

iron and the beams wrought-iron with hollow brick arches to reduce the weight of the floor. The weaving and combing sheds which were adjacent to the main building were single-storeyed with north-facing lights.

These large sheds each had a regular grid of columns whose modules were arranged to conform as far as possible to the dimensions of the machinery [35] and space occupied by the processes, within limits of economic spans. Whereas the previously mentioned northlight [36] was reasonably primitive, these sheds were extremely sophisticated. All the machines were driven from the basement by means of shafts and pulleys [37] so that there was no vibration in the light construction. It meant that this large area was unencumbered and unobstructed by the usual straps, wheels, drums and shafts. The heating and humidification of the weaving shed was piped underground from the boilers and spread through the shed by floor grills.

35. The weaving shed was 12 m x 6 m and the combing shed 6 m x 6 m (Shephard, 1987:15).

36. Wye Mill at Cressbrook in Millers Dale (Jones, 1984:30).

37. The total shafting was more than 3000 m long with a thickness of 350 mm to 65 mm in diameter and geared to revolve from 65-250 revolutions per minute (Fairbairn, 1857:175).

Staircases were designed outside of the main structure so as not to create obstacles in the floor plans and fire doors separated each level (Fig.14). Toilets and sanitary facilities [38] were accommodated on a decentralised basis, mostly on half landings in the main building and adjacent to the sheds. The works had two steam-engines that had an accumulated force of 1 250 horsepower which was generated by boilers below the ground, carefully covered with non-conductive material. The coal bins also were situated below the ground next to the railway line to facilitate easy delivery. The smoke from the engines was ducted below the ground to a chimney standing 82 m tall in the style of an Italian campanile. The main building had a central entrance, two large round-arched windows lighting the engine houses and was flanked by two ornate Italianate towers constructed in dressed stone features (Fig.15).

38. There was a total of 4000 persons working in the whole plant (Pevsner, 1976:279).

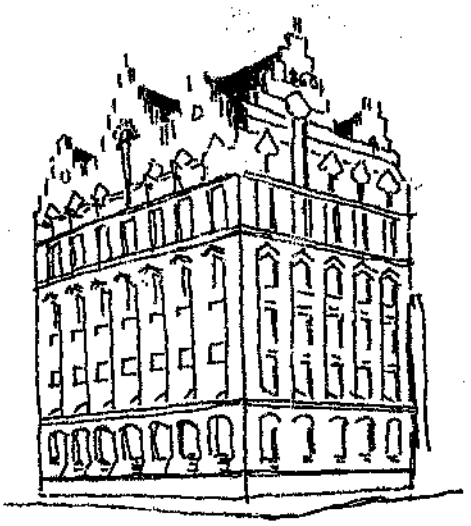
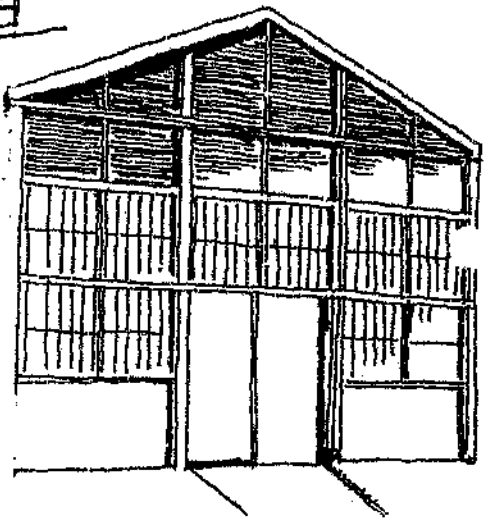


Fig.16 The London Printing and Publishing Co, in West Smithfield, London was built in 1860 and designed by George Somers Clarke [1825-1882]. The decorative elements were Gothic and formed a plinth. The main order, the gabled roofline and the internal framework again were cast-iron and the floors concrete [Brockman, 1974:31].



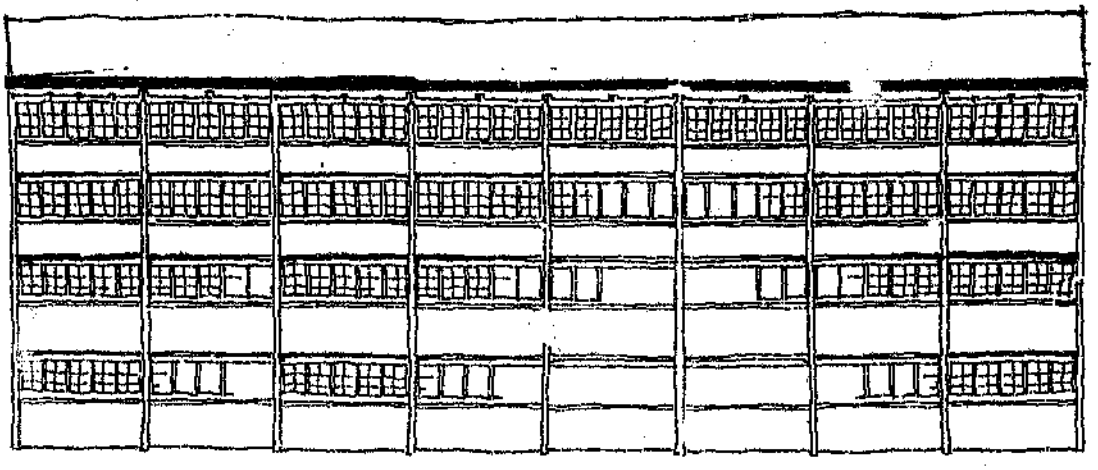


Fig.17 One of the earliest known British multi-storey iron-frame buildings functionally expressed. End and longitudinal elevations [Richards, 1958:66].

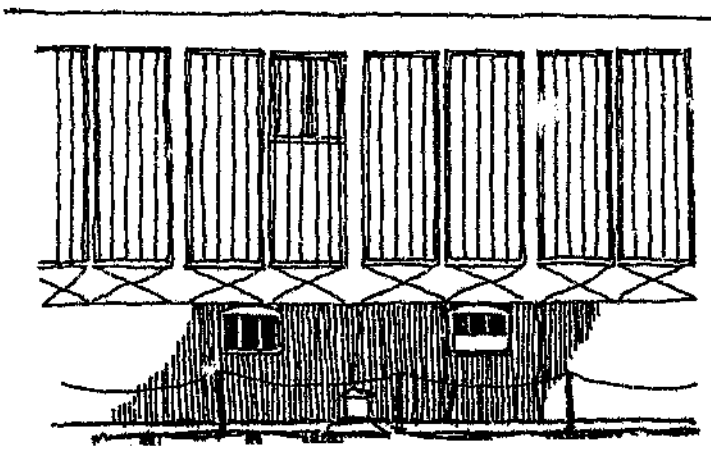


Fig.18 Iron-clad building at the Chatham dockyard [Richards, 1958:69].

The Great Exhibition of London [39] brought home to all classes of society the vast potential of the new industrial age. Many of the exhibitors such as Whitworth [40] were international leaders in machine manufacture, as has been seen in the engineering field and the design and construction of industrial buildings. The design of the Exhibition Centre had been decided without referring to the architectural profession. Perhaps the architects were conscious of the magnitude of the task and also their profession's failure to meet the challenge of the second half of the century [Bradford, 1962:17]. Many architects were not keeping pace with developments. They were still nostalgic and living in a world of revivalistic day-dreaming about the ancient styles [Fig.16]. There were architects [41] who argued that the time was probably near when a new system of architectural laws adapted to metallurgical construction would develop.

The Shearness Boathouse was the first [42] building in Britain to use H-section columns and beams designed by Greene [43]. It was a four-storey foundry ship-fitting shop and boathouse [Fig.17]. It was 70 m long and followed the East-Anglican tradition of construction using brick and white-painted weatherboarding. In this case, the modern version was an entirely uncompromising iron framework with bands of low windows and infill panels of metal creating the appearance of refined simplicity. It must be regarded as a prototype of modern frame construction. A lesser known boathouse [Fig.18] also by Greene, with many of the elements used so successfully, was erected at Shearness. Below the very tall windows the panels were strengthened by cross pressings and wooden weatherboarding again, but now it was used vertically.

During the second half of the nineteenth century, with industry undergoing its greatest expansion [44] the exhibition buildings constructed of longspan prefabricated iron [45] elements and either glass or metal cladding, were

39. The first International Exhibition of 1862 was held in Britain.

40. Sir Joseph Whitworth [1803-1887], mechanical engineer with an international reputation for the quality of his machine tools. Fairbairn in his address as President of the British Association at Manchester in 1861 said "Now everything is done by machine tools with a degree of accuracy which the unaided hand could never accomplish".

41. John Ruskin [1819-1900], champion of Gothic Revivalism, who later hardened against iron mainly because it was no longer handmade. William Morris [1834-1896] saw the machine as only part of the problem but turned his huge talent to the revival of the handicrafts [Nelson 1939:8].

42. Built in 1858-60.

43. Colonel Godfrey T. Greene [1807-1886], Director of Engineering and Architectural works at the Admiralty from 1850-1864 [Guedes, 1979:102].

44. In the weaving industry England was 8:1 ahead of Germany and 3:1 ahead of France.

45. The new materials, iron and after the 1860's steel, made it possible to achieve spans wider than ever before [Singer, Vol.V, 1965:61].

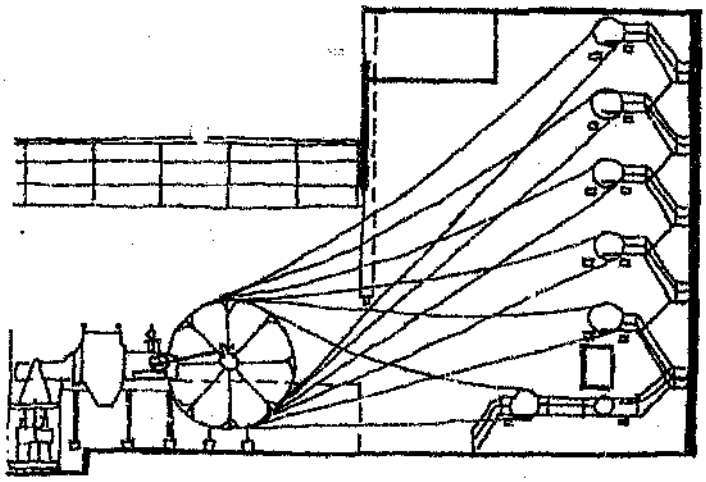


Fig.19 A cotton mill, c.1870, with a horizontal steam-engine turning a 10 m diameter flywheel which was grooved to take about thirty ropes. The pulleys turn the overhead shafts. The iron stair is for maintenance [Winter, 1970:22].

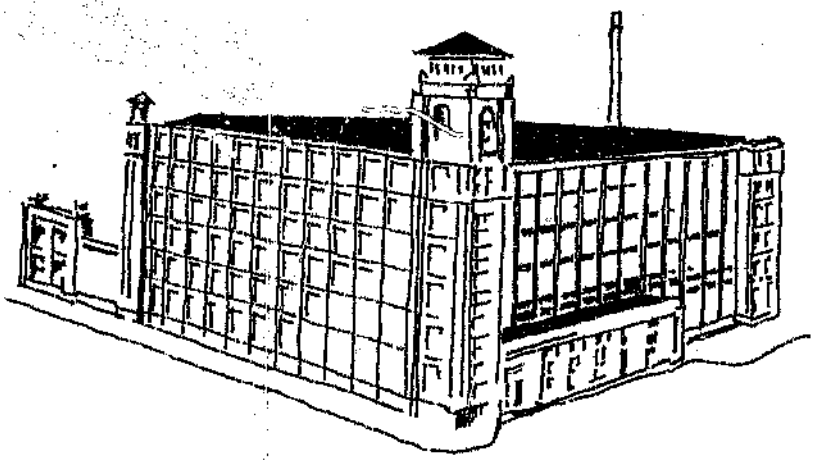


Fig.20 The No. 3 Mill of 1878 built for George Knowles and Son, Bolton. It was known locally as the "Glass Factory" because of the glass-and-iron wall on the right [Jones, 1984:149].

truly creative. This inspired engineers in the design of industrial buildings without directly influencing the shape [46].

The Italianate style continued unabated with chimneys and very large steam engines [Fig.19] playing a major role. British architects and engineers were being invited to Europe [47] to design and construct factories, thereby exporting the Italianate style just like the Palladian features had been carried over to the United States of America. This style was more conservative than Gothic. As happened in history, there were other signs which indicated an approach more in line with technical changes like the development of electrical power [48], the internal combustion engine [49], the use of petroleum fuels, automation and the development of synthetics [50] based on chemical manufacture, systematic and scientific knowledge.

Nearly 100 years had passed since Arkwright and Strutt had erected the first cotton-spinning mill powered by a water wheel and more than 150 years since that controversial silk mill was erected by Lombe, who had learnt about silk spinning and water wheels in Italy. There was no turning back. Engineers were totally committed to the use of iron, steel and reinforced concrete [51]. Even architects were not calling the newer, unadorned industrial building a "cheap style" anymore.

The Peel No. 3 Mill was designed by Woodhouse [52], who had resorted to a building consisting of two sides entirely made of glass and held in place by light iron pillars. This was a clever way of overcoming the low level of light. The latter was reduced by the close proximity of the company's two other mills [Fig.20]. So flimsy was its appearance that insurance companies [53] were hesitant to offer cover [Jones, 1984:148].

46. Towards the end of the century when industry was taken as a matter of course, this influence waned.

47. They were principally from Lancashire and Yorkshire firms and were building in Belgium, France and Germany.

48. Electrical condenser in 1782 by Alessandro Guiseppe Volta [1745-1827], the *Dynamo motor* by Antonio Pacinnoti [1841-1912] in 1861 and the theory of light and electricity by James Clerk Maxwell [1831-1879] in 1864 [Clark, 1985:215].

49. In 1859 James Young [1811-83] and Abraham Gesner [1797-1864] prepared kerosene from petroleum and oil wells were drilled in Titusville, Pennsylvania. In 1860 the first combustion engine was revealed by Etienne Lenoir [1822-1900]. Henry Ford [1863-1947] was born and Siegfried Marcus [1831-98] invented the carburettor.

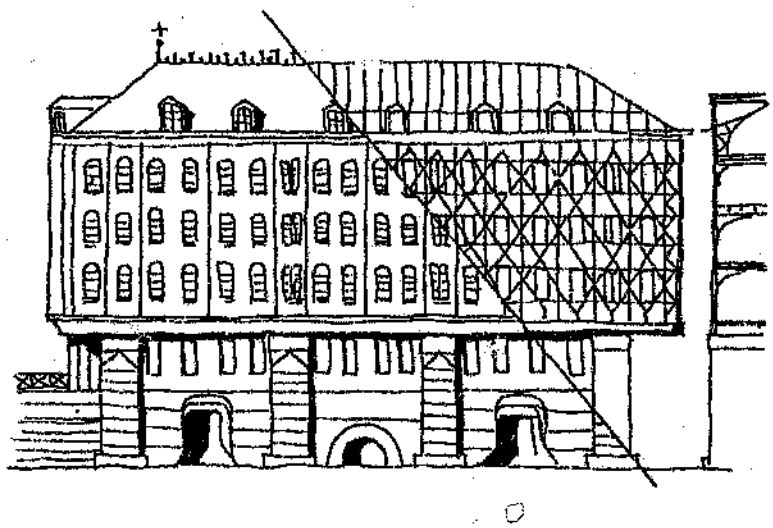
50. First synthetic dyestuffs were developed in 1856 by Sir William Henry Perkins [1838-1907] in 1862 "Parkesine" was shown at the Great Exhibition by Alexander Parkes [1813-1890] and John Wesley Hyott [1837-1920] patented celluloid in 1820.

51. Joseph Monier [1823-1906] built containers of concrete using mesh in 1849 and the first building was erected in 1867 where concrete was strengthened with iron bars, this was for the Paris Exhibition.

52. George Woodhouse [1827-1883] produced a number of unusual designs.

53. By 1890 insurance surveyors estimated that 40% of all textile mills in Britain had fireproof structures. Since 1880 all the mills erected were fireproof.

Fig.21 This construction took place at a time of monumental overdecorated architectural confusion in Europe [Munce, 1961:9].



The industrial potential of Europe and America was being developed, each country exploiting its local [54] circumstances. France, in spite of the disastrous loss of Alsace and Lorraine to Prussia, fared well in light industry. Germany expanded its mining, metallurgy and chemical manufacture while in the United States of America the Civil War [55], the first large scale industrial war of the century, opened the whole country to transportation [56]. The primacy of Britain could not be retained forever, in spite of its considerable accumulated capital and technical superiority. As its society became more rigid [57] other nations began to forge ahead [58]. The production of steel was the barometer of progress during the latter part of the century.

The Meunier chocolate factory in Noisel-sur-Marne was one of the earliest examples of the use of a skeleton frame. This elaborate and expensive building [Fig.21] was not approved of by all [Singer, Vol.V, 1965:475] and was regarded rather as an interesting freak than a genuine precursor of the completely framed building [59]. Piles were driven into the bed of the Marne river and four large masonry piers were built with a rolled-iron girder platform. A complete prefabricated skeleton of iron was erected, with diagonal lozenge-shaped stiffeners and a bridge-like structure that was both light and strong. It derived its inspiration from the methods used in wood construction. There were no projections horizontal nor vertical. Brickwork panels were used as infill between the structural elements that were defined by varicoloured tiles expressing the pattern of construction [60]. The machines in the factory were driven by three hydraulic turbines designed by Poucelet [61], which had become a more reliable and an efficient alternative to the water wheel [62].

As long as man has eaten grain there has been the problem of storage. As containers grew in size, the

54. In accordance with its geography, natural resources, national psychology and traditions.

55. With the secession of the eleven Southern States after the war of 1861-65.

56. By 1880 there were 320 000 km of railway lines.

57. Michael Farraday [1791-1867] experimented with electricity. Werner von Siemens [1816-92] and R.E.B. Crompton [1846-1940] pioneered electrical lighting, but it was Thomas Alva Edison [1847-1930], co-owner of the United Electrical Light Company, whose electrical motors were to replace steam-engines as prime movers during the 1880's [Singer, Vol.V, 1965:211].

58. By 1900 Britain produced 4,9 million tons, Germany 8 m and United States of America 11,4 m or half of the world's production of steel [Singer, Vol.V, 1965:61].

59. Designed by Jules Saulnier [1817-1881] and erected in 1871 [Singer, Vol.V, 1965:474].

60. This was an entirely different style at the time [Giedion, 1948:140].

61. Jean-Victor Poncelet [1788-1867], mathematician and military engineer [Guedes, 1979:97].

62. Powered the arc-lights used in the factory. In 1878 Edison's first incandescent lamps were used [Singer, Vol.V, 1965:210].

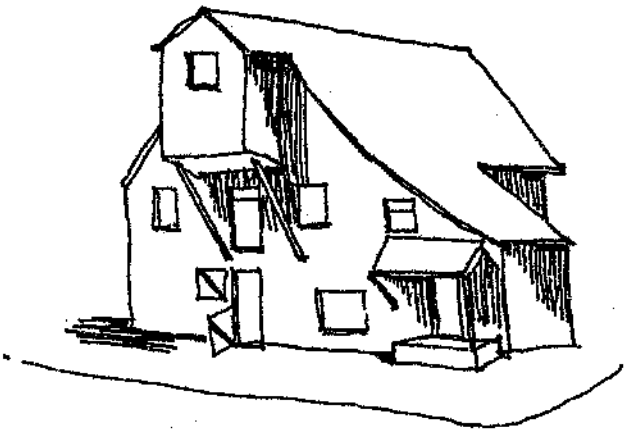


Fig.22 Bocking Mill in Essex on the river Pant was a typical wooden construction with white weatherboarding c.1750 [Richards, 1958:117].



Fig.23 City A and B elevators after 1880 in Buffalo, New York, on the Buffalo river [Banham, 1986:112].

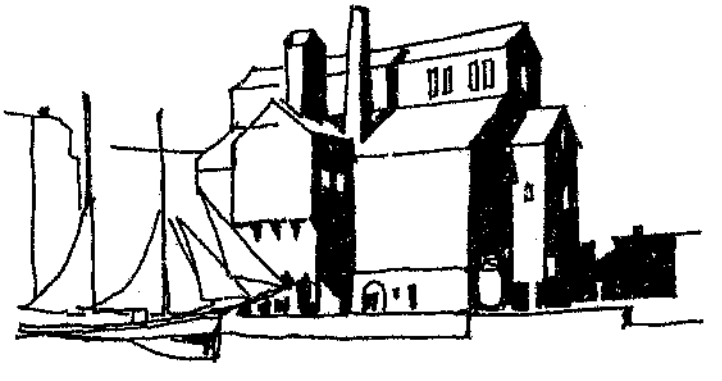


Fig.24 Bennet Elevator also at Buffalo after 1880 [Banham, 1986:112].

loading and decanting equipment increasad in size as well [63]. With the inception of mechanised farming [64], the water mills [Fig.22] and, later, the steam-engine mills [Fig.23] grew taller, while others like glass factories were flatter.

63. Hoists and pulleys were in use since ancient times and the screw conveyor since the time of Archimedes.

64. William Stanley Jevons [1835-82] made motion studies of the effect of different tools on the fatigue of workers.

The mills appeared to be unplanned compositions, but the functionally-determined arrangement of planes and angles gave these buildings vigour and their own coherence. One should note the covered weatherproof lift with its supports to hoist and lower products and also what appears to be the casual placing of windows. The mills may have been fairly mechanised, but much of the work was still done by hand. Various mechanisms for lifting grain were invented [65] so that it could flow down through the sequence under its own weight.

65. The steam driven mechanical bucket conveyor invented by Joseph Dart after Oliver Evans in 1843.

The Bennet [Fig.24] elevator shows a plain and apparently well-made structure with a tall, thin section, steep pitched gable roofs and arched openings at ground level. A kind of pedimented extension in the centre of its flat facade served as housing for the machinery, with a chimney stack for the steam-engine [66]. The average life span of a wood-and-brick elevator was about twelve to fifteen years [67]. The internal construction consisted of wooden bins, stairs, floors and ladders. Just like the textile mills, these grain stores and mills had atmospheres laden with a fine dust which was highly dangerous and explosive in the presence of lamps. The steam-engine and moving parts were not lubricated [Banham, 1986:113], which added to the risk.

66. The oil engine was patented by Joseph Hock in Austria and in 1873 at the Vienna Exhibition a public demonstration of electric motors was given. Both machines were still belt-driven as usual [Singer, Vol.V, 1965:163].

67. The internal atmosphere was heavily laden with grain dust.

Most of the problems and threats to structures stemmed from the liquid behaviour of the grain which exercised vertical as well as horizontal thrust. During the 1870s the first solutions were sought in cribbed bins [68]. During the 1860s riveted boilerplate had been tried, but due to

68. The rectangular bin was built of layers of planks laid flat and spiked together in a heavy frame.

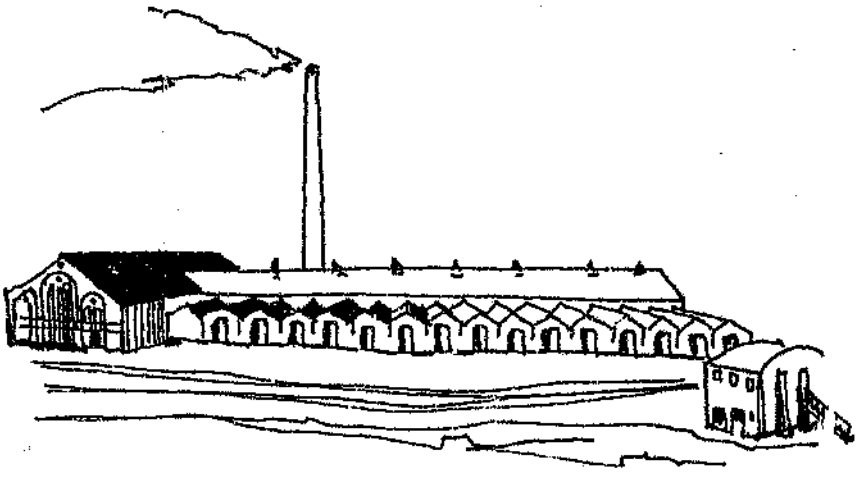


Fig.25 Plate-glass works at Cowley Hill belonging to the Pilkingtons [Jones, 1984:134].

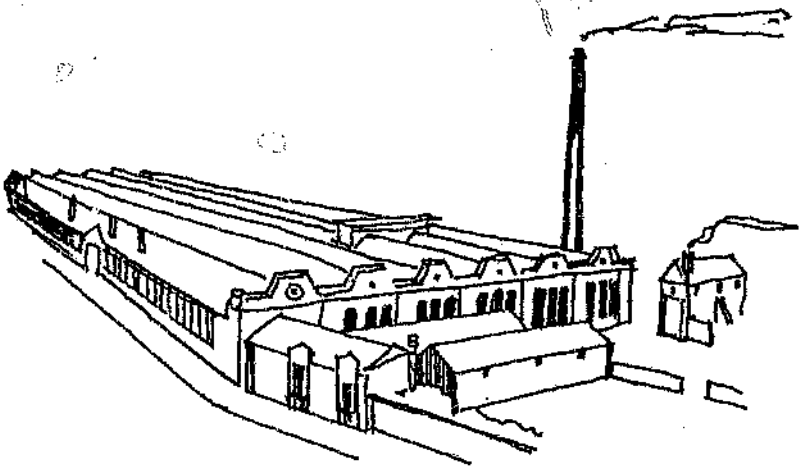


Fig.26 The 1879 Cadbury's purpose-built chocolate factory at Bournville. The gable-end did not reflect the pitched roof. The northlight is behind [Jones, 1984:194].

the specialised skills required to make the circular bin [69] it was not popular.

69. It was based on experience gained from boiler-making, but it was not rust or corrosion proof and sweated.

The demand for glass since the patenting of plate glass [70] caused a vast usage in the building industry and when Pilkingtons [Fig.25] decided to build a plate-glass factory, they chose a slight slope so that the storage and disposal of sand and liquid glass could be handled easily.

70. Plate glass was first made in the seventeenth century in France and several improvements were made in the nineteenth century, culminating in the Bicheroux process in 1918.

