NINETEENTH CENTURY BRICKMAKING INNOVATIONS IN BRITAIN: BUILDING AND TECHNOLOGICAL CHANGE

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ABSTRACT

This thesis analyses the process of technological change in the British brickmaking industry during the nineteenth century by examining the development of two separate but interrelated innovations. The first, brickmaking machinery, provided a mechanized substitute for the predominant hand methods of brick manufacture. The second, hollow bricks, was a machine-made product innovation generated by and dependent upon the widespread adoption of brickmaking machinery. Influenced by social constructivist theories of technological change, the thesis argues that both innovations were shaped by a set of key social relations which together comprised a technological system or network. Specifically, it shows how groups within the building industry participated in the creation of new brickmaking processes and products. The study begins with an evaluation of the traditional brickmaking industry and identifies various problems that generated the search for new technology. It goes on to consider how the attitudes and interests of the architectural profession stimulated inventive activity. Several early mechanized brickmaking processes are described and compared with emphasis on the way particular social groups were able to influence choices between competing paths of technical development and direct these innovations into specific forms. The study then examines the sources of demand for brickmaking machinery after mid-century and shows how characteristics of the market influenced the rate and direction of machine development. It also explains how the expectations and needs of consumer groups determined particular characteristics of machine design. Finally, the prominant role of architects in defining the form and use of machine-made hollow clay constructive units is discussed. The objective of the study is to demonstrate that during the nineteenth century technological changes were situated in and had a continuous reciprocal relationship with the process of architectural production.

LIST OF ILLUSTRATIONS

CHAPTER ONE

INTRODUCTION

British architecture during the nineteenth century was the product of rapid and extensive social, economic, intellectual and technological changes. Many historians have studied the evolution of architectural theories and styles during the century. Recently other authors have explored changing social and economic conditions that influenced the design of nineteenth century buildings. Much less has been written about the technological component of architecture, particularly the relationship between the development of new technology and the creation of architectural products. Existing studies of nineteenth century building technology usually attempt to show how new materials and techniques altered or modified architectural development. This thesis proposes to explore more deeply the relationship between technology and architecture by analysing the process of technological change. It will examine two technical innovations which were potentially significant to building in Britain during the period. Specifically, it will consider how various groups involved in the design and construction of buildings during the nineteenth century participated in the development of new technology. The objective of the study is to demonstrate that technological changes had a more complex and continual interaction with architectural production than previous historical accounts have indicated.

1.1.
Architecture and Technology: An Historiography

Scholars from various academic disciplines have investigated and written about the history of architectural technology; these have included architectural historians, industrial archaeologists, engineering historians and historians of technology. The resulting literature, while not particularly plentiful, is characterized by a diversity of motives, viewpoints, methods and conclusions reflecting the research traditions of each of these groups. Although these historical accounts have produced significant amounts of useful data about historic building materials and techniques, many have been limited by an uncritical acceptance of certain basic assumptions about the nature and behaviour of the technological component of architecture. Most authors considered technology and its relationship to architecture as unproblematic, that is, the functioning of technological phenomena was assumed to be familiar and universally understood. Technical development in architecture was traditionally treated as if it transpired independently from architectural development and essentially hidden from view. While some authors devoted substantial efforts to tracing and recording the progressive sequence of particular technological events, they only occasionally attempted to question the origin or evaluate the consequences of these events for the broader history of architecture. This approach has added little to our present knowledge of the complex interaction of technology and technological change with the process of architectural production.

Until very recently, little attempt was made within any academic discipline to understand the fundamental meaning and character of technology or to reveal the structure of technological change. Before any meaningful contribution can be made to the subject of architectural technology, it will be necessary to establish a working definition of the term "technology" and examine some of its essential characteristics. The purpose of this chapter is to identify and assess the meanings of technology and models of technological change that have been employed in previous discussions about the history of building technology and to construct a more useful conceptual framework with which to approach the study of technological change and nineteenth century architecture.

The literature about the history of building technology generally is divided sharply between accounts of pre- and post-industrial technology. The earliest scholars to study technical aspects of the history of architecture focused on pre-industrial handicraft technology. The primary emphasis of these authors was on material remains and the accurate collecting and classifying of information and samples. Technology was defined essentially as "artefacts" or "techniques". For example, during the nineteenth century a strong romantic and antiquarian interest in historic and foreign architectural styles and in "artistic" building materials resulted in the publication of detailed studies of ancient and medieval architectural remains and in the accumulation of vast collections of building stones, terracottas, ironwork, and other architectural sculptures and embelishments.

Around the turn of the twentieth century, vernacular revival and arts and crafts architects and scholars shifted the emphasis to simple local materials and traditionally crafted domestic buildings. But the methods of research and the focus on collecting and classifying remained the same. New historical studies emerged that meticulously traced the development in Britain of regional building types (Addy 1898; Hughes and North 1908), while other authors investigated a variety of regional craft traditions (Innocent 1908; Lloyd 1925; Briggs 1925). At the same time the systematic recording of structures began when the first volume of the Victoria History of the Counties of England was published in 1899 and the Royal Commission on Historical Monuments in England was established in 1908. Published studies from these sources provided architects with not only aesthetic inspiration, but also the basis for a structural idealism founded on craftsmanship and tradition.

The motivation for historical research of this type intensified when vernacular architecture was introduced as a course of study in the School of Architecture at the University of Manchester in the 1950's. A new generation of scholars with an appreciation for vernacular structures and traditional building techniques published new accounts of specific materials such as timber framing (Cordingley 1961; Mason 1964; Hewett 1969) and bricks (Brunskill and Clifton-Taylor 1977; Wight 1972), as well as wider-ranging historical studies of the general development of building materials (Davey 1961; Clifton-Taylor 1972; Jenkins 1965;

Salzman 1952). To these were added exhaustive surveys of vernacular buildings both at the national and regional level, many of which contained useful descriptions of the development of regional building techniques (Barley 1961; Briggs 1953; Brunskill 1974; Smith 1975; Penoyre 1978; Wood 1965; Wood-Jones 1963).