The principal building consisted of a large hall with thirty pot furnaces at the head of the process with ample space for casting plate glass. For four blocks the annealing kilns were arranged along the side of each nave. Nearby was a matching room, grinding shed, smoothing and polishing rooms and a warehouse. All these areas were covered with a series of pitched roofs which must have inhibited lighting and caused unending gutter trouble. The gabled roof of the casting hall towered above the surrounding building with narrow windows placed between buttresses which, from a distance, looked sectarian.

In June 1878 the Cadburys [71] purchased 7 ha of open country near Bourne, just south of Birmingham and were determined that their factory would be custom-built [72]. The factory, a rectangular one-storey block 110 m by 50 m wide, was lit by north-facing roof lights [Fig.26]. This measure was adopted because direct sunlight could be extremely troublesome in the manufacture of chocolate. Internally it was divided into stores and packing rooms.

71. George [1839-1922] and Richard Cadbury [1835-99] were Quaker industrialists and social reformers. Like Leverhume, William Hesketh Lever, 1st Viscount [1851-1925] who established Garden Villages for the workers [Jones, 1984:194].

72. Like in a weaving shed.

The differences between architects who still followed the historical styles and those who were more enlightened, became more apparent. There was an appreciation of the close connection between social and functional reasons for a structure and its treatment. This was most apparent in industrial buildings where the very reason for its existence was efficiency in design, layout, [73] purpose, appearance, materials and structure. The framed buildings

73. The pioneers of the early 1880's in management consulting and industrial engineering provided the value of scientific techniques. Frederick Winslow Taylor [1856-1915] used stop-watch measurements, while Frank Bunker [1868-1924] and Lillian Evelyn Gilbreth [1878-1972] developed time and motion studies to increase efficiency and, hence, output [George, 1968:150].

Fig.27 The 1884 Artic Oil Works in San Francisco. Not a very inspiring building that was designed by Ernest L Ransome [1844-1917]. In California at the time iron was so expensive that reinforced concrete was used for the frame structure [Banham, 1985:36].

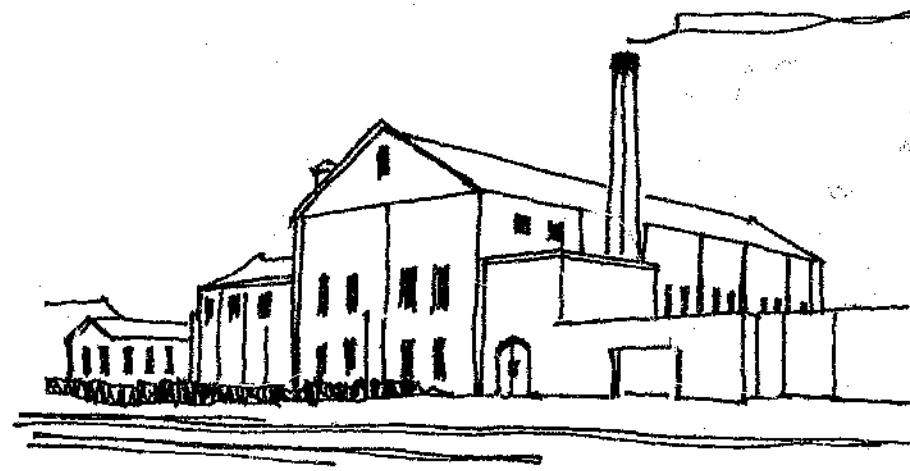
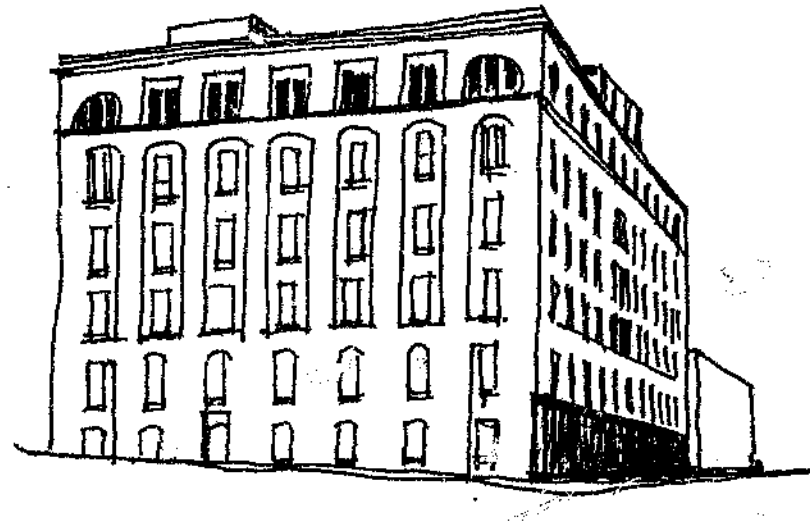


Fig.28 The first hollow tiles in modern times were made in 1873 by Doulton, later called the Royal Doulton Company of fine chinaware. The ceiling was keyed for plaster and the floor usually heavy boarded [Singer, Vol.III, 1965:480].



Fig.29 Dressed stone mill in Minneapolis [Banham, 1986:55].



[Fig.27] with their plain and ungarnished treatment found favour with industrialists. Some of these factories are among the best examples of early modern buildings. The first framed buildings were those where steel was used [74] for columns and beams. The columns were covered with lathing and plaster whereas the beams were protected by hollow fired clay [Fig.28].

Two major innovations developed parallel to and complemented each other, namely electricity [75], which allowed for wider buildings that were not so dependent on the outside window light as before, and the internal combustion engine which was driven either by petrol [76] or by oil [77]. The effects of the invention of the petrol engine on industrial buildings were enormous. Some of the largest plants ever developed were for the manufacture of motorcars. The diesel engine allowed small factories and workshops to develop their own power for electricity [78] to drive machinery, even if in the beginning it was still on the basis of the shaft and pulley.

Some of the mills [79] presented a facade of good, grey stone [Fig.29] and conventional or regular fenestration, which was dramatically broken by vertical setbacks in the panels. The deceptive simplicity [80] of the elevations lent height to what would otherwise have been a heavy squat building. There was no ornamentation except for the Roman windows on the corners of the top floor and the setbacks on the first and top floors.

It was nearly the end of the century and the design of industrial buildings was unconsciously moving towards aesthetic shapes and feelings which found their equivalents some decades later. The last hints of the eclectic were disappearing and it became impossible to hide the new structural forms developing from modern construction methods. Account had to be taken of the new shapes [81] caused by the use of new materials like

74. Not cast-iron but steel I-columns and beams that were rivetted together as a frame. The steel was more reliable than cast-iron [Guedes, 1979:97].

75. Sir Joseph Swan [1828-1914] and Edison experimented with carbonised filament, which was patented by J.W. Starr [1822-1847] from Cincinnati. By 1880 the incandescent lamp was manufactured in the USA and Europe. Nikola Tesla [1856-1943] invented the first AC electrical motor in 1888 and it was manufactured by Westinghouse [Singer, Vol.V, 1965:231].

76. Gottlieb Daimler [1834-1900] and Karl Benz [1844-1929] built a small, light, high speed engine and the first motor vehicle during 1884-1885 [Singer, Vol.V, 1965:170].

77. Rudolf Christian Karl Diesel [1858-1913] was the inventor of the first oil-driven engine in 1885 which became a commercial success. It was perfected in 1896 and was affectionately called "the Black Mistress" [Singer, Vol.V, 1965:163].

78. Before power stations were developed.

79. Pillsbury A Mill Minneapolis before 1885 by Leroy Sunderland Buffington [1847-1931] [Giedion, 1959:140].

80. The West India Dock, 1802-3, had similar vertical lines.

81. Flat roofs and deeper buildings. The safety elevator developed by Elisha Otis [1811-1861] now ran with an electrical motor [De Bono, 1979:149].

Fig.30 Two fire-resistant floor systems developed by Homan in 1889 where I-beams are protected by concrete [Singer, Vol.III, 1965:480].

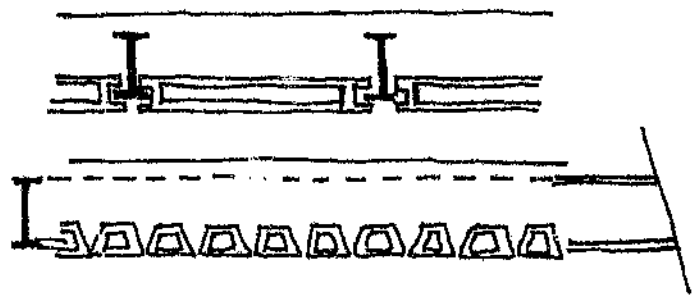


Fig.31 Factory erected in 1888-1889 in Alameda, California, with reinforced concrete walls [Banham, 1986:36].

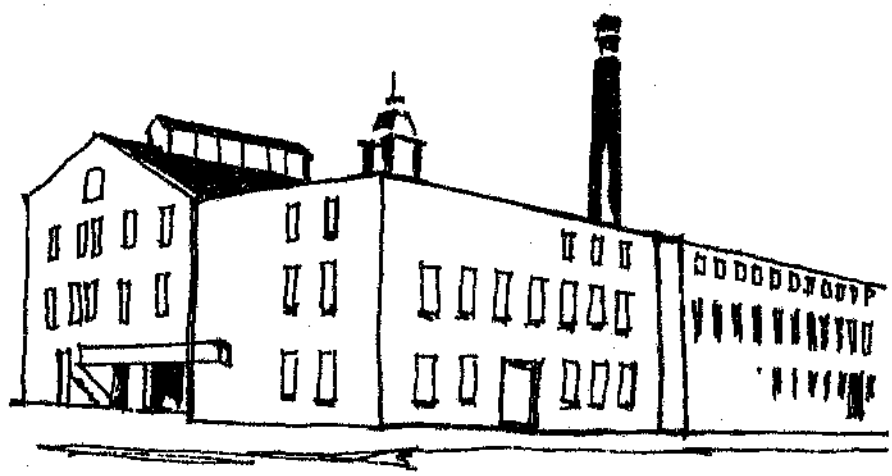
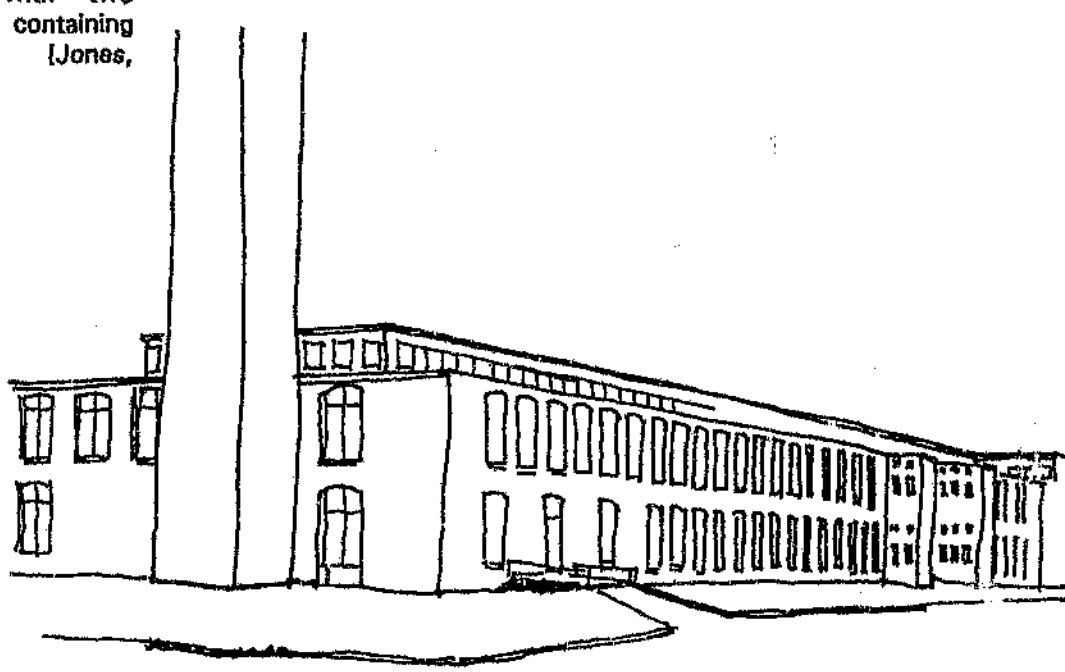


Fig.32 The two-storeyed building has a timber clerestory roof with two projecting blocks containing the lavatories [Jones, 1984:164].



concrete and the new innovations such as electricity. There was an equilibrium on the vertical plane [82] between the external structure and the internal spaces. The buildings were totally fire resistant [Fig.30].

82. Long since discovered in the horizontal of market halls and railway station structures.

The East Coast plant of Pacific Coast Borax [83] was designed by Ransome [84], the inventor of the concrete frame in its American version [Fig.31]. When this building was destroyed by fire in 1902 it became so hot that the steel roof twisted and melted into shapeless puddles, but the frame of reinforced concrete survived. This was a convincing demonstration of the appropriateness of these methods of construction. The concrete had simply, in this case, replaced the brick and stone outerwalls of the former utilitarian tradition. The windows and doors had segmented arched tops, which need not have been designed for strength. The flat concrete structure was simpler and cheaper, but Ransome would not break with custom where brick and stone were arched to avoid tension in the lower chords [85].

83. The first building in the East completely constructed with concrete floors, columns and external walls in 1897 [Guedes, 1979:99].

84. Ernest L Ransome [1844-1917] was decended from the Ipswich, England, dynasty of iron founders and engineers. In France Francois Hennebique [1842-1912] had also patented reinforced concrete in 1892 [Guedes, 1970:103].

85. This was Ransome's trademark until well after 1900 [Guedes, 1970:99].

In the case of the Alameda plant there was a combined use of a pitched roof and clerestory. This was seldom seen in a multi-storeyed building. This roof was common on single-storeyed worksheds. The flat-roofed profile with the stand up parapet around the top of the walls made the low pitch invisible from the outside.

A building which was the same pattern [86] used a similar technique, but in brickwork [Fig.32]. It consisted of two storeys, with the ground floor used for heavy machines and the upper floor for offices, shipping and purchasing rooms. The steam-engine which drove the heavy machinery was also situated on the ground floor near the heavy equipment. The screw-cutting lathes were all run with shafts, pulleys and belts off the side walls.

86. American Screw Co. from Providence, Rhode Island, moved to Leeds in Britain [Jones, 1984:164].

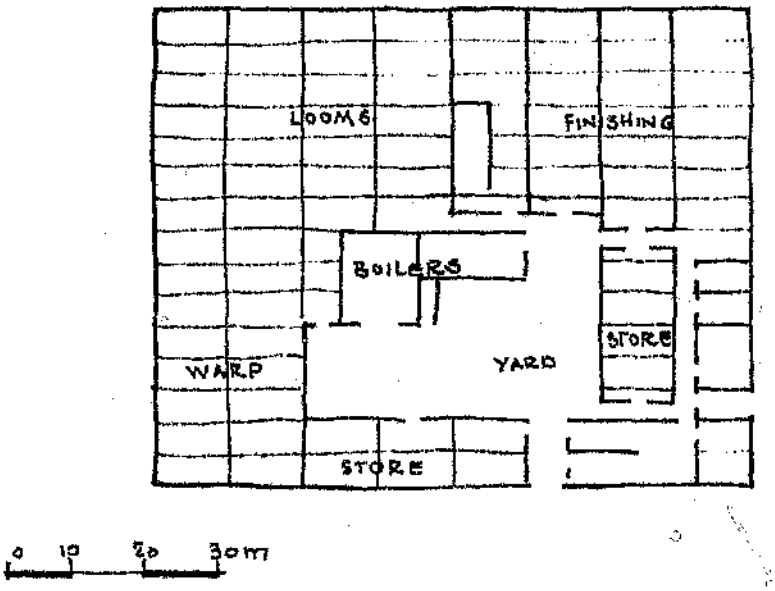


Fig.33 The "square" plan - a central yard with access to all departments [Jones, 1984:190].

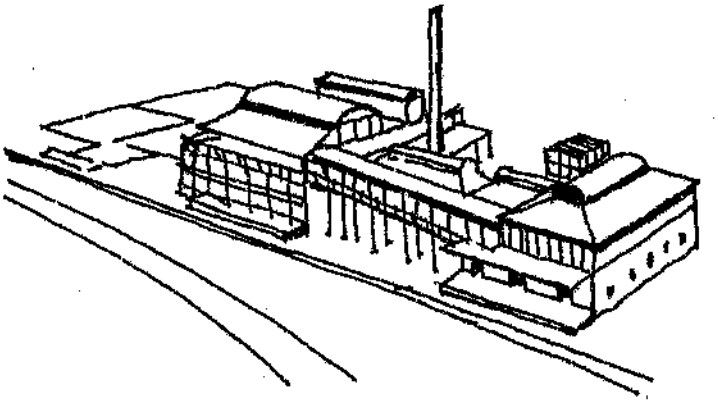


Fig.34 The view of the Riverina freezing works at Deniliquin New South Wales c.1895 [Singer, Vol.IV, 1965:47].

Many mills in England were still being erected four to six storeys high and most remained rectangular in plan to economise on material, heating and floor area. With the introduction of ring spinning and the new theories of production [87], sometimes called the "Management of Science of Precision" [George, 1968:86], it was realised that long, low buildings could suit the purposes of modern textile production. Sington [88] produced the plans for a single-storey mill [Fig.33] which had three spinning rooms and a card room [89], all arranged symmetrically around a central steam-engine room and a chimney. The bay alignment was along the east-west structural axis, so that together with the perimeter fenestration the northlights in the roof provided a steady light and cool rooms. It was thought that the cost of the additional land required would be offset by the lower cost of construction [90]. The layout on a continuous floor meant that the yarn, from the moment of delivery, could be moved through the various processes of manufacture with minimum handling and transport until the product was dispatched as packaged cloth.

The true ancestor of the assembly line was the meat-packing industry of Chicago [91] as it existed at the end of the nineteenth century. Here overhead trolleys were employed to convey carcasses from slaughter to packing, from worker to worker and from process to process, all at a steady pace. A true assembly line was created when stationary workers concentrated on one task, performing at a pace dictated by the machine, minimising unnecessary movement and dramatically increasing productivity. In this case [Fig.34] the preliminary dirty functions [92] were performed in an area separated by the boilerhouse engine room from the clean area [93], but connected by an inclined passage. In each section provision was made for road and rail delivery and dispatch.

87. Alfred Marshall [1842-1924] who wrote, Principles of Economics in 1890 and later in 1919 Industry and Trade, about industrial organisation and reconciling the cost of production with marginal utility principles [Morris, 1964:143].

88. Theodore Sington [1848-1926] wrote "Cotton Mill Planning and Construction" in the 1890's. It was the architect's responsibility to ascertain the dimension and output of machines to be accommodated.

89. The steam engine drove a dynamo which energised 200 000 spindles.

90. This seems to be an assumption which is very difficult to prove now. The only acceptable reasoning is that material could be easily moved and therefore running costs would be saved.

91. Automation and transfer machines had been in force in milling since the first windmills and water mills.

92. Slaughter, digester and preserving.

93. Cooling and chilling rooms.

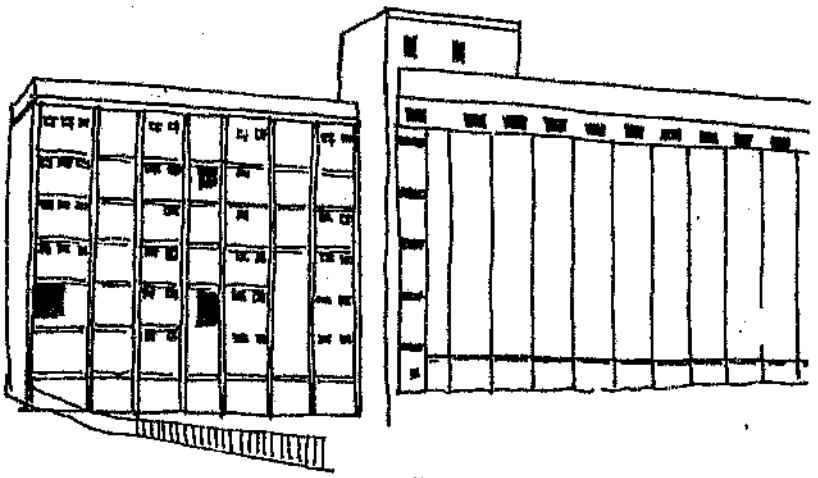


Fig.35 Reinforced concrete flour mill with machine rooms - milling, sifting, bagging and offices - on the left and the silos on the right. It was built at Swansea in 1897-8 [Jones, 1984:175].

Reputed to be the first to construct reinforced concrete building [Fig.35] in Britain, Hennebique [94] built a concrete sugar refinery at St Onen and the large Charles VI spinning mill at Tourcoing. The first forms used were similar to the repetitive post and beam systems typical of the first wooden and metal constructions.

As is the case with any process there is always the positive or evolutionary growth towards sophistication, but there is also the devolutionary or that which is negative. There was a deliberate attempt to create a new style [95] free of the imitative historicism that continued to dominate much of the nineteenth century architecture. The whole of the three-dimensional form was engulfed in an organic, undulating linear rhythm, creating a fusion between structure and ornament [96]. There was also the influence of Morris [97] and, before that, the influence of Marx and Engels [98].

The modern movement was consciously conceived in the last decade of the nineteenth century and its pioneers identified it with the Industrial Age. These pioneers admired the machine and most understood it.

94. Together with Napoleon Le Brun [1821-1901] they built the large flour mill for Weaver and Co. at Swansea.

95. Art Nouveau [1890-1910] also called Jugendstil, Style Moderne, was used in architecture, jewellery, glass, posters and illustrations.

96. In jewellery, fabrics, glass and ceramic this is quite acceptable. In fact it could be desirable, but was directly opposed to the architectural values of reason, clarity and logic of structure.

97. William Morris [1834-1896] who tried to re-establish the native English style and handicrafts revival.

98. At the turn of the century Marx and Engels, who also wrote Das Kapital in 1867, were thought to have been the most influential thinkers of the nineteenth century on political philosophy and economic theory. This theory has now been wholly debunked.



Fig 1. Tourcoing, a textile town in Flanders where the Charles VI spinning mill was erected in 1895 by Hennebique [Pevsner, 1976:287].

CHAPTER EIGHT : EUROPE AND U.S.A.

Technology is neutral, it can have desirable or evil effects, depending on the uses which man makes.

[Kranzberg, Vol.I, 1967:10].

Towards the end of the nineteenth century a new economy had begun to rise that was based on recent inventions like electricity [1] and light metals [2], a growing perfection of all machinery and automation and the development of concrete [3]. These physical innovations [Fig.1] must not be allowed to obscure the human changes that were taking place in the industrial field. There was a separation of managers and workers, [4] both being specially trained and many being advised by consultants [5].

Management was changing from day to day. Hit and miss methods to herald the beginning of scientific management and the term was also first used. Organisations were formed, journals published and views exchanged [George, 1868:85].

A trend seen among workers was the change from craftsman to machine minder and from labourer to semi-skilled factory worker [6], all taking place within the scheme of mass production. As the machines became more and more sophisticated, the workers were also required to handle more sophisticated tools and equipment [7]. The rationalisation of production had up to then and would in the immediate future mean the rationalisation of man [Carr, 1967:144]. Men, even primitive men, were learning to use complicated machines and, in doing so, were learning to think and reason.

The industrial development of the last 400 years has beyond doubt been a great period in history and although there have been many abuses, to have stayed the progress

1. The rapid development of a range of small motors encouraged flexible planning [Singer, Vol.V, 1965:231].

2. Continuous hot-strip rolling process. In 1902 the American Sheet and Tin Plate Co. developed continuous sheet milling [Singer, Vol.V, 1965:477].

3. In 1903 Ransome, who had by then erected a number of concrete buildings, took out a patent in America for the first fully concrete framed building at Greenburg Pennsylvania [Guedes, 1979:99].

4. There were few separate administration blocks.

5. F. W. Taylor and the Gilbreths, who complemented each other [George, 1968:136].

6. The craftsman's traditional skills were superseded by modern technology and human judgment was replaced by scientific measurement [Brown, 1968 :11].

7. Tight and exclusive unions are one of the main obstacles to progress.

Fig.2 Fiat's oldest building in Turin, 1898 on the Corse Dante. It was based on a well-established brick-building tradition. Note the natural lighting on the first floor [Banham, 1986:240].

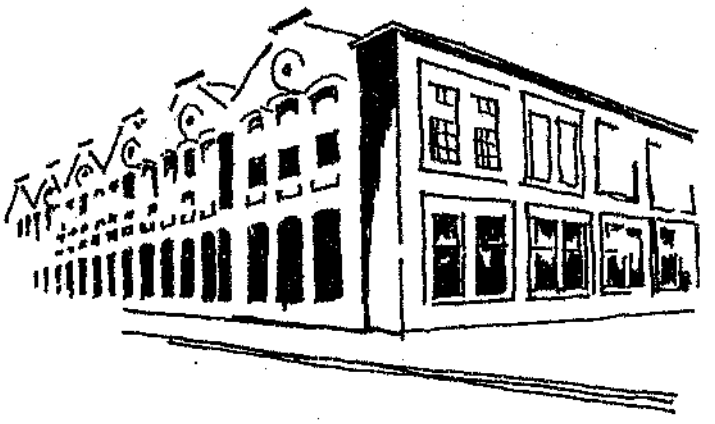
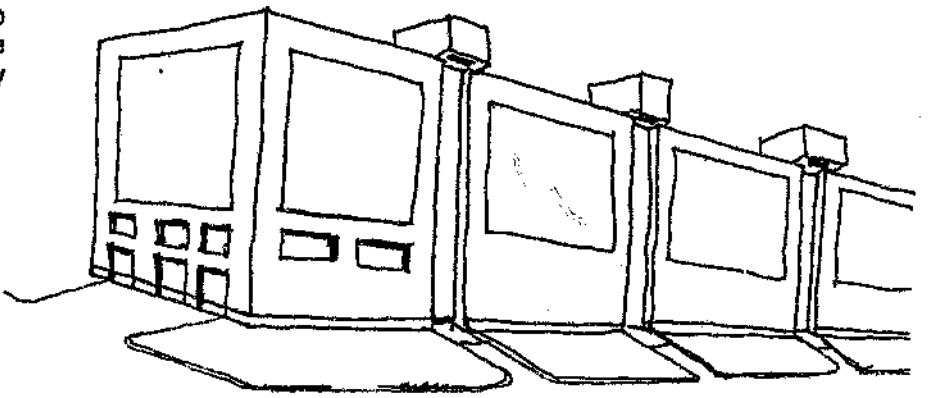


Fig.3 Dutch dock warehouse. Machine rooms for the hoists interrupt the skyline. These lifts delivered goods to the various levels in the building, which was artificially lit [Guedes, 1979:103].



to avoid the cost would have been unrealistic. Those who pay the cost are rarely those who reap the benefits.