These studies shared a common methodology based on careful investigation of the material remains of buildings and accurate recording of evidence. They established analogies with known techniques and surmised the purpose for artefacts and the means for making them. While many early works contained implied value judgements about the superiority of hand-crafted buildings, recent publications such as those by the Royal Commission on Historic Monuments of England, are reasonably objective and go further in attempting to relate traditional objects or techniques to the wider social or economic climate. Valuable for their thorough descriptions, measurements and photographic catalogues, studies by vernacular historians provide a starting point for comparing later innovations and changes in building methods.

Industrial archaeology, established as an academic discipline in Britain in the early-1960's, widened the scope for the study of architectural technology to include industrial artefacts and scientifically derived techniques, termed "industrial monuments" by its founders (Hudson 1963). According to one source, industrial archaeology was "best thought of as the field study of technological change" (Bracegirdle 1973, p. 1). Its practitioners continued the methodology adopted by historians of pre-industrial building technology, that is, they collected and classified surviving artefacts and measured, photographed, and described industrial objects and sites (See, for example, Hay and Stell 1986). Publications, however, frequently slipped into nostalgia in order to glorify what was called the "functional tradition" of eighteenth and nineteenth century architecture. These included buildings for industry such as factories, railway structures, gas works, and industrially derived materials like iron and glass (Richards 1958).[1] Unfortunately, many of these studies were generally non-interpretive. They did not explore important questions such as why or how these objects or sites came about. Placing industrial objects in a wider context was undertaken only to "help make work in the field all the more meaningful"(Bracegirdle 1973, p.5). Yet, despite their artefactual and preservationist tendencies, the work of industrial archaeologists has been vitally important for other disciplines. The recording and preserving of technical data and industrial objects provides other historians with valuable first-hand research material, and allows them to study technology at close range.

Engineering historians went somewhat further in attempting to answer questions about the origin of new building materials or construction methods. Until very recently there were generally two types of engineering histories, those written by biographers that dealt with the lives of engineers and those written by technologists concerned with purely structural development. Both types of histories attempted to explain new technology by emphasizing the role of science. According to many of these authors, technological development in architecture was synonymous with scientific development, or as one author wrote, it was "the gradual penetration of the abstract scientific way of thinking into the field of building construction" (Straub 1952, p.xvi).

Many engineering historians continued the tradition of the nineteenth century romantic biographers such as Samuel Smiles who wrote Lives of the Engineers (1861). Others focused on major scientific "breakthroughs" and the careers and achievements of a handful of great engineers. In both cases the engineer was seen as the heroic theoretician applying scientific priniciples to revolutionize building construction. These accounts tended to amplify the significance of the engineers' contribution to architectural development. They appeared often to be an effort to justify the emergence of the engineering profession and to define its separate role in relation to the architectural professional. In writing about this division, Heather Martienssen observed: "Not only does he lay claim (through his spokesman, the engineering 'historian') to the best and most important buildings of antiquity, but implies with equal imperterbability that their designers were his own forebears...This 'thinking back' found in some modern books on engineering is not truly the history of engineering at all, but a scramble after ancestors for the portrait gallery of an 'arriviste' society" (Martienssen 1976, p. 41 and 46). Looking back for the most spectacular displays of technological virtuosity only distorts our understanding of technical progress in nineteenth century architecture.

Other engineering histories examined in minute detail the purely technical aspects of structural development. Many of the contributions to The Journal of the Newcomen Society have fallen into this category. Each new material or construction technique was treated as an isolated phenomena related only to prior and subsequent inventions along a sequential path of development. This approach upheld the view that technological development is self-perpetuating. Rowland Mainstone, writing in Developments in Structural Form in 1975, stated that his purpose was "to consider the development of new forms as a continuing process from the structural point of view" with an emphasis on "structures and elements that have marked significant steps forward in widening the range of possible future choices" (Mainstone 1975, p. 23). Many studies of this type also tended to look back in history to establish an easily understood line of development leading to the present day. For example, in An Historical Outline of Architectural Science, H. J. Cowan wrote that his intention was to deal "only with those aspects of science and engineering which have influenced current architectural design" (Cowan 1966, p. vi). These works are valuable for the important information about names, dates and patent numbers which they have provided, but they do not look beyond scientific theories or the empirical activities of a small group of men to account for the origins and evolution of most 19th century building innovations.[2]

Traditionally, architectural historians who dealt at all with the subject of technology were fascinated by the historical development of "new" materials such as iron, steel, concrete and glass. The intention of many of these historians was to isolate the earliest, largest, and most novel examples of the use of these materials. Historians were concerned primarily with how the discovery of new materials resulted in new styles of architecture thanks to the "far-sighted" architects or "daring" engineers who used them. Like many engineering histories, the nineteenth century was ransacked for construction methods that anticipated significant twentieth century architectural forms. Nineteenth century building technology was analysed from the point of view of twentieth century knowledge and interests. This approach often resulted in value judgements about the failure of nineteenth century architects to recognize the structural potential of new materials. Sigfried Giedion stated: "In the nineteenth century...construction was particularly important for the architectural knowledge which lay hidden in it. The new potentialities of the period are shown much more clearly in its engineering constructions than in its strictly architectural works. For a hundred years architecture lay smothered in a dead, eclectic atmosphere in spite of its continual attempts at escape. All that while, construction played the part of architecture's subconscious, contained things which it prophesied and half revealed long before they could become realities" (Giedion 1954, p.24). Studies of this genre tended to select past events to create an acceptable progressivistic explanation for the development of modern architectural styles.