The economy which had focused on a relatively narrow complex of industry - coal, iron, heavy engineering and the railway phase [8] - moved to machine tools, chemicals and electrical equipment [9]. Industry now demonstrated its capacity to move beyond the original industries which powered the take-off to a period [10] where the skills would be such that it did not produce everything, but had the capability to produce anything it chose [Fig.2]. Man has now become the trustee of industrial evolution [Huxley, 1948:578].

Evolution was not a single linear progression of rational innovation [Banham, 1969:31]. In Britain there was such a level of prosperity and confidence that it was not necessary to pay attention to those heretics who supported the cult of facts [Carr, 1967:20]. There were breaks and flashes of startling originality, such as those innovative factories executed by the Europeans [Fig.3] and Americans [Jones, 1984:203] in the earliest years of the twentieth century. The works of Behrens and Gropius [11] indicated the large gap between Europe and Britain [12], while the automobile [13] factories by Kahn [14] became the premeditated proving grounds for new ideas in architecture and engineering.

During the 19th Century, the chief disadvantages of industrial buildings were their short spans and bad illumination, but in the early 20th Century the demands of the manufacturers, technological advances of the planners and the message of the managers slowly overcame these restrictions. It was easy to slip into the use of the term mass-production [15] without realising how revolutionary a departure in manufacture it represented. The manufacturers wanted unrestricted space and the planners who accepted the challenge made this possible by using

8. The take-off is the interval when the old blocks and resistances are finally overcome [Rostow, 1969: 40]

9. The drive to maturity or fourth phase, in accordance with Rostow, is when modern technology over the whole front progresses - also called the Neotechnic period [Geddes, 1915:74].

10. Not all the countries reached these stages at the same time. It was the ability to adopt new ideas, take full advantage of vital resources that converted this stage into a commercial viability [Mumford, 1946:215].

11. Peter Behrens [1868-1940] who in 1907 designed his first factory, and Walter Adolph Gropius [1883-1969] who worked for Behrens from 1907-1910 [Banham, 1960:69].

12. Most of Britain's industrial buildings were a masquerade of Harlequin or eclectic architecture [Jones, 1984:131].

13. Packard, Chevrolet and Ford [Guedes, 1979:99].

14. Albert Kahn [1869-1942], who erected his first industrial building at the turn of the century [Nelson, 1939:10].

15. The principle of the division of labour and the specialisation of skills had already been applied in Ancient Greece. Babbage, Whitney and Brunel had established production lines, but the automobile industry developed the moving-belt conveyor in America [De Bono, 1979:178].

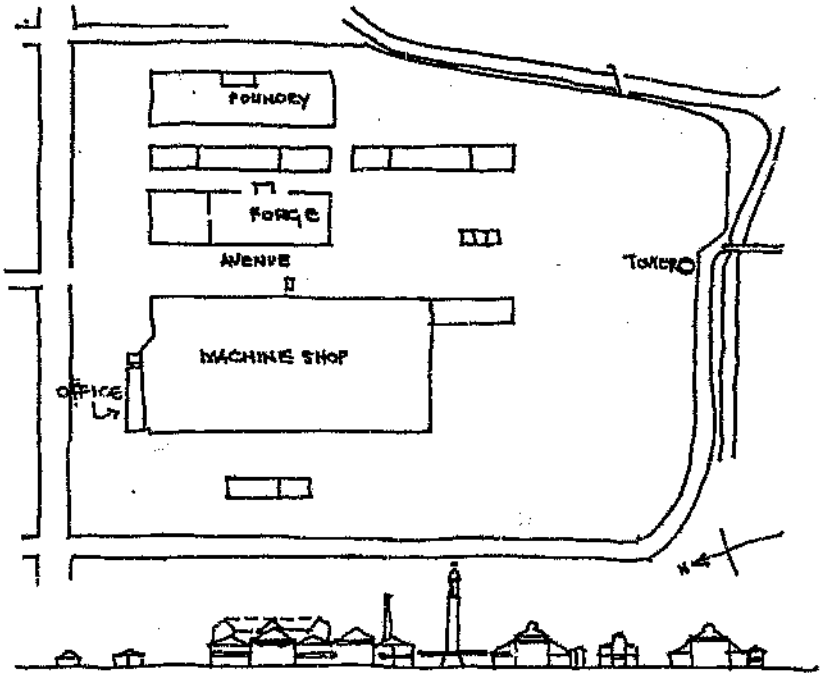
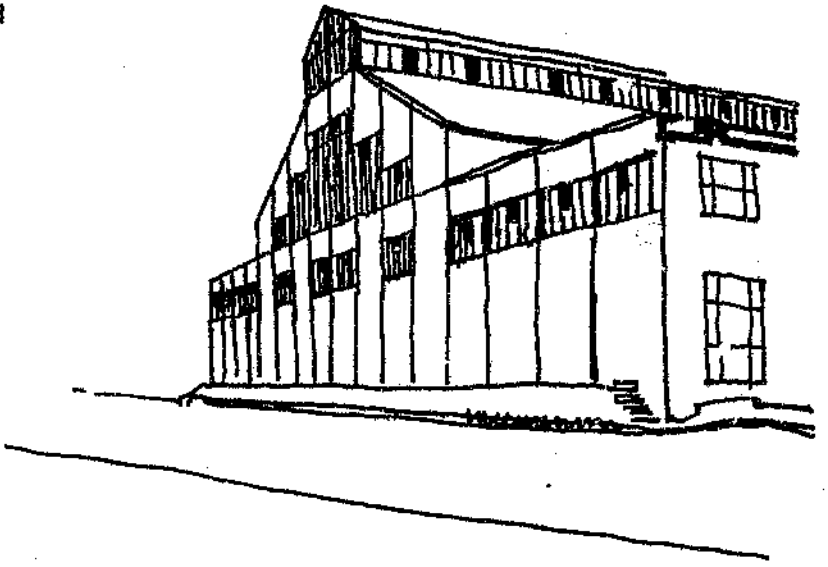


Fig.4 The original Trafford Park works of 1902. The total area comprises nearly 75 000 sq metres [Dummelow, 1949:42].



Fig.5 The natural roof lighting is spread evenly over the whole production area [Jones, 1984:210] and [Anderson, 1981:22].



the most advanced materials. The managers however, could within this space, plan their mechanisation and manpower to increase production. It became the optimum use of man and machines within a physical envelope [16], as Ford called it.

What better factory is there to illustrate the new manufacturing methods than the British Westing House [17] Electric and Manufacturing Company erected at Trafford Park [18]. Its conception and erection was primarily in the hands of Americans [19], who from the onset planned on a colossal scale using their experience gained in the United States. At the time Britain lagged behind Germany and America in industrial electrification and traction. It was felt that with the impressively dense rail-traffic far more electrical equipment could be manufactured. Kelvin [20] thought that there would be an advantage to combining the manufacture of prime movers and electrical machines in the same works. The site was accessible by rail, road and water, with ocean ports at Manchester and Salford, abundant coalfields and a vast supply of labour. A team of contractors [21], using the most modern methods of erection [22], built eight of the ten buildings within ten months.

The huge sheds which covered the main manufacturing processes were of prefabricated steel which was brought on to the site, erected and riveted together and travelling cranes were incorporated in the roofs. The largest [23] of the machine shops was divided into five aisles [Fig.4] running parallel with each other and the outside and central assembly lines had galleries which formed the second floor [Fig.5]. The two main aisles had spans of 30m and rose 26m to the ridge to provide sufficient space for the manufacture of the enormous electrical and gas generators, and tramcars [24]. The whole works was arranged according to the most logical method of progression. The raw materials arrived at one end and

16. Henry Ford [1863-1947] formed the Ford Motor Company in 1903 and the first Model T appeared in 1908 [Munce, 1961:40].

17. George Westinghouse [1846-1914].

18. These works were conceived on a green-field site and erected in 1900-2 [Jones, 1984:210].

19. The North Americans were the leaders in designing low steel structures [Munce, 1961:179].

20. William Thomson, 1st Baron Kelvin of Largs [1824-1907], became Lord Kelvin in 1892 and was technical advisor to Westinghouse [De Bono, 1979:284].

21. Designed by the Pittsburg Works and based on similar buildings there.

22. Tracks for the delivery of materials on the large site and riveters with automatic tools, and steam hoists for lifting bricks and steel [Jones, 1984:210].

23. The area covered was 300 m x 150 m and in 1949 was still one of the largest in the world [Jones, 1984:210].

24. Generally the scale of the building was commensurate with the size of the object that was manufactured. See also the large Turbine hall of AEG in Berlin, 1909, where large generators were constructed [Jones, 1984:210].

Fig.6 Sketch based on a photograph of the works taken from a balloon 1903 [Dummelow, 1949:38].

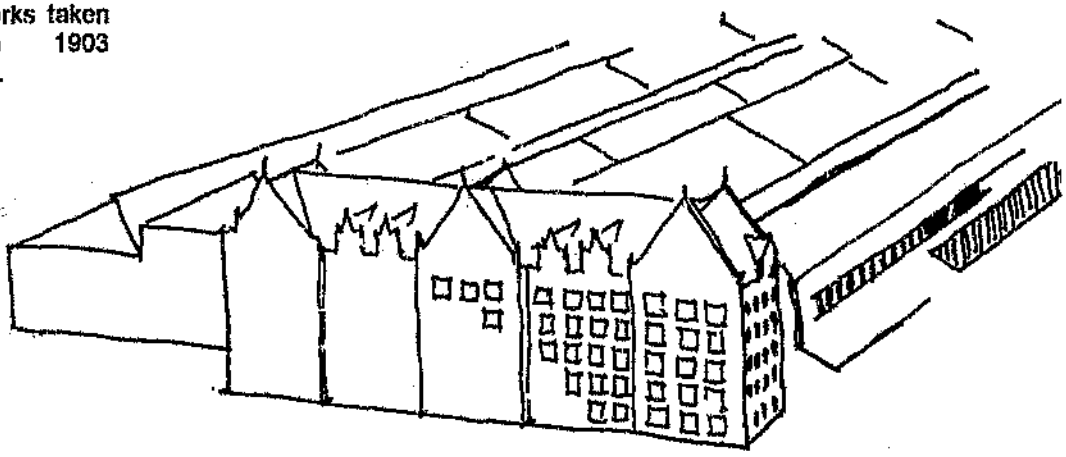
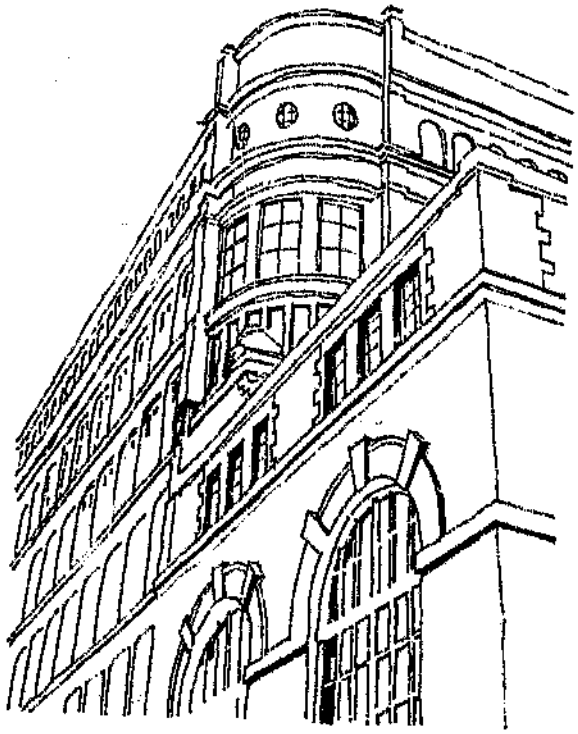


Fig.7 Part of No.3 mill [1915] Swan Lane. Notice the variety of window forms. The bright red Nori bricks were from the Accrington district. The design was neither utilitarian nor imaginative [Jones, 1984:186].



passed gradually down the aisle from process to process until they left the machine shop in a finished state. At the sides of the main aisles were four smaller sheds which were comprised of various foundries, forges, pattern shops and stores which fed into the assembly aisles. The structure clearly reflected the method of manufacture, its direction and scope.

It was not the factory building as such that was having any direct or important effect on architectural design, but the accumulated influence of the machine environment that showed the path for the new architecture which, as a rule, was still cheap, clumsy and certainly not too efficient in layout [Nelson, 1939:7].

The plant at Trafford also had a six storied block of offices [25] fronting onto the main street [26] attached to the works. This, with the exception of the gables [Fig.6], indicated that the design was straightforward and functional, with no attempt at architectural ornament. The steel-framed work sheds and all other buildings had simple infill brick walls, pierced with large timber-framed windows [27]. A water tower with a copper dome [28] provided the pressure for the hydraulic lifts and sprinklers [29] and the whole was considered an example of bold factory planning.

At the same time some of the world's largest [30] spinning mills, designed by Stott [31] were built at Swan Lane in Britain. The factory was powered by a steam turbine engine and the spindles were driven by electric motors manufactured by Siemens Bros. Ltd., electrical engineers. This enormous mill was built in stages, with Mill No. 1 housing the offices and the engine house. It was erected centrally in relation to the envisaged expansion. Further sections were added as they were required. The engine house became the focal point [Fig.7], with the emergency staircases placed two-thirds from the centre and balancing

25. The office block was a copy and virtually identical to that in Pittsburg, USA.

26. The local British architects, Charles H Heathcote [1850-1938] and his sons Ernest H. [1877-1947] and Edgar H. [1882-1972] from Manchester, had considerable industrial building experience, but could not have had much influence in the designing of these buildings [Jones, 1984:209].

27. The whole works was erected in fifteen months instead of the period of 60 months calculated by British contractors [Jones, 1984:210].

28. The only concession to any architectural detail.

29. Also an innovation.

30. Mills No. 1 and 2 contained a total of 210 000 spindles [Jones, 1984:185].

31. Sidney Stott [1858-1937] who with his sons, had designed more than 100 cotton mills and extensions [Jones, 1984:184].

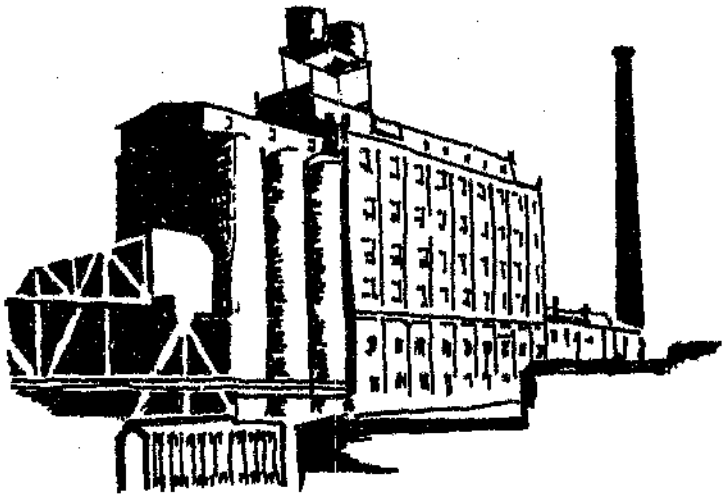


Fig.8 The large Washburn-Crosby grain elevator in Buffallo, New York, by Bateman and Johnson 1903 [Banham, 1986:144].

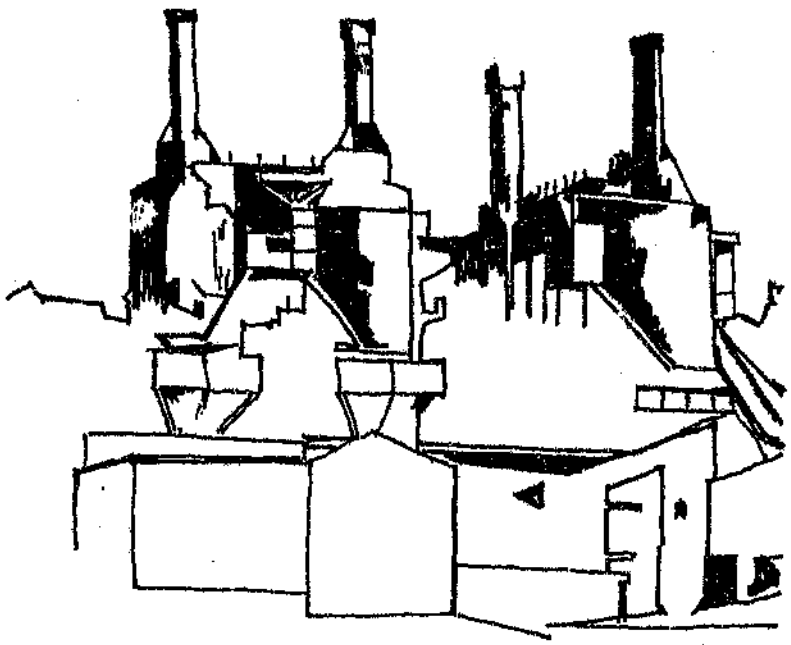


Fig.9 The forms that had been required by some newer industries inspired the design of the industrial buildings of the modern movement. The above illustrates the Lancashire iron smelting ovens [Herbert-Stevens, 1967:8].

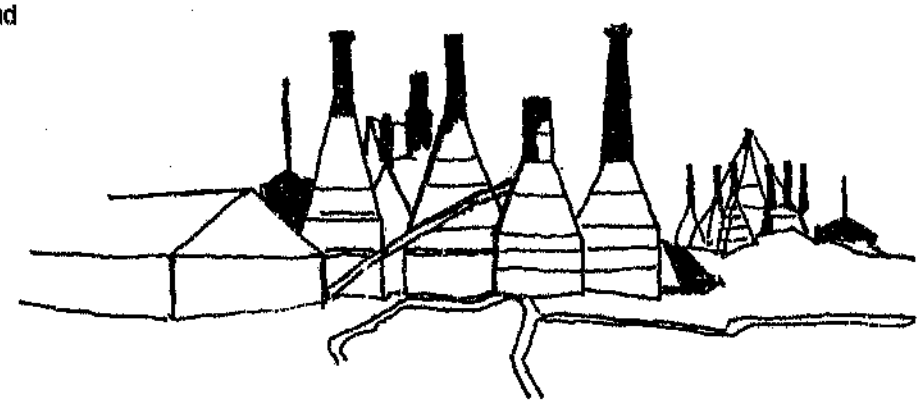


Fig.10 Chalk kilns in Holland [Herbert-Stevens, 1967:7].

the whole. The No. 1 mill was constructed in 1902, No. 2 in 1905 and No. 3 in 1915.

At the turn of the century [Fig.8] the industrial lead was held by America. The Germans also promoted the new development that had taken place in construction and materials since the latter part of the nineteenth century. There appeared to be an unlimited range of materials to choose from, but progress was slow to follow the logic of novel structural possibilities [32] through to outward forms [Figs.9 & 10]. The search for a new architecture in Britain had not taken the form of a complete historical rejection and this was not to change for some time.

It was no coincidence that management continued playing the role it did in the development of industry. Just as during the early growth of industry [33] in Britain, the United States of America now applied itself to a similar phase [34]. In Britain inventions and finance had stimulated the growth of industry. In the U.S.A. management was being advanced now to stimulate the mass production based on mass consumption.

With the advent of manufacturing processes increasingly powered by electricity which could be started or delayed economically [35], it was considered that factories could decrease in size. With the use of assembly line principles, units to be assembled could be made elsewhere and then stored. This was not always possible, as many plants manufactured parts and assembled them. As the production tempo increased [36], the buildings increased in size. Later the thousands of small machine shops powered by electricity became more familiar and small power tools became a best-selling commodity. The change from steam and oil to electricity relaxed the concentration of machinery around the single driving shaft.

32. The L'Art Nouveau from 1900-1914 was a relapse where the naturalistic ornament of style which was flashy, twisting and undulating was supposed to be the new means of expression of science and technology [Guedes, 1979:49].

33. The period post 1750 when most of Britain was imbued with a sense of industrial progress [Huxley, 1953:578].

34. Most of the physical problems had been solved but institutionalised management problems were still to be solved. F. W. Taylor wrote "Shop Management" in 1904 [Owen, 1966:115].

35. Steam-engines had to run at full power continually to be economical. Starting up or slowing down was time consuming and expensive.

36. These large buildings to be economically viable required at least three working shifts per day. This also increased the cost of heating and servicing.

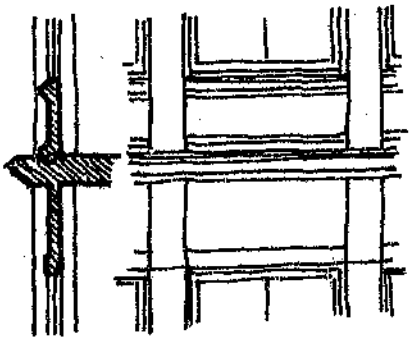


Fig.11 Patented system for projecting floor slabs, 1902 [Banham, 1986:67].

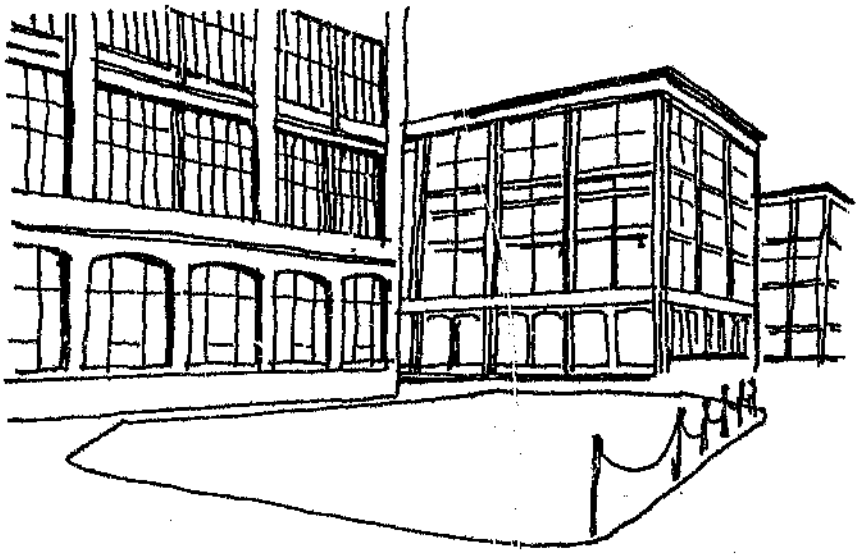


Fig.12 Begun in 1903 and completed in 1906 in Beverley, Massechusetts [Banham, 1986:69].

It was not realistic to just spend thought and care on the offices and entrance gates nor can the factory buildings just be written off as industrial. Some large forms did seem acceptable [37], but multi-storeyed spinning mills with chimneys and a railway viaduct were not. The mechanism of acceptable association is complex and subtle and has many components which fall predominantly in the group of cultural precedent and that of structures that serve economy and function alone. Some designers, generally those from Europe [38], felt that articulation could make anything acceptable while many others [39] felt that industry cannot be humanised, that space was valuable, circulation complicated and the industrial atmosphere hard [Gibberd, 1953:169]. In other words, the Americans were the pioneers of new materials [40] while the Europeans took the ideas and turned them into the international style which was brought back to North America later [Banham, 1986:21].

Reinforced concrete frames had been used [41] before but now they came into their own in industry. They were being used simultaneously by Ransome [Fig.11] at the United Shoe Machinery Company [Fig.12] and by Kahn for the Packhard factory in Detroit. The post and beam construction was fireproof and daylit and the same style and construction has been used continuously up to the present.

The most advanced concrete-frame daylight factory [42] was one also designed by Ransome in 1903 for the second phase of the Pacific Coast Barax building in Bayonne, New Jersey.

The United Shoe Machinery Company [43] plant consisted of three very long production buildings. The lower floor was a walled basamento pierced by Ransomes usual segmented arched windows, while the three top floors

37. Renaissance cathedrals with high roofs and bell towers and Roman water viaducts became aesthetically acceptable [Gibberd, 1953:177].

38. Kahn stated of Behrens and Gropuis that they were critics rather than architects [Nelson, [illegible]].

39. Mostly American, who recognised that the population of the USA had trebled from 1850 to 1900, but the industrial value had increased elevenfold [Walters, 1937:26].

40. This argument was further complicated by the dichotomy of steel versus concrete [Giedion, 1959:326].

41. In Europe by August Perriet [1874-1954] a multi-storeyed apartment block in Paris, 1903 - and by Ransome on the American east coast [Banham, 1986:75].

42. Term first used in 1985 [Banham, 1986:20].

43. This firm financed the Fagus Shoe Factory, built by Gropius and Meyer in Alfeld in 1911-1913 [Banham, 1986:68].

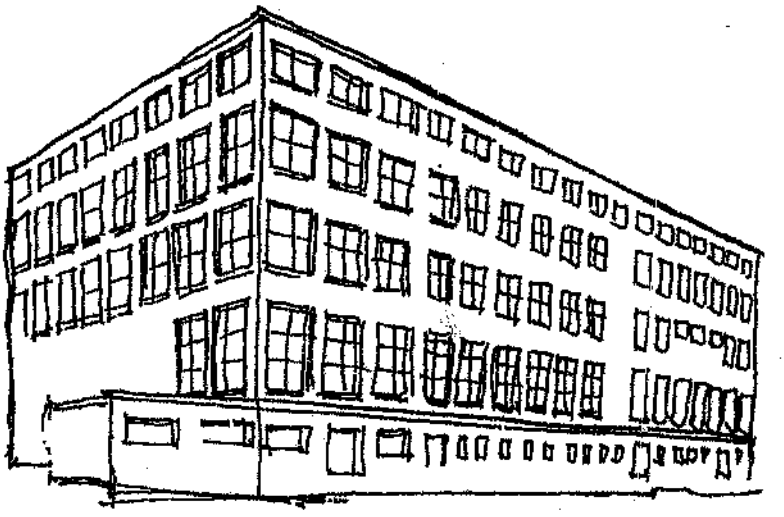


Fig.13 The system received the patents on its last remaining special components applied for in 1902. The external aspects are disciplined, clear and totally free of architectural detailing or projecting floor slabs [Banham, 1986:73]..