Recent histories of nineteenth century architecture have continued the interest in stylistic development, but made greater efforts to broaden understanding by considering social influences and patronage in the emergence of new building types and architectural styles. For example, Anthony D. King, in his volume entitled Buildings and Society, asked: "What can we understand about a society by examining its buildings and physical environment? What can we understand about buildings and environment by examining the society in which it exists?" (King 1980, p.1). After decades of scorn by modernist propagandists, new historical works frequently argued for the validity of nineteenth century historicism and stylistic eclecticism by showing their social and cultural significance.

But for the most part, architectural historians have remained uncomfortable with technical aspects of the structures they studied and have accepted implicit assumptions about the nature of building technology. Usually it was seen as an external phenomenon progressing separately from architectural development. Dixon and Muthesius wrote that "Victorian designers were able to use new building materials *made available by the Industrial Revolution*, and in so doing they created some of the most original and spatially exciting buildings of the period" (Dixon and Muthesius 1978, p. 94, my emphasis). Technology also was understood to be dependent upon science and manifested in the work of engineers rather than architects: "The story of iron was largely a technical one, whose characters were engineers or embryonic scientists, telling of a gradual revolution in building method" (Jones 1985, p. 80). As a result of these attitudes, even recent architectural histories continue to focus on the biggest, most familiar or first examples of technical innovations. In many ways they have offered some of the most uncritical accounts and simplistic conclusions about nineteenth century architectural technology.

Occasionally authors from other disciplines contributed works which commented on particular aspects of architectural technology. Some of these added a new dimension to the problem of technological change and nineteenth century architecture. A significant example was Marian Bowley's Innovations in Building Materials (1960). Bowley attempted to identify the economic factors that influenced innovations in building technology, and to establish broad conclusions about the industrial structures and economic conditions that were most conducive to technical innovation.[3] As an early contribution to the study of the process of technological change, this book was particularly valuable for the diversity of economic forces it examined. Despite the fact that Bowley's discussion rarely went beyond the issues of supply and demand or general market conditions, her study added a new dimension to the problem of technological change in nineteenth century building. But its usefulness was limited by the author's narrow selection of case studies, avoiding those without good statistical sources, and the complexity of both her system of classification and her conclusions.

C.G. Powell also briefly addressed the problem of technological change in his book, An Economic History of the British Building Industry (1980). In considering nineteenth century building technology, these works perpetuated the idea that nineteenth century architects were disinterested or incapable of dealing with technical progress. Both Bowley and Powell attempted to explain this in terms of "lack of interest", "lack of training" (Bowley 1966, p.27), or "preoccupation with style", "high cost" and "technical conservatism" (Powell 1980, p.24). While their conclusions may partially be correct, the whole question of the adoption of new technology by nineteenth century architects has remained generally unexplored.

Although the study of the history of architectural technology has drawn from a variety of sources, there are some similarities in the existing literature. Most authors demonstrate a fundamental disparity in their approach to the subject. While all accept the importance of technical change in nineteenth century architecture and building, they usually avoid the difficulty of a direct consideration of the precise relationship between technology and architectural production or of the process of technological change in the context of architectural development. This has led many authors to accept some popularly held beliefs and to rely on oversimplified concepts or models about the nature of technology and technological change. These beliefs not only determined what was examined in each study, but also reinforced some general biases within each discipline.

Some common assumptions and generalizations emerge from a review of the above works. They can be summarized as follows. First, technology is accepted as a passive and autonomous factor in relation to architecture. New technology is seen as an exogenous factor -- "things" that are created elsewhere and made available by industry for architectural designers to use. Advances in technology are also believed to lie outside the realm of architectural development, dependent instead upon scientific development. This is based on the idea that technology is the practical application of previously discovered scientific principles and theories, or what is commonly referred to as "applied science". While technology is believed to be the final form of scientific discovery, then the new discovery or invention is the most significant aspect in any discussion of technical change in architecture.

Second, most of the literature treats the emergence of new materials and techniques as unproblematic, believing they come about as a result of "key" discoveries made by scientific leaders or heroic inventors. The sources of new inventions are seldom questioned. The primary focus is on the major scientific "breakthroughs" and the achievements of a handful of great men. The emergence of new technology is either seen to be essentially inexplicable, based on revelation, intuition or acts of insight that cannot really be analysed, or it is ascribed to empiricism and the genius and persistance of the "scientifically" trained inventor. Much of the history of architectural technology is written around important dates, key inventions, and the associated familiar names of great inventors such as Bessemer, Aspdin, Fairbairn, Brunel, Paxton, etc. Alternatively, it is written around the buildings which represent the first or most famous uses of particular new technologies -- the Crystal Palace, St. Pancras railway shed, Bage's mill, etc. It focuses primarily on the innovations that have proven durable, "successful" or particularly useful to twentieth century designers.

The emphasis on major achievements and great individuals has perpetuated a third generalization that stresses the revolutionary nature of technological change in architecture. This reflects traditional thinking about the Industrial Revolution which has been called "one of the great discontinuities of history" (Hartwell 1971, p.42) or "a great upheaval" (Flinn 1966, p.1-5). Authors who accept this idea accentuate significant breaks with the past. Much of the resulting literature emphasizes the most radical types of new building technology and the most decisive changes from traditional building practice. It ignores small changes and judges holdovers of traditional techniques as outdated or conservative.