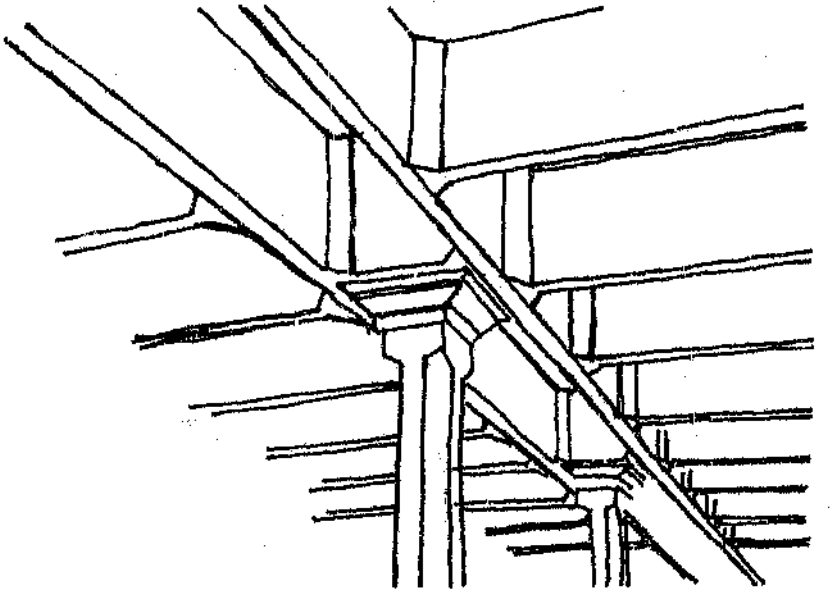


Fig.14 The internal floor beam and column capital clearly indicates the highly sophisticated nature of the design and construction. The closely spaced beams create a regular, monolithic three dimensional grid giving the impression of cleanliness, all neatly filleted at the connections [Banham, 1986:79].

were totally glazed [Banham, 1986:68]. The cornice was simply coved.

There were no architectural details in the conventional sense. The columns were square and the light window mullions occur horizontally and vertically at half bay. The whole concrete frame was excellently fairface.

There were linking structures between the production buildings, breaking the alleys to form courtyards or lightwells which contained the offices and cloaks. These had been detailed slightly more elaborately in order to reduce the scale. The buildings impressed by their sheer quality of design and construction and the original conception puts it into a class of its own up to that time. Internally precast beams were dropped into the slotted heads of the columns, which were octagonal in section and grouted to lock in the reinforced beam ends.

The second phase of the Pacific Coast Borax building at Bayonne [Ransome, 1912:12/13] also consisted of three storeys and an attic on a basement [Banham, 1986:73]. In its purest surviving form, the external aspects [Fig.13] of this, the first true daylight factory, have a unique historical place. The system [44] of construction was essentially a kit of parts which carried all the marks of experience.

44. The Ransome system offered a number of different prefabricated hollow column types and column heights [Singer, Vol.V, 1965:491].

The United Shoe Machinery Company floor construction was a reinforced concrete reproduction of the steel-beam and infill construction used in the traditional mill construction. The Borax building [Fig.14] had a flat concrete slab supported by very deep, thin beams which spanned transversely between primary beams twinned at each column capital head [45]. The floors appear simply to be stacked floor on floor. Externally economic considerations may have led to the elimination of the

45. The beams are 600 mm deep and similar to the wooden beams traditionally used [Banham, 1986:75].

Fig.15 The exterior could scarcely be described as eye-catching [Pevsner, 1976:287].

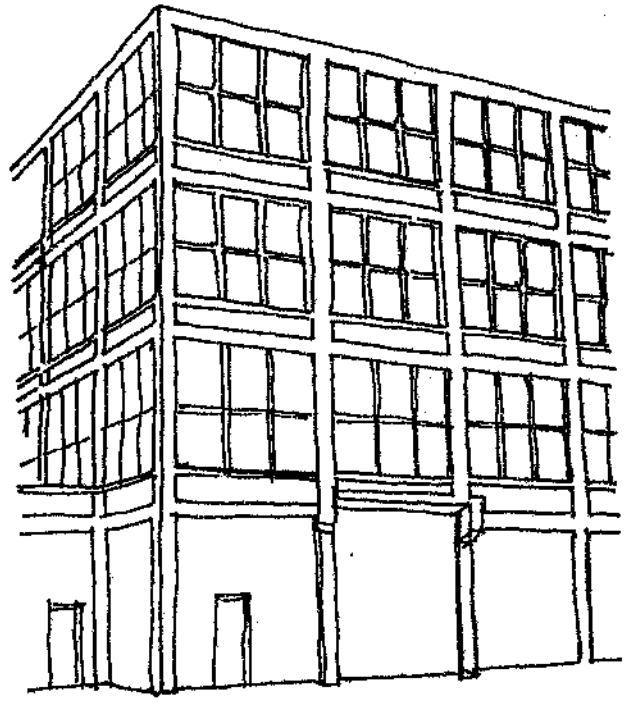
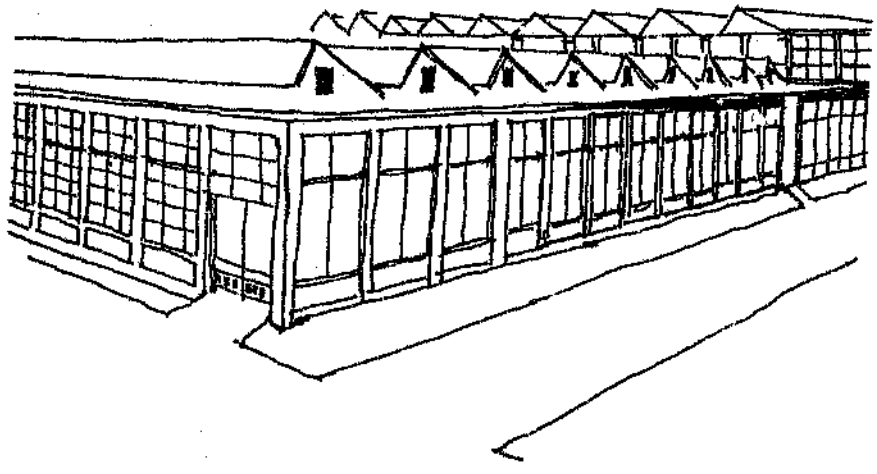


Fig.16 The Manufacturing and assembly buildings, both one-storeyed were at the heart of the plant and interrelated structurally. The assembly was much higher than the manufacturing plant and for some or other reason the monitors faced east and north. Perhaps it was the direction of the production flow, regardless of the light [Hildebrand, 1974:40].



projecting floor slabs [46] with the edge flush and the outer face producing the all-glass frame and infill wall.

Detroit was predestined [47] to spawn factories as a result of the automobile industry and was to become one of the major industrial-commercial complexes in the United States. The men [48] who created the automotive industry possessed extraordinary vision in solving the problems of housing the new industries. They literally, if unconsciously, forced [49] a revolution in design with new technologies and innovative engineering and their thoroughly materialistic demands of economy and low maintenance resulted in some of the finest modern industrial buildings.

These buildings may have been two centuries in the coming and their classical-framed form emerged in 1900 [50] for an extremely short interlude in the history of industrial planning. The best of them are superb examples of engineering intelligence and designer craft [Banham, 1986:30].

The Packard 10 Building in Detroit consisted of two directional 10m spans achieved in concrete and was destined to have a considerable influence on contemporary American Architecture [Fig.15]. The front of the building was graced by such traditional features as rusticated door cases, ornamental tiles and decorative brick bonding. The back of the building which was the best elevation, was stripped of everything but the bare essentials.

The contribution of Kahn in the Geo. N. Pierce plant in Buffalo was confined to the engineering and the design of the innovative [51], single-storeyed and monitor-lit production shop [Fig.16]. Some other structures on the site such as the garage, brazing building and power house were all as mean-minded, rational and graceless as Packard 10 [Banham, 1986:87].

46. Admired by modernists for its radicalism [Banham, 1986:72].

47. Origin of the pioneer wagon industry based on forests and the training of artisans.

48. Ford was the world leader amongst them and won the automotive revolution within two decades [Herndon, 1970:83].

49. Kahn used reinforced concrete for the Packard 10 Building in Detroit [Nelson, 1939:17]. It was the first reinforced concrete factory used for the automotive industry in America.

50. It reached a startling and precocious maturity by 1910 [Giedion, 1959:320].

51. Similar to the Titus Salt Weaving Shed, Saltaire Mill of 1851-1853 [Winter, 1970:62].

Fig.17 The rigid structural module is adapted to the manufacturing needs of every building. Note how the administration is just tilted slightly and parallel to the street [Hildebrand, 1974:37].

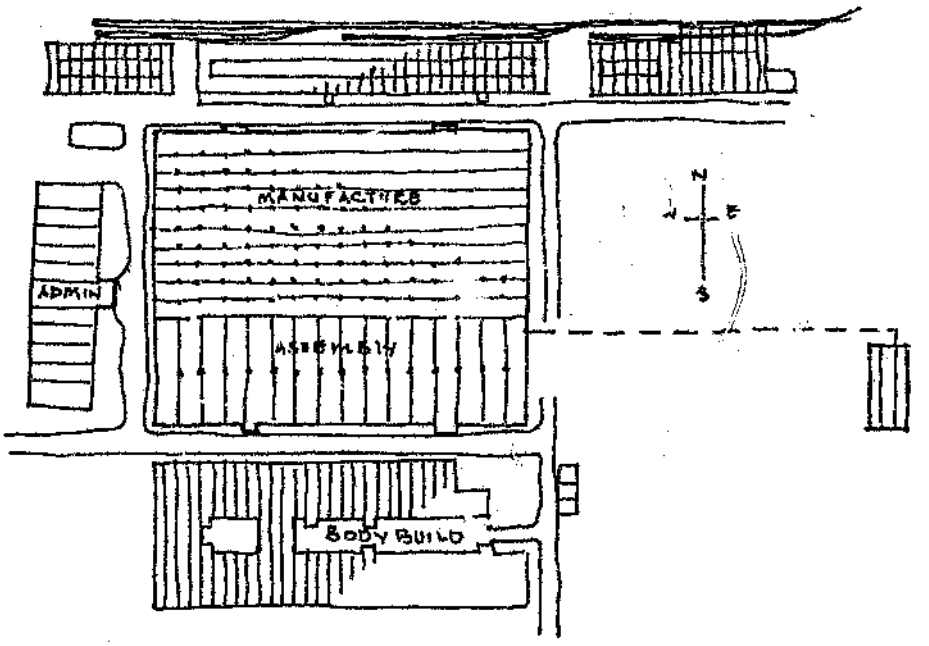
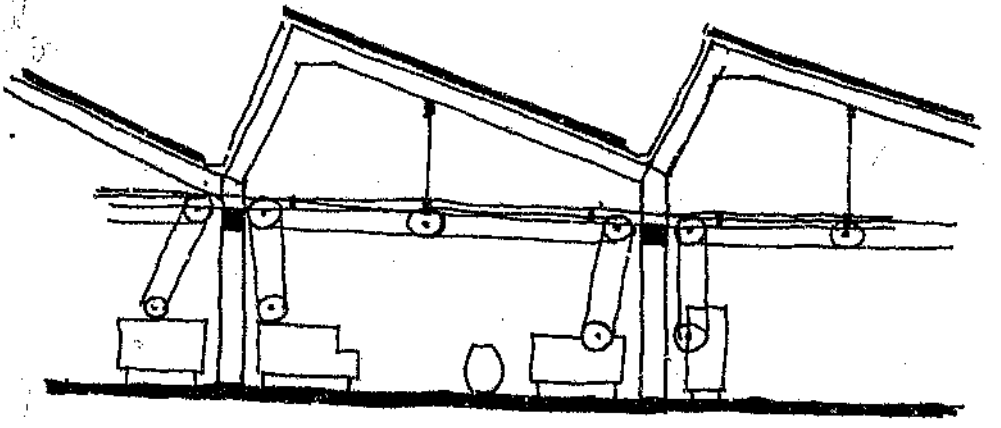


Fig.18 The manufacturing building, showing the concrete roof lights and I-beam supporting shafts [Hildebrand, 1974:41].



The various operations were located in buildings of varying structural requirements, interrelated by a common structural module. Through multiples and submultiples all were related along the lines of circulation determined by the flow of the work [Fig.17]. The plant was organised on a single floor with the manufacture horizontally organised and the plan dimensions no longer limited by side lighting because of overhead roof lights.

This remained a contradiction, as the rooflight was in competition with the method of driving the machines. The power house was removed from the centre of gravity of the manufacture and all machines were still driven by the shaft-and-pulley principle. The shafts were overhead [52] and attached to the roof structure on a steel-beam grid [Fig.18]. A large amount of the natural roof lighting was lost in the process.

Just as the Packhard 10 Building introduced the multi-storey concrete daylight factory to the automotive industry, the Arrow Pierce building with its roof lights reflected the horizontal development in the same industry [53]. This development was not lost on the avant-garde architects [54] in Europe, who admired the forms created by sometimes little-known American engineers. These buildings that were to influence the rise of the European modern movement [55] combined symmetrical and severe repetitive composition with large areas of glass. Any search for an understanding of the reasons why these factories were so acceptable involves some attempt to understand the ambitions, expectations and frame of mind [56] that drove these founding fathers of the new movement to adopt these utilitarian models.

The lead was taken by Behrens [57], who became the architect for the new Turbine Factory in Moabit, an industrial suburb of Berlin. The factory, which was designed for the manufacture [58] of large turbine engines,

52. In the Assembly building there were two three-ton cranes, spanning 30 m, which ran the length of the building on concrete girders [Hilderbrand, 1974:43].

53. The large scale steel structures were not yet universally used. The battle between steel and concrete, low or high, was still to come [Singer, Vol.V, 1965:477].

54. Hans Poelzig [1849-1936], Erich Mendelsohn [1887-1953], Alvar Aalto [1898-1976], Peter Behrens [1868-1940], Walter Gropius [1883-1969] and many others [Guedes, 1979:98].

55. The Deutscher Werbund was founded by Herman Muthesius [1861-1927] in 1907 [Guedes, 1979:49].

56. The German philosophers' definition of Zweckmassigkeit or functionalism and Sachlichkeit or objectivity prevalent at the time [Shand, 3, 1934:84].

57. An imaginative middle-aged painter-cum-designer who became AEG artistic designer in 1907 to improve the appearance of their lamps and other accessories [Hildebrand, 1974:62].

58. In 1903 the first steam turbine-driven alternating-current generator was put into service in America. By 1907 insulators made possible the transfer of high voltages and the Tungsten lamp was discovered [Mallick, 1951:24].

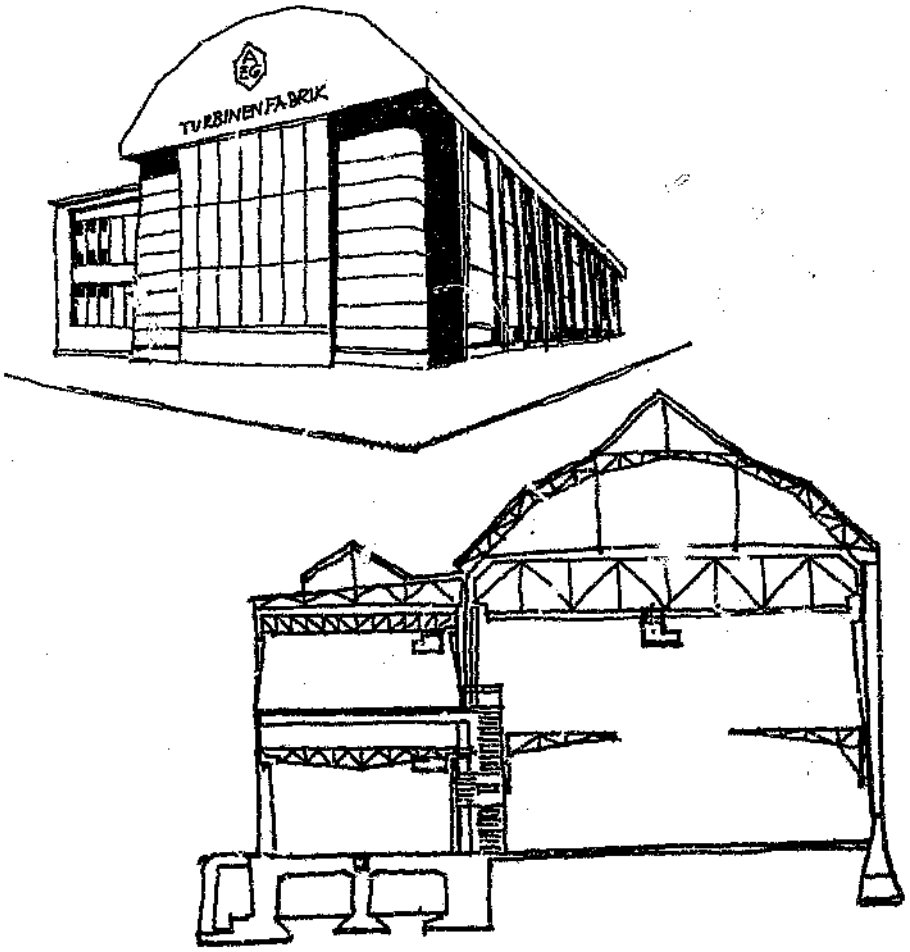


Fig.19 The 1908 Turbine assembly hall and, almost classical, factory building for AEG. The roof profile of six facets resemble a gambrel. The central facets are a double-pitched skylight so that the actual roof section resembles a gable [Gloag, 1958:335] and [Buddenseig, 1976:115].

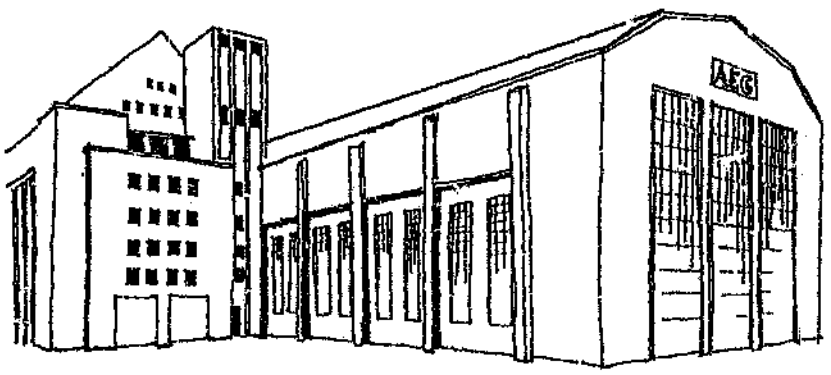


Fig.20 The 1912 Heary assembly building [Buddenseig, 1976:125].

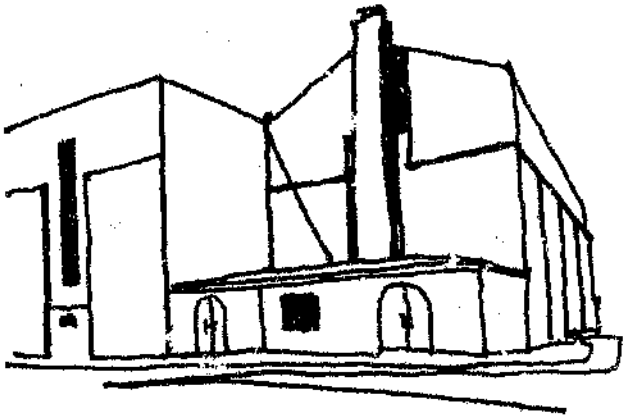


Fig.21 The Anker linoleum factory of 1912 designed by Heinrich Stoffregen who was a much more tough-minded Werkbund Expressionist [Banham, 1960:60].

was constructed [59] of 22 steel girder frames enclosed in tapered non-bearing concrete corners and divided by horizontal steel bands. This appeared to support the gables, imparting a monumental massiveness [Fig.19] which may not have been intentional. By making use of modern construction techniques and bold handling of the simple elements of steel, glass and concrete, Behrens created a building of force and influence.

The structure was not expressed on the facade. The glass was stretched taut over the framework, with knife-edge corners. The massive buttresses deviated from structural purism to create an effect which was not functional [60]. Despite the classical severity, Behrens consciously tried to transform the factory into a dignified place of work and at the same time demonstrated his ability to clothe industrial needs in forms that might be recognised by his contemporaries [61] as architectural [Fig.20]. In the Grossmashcienenfabrik Benrens seemed to sense that, whether glazed or solid, the walls and the roof are only an envelope drawn over a vast bulk of industrially usable space [Banham, 1960:83]. This idea was taken further by Stoffrengen who championed the idea that good standards of design and craftmanship [62] had to be maintained in mechanical mass production [Fig.21].

The industrial and economic expansion that was taking place in pre-war Germany was presenting a handful of men with visions of a new architecture that should come to terms with the advances in technology and industry [Sharp, 1966:27]. These architects, mostly from the Deutcher Werbund, thought it was their responsibility to make a building the working answer to practical and functional questions, but at the same time wanted to create something of a monument in its own right and a symbol of its time.

59. 133 m x 27 m, with a crane moving along the long axis and swivel cranes at the columns [Banham, 1960:60].

60. In 1911 the Behrens atelier was the most important in Germany. Many architects like Ludwig Mies van der Rohe [1886-1969], Gropius, and even Charles-Edourd Jeannevet [1887-1965], known as Le Corbusier, worked there [Giedion, 1959:475].

61. Influenced by William Morris [1834-1896] in the beginning and finally by Muthesius, who expanded his ideas that form be determined only by function and that ornament can be eliminated [Gloag, 1958:327].

62. Their contact was in mid-1908.

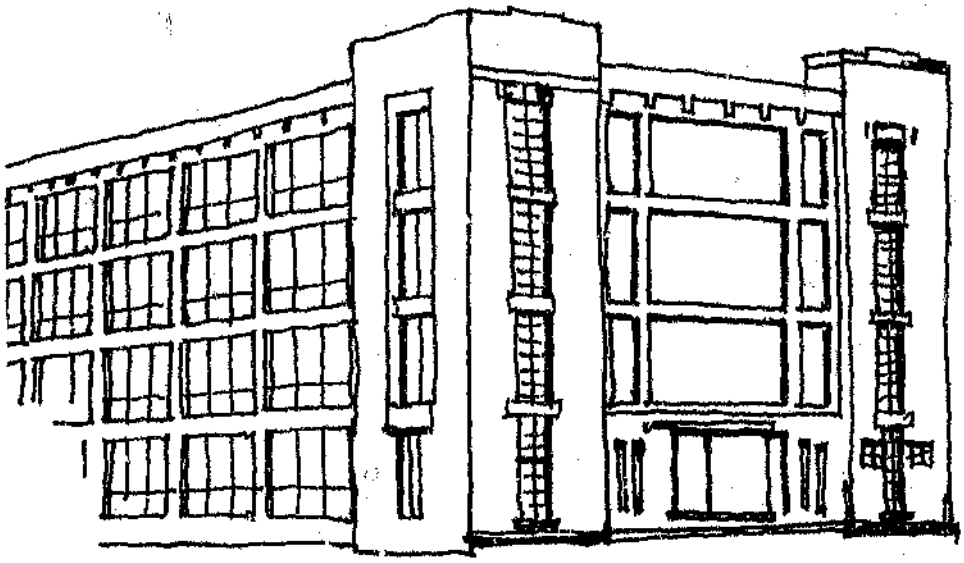


Fig.22 The Ford Plant, Highland Park. The first unit, known as the Old Shop from the southwest [Hildebrand, 1974:47].

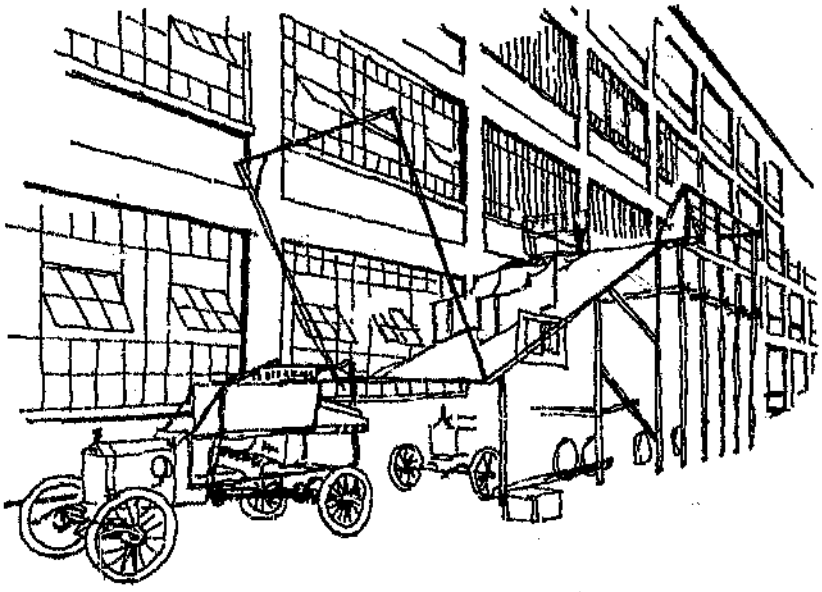


Fig.23 Model T body-to-chassis experimental mock-up thought up by advertising agents. This operation was performed in the unusually high-ceilinged assembly hall [Hildebrand, 1977:50].

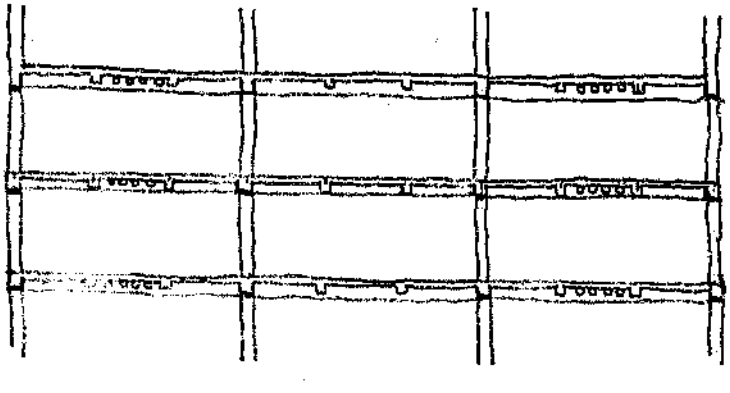


Fig.24 Typical interior with a flat slab construction cast integrally with the beams. Note the small holes in the outer bays for services [Hildebrand, 1977:49].

Neither Ford nor Kahn, who had just been commissioned [63] to do the Ford Highland Park Plant [64], had any illusions about testimonials or symbolism. They just applied the latest technology and management techniques. These new plants were so large and organised that they were monumental and symbolic of the time [Fig.22].

In March 1908 Ford introduced his Model T. His mind was already on a new and better factory for producing it as the existing Piquette Plant [65] was not adequate to handle the volume that they intended to produce [66]. The building was conceived as a three-dimensional matrix or grid where raw materials or parts were hoisted to upper levels to filter down by gravity chutes through the various processes of manufacture [67] and sub-assemblies [Fig.23]. This enormous four-storeyed building [68] was 284 m long, had columns spaced at 6,6 m along the length and three bays of 8,2 m made up the 246 m depth. There were four decentralised utility elements on the southwest side which included elevators, stairs and toilets. These were located outside the main body of the building so as not to interfere with the manufacturing space. The utility elements, including those on the corners and the cornice of the building's roof, conceded limited ornamentation. This was in contrast to the very strict vertical and horizontal structure that held on the same plane as the windows [69].

The building [Fig.24] provides an interesting example in the evolution of industrial buildings [Hildebrand, 1974:51]. It was not quite as original as Kahn believed nor was it a prototype significant for the future [70], but it served Ford for 50 years.

As industry became more capital intensive and the consumer market more affluent, the reward or failure also became greater [Herndon, 1970:12]. The conveyor belt became the heart of the manufacturing process [71]. The

63. Called the Old Shop, 1908. The New Shop was erected on the same site in 1914-15 [Hildebrand, 1974:43].

64. Ford had used gravity chutes to transfer parts and materials [Hildebrand, 1974:50].

65. There were 15 million Model T Fords sold. In 1910 Ford built 21 000. Within 12 years, in 1922, 240 000 were built and sold per year [Herndon, 1970:89]

66. Ford wanted to consolidate all operations under one roof and all major operations on one floor [Hildebrand, 1974:51].

67. Designed in the latter part of 1908 and occupied on New Year's Day, 1910.

68. The window sashes were of steel imported from England.

69. The powered, moving assembly line designed in 1908 would soon discourage multi-storey schemes [Singe[illegible].V, 1965:641].

70. It was demolished only in 1959.

71. The Tin Lizzie conveyor belt was approximately 280 m long, the length of one storey at the Old Shop [Hildebrand, 1974:44].

72. His job was to remove all skill from the individual.

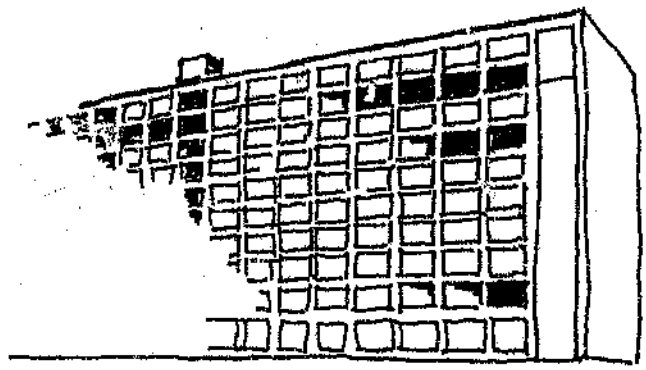


Fig.25 The building was erected in six months with an unusual form of reinforcement, each being two floors high [Banham, 1986:91].

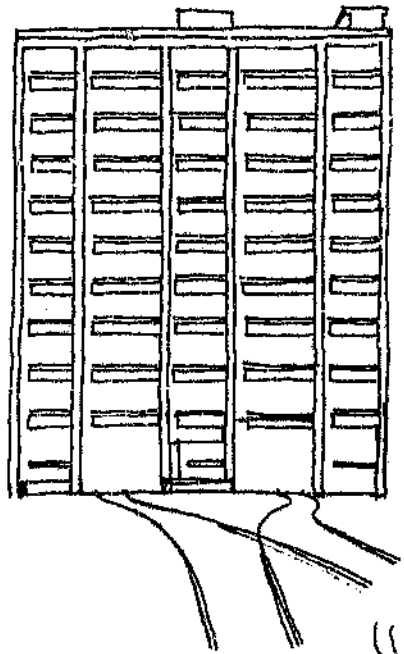


Fig.26 The end elevation indicating different sized bays [Banham, 1986:93].

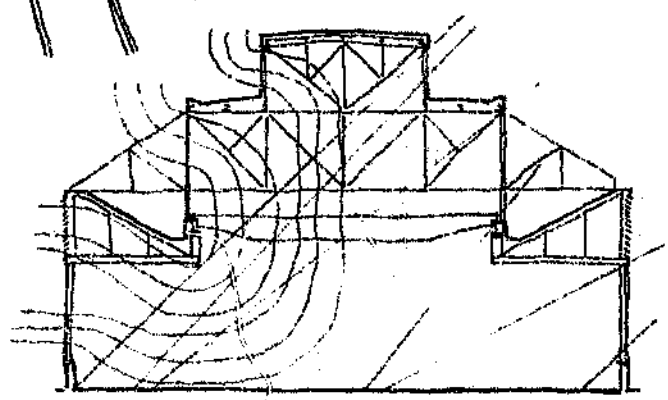


Fig.27 The structural section shows the paths of light and air circulation [Hildebrand, 1974:57].

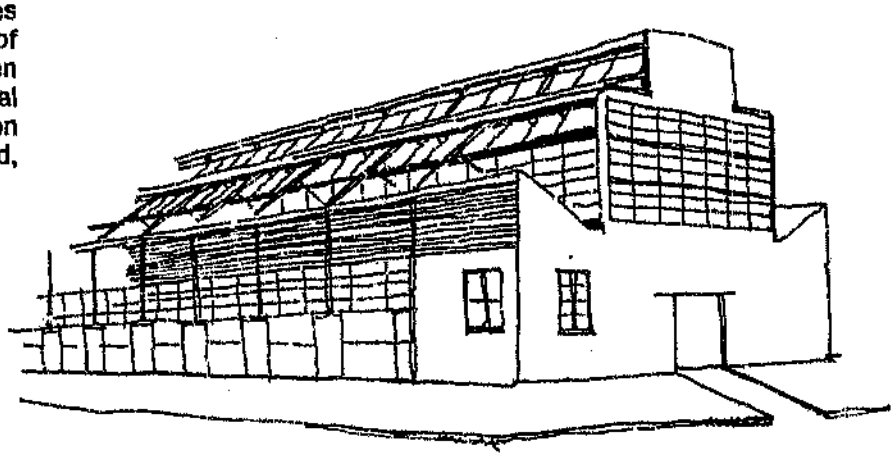


Fig.28 This amazing structure with its steel flying buttresses has all the positive elements of the large open space as seen at Westinghouse with additional lighting and ventilation requirements [Hildebrand, 1974:56].

systems engineer [72] was to become all important [Burns, 1968:137], based on the need for speed and interchangeable parts [73].

The Larkin Terminal Warehouse [74] and the Packard Forge Shop [75] were contemporaries, but completely different due primarily to function. The Larkin Building carried on the tradition of the daylight factory. It was built to accommodate the packing, handling and shipping facility [76] of this enormous mail-order business [Fig.25]. The tall, long, narrow-format structure stands astride the railroad tracks [77]. Its ten storeys are divided into five functional bays of unequal width [Fig.26] and the wide bays straddle two lines each, the narrow bays forming the loading platforms when operating at maximum capacity. four freight trains can unload or load simultaneously. Goods doors at the loading docks in the exterior ground floor walls handled the horse-drawn or gasoline-powered trucks often seen on the streets of Buffalo.

The details consisted of flatfaced columns with rectangular sections and the exposed arrises stood proudly with chamfered edges to prevent spalling. A low apron of red brickwork was topped with a plain concrete sill, carrying three sashes of industrial wooden glazing. The Packard Forge [78] broke with tradition. Buildings [79] on the site were single-storeyed, constructed of steel with the provision of a ten-ton craneway, spanned 12,5 metres along a column free wall, was 23 metres wide and 115 metres long. The crane was suspended over space with no supports [Fig.27] beneath the zone of operation. The structural configuration allows for excellent lighting and ventilation [80] and was in sum total more than the height of the building. There were 23 bays placed at 5 m intervals. The continuous horizontal runs of fenestration and ventilation louvres bypassing the structure presage the later curtain walls that became a Kahn signature [Fig.28] and a motive of style of so many modern architects.

73. In Europe cars were still handcrafted. Ford was to make 60% of all motor cars in the 1920s while paying the highest wages in the business.

74. Designed by Lockwood, Greene and Company and built in 1911 in Buffalo, New York [Banham, 1986:88].

75. Designed by Kahn.

76. The length of the building was 200 m.

77. As illustrated in 1911.

78. Most additions were repeats of the Number 10 Building [Banham, 1986:84].

79. In terms of total building height 52% of the wall was open for ventilation and 70% for glazing.

80. Of Beverly, Massachusetts - the prime investor in the Fagus works [Banham, 1986:11].

Fig.29 The unsupported corners are in contrast with the elements of the composition [Banham, 1960:57].

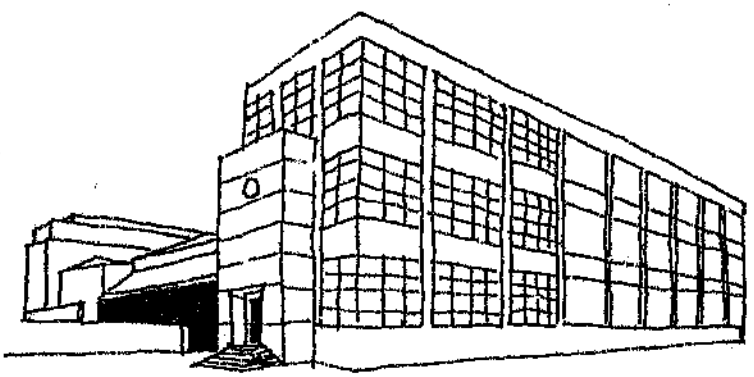
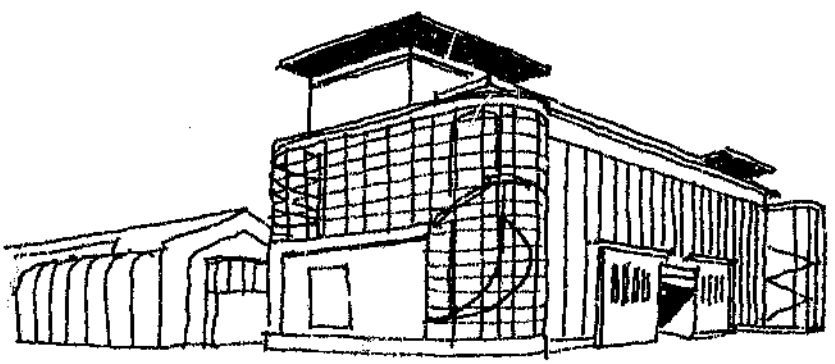


Fig.30 The Fagus second phase with a solid door and entrance, flanked by the famous flying staircases, in the glazed corner [Risebero, 1979:210].



The United Shoe Machinery Company [81], the firm which erected one of the first daylight factory buildings, must have had some influence [82] on the Faguswerke at Alfeld-auf-der-Leine, but this appears not to be correct. Benscheidt had already appointed Werner [83] to do the planning when he was approached by Gropius for the project [84]. As a compromise Gropius was appointed to design selected elevations as some of the foundations of the factory were already being cast [Banham, 1986:187]. This cuts across the image of Gropius as a super-pure functionalist whose designs grew out of the innere wesen [85] which might be the motto of the young Werkbund architects.

Wer is weise, wer ist gut,
Wer nach seinein wesen tut.

To be fair, the designs that Gropius [86] was responsible for immediately became an internationally acclaimed success. The workshop and administration and drawing offices [Fig.29] admittedly were not as exposed as the owner might have liked. The Cubic three-storey concrete frame was surrounded by a wall of steel-framed glass panels, forming the corners as well as the front and sides. The building was supported by narrow brick piers deprived of all ornament, creating a transparent volume [87]. The role of the wall was restricted to that of mere screens which stretched between the upright columns of the framework [Fig.30] to keep out rain, cold and noise. Glass was assuming ever greater structural importance.

There appeared to be some mutual respect for each other's work. Despite their differences of interpretation, the fact remains that Kahn, Behrens and Gropius [88] may never have attained architectural greatness without industrial patronage [Hildebrand, 1974:62].

81. Gropius only visited America in 1928, but the owners of the existing Fagus factory, Carl and Karl Benscheidt who were father and son, negotiated machinery for Carl's new factory on a green-field site [Banham, 1986:11].

82. Edouard Werner, a local architect from Hannover [Banham, 1986:185].

83. This was done by letter quoting Behrens, and here he had worked as reference [Banham, 1986:186].

84. With Adolf Meyer [1881-1929].

85. Inner nature or even soul [Banham, 1960:75].

86. In contrast with the massive corners of Behrens [Hildebrand, 197

87. Kahn admired the work in Germany. Gropius wrote in Jahrbuch des Deutchen Werkbundes 1913 that America was the Mutterlande der Industrie, [Banham, 1986:9] describing amongst others the grain elevators of Montreal and Fort William, United Printing Co, Cincinatti, Ford Motor Company and Continental Motors, Detroit [Hitchcock, 1939:36].

88. All exploited new materials to enclose new space-enclosing forms [Hildebrand, 1974:64].

Fig.31 Fiat Lingotto plan in Turin, Italy, 1914-1926 [Banham, 1986:238].

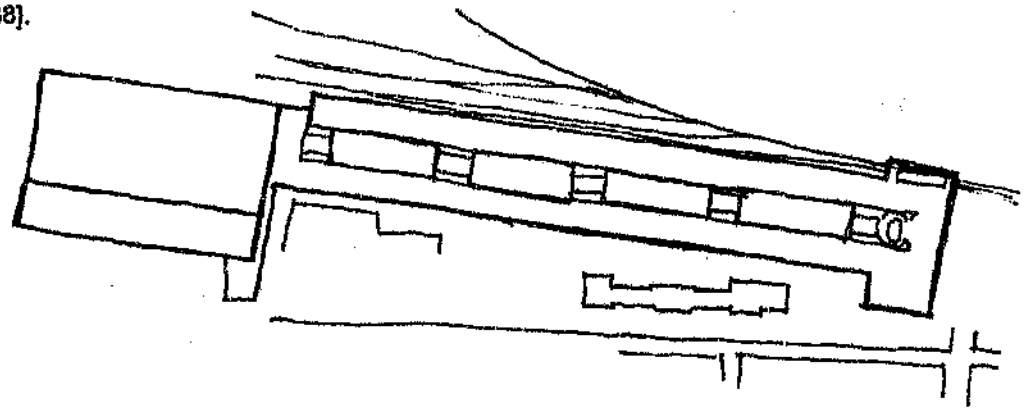


Fig.32 Fiat-Lingotto. Details of the facade and section at the spiral ramp [Banham, 1986:248].

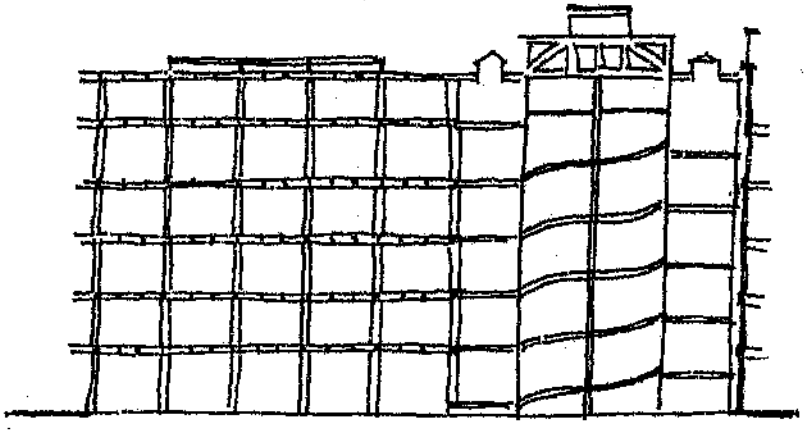
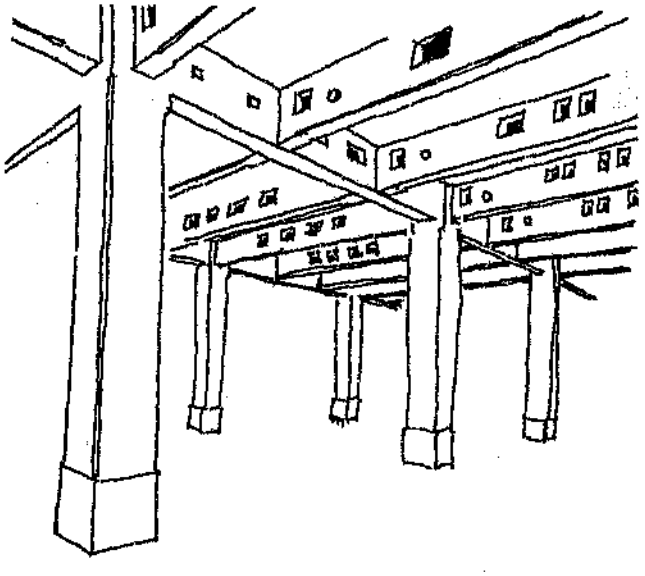


Fig.33 Recognition that the well-serviced building had to allow for versatile openings in both directions [Banham, 1986:245].



The years just before World War I [89] brought about a number of fortuitous events, some significant and others only of fringe benefit to the development of the industrial building form [Fig.31].

The most important factor was the moving belt, a technique that consisted of two basic elements, namely a conveyor system [90] or belt and workers [91] limited to single repetitive tasks. Despite its deceptive simplicity, the technique required elaborate planning and synchronization. There was an upsurge of interest in scientific management. This breakthrough had been planned for nearly a decade. Managers had been conscious of the body of logical and practical principles incorporated in a comprehensive system of management techniques [George, 1968:93]. As the principles of scientific management were applied in the motor and other industries, objections arose in unions. They approved of efficient production and increased wages, but condemned the speed-up and the abuse of the human element and this caused a decline in quality and productivity [92].

Two fringe benefits that resulted were the neon gas lamp [93] and the Gestalt theory [94] which, when applied to industrial buildings, implied that they cannot be solved in isolation but the problems must be seen as a whole.

The most important industrial building of this period was neither in the United States of America nor in Germany, but in Italy [95]. The resemblance to the daylight factory ends there as the building is a single form consisting of two close parallel blocks over 500 metres long, linked by five cross-blocks and five floors high [Fig.32]. On the roof was a high-speed motor car testing track [96] which must have been the folly of the early century, with a magnificently detailed mushroom column and concrete bridge construction. The column spacings of 6 m was close to the American standard, with cross beams at

89. Ford displayed a complete assembly line mass production of motor vehicles. The price of the Model T dropped from $950 in 1909 to $360 in 1916 to $290 in 1926 [Hildebrand, 1974:44].

90. Since the 1830's in the meat packing industry in Chicago, overhead trolleys brought the work to the worker. Ford started with flywheel magnetos, then the body work and lastly the whole automobile [Hildebrand, 1974:91].

91. Mostly unskilled workers and large hierarchy of supervisors, managers and consultants [Hildebrand, 1974:91].

92. Hugo Munsterberg [1863-1916] wrote Psychology and Industrial Efficiency in 1913.

93. Invented in 1910 by Georges Claude [1870-1960]. The first deep-plan windowless factory was only erected in 1928 [Guedes, 1979:100].

94. Max Wertheimer [1880-1943] wrote a paper on the Psychology of Gestalt explaining that the whole was better than the parts.

95. In 1914 the design began for the Fiat-Lingotto factory in Turin. The site work was started in 1916 and was delayed by the war until the opening in 1920, a building too late [Banham, 1986:237].

96. Widely illustrated by the modern movement, especially in the 1930's. It was later used for bicycle racing [Banham, 1986:244].

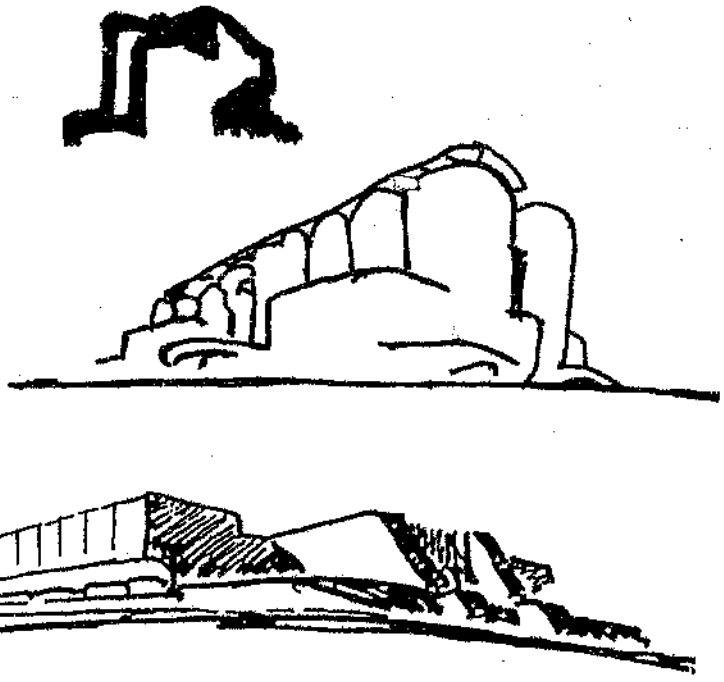


Fig.34 Sketches of concrete elevators and a motor assembly building, as prepared by Mendelsohn [Banham, 1986:10] and [Banham, 1960:174].

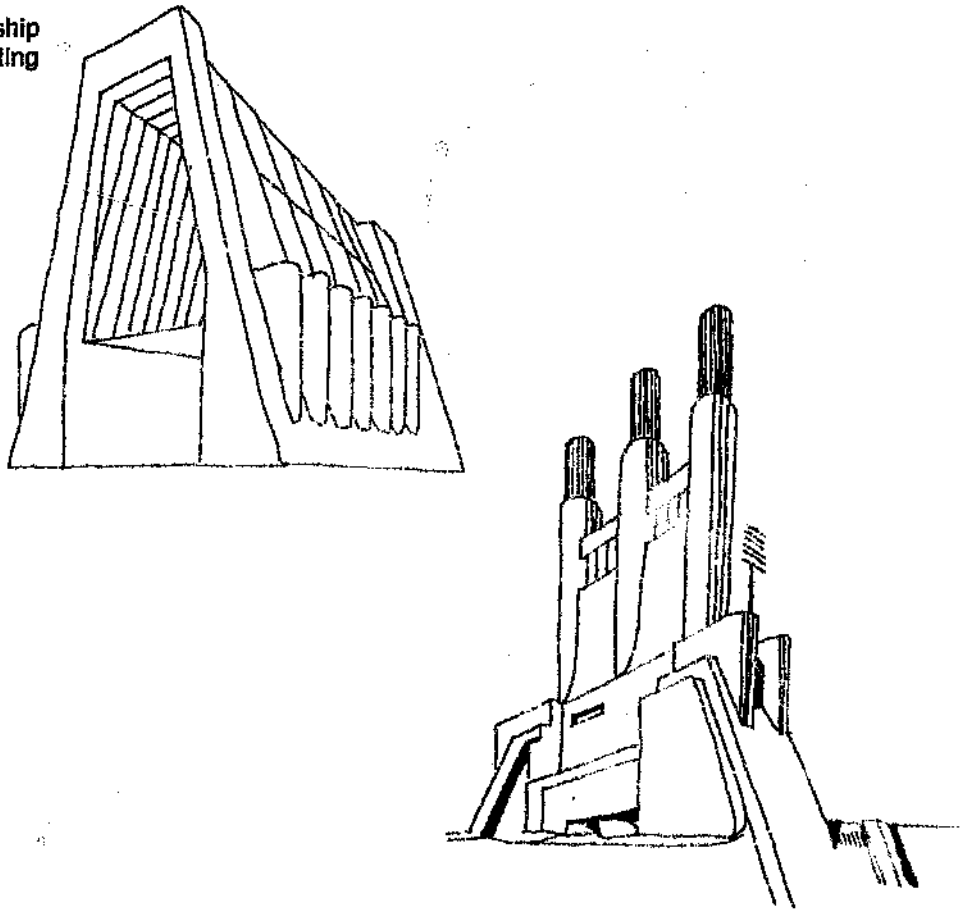


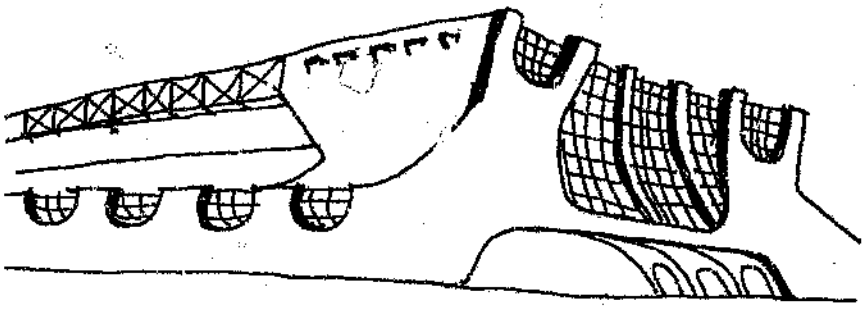
Fig.35 Projects for an airship hanger and electric generating station [Banham, 1960:117].