Finally, many of the traditional histories of architectural technology present a linear-sequential explanation for the process of technological change. They assume technical changes occur in a logical cause and effect sequence and that all the events in the process can be ordered and arranged in a linear pattern from one stage of development to another. This reinforces the preoccupation with discovering "first uses" or prior inventions and the focus on great events. Arnold Pacey believes, "our habitual style of writing and analysis, whether in sociology, economics or technology, is itself basically linear. Its aim is usually to understand in depth rather than to broaden awareness. It is a style based on following logical connections, pursuing meticulous detail and measuring whatever can be measured. Unless it is skilfully used, the very literary form of such discussion can itself trap one into a narrow, linear view" (Pacey 1983, p. 34). Since the choice of historical events examined is arbitrary when adopting a linear-sequential model, it can lead to inaccurate and incomplete analyses as well as premature judgments. According to Edwin Layton, "linearization is a way of simplifying data in order to manipulate it statistically" (Layton 1977, p. 205). The events chosen are often those which reinforce the biases or satisfy the motives of the author, whichever discipline he is from.

Another danger of linearization is the tendency to view technical progress as inevitable. Technical advance appears to be governed by an inescapable inner logic or technological imperative. This, according to Eugene Ferguson, suggests that "the whole history of technological development had followed an orderly or rational path, as though today's world was the precise goal toward which all decisions, made since the beginning of history, were consciously directed" (Ferguson 1974, p. 19). "Discovery-push" models believe each new invention or technical solution creates a necessary progressive response. This leads to the conviction that the ultimate use (or the one we know from hindsight) a new technology acquired is the one it was compelled to acquire from the "laws" governing its development. Emphasis is then placed on a search for something inherent within the technology itself, or the "true" and "correct" form of the technology.

It is evident from a review of the existing literature that the prevalent beliefs contained in many works are a form of technological determinism. This approach may have provided adequate explanations for the concerns and motivations of authors at the time, but it allows too many incomplete analyses, one-sided views and hasty judgements. There appears to be a need for a reinterpretation of many aspects of building technology, particularly in the nineteenth century. A re-evaluation is needed based on a clearly articulated conceptual framework that will allow us to define more precisely the relationship between technology and architecture and to understand how technology changes. Scholars from various disciplines, loosely incorporated under the title "technology studies", have attempted in recent years to construct a more accurate and useful framework for the study of technology and technological change. A more integrative approach to the subject has been proposed. The remainder of this chapter will describe the basic characteristics of this approach and suggest how it may be used to enhance our understanding of the complex interaction of technology and technical development with the process of architectural production in the nineteenth century.

1.2.
An Alternative Approach to the Study of Technological Change

Systematic attempts to formulate a meaningful theory or model for the study of technology and technological change usually begin with the difficult problem of definitions. The five-volume Oxford History of Technology defined technology as "how things are commonly made or done" and "what things are done or made" (Singer, Holmyard and Hall 1956, p.vii). Recently this definition of technology has been expanded to include "knowledge" as an important dimension. Edwin Layton observed, "a common synonym for technology is 'know-how'" (Layton 1974, p.34). This expansion of the definition has been accompanied by an extensive debate about the sources and content of technological knowledge, focusing on questions such as, "what is *knowing* in a technological context?" (Hall 1978, p.94). The discussion also has centred upon distinctions between technological knowledge and scientific knowledge or "the problem of the science-technology relationship" (Mayr 1976, p. 663). While it was commonplace in the nineteenth century to refer to industrial products as being the fruits of applied science, twentieth century historians have misplaced the emphasis of the expression and attempted to convey the idea that technology, after a certain point in time, owed its very existence to scientific principles and theories. But according to recent scholars, this presupposes that a distinction can be made between science that is applied and science that is not, or as it is commonly called "applied science" and "pure science". Michael Fores pointed out that "a piece of scientific knowledge has not undergone any change when it is used (or applied to use) by a technical specialist (or by anyone else)... for 'unapplied science' is exactly the same as 'applied science'." He also wrote, "the purest of the 'pure' in science turns out to be the most basic, as well as the most applicable and the most often used" (Fores 1982, p. 181-182).

Further, to say that technology is merely the final realization of some form of scientific theory assumes, according to A. Rupert Hall, that there must be some direct suggestions concerning the utility of their theories coming from the scientists themselves. But attempts to demonstrate this link historically have failed. As Hall points out, many novel ideas for doing things in a better way formulated by scientific theorists were either "unnecessary or impractical in the prevailing technological context" and, conversely, many of the really useful technological advances made during the Industrial Revolution were accomplished in complete ignorance of scientific theories (Hall 1978, p. 137). A result of this discussion has been the recognition that the old assumption that technology "applies" what science "*discovers*" is *too simplistic* to use as a model for historical analysis.

Emerging from the vast amount of literature generated by the debate is the idea that science and technology are both social phenomena whose distinctions refer only "to bodies of knowledge, to activities, to the goals and motivations behind such activities, to forms of education, to social and professional institutions, etc."

(Mayr 1976, p.667).[4] There were some who believed the entire science/technology debate was counter- productive (Buchanan 1975, p.492). But the issue of definitions and parameters ultimately generated a whole new conception of technology and a new programme for technological studies concentrating on the social environment that creates artefacts, techniques or technological knowledge rather than merely on the products themselves. Historians of technology joined forces with sociologists of science and sociologists of technology (and to some extent economic historians) to establish the premise that technology, like economic or political systems or even architectural products for that matter, is an aspect of the way we live socially and is shaped by social factors (MacKenzie and Wajcman 1985, p.2).

Accepting this shift in emphasis, the relevant questions that should now be asked are why and how particular social systems produce a range of technological choices with particular sets of characteristics? To answer these questions it is necessary to examine the technical choices more closely, or as Layton observed: "What is needed is an understanding of technology from the inside, both as a body of knowledge and as a social system. Instead, technology is often treated as a 'black box' whose contents and behaviour may be assumed to be common knowledge" (Layton 1977, p.198). But how do we look into this "black box" of technology while at the same time avoid the pitfalls of technological determinism? Various approaches have been suggested.