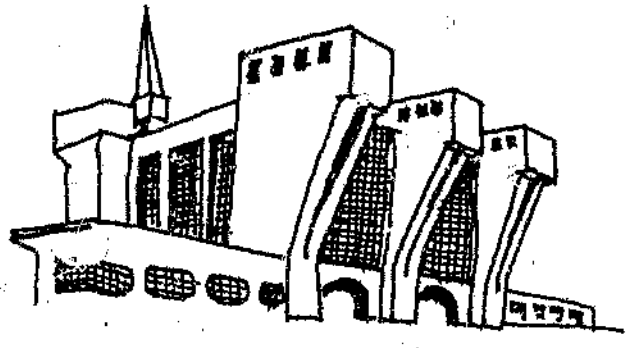
regular intervals. These beams were perforated [97] for service in both the longitudinal section and the cross-section [Fig.33]. As a symbol of the modern Italian factory it was a triumph and a formidable presence in industrial Turin, but because its message was so late it closed the period of industrial archeology.

97. Large and small holes calculated to support all the services [Banham, 1986:242].

Mendelsohn was the architect whose highly imaginative architectural sketches made use of modern materials and construction methods to express what he saw as organically unified buildings [Fig.34]. Another architect Sant' Elia [98], felt that a complete break with architectural styles of the past was necessary and historic solutions should be avoided. He prepared hundreds of drawings depicting various aspects of highly mechanised and industrialised buildings [Fig.35]. Sant' Elia volunteered for army duty at the outbreak of war and was killed at the battle of Monfalcone in October 1916.

98. Antonio Sant' Elia [1888-1916] prepared an essay concerning his version of Futurist architecture.





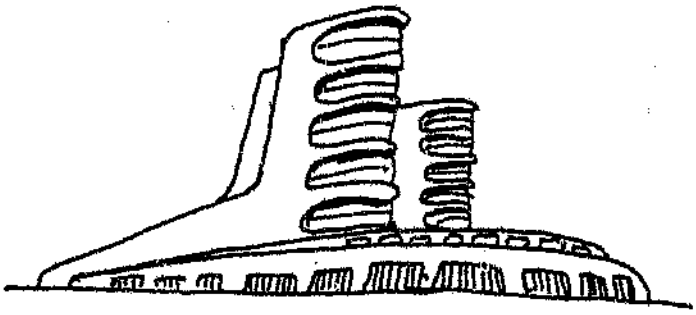


Fig.1 Eric Mendelsohn. Project for a car-body factory 1914 which cannot be written off. This expressionist fantasy shows important structural ideas and his concept of dynamism. The other two sketch projects were completed between 1914-1918. The first is for an industrial building and the one on the right for an optical factory [Risebero, 1979:221] and [Munce, 1961:59].

CHAPTER NINE : MASS PRODUCTION

Ford told Sorenson "They can have any color they want as long as it's black." In 1916 you could buy five models but not one option. You took it or left it.

- [Herndon, 1970:89].

Recent history is notoriously difficult to record because of the vast accummulation of divergent material and the problem of distinguishing the significant. One fact stands out clearly, namely that despite the immense achievements of technology and management up to the early 1900s, the decades between the two World Wars witnessed more advances across a wide range of activities than the whole of previously recorded history. The pragmatic leadership in the construction of industrial buildings passed from Britain and Europe to the U.S.A. It was based mostly on their innovation and ability to adopt new ideas [1], together with their immense natural resources.

Mass-production in the automotive industry coincided with the emergence of large-scale business organisation because only large-scale finance could make the heavy investment in plant and tooling [2]. There was no scope for haphazard plant location [3]. The sequence of operations and machine loadings were now properly planned and upgraded continually [4].

Compared to other European countries, Germany had a clear lead in the aesthetics of factory buildings [5]. This was not an entirely new creation. At one end of the spectrum [Fig.1] were the Futurists [6] and Expressionists [7] and at the other end of the German environment was the work of Gropius at the Werkbund Exhibition [8]. The Mendelsohn car-body factory is the easiest to decipher. It was more than an expression of the internal forces of the building. It showed the dynamism of the steel

1. The client was Ford, the architect Kahn and the consultants Taylor and Fayol. The available inventions were electric motors and lights, iron structures, glass in sheets, the development of concrete and mass production as a technique [Taylor, 1947:37].

2. Power tools - powered and hand-operated machines for drilling, sanding, grinding, chipping and routing, mostly powered electrically and, when available, pneumatic [Guedes, 1979:99].

3. Two dimensional block templates were cut out and used for the planning of the plant [Mallick, 1951:94].

4. 1913, the period of take off [Drucker, 1969:4]. Britain was slowing down, the USA, Western and Central Europe and Japan were in take off and Brazil, Canada, Mexico and Australia were on the threshold of emergence.

5. Behrens, Roelzig, Stoffregen and the historian Hermann Muthesius [Guedes, 1979:49].

6. Futurism died with Sant' Elia [Giedion, 1959:319].

7. Mendelsohn, who stated that function without sensibility remains mere construction [Banham, 1960:168].

8. Gropius and Meyer designed the Model Factory at the Werkbund Exhibition in Cologne in 1914 [Sharp, 1966:27].

Fig.2 The plan of the Werkbund "Fabrik", an elementary composition according to academic precepts and not industrial discipline [Banham, 1960:51].

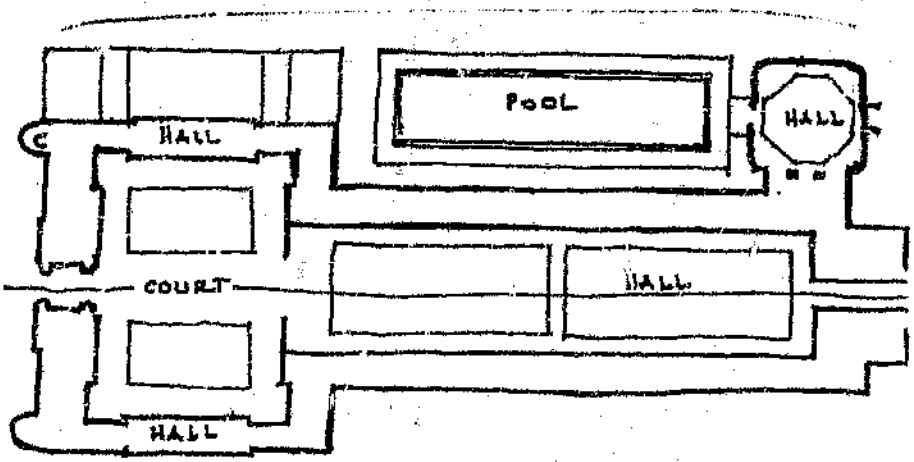


Fig.3 Classical glass elevation on the south side showing the north elevation from the courtyard. The south elevation is the more famous because of the round nosed staircases. Both are expression of glass [Banham, 1960:62].

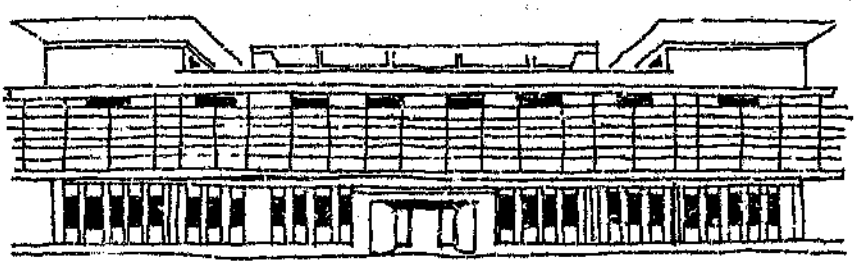
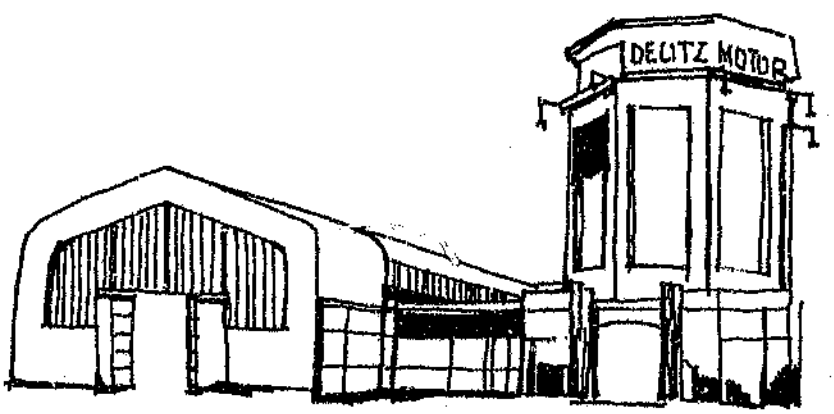


Fig.4 The north side showing the end elevation of the machine hall and the Deutz pavilion [Pevsner, 1960:216].



construction, the gantries and lattice trusses which drew the forms together while the corner blocks strained forward to absorb the loads which were transmitted [Banham, 1960:168]. This dynamism had broader connotations as it exhibited an architecture that determined its own standards which instinctively perceived, compared, measured, divided and proved [Sharp, 1966:181].

Every material, as is the case with all matter, has fixed conditions which demand a form that makes full use of its technical potential [9] and is not bound by locality. Iron in conjunction with concrete, were the materials of the new style which were used in response to both tension and compression and would lead to a new logic.

9. Mendelsohn wrote about German Expressionism and the use of modern materials and construction methods to express organically unified buildings [Risebero, 1979:222].

The Werkbund model Fabrik [Fig.2] consisted of a small office block, exhibition centre at the south side [Fig.3] and a large machine hall at the north side [Fig.4] with a change of function occurring between the two. The architects, who were not bound by the enforced discipline of an industrial production layout, were free to arrange the elements for display of machine tools, including a pavilion for a gas motorcar. The office block was axially about the main entrance. The axis ran back through the courtyard and down the centre of the machine hall. The offices also ran bi-axially to the main axis with the Deutz pavilion aligned as a tertiary axis. The plan shows identical patterns of set-backs on both sides in spite of a complete collection of the modern eclectic sources of the time [10].

The glazed office block, with windows rising continuously for three storeys, wrapped around the front corners with staircases that stood proudly in glazed half-drums and rose the full height of the main facade without any visible means of support [11].

10. The offices were similar to the glass facades of the Fagus factory, the machine hall guided by the AEG turbine hall and the pavilion influenced by the gas and water towers of Behrens and Poelzig [Banham, 1960:85].

11. This technical innovation has enjoyed considerable success since.

Fig.5 The hanger was cast in concrete and was 83 m wide, 50 m high and 300 m long. There were three of them [Le Corbusier, 1927:284].

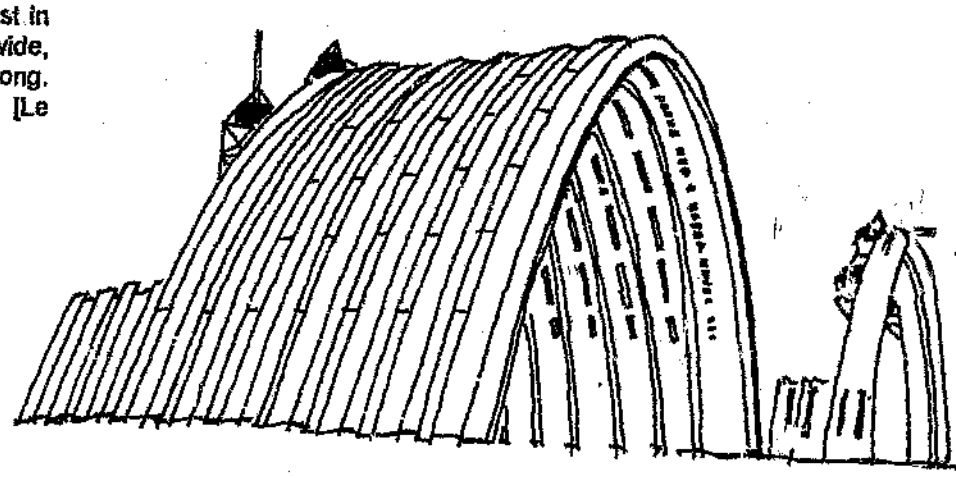


Fig.6 Thin exposed concrete tracery with various domed roofs [Le Corbusier, 1927:283].

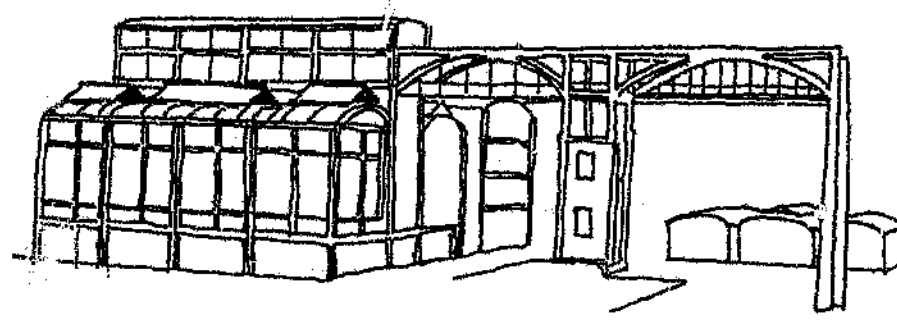
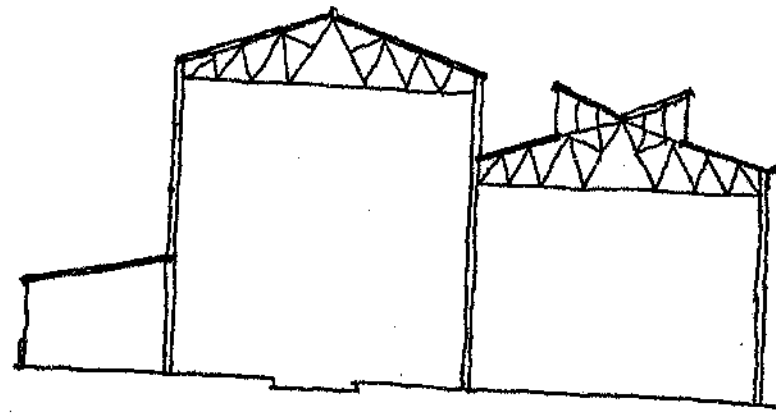


Fig.7 Standardised and mass-produced sheds for a standardised and mass-produced item [Hildebrand, 1974:96].



The north gable ended simply in form to have the appearance of being a prototype of the standard units drawn from industrial production, while the pavilion and the west elevation was reflected in a pool [12].

Concrete was a powerful medium not always recognised by architects, but the French engineers [13] who were responsible for the erection of the hanger at Orly Airport near Paris [Fig.5] saw the potential when confronted with the problem of constructing and housing enormous dirigible motor-driven balloons [14]. The French flair was also seen in a coke-washing plant [Fig.6] designed by Freyssinett.

It was only in France that ferro-concrete could be used without any hesitation. Building legislators in the rest of Europe distrusted the elegant constructions of lightness and precision resulting from the use of ferro-concrete. Le Corbusier laid down some points he considered important [15] with regard to the contemporary design by architects which were not specifically for industry, but were applicable.

The Americans [16] chose to reject the concrete daylight factory at this stage and concentrated mostly on simple one-storey, modified sawtooth-roofed plants [17]. Ford was convinced that the proposed boat for anti-submarine work could be mass-produced like the Model T. The Rouge site was ideal as it was served by several major railway lines, the river was linked to the ports of the Great Lakes and the shallow draught boats could be launched directly into the channel.

The Plant [18] consisted of five immense aisles, 17 m wide, 560 m long and 15 m high. This enormous volume exceeded by far that which Kahn had ever designed [19]. The great building is impressive even today. All the aisles had monitor or clerestorey lighting [Fig.7], steel sash

12. This may be called a Fabrik, but it was never intended for production [Giedion, 1959:393].

13. Eugen Freyssinet [1879-1962] invented pre-stressed concrete in 1928, Auguste Perett [1874-1954] designed the Esders sewing workshop in 1919. Dykerhoff and Widmann experimented with thin shell roofs [Le Corbusier, 1927:284].

14. Used extensively, this gas-filled cigar-shaped airship was popular until 1937.

15. The pillar, the functional independence of skeleton and wall, the plan libre and the free facade.

16. Principally because of the vast resources of coal and iron ore.

17. The Eagle Submarine Chaser Plant for Ford Motor Company on the Rouge River in 1917 [Hildebrand, 1974:92].

18. Known as the B Building [Hildebrand, 1974:93].

19. Ford had planned it for two years. He was commissioned to start on 17 January 1918, completed the operation in May and the first boats were launched on July 10 of the same year [Hildebrand, 1974:92].

Fig.8 The elevation of the Eagle plant showing the interplay of roof shapes and the windows punched into the brickwork veneer. [Old or new] [Hildebrand, 1974:97].

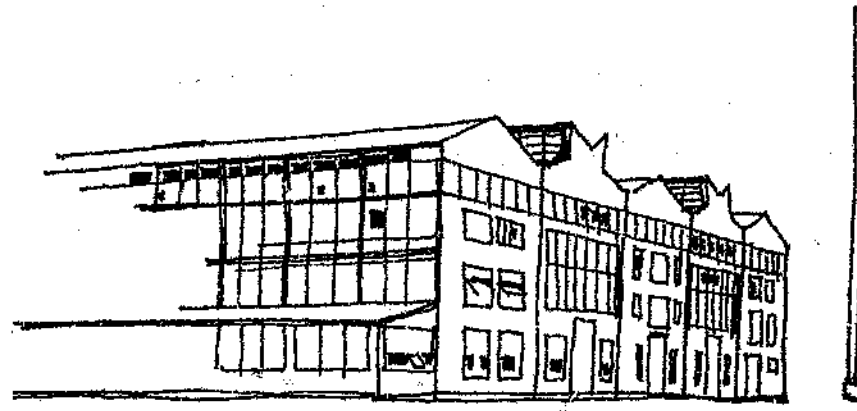


Fig.9 The building completely stripped down to a straight-edged prismatic form [Banham, 1960:289].

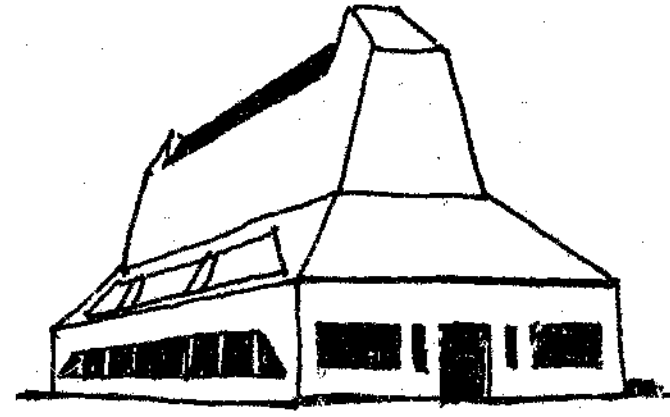
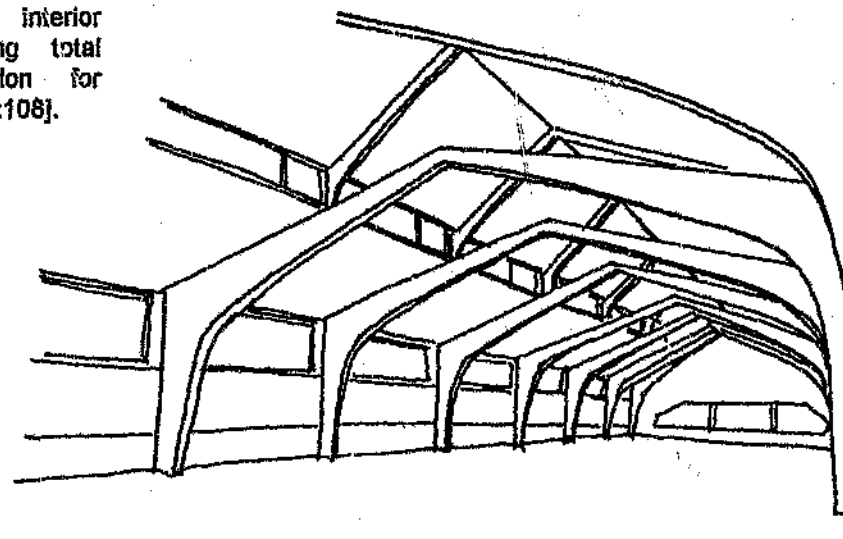


Fig.10 Impratical interior construction indicating total lack of consideration for services [Munce, 1961:108].



windows, double tapered top chords carried the roof loads and the roofing was done with cement tiles. Running parallel at the sides were low aisles which housed stores and other subsidiary functions such as toilets. These aisles were constructed of timber with asbestos sides to facilitate expansion. The Eagle plant was significant for four reasons. It enclosed an immense and complex operation within a simple, direct and economical plan and represented a major commitment to one-storey construction in light, thinly clad enclosures [Fig.8] in a remarkably short period of time [20].

These buildings were completely functional and therefore they are beautiful [21] as a good machine is beautiful. To the architect they may mean one thing [22], to the engineer another and to the industrialist something else, but essentially their significance lie in the fact that the buildings express the character of the period and may even have pointed the way to the future [Nelson, 1939:14]. Kahn was right but for the wrong reasons [23]. Industry was fully committed to the principles of mass-production with all its positive and negative aspects, while the battle for serious but appropriate architecture had been won [24] in Germany [Pevsner, 1976:288].

The Luckenwald hat factory by Mendelsohn [25] appeared to have been designed from the outside in and marked the end of his Expressionist period. The vat-dye and drying tower showed a plain and elegant functional form [Fig.9], but did not reflect a practical interior design [Fig.10]. The extensive use of oblique and diagonal forms, tapered columns and beams formed a structure contrary to the factories of the period, where equipment and machinery were still fed with shafts, pipes and tubes and were lit from above.

Not all the functional buildings were being erected in the great industrial centres. Many were built by unknown

20. By 1919 the plant had been converted to build Model T bodies and Fordson Tractors [Hildebrand, 1974:99].

21. This was Kahn speaking as it appeared in the August 1938 issue of Architectural Forum.

22. Its expressionist appearance was determined by the advanced methods of production where the assembly line was suited to the single-storey [Giedion, 1959:394].

23. Mass production created universal wealth, but immense social problems. These were the turbulant times of 1868 to 1918 [Drucker, 1969:7].

24. Affected, but then Pevsner was born in Leipzig.

25. Constructed from 1921-1923 [Banham, 1960:289].

Fig.11 Anthracite breaker in Locust Summit, USA [Winter, 1970:96].

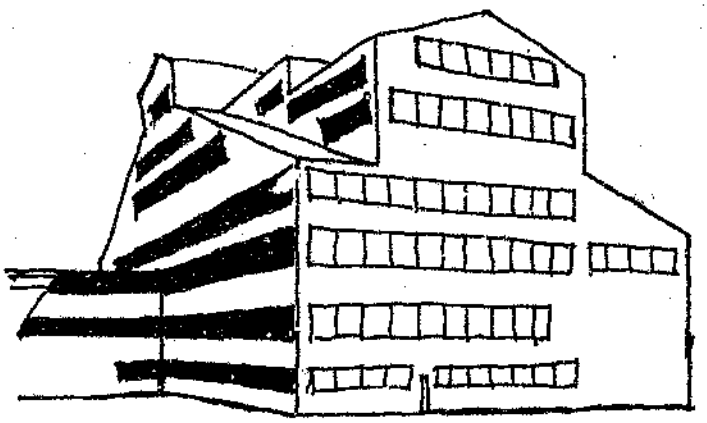


Fig.12 The highest monitor roof occurs over the furnaces where temperatures are greater [Hildebrand, 1974:103].

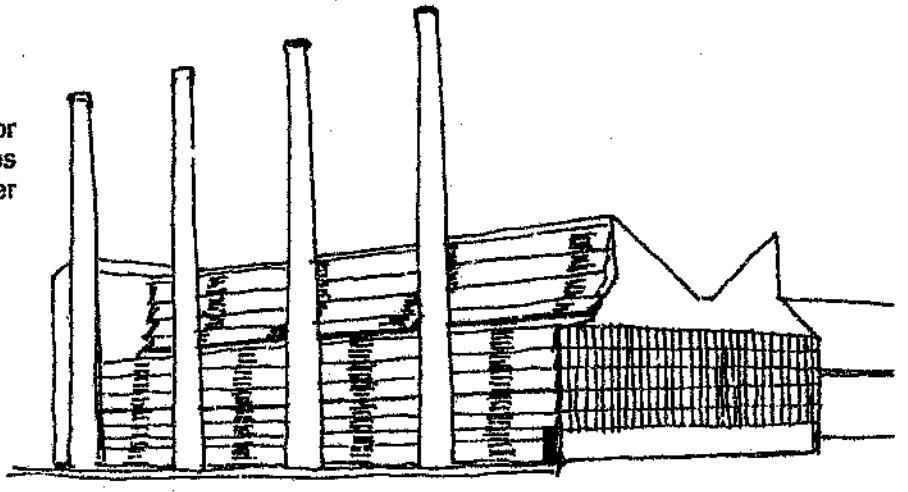
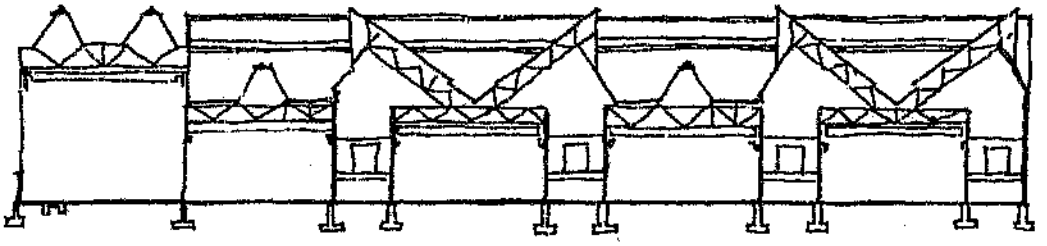


Fig.13 The higher monitor runs parallel to the production concentrating on the furnace line [Hildebrand, 1974:106].



works engineers in obscure parts of the country [Fig.11]. This anthracite breaker was constructed of light steel clad in asbestos-cement. Again the question arose whether efficient function did not automatically produce beautiful form and, if it did why bother with all the double talk about art [Blake, 1958:103]. The Luckenwald hat factory while not based on reality has been internationally acclaimed while the many anthracite breakers are ignored. This hat factory did not reflect form following function, but Formspiel [26]. It goes against the grain to bestow form from the outside in an abstract module [Sharp, 1967:79].

26. The play of form or formplay.

The Ford Motor Company wanted a factory capable of producing more than one million square metres of polished glass anually. After preparing the process diagram [27] the task began for Kahn who had to devise the appropriate physical enclosure for this process.