The process of technological change by which one artefact or technique displaces another has been analysed by examining "stages" along an evolutionary path to technical progress. Distinctions are made between the moment of invention, the period of innovation or development, the diffusion or transfer of a new technology, and its ultimate impact upon society.[5] But this diachronic approach with its emphasis on developmental phases implies sequential isolation of events, cause and effect relationships and recognizable discontinuities, all of which are characteristics of linearization. It does not reflect the "complicated, branching network" of interacting social and technical events that are often revealed when more perceptive in-depth historical case studies are undertaken (Layton 1977, p. 205). For instance, we may ask at what point is a new technology really invented? Does it originate at the moment of the first idea, when the first plan or model is produced, or at the stage when the invention is finally patented? Sould we perhaps go back further and date its inception to the first indication of a technological problem waiting to be solved?

Similar questions may be asked about other stages in the evolution. For example, once an artefact or process is recognized as a *new invention*, is it *immediately* commercially feasible or marketable? Diffusion is concerned with the displacement of older technologies by superior new ones. But how are these evaluations of superiority made? Furthermore, discussions about diffusion frequently involve observations about the rate of adoption or judgements about a lag in the adoption of particular technologies. How can we measure the rate of diffusion? Nathan Rosenberg has asked another important question, "how slow is slow?": "When we speak of diffusion as being relatively slow, we are obviously implying some sort of dating procedure as well as expressing a comparative or absolute judgement. It should be noted at the outset that whether inventions are measured as diffusing rapidly or slowly depends in large part upon the selection of date" (Rosenberg 1972, p. 6). It is apparent that the dating of inventions and the selection of events as part of a linear-sequential model of the innovation process is both arbitrary and idiosyncratic. As one author points out, it has been "the basis for a number of well-known historical falacies" (Layton 1977, p. 205). Thomas Hughes reminds us, however, that we should not eliminate entirely consideration of phases in the analysis of technological change. Rather we must be aware that these stages "are not simply sequential; they overlap and backtrack"; invention, innovation and diffusion do occur throughout the development of new technologies, "but not necessarily in that order" (Hughes 1987, p. 56).

A more illuminating and potentially valuable approach is one that investigates the social processes involved in the development of a new technology and recognizes that society and technology interact as part of a "seamless web" (Bijker, Hughes and Pinch 1987, p. 11). This means the hard distinctions between social, political, economic, technical, scientific and other abstract categories overlap and become obscured. Several analytical programmes which reflect this perspective have been suggested for structuring studies of technological change. One uses a "systems" metaphor to describe how artefacts, institutions and their environment work together as interlocking components to solve critical problems in "reordering the physical world to make it more productive of goods and services." Innovators and their associates are seen as system builders who must manipulate the components in order to reach their desired goals (Hughes 1987 p. 51-82). In the "network" approach, technological form is "engineered" by a group of heterogenous yet interrelating "actor"-elements (the same social, economic, political or technical factors). Because of their disparity, the components are seen to be adversarial in that they are "difficult to tame or hold in place." Heterogenous engineering is required to weave the elements together into a self-sustaining network. The purpose of the historian is to "discover the pattern of forces as these are revealed in the collisions that occur between different types of elements" (Law 1987 p. 114).

Another method for structuring technological case studies is called the "social constructivist" approach. It too asserts that the characteristics of artefacts and processes are constructed by individuals or groups in the social environment. Because the relevant social groups have different ideas about the form and meaning of new artefacts, the developmental process is "a multi-directional flux that involves constant negotiation and renegotiation among and between groups shaping the technology." When all the groups agree that a problem is solved, "closure" or stabilization occurs (Pinch and Bijker 1987, p. 17-47). In addition to the seamless web concept, all of these programmes share an interest in "thick description" or the "content" of new technologies and their environment (Bijker, Hughes and Pinch 1987, p. 107).

A useful starting point for the study of technological change may be to evaluate the propensity and capacity of a particular society to formulate technical problems and to identify specific forces which not only facilitate technological solutions, but also push problem solving activities in particular directions. The conditions for technical change can only be found in the functioning of the larger social system. Stated simply these include a society's predominant values, political, legal and social institutions developed to support those values, and basic economic incentives and capacity. Nineteenth century institutions, values and incentive structures in Britain go back to the roots of the Industrial Revolution. Social, economic and political historians, seeking explanations for why capitalism and modern industrial technology first emerged in Western Europe (and especially in Britain), have provided a comprehensive analysis of British society from the eighteenth century (White 1962; Perkins 1967; Landes 1969; Musson and Robinson 1969; North 1981; Von Tunzelmann 1981; Pacey 1983; Berg 1985).[6] But social values, institutional structures, and the interaction of demand and supply determinants cannot by themselves explain the *generation* of particular technologies. These emerge only when inventive activity is directed towards the solution of a specific (usually economic) problem.

According to Nathan Rosenberg, in a free market economy (as existed in Britain during the nineteenth century) the expectation of profits and the incentive to reduce costs is constant. An individual or group under competitive pressure may consider a variety of technical improvements which will help maximize profits. Economists have called this the factor-saving bias of technological change (Rosenberg 1969, p. 2-3; 1982, p. 14). In choosing where to apply a new process innovation or product improvement, a decision-maker is likely to identify the problem or problems which pose the most restrictive or immediate constraints to his profit-making, or "bottlenecks", and initiate exploratory activities to solve these often short-term problems. "There have existed a variety of devices at different times and places which have served as powerful agents in formulating technical problems and in focusing attention upon then in a compelling way" (Rosenberg 1969, p. 4, and 20). Rosenberg called these "inducement mechanisms" and "focusing devices".

Shortages accompanied by sharply rising prices, industrial conflicts, accidents, disasters, restrictive legislation, and technical imbalances between interdependent processes are among the agents that can forcefully demonstrate shortcomings in the existing technology and point to the need for a superior substitute. In recent studies Thomas Hughes has used the term "reverse salient" to refer to the same phenomenon. Reverse salients are components in a technological system that fall behind or are out of phase with the others and require urgent, often inventive, attention for the system to survive (Hughes 1983, p. 13). In any study of technical change, an exploration of problem formulation and eventual solution can reveal much more about the generation of a new technique or product than merely dating an invention or identifying its inventor.

But exactly where, we may ask, do new technologies come from? Within the framework of larger social forces, new inventions are the result of a gradual accumulation of knowledge, small improvements and modifications to earlier technologies. Numerous individuals participate in this process, although the patent office and some historians persist in perpetuating the myth of the "heroic" inventor, "the one actor who happens to have been on the stage at the critical moment" (Rosenberg 1972, p. 7; 1982, p. 49). This is not to diminish the imagination or creativity involved in the inventive process, but to point out, as MacKenzie and Wajcman do, that this effort "lies above all in seeing ways in which existing devices can be improved, and in extending the scope of techniques successful in one area into new areas" (MacKenzie and Wajcman 1985, p. 10). Various authors have demonstrated that inventive activity is an aggregate effort. Karl Marx wrote that "a critical history of technology would show how little any of the inventions of the eighteenth century are the work of a single individual" (Quoted in Rosenberg 1982, p. 6). Similarly, in Inventing the Ship, S. C. Gilfillan described technological change that was "a perpetual accretion of little details... probably having neither beginning, completion nor definable limits" (Quoted in MacKenzie and Wajcman 1985, p. 10). Thus, in solving technical problems the choice of technique or the precise character of a new product ordinarily will be linked directly to existing techniques and products rather than being entirely new notions or dramatic departures from the past.

Another important characteristic of new technologies is that they are typically "crude and inefficient at the date when they are first recognized as constituting a new invention" (Rosenberg 1972, p. 10; Samuel 1977, p. 51). In some cases the imperfections are such that it is impossible to recognize the clear superiority of new artefacts or practices over older ones. In traditional language, this initiates a developmental period during which a new invention is transformed into an innovation (Layton 1977, p. 198). According to Thomas Hughes, "the invention changes from a relatively simple idea that can function in an environment no more complex than can be constituted in the mind of the inventors to a system that can function in an environment permeated by various factors and forces" (Hughes 1987, p. 62-63). What this means is the new technology is made commercially feasible. In reality this period overlaps with the original process of problem solution and invention in that critical inventive activity continues while production problems are worked out and the innovation is altered and refined to suit the needs of its users. It also encroaches upon the next developmental stage, diffusion, as new products or practices are tentatively tested in the market. During this process consumers play an important active role. Frequently, it is only when an innovation is employed in real-life situations that inventors or manufacturers are able to pinpoint defects or imperfections in design and make the necessary modifications to bring it in line with consumers' expectations (Rosenberg 1976, p. 526). In this respect we can say that the form a new technology ultimately acquires is determined by use.

Many studies of technological change have been preoccupied with the process of technological diffusion. This is because it is only through widespread adoption that the impact of new techniques or artefacts can be felt. Economists like Nathan Rosenberg have been interested primarily in how technical change contributes to economic growth or "the rate at which new techniques, once invented, have been translated into events of economic significance." Specifically, Rosenberg is concerned with identifying factors that can account for "variations in the rates of acceptance of different inventions" (Rosenberg 1972, p.3). Historian Ruth Schwartz Cowan, on the other hand, believes that focusing on the diffusion of new technologies, or what she calls the "consumption junction", gives us a vantage point for viewing the process of technological change "from the inside out." According to Schwartz Cowan, the consumption junction is "the place where technologies begin to reorganize social structures" (Schwartz Cowan 1987, p.263). Both agree that the principle focus of diffusion studies should be the decision-making process. A great deal may be learned about the diffusion of new technology by examining the variety of factors which influence a user's decision whether or not to adopt an innovation.

To gain an insight into the decision-making process, three aspects could profitably be investigated: first, the full range of advantages and disadvantages new technologies present to a prospective user; second, the consumer's ability to estimate the risks and uncertainties involved in adoption; and third, the variety of alternatives that a decision-maker has available to consider. As we have seen, the advantages of a new invention are not always immediately apparent. When new products or techniques are first introduced they often lack the full complement of attributes they ultimately acquire. Modifications and refinements must be made over a period of time in response to use and feedback by consumers. Only then will their superiority over existing technologies be established. Furthermore, users may lack the skills necessary to fully exploit complex new technologies, and a learning period may be needed while new skills are acquired. Similarly, new inventions may be so novel that existing complementary processes will impede their successful functioning and thus discourage adoption. Often they are able to fulfil their potential only when additional improvements are made to the older interconnected technologies (Rosenberg 1972, p.21). For this reason various authors have pointed out that generally "technologies come not in the form of separate, isolated devices but as part of a whole, as part of a system" (MacKenzie and Wajcman 1985, p. 12; Rosenberg 1972, p. 21; Bijker, Hughes and Pinch 1987, p. 11; Law 1987, p. 113).

One author has observed that "virtually all innovations involve technological and economic risks at all stages of diffusion" (Gold 1983, p. 120). Consumers' appraisals of the potential benefits or hazards in accepting a new technology may be influenced by a variety of factors. For example, value judgements fostered by particular social groups or acquired from past experiences may disuade them from adopting an innovation (Gold 1983, p. 113). Conversely, persuasive evidence of the success of new technology derived from convincing advertising or from satisfied friends or colleagues may sway a decision. In the context of the firm, Nathan Rosenberg has suggested that an entrepreneur's expectations concerning the possible rate of *future* technical improvements may delay his decision to adopt: "A firm may be unwilling to introduce the new technology if it seems highly probable that further technological improvements will shortly be forthcoming" (Rosenberg 1976, p. 525). This creates a difficult dilemma for the manufacturer of a product innovation. He must stabilize his product sufficiently to persuade potential buyers, but at the same time continue to improve it to meet consumers' expectations and to keep ahead of the competition (Rosenberg 1976, p. 530).