27. Plant layout was prepared in-house by Ford engineers who also designed the machinery.

Four great furnaces were arranged across the south end [Fig.12] while the storage of raw materials was housed just west of the furnaces. Each furnace fed three process lines. All the functions were contained in a building of 92 m x 247 m.

The bays were all framed by simple trusses on two columns, which also carried the cranes. No attempt had been made to use glazing, only on the north side, as the monitors faced all four directions [28]. The monitors did not match the production lines [29] and the structure appeared unnecessarily complex. The only sophistication was its great height and the light [30] above the furnaces [Fig.13].

28. The sawtooth became toned down and as far as it is known was not used by Kahn after the late 1920s [Hildebrand, 1974:111].

29. The roofing shape was bizarre.

30. North and southlight alternatively.

The brick masonry was only 4,5 m high, the walls above that being exclusively of glass and corrugated sheet iron. The structure was not expressed on the exterior. The cladding passed outside the frame [31] which gave rise to a fairly smooth exterior, the accent being on the horizontal

31. An economic exercise based on easier detailing, cheaper fenders and faster construction.

Fig.14 The Open Hearth building of 1925 clearly shows the effect of the various functions [Hildebrand, 1974:116].

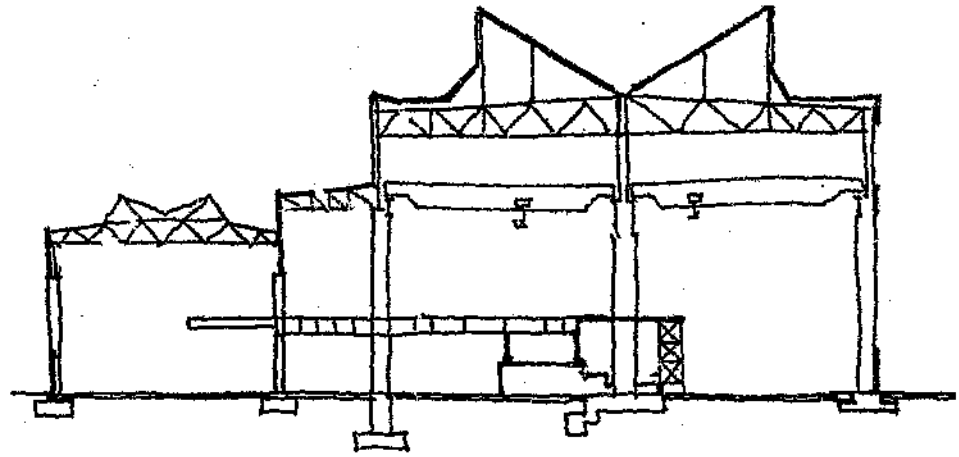


Fig.15 The scale is reduced to something more human as it is not a manufacturing plant but an assembly plant [Hildebrand, 1974:119].

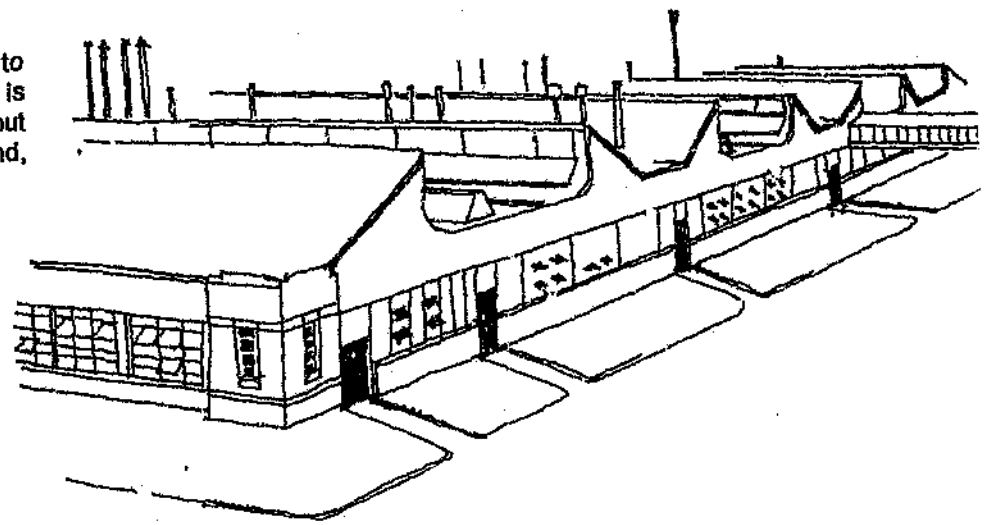
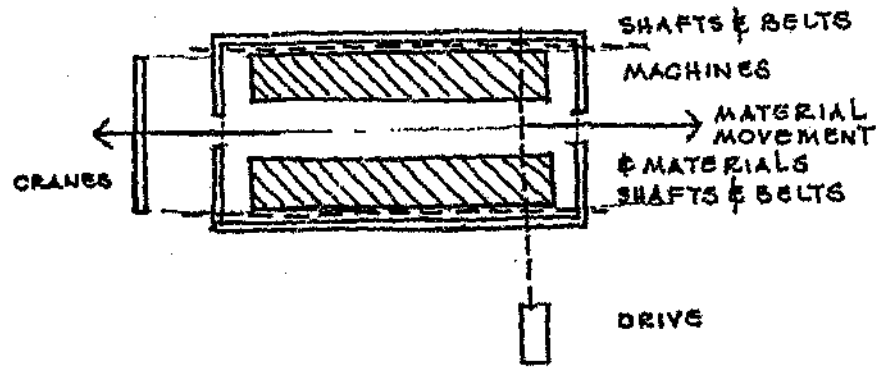


Fig.16 With the coming of electricity came the freedom of mechanization. Electricity allowed the placing of machines anywhere in the plant and not based on the rigid unidirectional method caused by shafts and belts, cranes and overhead lighting [Guedes, 1979:100].



In broad, uninterrupted planar sweeps. The furnace building resulted in a simple, but economical prismatic envelope [32].

In keeping with his goal of self-sufficiency, Ford planned [33] the Open Hearth building to supply the Company with steel using the revolutionary process of continuous production. This involved constantly keeping a reservoir of molten metal in the furnaces which could be drawn off when needed [34]. The building, which was 80 m x 350 m, was related purely to the furnace operation. The large monitors centered over the furnaces provided maximum light and ventilation to that area and the smaller side buildings [Fig.14] were used for the transportation of raw and processed materials. The materials were heavy and difficult to handle, so railway trucks on tracks were used. When drawing off the molten metal, vat cars were driven directly under the ladles where it was drawn off.

The Motor Assembly Building [Fig.15] represents the greatest refinement in treatment of the Kahn envelope [Hildebrand, 1974:117]. The roof was very similar to the glass plant [35] with a simpler overall configuration. It was thought that this assembly building would provide the link between all the plants at Rouge [Fig.16] and the factories that Kahn was to plan towards the end of the next decade [36].

Industrial buildings consisted broadly of the processing of material or of the assembly of components. It might have been expected, even in those early days, that the specialisation in the U.S.A. would have led to closer tailoring [37] of the factory envelope to the product.

Other types of roof covering were also perfected in this period The north-light, first used in the weaving sheds in Britain, consisted of rows of columns running east-west. Standard-framed simple trusses, with the roof beams

32. Determined by the function, admittedly overdone and extremely large.

33. Glass plant, coke ovens and by-products 1922, Job Foundry 1923, Cement Plant 1923, Open Hearth 1925, Motor Assembly 1924-1925, Pressed Steel and the Spring and Upset, including innumerable small buildings and structures, all at Rouge [Hildebrand, 1974:111].

34. This meant simultaneous drawing off and replenishment and immediate transfer to the forges elsewhere. The method did not prove successful [Hildebrand, 1974:111].

35. Without the plant layout to give sufficient reason.

36. The demise of the Ford Model T in 1927 and the birth of Model A [Hildebrand, 1974:117].

37. This in spite of the Kahn desire to always be functional.

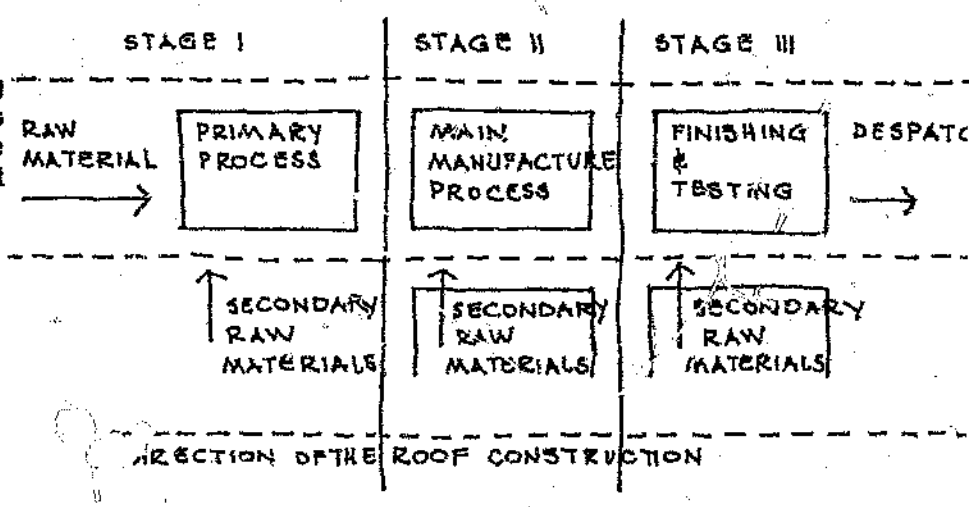


Fig.17 The making of anything requires a chain of operations to bring about the transformation of the object [Wallis, 1980:71].

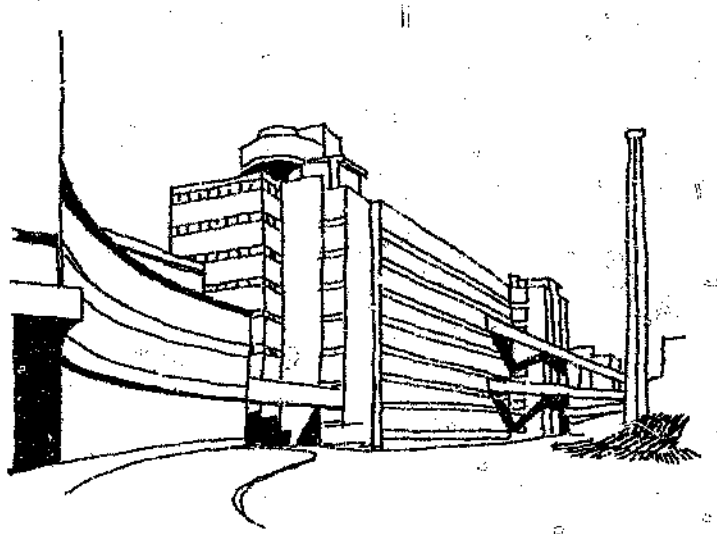


Fig.18 Expression through the machine implies the recognition of aesthetic terms such as precision, calculation, simplicity and economy [Munce, 1961:11].

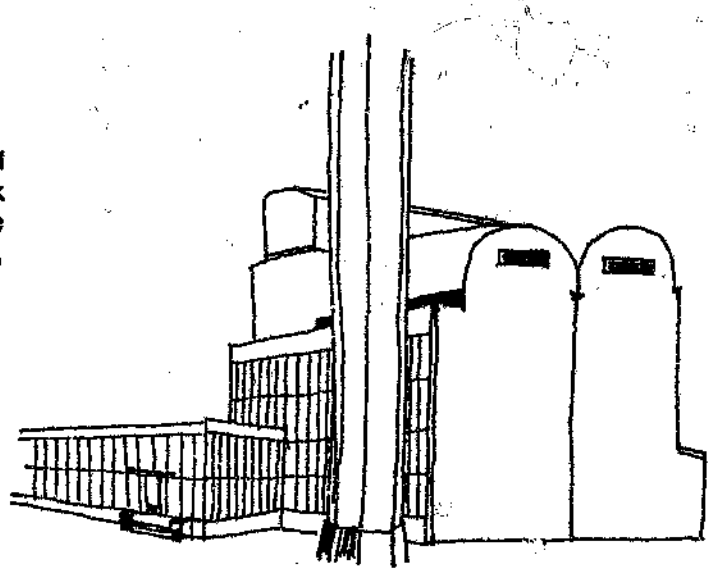


Fig.19 The rarely-illustrated boiler room and smokestack which is so functional as to be self explanatory [Henn, 1955:41].

attached to the top of the north truss and at the bottom of the south truss, were covered with corrugated metal. This culminated in a gutter at the end of a 60° slope. The gutter was flush with the downpipes and set into the columns. This method of roofing was very economical with the columns generally placed at 13 m. The flexibility [38] of the factory was limited by the column spacing and because light, even if borrowed [Fig.17] as in a northlight, casts a shadow. Flexibility is further limited by placing the working line runs at right-angles to the windows above [39].

In the Ford Assembly Plant the problems were overcome by shielding the exposed windows with louvres so that production lines could run parallel with the window lights in the roofs.

One of the finest [40] factories in Europe was erected in Rotterdam in 1928 for the Van Nelle Tobacco Company. The main building was an eight-storey block of reinforced concrete with mushroom headed columns [41] and clad externally with curtain-wall glass [Fig.18]. This elegant building still stands today, undiminished in quality and the finishes unimpaired by the ravages of the war or the passage of time. The architects were forced to consider not only the fabric of the building and the processes taking place [42] within it, but also the well-being, health and morale of the workers [Munce, 1961:10].

Expression through the machine without addition to the arrangement of form is done by presenting the machine just as it works. It, therefore, is not an aesthetic principle at all. The machine simply works, and because it works it is not noticed [Fig.19]. It is the natural handling of materials and the rationalisation of design for mass production that bring about simplicity, cleanliness and good sense. This need not mean "forms follow function" [43] and does not mean that form grows from

38. Electricity also allowed for the sociological concept of group endeavour according to Elton Mayo [1880-1949]. In 1927 he also studied the effect of illumination on production [Sugden, 1968:520].

39. This type of roof configuration is still in use throughout the world namely northlight in the Northern hemisphere and southlight in the Southern hemisphere.

40. Rationalist building designed by Michel Brinkman [1873-1925], L C van der Vlugt [1894-1936] and Mart Stam [1899-], a Bauhaus trained architect [Banham, 1960:297]

41. Already in use in 1910 in a warehouse in Zurich by Robert Maillart [1872-1940].

42. The plan is the generator [Le Corbusier, 1927:26].

43. Louis Sullivan's empty jingle [Banham, 1960:320].

Fig.20 An uncompromising all-purpose envelope with vertical windows for psychological purposes only [Reconstruction-Author].

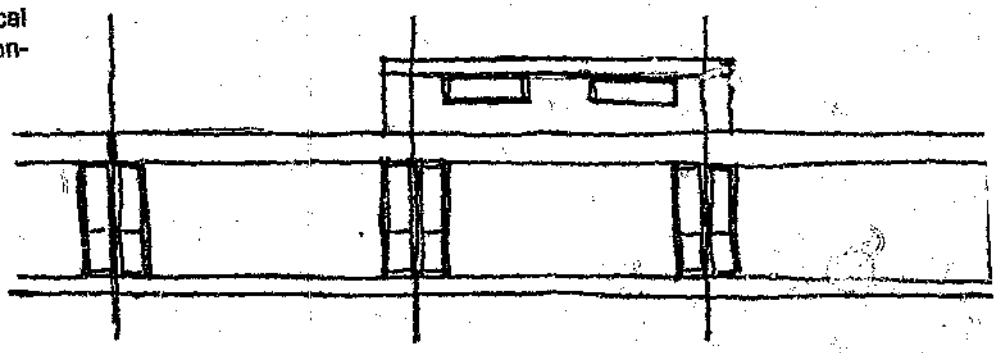
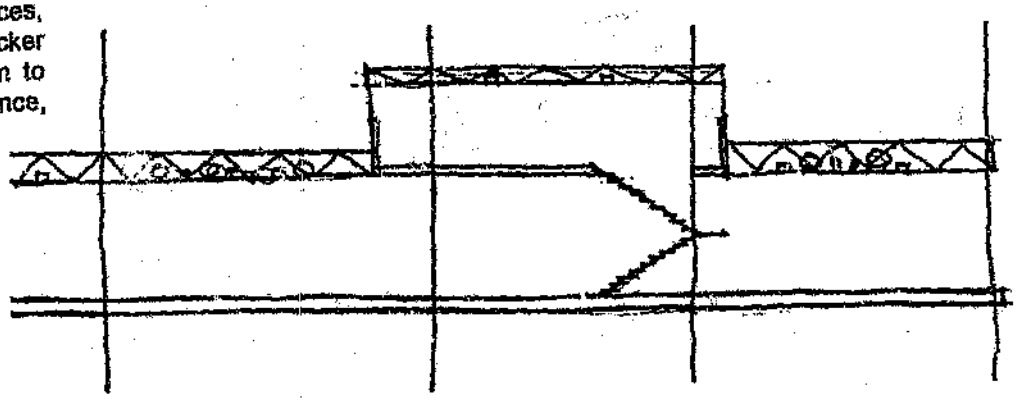


Fig.21 Suspended services, walkways, toilets and locker rooms with staircases down to production floor [Munce, 1961:41].



functionalism, but that it is appropriate to or an interpretation of it.

The single-storey factory became almost universally accepted as mass production and horizontal transportation became more advanced than vertical transportation which was done by the construction of slow lifts or the dubious advantages of gravitation. The structural grid was still determined by economic clear span requirements, but without directional limitations [44].

44. The windowless factory with no roof lighting was now born. The first deep-plan space with conditioned air was planned by Simon Saw and Steel Company in Fitchburg, Massachusetts, in 1929 [Allen, 1953:17]. Due to the depression it was erected only in 1939.

With or without roof lighting, the single-storeyed factory roof had to be able not only to carry the loads created by production methods, but also to accommodate unexpected loads and new facilities fairly readily. Production changes could be brought about within economic reason and new plant and services installed without unnecessary delays in production or expense.

The windowless factory [Fig.20] can be seen as an attempt to provide a solution for the broad mass of medium-sized processing and assembly industrial buildings. It presented the highest practical degree of adaptability within a single adaptable building that would house an increasing variety of industry [45]. The monitor-type roofing of the shed, no matter what its orientation, let in three times more heat than the flat, windowless roof [Manning, 1962:631], while the loss of heat by air changes during winter could be more significant than loss through the structure. Within one year of construction [46] the loss of natural light through obstruction and dirt could be as high as 1/3 to 1/2 of the calculated figures. The psychological effect of being out of touch with nature was overcome by placing vertical strip windows in the side walls [47].

45. Simon Saw and Steel Company conditioned their factory atmosphere and based it on borehole water so deep that the temperature remained constant all year round. They were also one of the first factories to use the fluorescent lamp which was invented in 1934 [Munce, 1961:41].

46. Most factories use artificial light throughout winter and during night shifts [De Bono, 1979:149].

47. A good idea, even for factories with natural lighting.

48. 1928 - $40M for factories in the USSR.

With the depression most industrial building was stopped for half a decade, but Kahn obtained [48] a commission

Fig.22 The cantilevered southern elevation with its covered loading bays [Brockman, 1974:168].

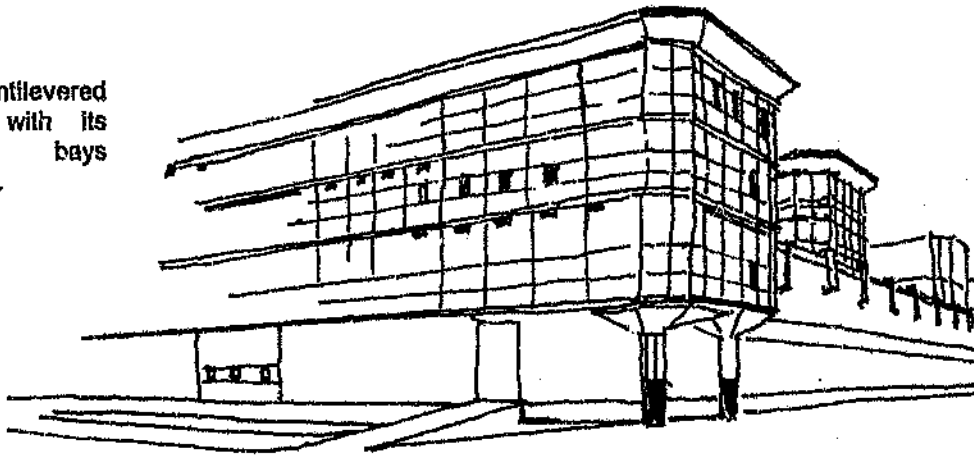


Fig.23 Vast, roofed open space with the manufactory floor three floors below [Winter, 1970:74].

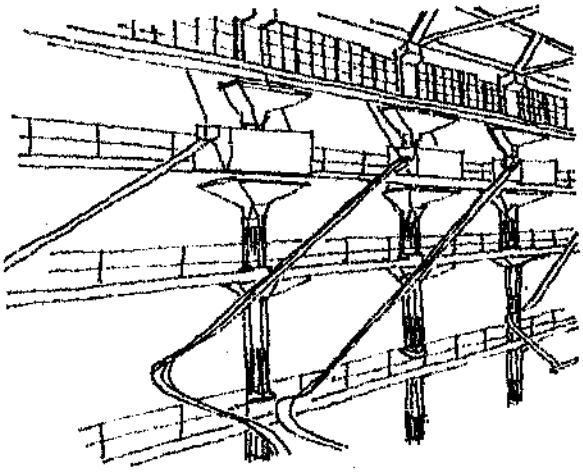


Fig.24 The Dagenham works of Ford under construction in October 1930 [Jones, 1984:209].

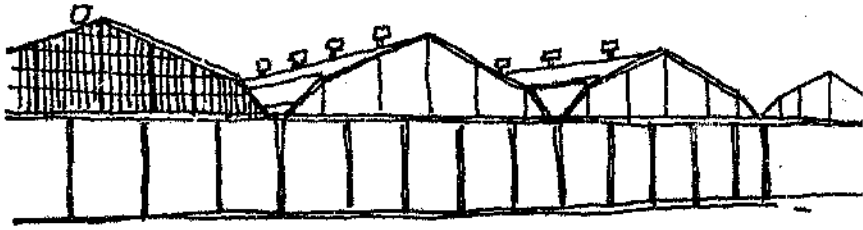
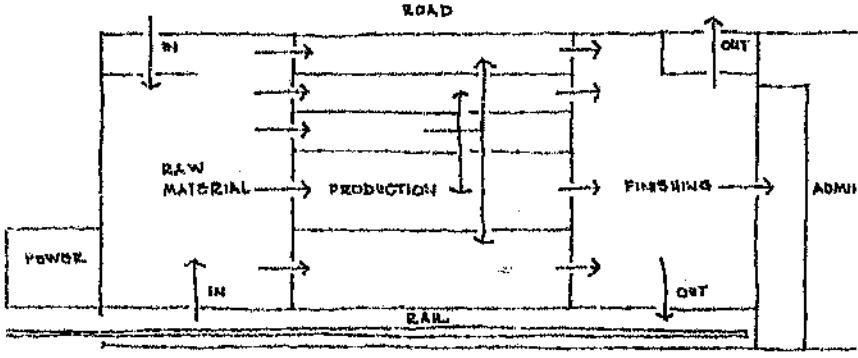


Fig.25 The flow diagram shows straight line planning in Lady Esther Ltd [Nelson, 1939:26].



from the Soviet Union where much experimentation with window factories was done [Fig.21]. The controversial abandonment of natural light and air depended only partly on extreme climatic conditions [49] and was not generally accepted anywhere else in the industrial world despite its general use in the United States of America.

49. During the 1939-1945 war the windowless factory was fully tested in coastal blackout zones [Allen, 1953:18].

In Britain, Boots erected a wet process pharmaceutical factory [50] which was a great pioneering gesture. It was an elegant [Fig.22] reinforced concrete structure with large concrete mushroom columns. There were three four-storeyed manufacturing galleries encased in steel framed curtain walls which provided for natural illumination. The concrete roofs were pierced by circular glass lights, while between the buildings on the first-floor level the manufacturing hall [Fig.23] was covered with a reinforced glass roof and bridged by concrete walkways at all levels. The materials prepared in the four-storey halls were dropped onto the manufacturing floor by gravitation chutes.

50. At Beeston Nottinghamshire, 1930-1932. It was designed by engineer Sir Owen Williams [1890-1969]. The dry-process factory was erected in 1937, but was less acclaimed [Jones, 1984:206].

The rejection of ornament, a near nakedness and the total reliance upon function and structure which dictated the appearance were dependant on the lessons learnt previously from industrial buildings [51].

51. Behrens, developed by Gropius and Van der Vlugt.

The first integrated car factory of any substantial size [52] in Britain was constructed at Dagenham on the Thames in 1931 on a piece of swampland [53]. Various manufacturing processes took place within this huge complex ranging from blast furnaces to the assembly of motorcars [54]. The enormous assembly sheds [Fig.24] were constructed with a steel framework and an uninterrupted floor space so that various manufacturing processes could follow one another in logical order [55].

52. Ford came from Cork in southern Ireland where the first Ford factory was erected [Herndon, 1970:XIII].

53. 22 000 piles were driven into a site of 140ha.

54. Designed by Heathcote and Sons, who had also been involved in the Westinghouse project some years before [Jones, 1984:210].

55. Production started during the Depression and the first of the popular Fords cost £100 in 1933.

With the international demand for cosmetics many factories were erected with plants which were somewhat

Fig.26 The roof configuartion is parallel to the production floor shown on the enlarged section [Nelson, 1939:85].

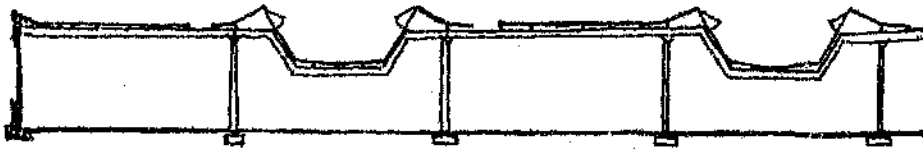


Fig.27 Studies were done by Kahn of the foot candles, based on window brightness of 100 candles per sq.ft. [Guedes, 1979:99].