Finally, the decision-making process is made more difficult by the fact that in most cases a prospective consumer is confronted by a variety of competing technical options which must be evaluated. Once a radically new product or technique appears, it is often followed by a cluster of imitations which hope to compete with the original. Similarly, not all new inventions will be radical advances. Many are recognized as simply amendments or refinements to previously known technologies. The differences between alternative new technologies may seem insignificant to the outsider, but to the decision-maker they may constitute a bewildering choice. The technical choices available to consumers also will include existing techniques and products as well as innovations. The contrast between new and old technologies may sometimes seem greater, but it has been observed that many innovations "appear to induce vigorous and imaginitive responses on the part of industries for which they are providing close substitutes." Thus, as existing technologies continue to improve and develop, they are better able to compete with new inventions and the two sometimes coexist for long periods of time (Rosenberg 1972, p.26). Indeed, many older technologies are never entirely displaced, but the scope for their application becomes more specialized. Examining the full range of available technical choices encourages us to try to ascertain what these alternatives looked like from the perspective of the consumers and to understand which came closest to fulfilling their expectations.

Focusing on the decision-making process in studies of technological change is valuable for three reasons. First, it emphasizes the fact that at any given time "the technological future is, inevitably, shrouded in uncertainty" (Rosenberg 1976, p.523). The prospective adopter of a new product or process cannot possibly know in advance the outcome of his choice. Awareness of this fact enables the investigator to avoid retrospective judgements about the behaviour of consumers in the past. As Bela Gold observed, there are "enormous differences between hindsight perspectives and expectations about the unknown future. For example, hindsight judgements tend to stress *ex post* criteria instead of those which loomed largest when the decisions were made; hindsight evaluations are also more likely to rationalize whatever results were actually realised, crediting favourable outcomes to sound decisions while blaming unfavourable outcomes on external developments." Gold and others agree that such criticisms, launched "from the safety of hindsight perspectives", constitute irresponsible scholarship (Gold 1983, p.109; Schwartz Cowan 1987, p.263).

Likewise, the ultimate success or failure of a particular technology is completely irrelevant in a proper analysis of technological change. Trevor Pinch and Wiebe Bijker point out that many scholars prefer to ignore failed innovations and write only about the successful ones, relying on "the manifest success of the artifact as evidence that there is no further explanatory work to be done." But they stress that "the success of an artifact is precisely what needs to be explained" (Pinch and Bijker 1987, p. 22 and 24). An impartial examination of the decision-making process gives equal consideration to innovations that ultimately are proven ineffective as to those that eventually become popular because it is concerned only with the variables that influence consumers' behaviour at the time when the choice is being made. At any given moment, all inventions have the potential to succeed. As we have noted, according to the social constructivist view of technology, success ("closure" or "stabilization") occurs when all the relevant groups involved agree that a technical problem has been solved (Bijker, Hughes and Pinch 1987, p. 12). Ruth Schwartz Cowan stated that the task of the historian "is not to glorify the successes but to understand why some artifacts succeed and others fail" (Schwartz Cowan 1987, p. 261).

Finally, this perspective makes us aware that there is not only one perfect solution to a particular technical problem. The development of a new technology necessarily involves the contributions of a large number of individuals or social groups. Specific problems are defined by the various meanings these groups assign to artefacts or processes. In other words, the need for a new technology only arises when members of one group or a combination of groups decide that an old technology is no longer satisfactory. The interests and attitudes of these groups not only define the problem, but they also determine what constitutes an acceptable substitute. Because both the problem and the solution are defined by the relevant groups, there is a great deal of flexibility in the development of an innovation. "Almost everything is negotiable" and so there are many possible ways an innovation may be designed (Pinch and Bijker 1987, p. 26). Because of the disparity of the social groups involved, however, they may not always agree on the precise nature of the problem or the ideal form of the solution. Thus, controversies or disputes inevitably arise both within and between groups. Only when a consensus is reached or one group imposes its favoured solutions onto other less powerful groups can a particular alternative be seen to "succeed". Both the "social constructivist" and "network" programmes stress the importance of controversies or conflicts as a way of revealing the interpretive flexibility of new technologies.

The remaining chapters in this thesis have been substantially influenced by the concepts and methodologies outlined in this section. They propose to analyse the process of technological change by examining two separate but interrelated innovations in brickmaking during the nineteenth century in Britain. The first, brickmaking machinery, was a process innovation that provided a substitute for older hand methods of brickmaking. The second, hollow bricks, was a product innovation made possible by the widespread adoption of new machinery. Although neither of these were radical innovations, they both had the potential to profoundly affect the construction and appearance of nineteenth century buildings.

The intention of this study is to demonstrate that the design, content and use of both inventions were shaped by a set of key social relations. It will attempt to portray the "seamless web" character of technological development by focusing on the variety of ways that basic economic conditions, social institutions, industrial organization, aesthetic conditions and cultural attitudes determine technological form. Factors or elements that surface repeatedly in the following chapters -- demand for building, the changing structure of the building industry, the contribution of architects -- are not to be seen as functioning separately. Rather, they are active components or "actors" in a developing technological system or network.

The study begins with an evaluation of specific forces within the brickmaking industry that pushed problem-solving activities in certain directions. It goes on to consider the concerns of the architectural profession, a social group outside the brickmaking industry, and its role in initiating technological change. Next, two types of early mechanical brickmaking processes are described and compared. A valuable research site for this and later chapters was the Patent Office, not because of any inordinate significance attached to patents in the process of invention, but because of the "thick description" they provided. The introduction and evolution of a third mechanized process was greatly facilitated by several potent factors in the decades around mid-century. These are explored in the following two chapters with a special emphasis on the way particular social groups or institutions were able to influence choices between competing paths of technical development and direct innovations into quite specific forms.