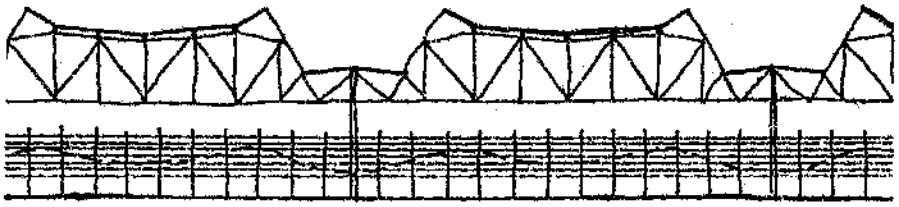


Fig.28 The section shows a totally different construction to the usual with the columns placed in the main monitor. This did not change the monitor shape [Hildebrand, 1974:169].

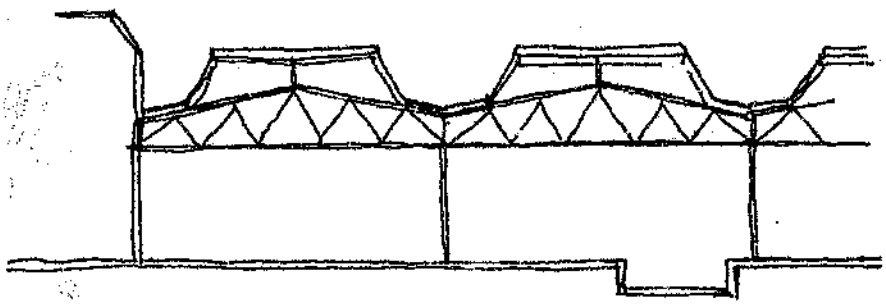
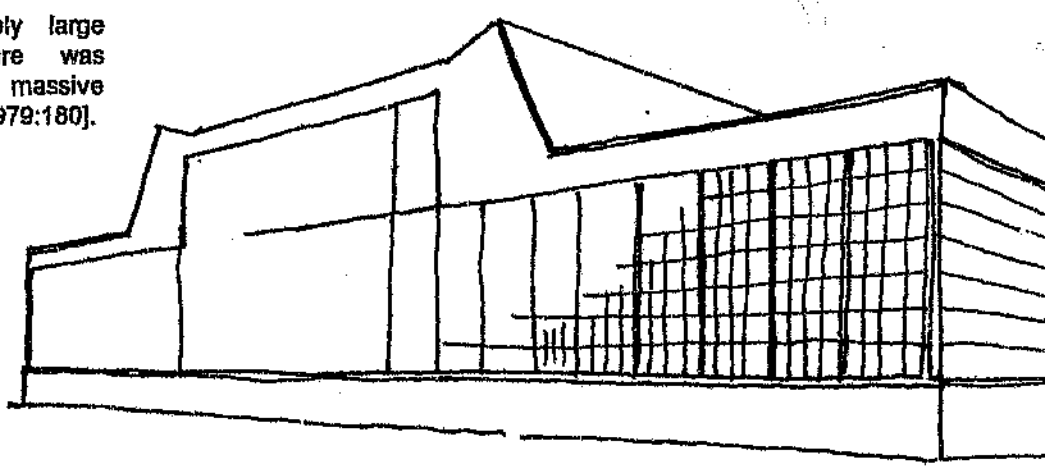


Fig.29 This extremely large open plan structure was supported by two massive trusses [Hildebrand, 1979:180].



reduced in size because highly expensive small objects were manufactured. The factories mostly had well planned production layouts prepared [Fig.25] in single-storeyed plants which would permit efficient handling [56]. Raw materials were received at one end of the building and moved through without crossing or retracing production lines. Therefore there was no congestion or lost motion and it led directly to despatch. The plans invariably made provision to extend the various production departments in parallel sections which gave a desired flexibility, allowing departments to be rearranged, increased or decreased in width at will. In the case of the Lady Esther Ltd [57] the floor to ceiling height was established at 5 m [Fig.26]. The steel I-beams were bent into monitors for light and ventilation.

56. The Lady Esther Ltd., Illinois, designed by Kahn; Coty Cosmetics 1933 and Gillette Blades 1936, designed by Sir Banister Fletcher [1866-1953] and Berlei Corsets 1937, mostly found on the Great North Road, London.

57. Millions of small, light and expensive units were handled per year. Many of the other plants were also in the region of 5 m but many, like Berlei, had equally finely detailed northlight roofs.

During this time indust[illegible]really accepted the expressionistic principles [illegible]rtain industries, especially those in fashion [illegible] gave a lot of thought to the very importa[illegible]ns to provide the right overt image [58] for the manufac[illegible]

58. At this time - the late 1930s - the dominant fashion was Art Deco. Colour schemes were bright and cheerful and the floors highly finished and clean [Jones, 1984:213].

The steel truss and monitor roof now seemed to be applied [59] to just about all the projects designed by Kahn, regardless of the product or its size. After the construction of the Hamilton Standard Propellor Company [Fig.27] at Hartford, Conneticut, tests were done to determine the validity of the monitor design, the brightness factor determined 1,5 m from the floor [60]. The diagram shows a relatively flat profile indicating a well designed roof from the environmental perception.

59. In 1938 Kahn was responsible for 19% of all architecturally designed industrial buildings in the USA [Nelson, 1939:15].

60. Ergonomics or man-machine relationships, later referred to as Human Factors engineering from 1920-1930 [Drury, 1981:296].

The Chrysler Corporation assembly building built in Detroit in 1937 and also known as the Half Ton Plant, showed the monitors at right angles with production [61]. The manufactured steel I-beams were more distorted [Fig.28] than any roof before. The Export Building, which stood quite separate, where the inal inspection was done for

61. The assembly building monitor runs north-south and the export building east-west [Guedes, 1979:99].

Fig.30 Diagrammatic draw-ing of the storage building [Hildebrand, 1974:175].

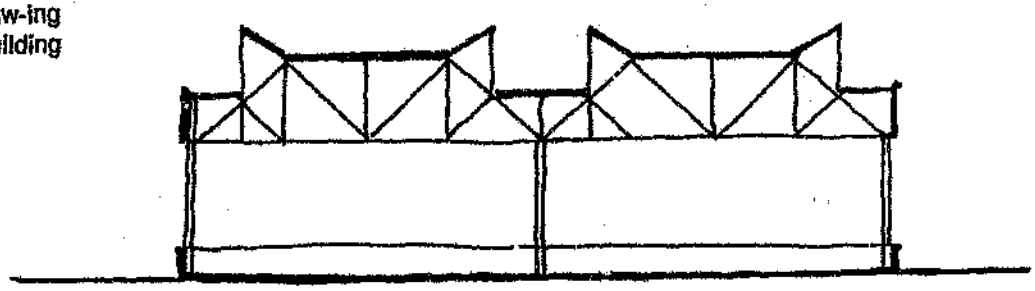


Fig.31 The great trusses spanning the whole floor and the section showing the monitor construction [Nelson, 1939:37].

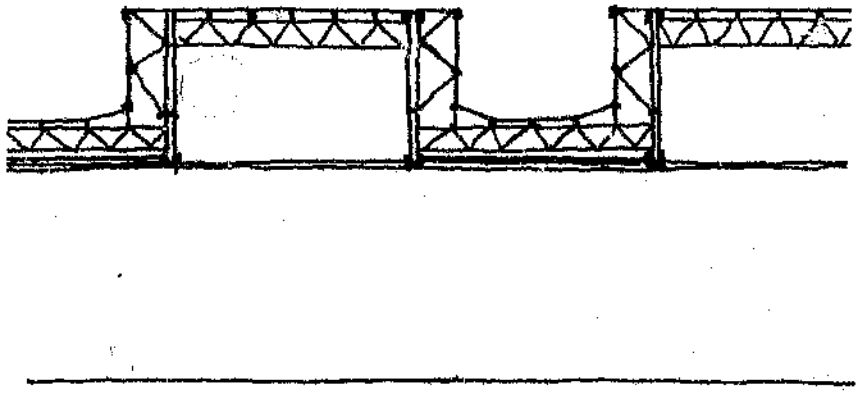
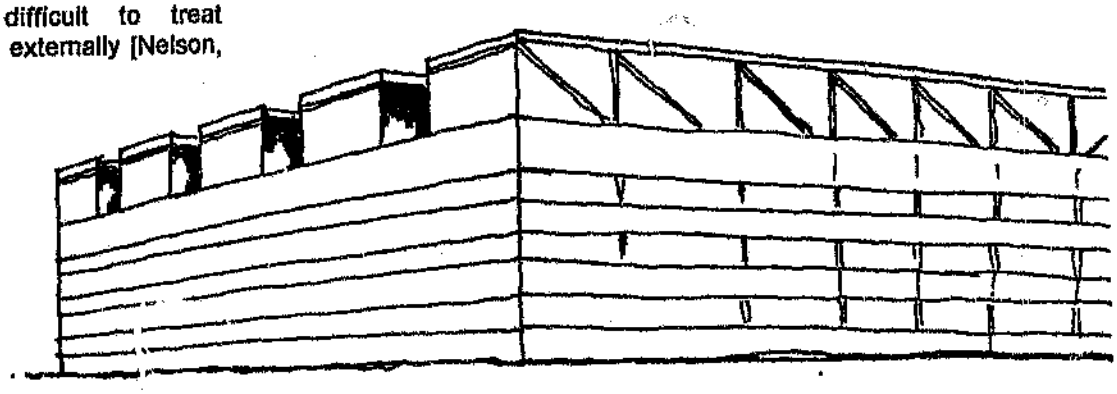


Fig.32 This massive box was extremely difficult to treat successfully externally [Nelson, 1939:39].



despatch had an enormous area covered by one large monitor [62]. While the outside shapes remain generically similar [Fig.29] the inside structures changed to accommodate the process with, hopefully, an economical design. What is strange is that the monitors were employed for a variety of uses and they were also placed at right angles to each other on the same site.

62. The assembly building is 133 m x 416 m and the export building 40 m x 80 m.

Perhaps the most refined of all the monitor roofs was that of the Curtis-Wright Storage Building [Fig.30] constructed in Buffalo, New York in 1938 where the steel was clean, uninvolved and of the no-nonsense type.

The greatest pre-war demonstration of steel truss and monitor construction was the Glenn L Martin Company Aircraft Assembly building which was built in 1937 in Baltimore, Maryland. The client required an enclosed space of 100 m x 150 m [63] without any interior columns [64] so that forty aircraft could be assembled at any one time [Fig.31]. Aircraft assembly cannot be done on a moving line. The planes are located at station points on the floor. The great depth and wide spacing of the main trusses admitted light through the flank of the trusses. The monitor sash was framed 2,5 m from the face of the truss.

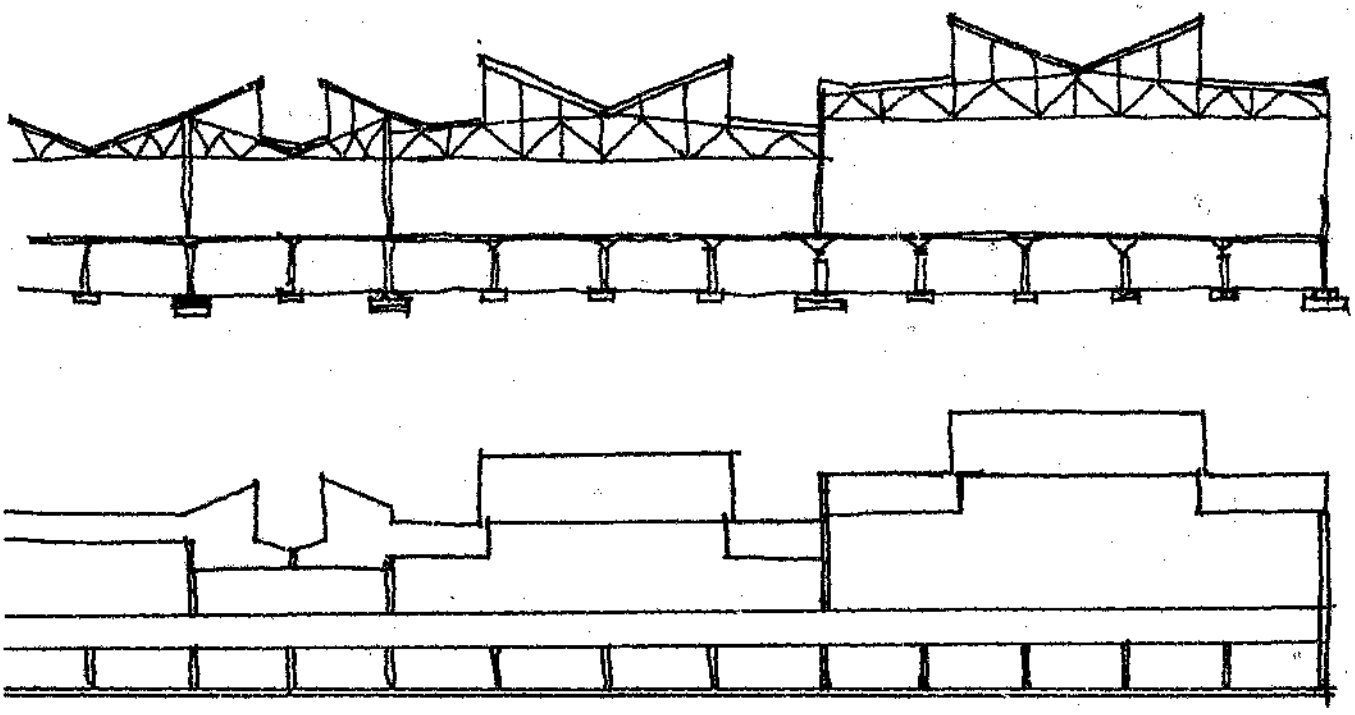
63. Glenn Luther Martin [1886-1955] believed that aircraft would become much larger. Bombers and flying boats assembled here played an important role in WW II [Hildebrand, 1974:183].

64. The 100 m flatspan trusses were the longest in any building to date. A door, consisting of three leaves 15 m high closed the one end [Guedes, 1979:100].

The fitters, millwrights and erectors had to climb the various parts of the assembled frame to perform the processes manually. This means that the lighting and heating had to be equal throughout the various levels of operation. The monitors would give an even spread of light while the heating was planned underfloor with outlets near the outside walls and a line of grilles along the centreline of the building.

The impact of the vast exterior, because of its massive scale, is extremely difficult to perceive [Fig.32] and in an attempt to incorporate some humanising influence broad

Fig.33 The section indicating the different heights of manufactory and sub-assemblies and the elevation with its cosmetic cover, hiding the true construction behind [Hildebrand, 1974:196].



bands of fenestration were constructed on the main elevations. This was aesthetically not successful and it must have been extremely irritating to work in an environment with harsh light and shadows cast over the floors and objects being assembled.

Early in 1939 the Glenn Martin Assembly Plant was extended [65] to include the manufacturing plant. This plant was a combination of parts-manufacturing facilities which necessitated the large-volume bays and the sub-assemblies in the lower bays [Fig.33]. Europe and the U.S.A. were preparing for Wolrd War II. The plant was planned, erected and in production within 16 months.

65. Approximately 49 000m^2 of plant.

PART THREE: RESULTS AND CONCLUSIONS

CONCLUSION

The bees plunder the flowers - but afterward they make of them honey - the pieces borrowed from others he will transform and blend them to make a work that is all his own, to wit, his judgement.

[Michel de Montaigne, 1958:111]

In the introduction to this dissertation the author identified various questions with regard to industrial design which had manifested during the course of his research. He has, through an academic framework, sought to find answers to these and other questions and has reached several conclusions.

This dissertation proves first and foremost that there is an aesthetics of functionalism in the field of industrial buildings, thereby validating the writings of Greenough and others who stated that *form follows function*.

Man, physically a weak creature, has created structures in which machine-assisted work can be done. The initial structures were the slow but powerful water mills, which squatted low over the streams to draw power from the moving water. This was followed by the fast but weaker windmills, which were tall in order to scoop the wind. Later, as man understood the mechanics of gears and materials better [1], these structures increased in size and the factory system came into existence.

1. Part One, Chapters One to Three.

As man discovered that he could handle great masses of energy, principally developed to run a large number of machines in one building [2], the buildings were adapted in shape and size to accommodate these new methods.

2. Part Two, Chapters Four and Five.

With the development of inorganic steam power, the mills could be moved away from the limiting power of water to the coal fields, where enormous multi-storeyed structures were erected in which hundreds of machines were housed and hundreds of factory workers employed. The structure and method of dispersing power remained the same, but the size of the buildings increased tenfold [3], with commensurate social and pollution problems.

3. Chapter Six.

The next change in form occurred when steel structures influenced the opening up of the facade, the thin-skin factory [4], and at the beginning of this period the decorative elements were often produced from pattern books.

4. Chapter Seven.

A more evident and serious change in form occurred with the physical inventions of electricity, light metals and concrete and as a result of the management's tool-perfecting machinery and automation layouts. The management and workers were separated for the first time when the administration offices were separated from the factory. The role of management now also became a major factor in the change in form.

Electricity made decentralised power sources possible, which allowed for working surfaces on one level, with light from above and not from the side. The American architects started constructing factories of many square hectares, while the European *avant garde* architects erected many beautiful industrial buildings based on their philosophy of style rather than on the function of these buildings. Mass-production buildings are an extension and perfection of decentralised power and of management layouts and techniques [5]. The larger the object being made, the larger the structure appears to be.

5. Chapter Eight.

The second conclusion regards the relationship between technology and form. Through this dissertation the author

contends that *technology has not been the only influence on the change in form.* The change was holistic and occurred as a result of many influences. The advance of knowledge as a source of growth, and consequently change, cannot be measured directly. It includes many aspects, but in the case of industrial buildings the main concern is technology - knowledge of the physical properties of things. From the above it becomes quite clear that when technology changes, whether it be production, the method of manufacture, the products being made or the material being used for construction, the form of the industrial building changes. Other recognised pressures such as sociology, philosophy, religion, economy and management all have roles to play. Each overlaps the other to some extent and all could be important, but there is no way in which to provide a quantitative comparison.

The initial phases of the evolution of industrial buildings must be seen as intuitive or instinctive, even accidental. It is quite obvious that what appears to have been piecemeal discoveries during the initial period was, in fact, the transformation of accessible information from other and related spheres [6] like shipping and church building. Neither the layman nor the scientist see the world piecemeal or item by item and both have the ability to sort out whole areas from the flux of experience.

6. Part One, Chapters One and Two.

This ability enabled man to realise that he could increase his production by mechanical means. Accidental evolution changed to planned evolution and the time came for a continuity of direction. If evolution was guided, could one not then expect it to be perfect? There is no evidence that this is possible, since man is imperfect.

The question of resources, their availability and the knowledge required to exploit them remains. There were resources without the necessary knowledge to exploit

them and there was knowledge without adequate resources to exploit it. As the technological evolution grew [7], not only in depth but also in scope, so a concentrated effort was made to overcome any lack of technology, material, concepts or knowledge.

7. Part Two, Chapters Four to Nine.

The third conclusion reached by the author is that *without man there would have been no technological advances.* In the beginning man concentrated on group knowledge and every tool embodied the collective empirical experience of countless generations. Materials and methods of manufacture were preserved by social tradition and imparted by precept and example to each new initiate into that tradition. When innovation did occur, action stemming from that innovation at any given time constituted a complementary part. Most technical knowledge is a legacy from earlier times and confirms that essential continuity is involved. The role of innovation must, however, not be underestimated, because in periods of great innovation [8] substantial technological changes occur.

8. Chapter Four

Inventions during the earlier periods were usually the effort of an individual whose single idea at a particular moment changed the course of development. Nothing is as powerful as an idea. Even single ideas have fundamentally and dramatically changed many human institutions. They have changed man's environment and, indeed man himself. During the later stages of the technological evolution, innovation was almost always a group process. All that was required from both the individual and the groups was the avowed purpose of man's technology to modify and control the natural environment.

The fourth conclusion deals with the nature of the process of change. It is clear that it is not possible to stop change. Neither society nor technology can remain in equilibrium - it has to change and these changes will continue. The

tempo may be leisurely, advanced or even inadvertently turned back. It is not unreasonable to accept change nor the fact that there has been change, that it is still changing and there will be change in the future.

For the purpose of this dissertation we can conclude that *the process of change in industrial form was both evolutionary, revolutionary and devolutionary*. It changed from the rudimentary or simple to the complete and complex. Evolution and revolution are reciprocal and complementary concepts which are not mutually exclusive or opposite, as both characterise a transitional process. Evolution is a slow and gradual change and revolution is a sudden or abrupt change with swift transformation. Evolution is also a safe and cognitive process, while revolution can be mindless and violent.

As indicated in this dissertation, the more acceptable theory must be that evolution and revolution operate simultaneously and that, like a mosaic, some parts of the organism change more rapidly than others. There are therefore long periods of relative evolutionary stability, punctuated by the sudden appearance of periods of intensive change. Also, the long periods are relatively easy to understand [9] and the short or smaller periods much more difficult.

9. The Evolutionary process features in Part One, Chapters One to Three the revolutionary in Part Two, Chapters Four to Nine.

It is no accident that the emergence of Newtonian physics in the seventeenth century, the economics of Victorian England and the quantum mechanics of the twentieth century all preceded revolutionary periods. By deploying these extraordinary processes, either singly or in groups, and by concentrating attention on them, major industrial change has been achieved.

During periods of continuous increase in power and in the precision of methods, it is easy to neglect periodic upheavals and discontinuity. As technological expansion

is used selfishly and greedily and results in physical and psychological pollution and an occasional devolution of direction, the side effects become strange and, more often than not, potentially hazardous.

The single largest setback industry has suffered has been the influence of the enormous urban structures which were built during the steam period in the early nineteenth century. This period of the "satanic" mills was characterised by smoke billowing from every chimney and child labour which still have an impact [10] on industry today. The attempt to return the classical facade to industrial structures during the same period was mild and merely a hesitant gesture in order to humanise the hard realities of the technical progress at the time.

10. Chapter Six.

Consequently, results need not be perfect in order to be beneficial, but extinction is due ultimately to an inability to respond to selective pressures. Some of these pressures are: management which is often more destructive than constructive, soulless buildings, monotonous jobs and a lack of fuel, mineral and energy resources. It proves, however, that an evolutionary process can be regarded as progressive in spite of some degeneration. It appears therefore that man has progressed by the pressure of his needs and by the insistance of his opportunities.

The recurring cycles or patterns of differentiation and specialisation, followed by reintegration at a higher level, become clear. Periods of creative anarchy follow periods of incubation. Each advance has a constructive and destructive aspect, a thawing of orthodox doctrines and the resulting fertile chaos. To state that a pattern is recognisable implies, firstly, that there are patterns and that they can be defined as multi-dimensional stimuli.

The transfer of allegiance from pattern to pattern is an experience of conversion which cannot be forced. It is

during this transfer or linkage, when the traditional or past pattern is sacrificed and the new pattern embraced, that the process speeds up. From the transfer, as indicated in this dissertation, it appears that in this inevitable struggle the traditionalists have continued on their course indefinitely and often became better adapted to meet the difficulties and dangers of competition. The fitter and stronger innovation eventually overcomes this transition.

During this period of change, it appears that pressures build up to such an extent that new ideas are sown on prepared soil. The old system does not collapse, however, in spite of its inadequacies, and change then fills the gap. Innovation takes the upper hand over a long period and, in spite of resistance, advances to a new pattern. The old pattern never dies completely. Windmills and water mills are still operational throughout the world and are often rejuvenated by new technology. Steam power, in spite of the major pollution it creates, still generates the most electricity in the world.

After examining the process of change within the limited field of the evolution of the industrial building form, the author completely agrees with the findings of Mumford and Giedion before him, but wishes to add that the periods of change were self-contained and similar in concept, but not in form. Although they were not equal in duration, they indicated a change in pace - they became shorter and more revolutionary.

Unlike the chrysalis which changes its body and thereby the nature of its being, the nature and essence of the industrial building as an enclosed space in which something is produced remains constant. Because of its dynamic nature, this process of change in the industrial building form may never reach its conclusion. However, since it has been determined that there is an aesthetics of functionalism in the evolution of the industrial building

form and that form does actually follow function, man's ability to anticipate advances and changes in technology and society may contribute to a more holistic approach to the consequential advances and changes in the industrial building form.

DEFINITIONS

Every historian would agree, I think, that history is a kind of research or inquiry.

[Collingwood, 1989:9]

EVOLUTION

The process of evolving, opening out, and unfolding of development and growth from the rudimentary to a more complete state. The pace appears to remain constant and in control.

REVOLUTION

The process is the same except that the pace of change may be so great that it is difficult to control and may overthrow the established norms.

DEVOLUTION

The process is opposite to that of Evolution and Revolution where the development reverses its growth and withdraws into itself and collapses.

FORM

The visible aspect of a thing, its shape or mass, surface and configuration. The word Gestalt is used in modern German to denote form in a holistic manner and has become internationally acceptable.

TECHNOLOGY

The systematic scientific study as a special branch of human activity. More generally, the term is used for any application of the discoveries of science. The word itself in classical Greek means techne or art and craft with logos, word or speech. In modern terms it has become the means by which man seeks to change his environment.

EOTECHNIC

The Eotechnic phase was the dawn age of modern technics consisting of the water-and-wood complex.

PALEOTECHNIC

The Paleotechnic phase is the second industrial revolution consisting of the coal-and-iron complex.

NEOTECHNIC

The Neotechnic phase represents the third development in the machine and consists of the electricity-and-alloy complex where society is pre-occupied with mechanical problems and purely mechanical solutions.

MANUFACTURE

The action or process of making or fabricating something either by physical or mechanical power.

MECHANIZATION

The making and use of inanimate devices such as machines and tools concerned with motion, force and the production of power and goods.

MASS-PRODUCTION

A large output of identical objects or interchangeable parts manufactured by forming a method of organising the process to attain high rates of output at decreasing unit costs. This process is usually based on specialisation of human labour and the use of tools and machines.

INDUSTRIAL BUILDING

The term is liberally interpreted to c ver a spatial enclosure where men and machines manufacture something.

MANAGEMENT

The action or manner of managing, administering and executing control which encompasses operations research, systems analysis and management-information systems.

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