The study then moves into the "consumption junction" where competing processes are analysed with respect to their ability to meet the expectations and demands of consumers. These chapters consider not just prospective purchasers of brickmaking machinery, but also the architects who were influential consumers of clay building products. They focus on attitudes and interests of the relevant consumer groups, on disputes or controversies over productivity and standards, and they attempt to show, where possible, how the decisions that were made affected precise design characteristics of the new machines. The final three chapters constitute a separate case study of hollow bricks. The method of analysis in these chapters is the same but there is a greater emphasis on the influence of architectural professionals because they were primary rather than secondary consumers of this new building product. In addition to patent statistics, these chapters rely heavily on nineteenth century architectural periodicals and professional publications for detailed accounts of opinions, debates and the results of testing.

A secondary theme that clearly emerges in this study concerns the relationship between technological development and the creation of architectural products. As we have seen, both activities are consequences of the functioning of the social environment. Clearly, it would be a mistake to describe their relationship simply in terms of one having "effects" on the other. But many previous authors have persisted in their efforts to show the effects of new technology on nineteenth century architecture. It is not the intention of this thesis to challenge or refute the conclusions of these authors, but rather to provide a more direct and balanced view of this relationship. Consequently, it will ask what effects did the architectural profession and the building industry have on the development of new technology? By adopting the approach outlined above, this thesis hopes to show that during the nineteenth century innovations in technology were situated in and had a continuous reciprocal relationship with the process of architectural production.

NOTES

1. Peter Mathias has critically (and perhaps unfairly) described the work of industrial archaeologists as "the Industrial Revolution in aspic" (Mathias 1983, p. 16).

2. Recent scholarly studies have taken a more socially interpretive approach. See, for example, Weiler (1987).

3. See also Bowley's The British Building Industry: Four Studies in Response and Resistance to Change (1966).

4. See also Layton (1977, p. 209): "The divisions between science and technology are not between the abstract functions of knowing and doing. Rather they are social", and van den Belt and Rip (1987, p. 139): "The relationship of science and technology is not represented as a hierarchical one, with science having 'implications' for technology and technology 'applying' the findings of science; rather, the relationship is a symmetrical one, with both forms of activity possessing their own distinct cultural resources although both may also, occasionally or more regularly, draw on the cultural resources of the other."

5. See Layton (1977, p. 198) for definitions of these terms.

6. For a summary of some of these works see Rosenberg (1982, p. 8-14).

CHAPTER TWO

THE BRICKMAKING INDUSTRY AND MECHANIZATION

2.1.
The Traditional Brickmaking Industry

Bricks were used first in Britain by the Romans, but brickmaking, as practised on the Continent, was reintroduced into East Anglia only in the late thirteenth century and spread slowly to other parts of the country (Wight 1972). By the middle of the eighteenth century bricks had become a fashionable and prevalent building material and most English towns or parishes had at least one brick kiln to supply its needs. Although brickmaking was traditionally a relatively small industry, it formed an important part of the local economy in many areas. The structure of the industry and the methods used in it were gradually developed over a long period of time in response to the variety of physical, social and economic conditions encountered in different regions of the country.

Clay suitable for brickmaking was abundant and generally accessible in surface deposits in most locations (National Brick Advisory Council 1950). Little capital or plant was required to begin brickmaking operations when hand methods were used. As local building projects created a sufficient demand for bricks, new works often were opened to supplement the supplies available from permanent kilns. Brickmasters frequently were employed in other trades, such as farming or building, and entered the industry as a part-time occupation or for a short-term investment. Some even rented the land they worked. Once the brick earth was extracted to a certain level or building activity slumped, many operations closed down and the land was returned to cultivation (Dobson Part 1 1850, p. 87).

A predominant feature of the traditional industry was its inherent seasonality. For the most part, the entire process of brickmaking was carried on in the open air and was subject to the uncertainties of the weather. The clay usually was dug in the autumn or winter and left in heaps to break down the lumps and make it more easily worked. Tempering and moulding only commenced in March or April after the danger of winter frosts had passed. From then until the following autumn brickmakers worked extremely long hours, sometimes as much as thirteen hours a day, to maximize production during the spring and summer months (British Parliamentary Commission, hereafter BPP, Childrens' Employment Commission 1866, p. 103).

Even during the brickmaking season, work frequently was obstructed by inclement weather. The newly moulded "green bricks" especially were vulnerable to damage. Before burning these usually were stacked in open-air hacks to dry for up to six weeks, protected from the weather by a covering of straw matting, tarpaulins and, later, wooden boards with louvres (Cox 1989, p. 9). Damage to hacked bricks because of severe rainfall or unexpected frost was not uncommon. Attempts to hurry the process and burn the bricks before they had dried sufficiently jeopardized the soundness of the finished products. In southern works the bricks were burned in clamps also open to the weather rather than in kilns, thus potentially exposing the outer layers of bricks to additional damage (Architectural Publication Society Vol. 1, p. 139; Dobson Part 2 1850, p. 26). Sometimes a few flimsy and temporary buildings were erected in the brickfields, such as rough thatched moulders' huts or lightweight drying sheds open at the sides (Samuel 1977, p. 31-32). In Nottingham and the Midland counties drying sheds occasionally were warmed by flues running under the floors to provide protection against frost (Rivington 1879, p. 93). In most of the country, however, the temporary and seasonal character of the work meant that brickfield owners had little incentive to invest in buildings or expensive equipment. Natural environmental factors were accommodated as far as possible and brickmakers accepted a certain number of ruined bricks as an inevitable outcome of their business.

The difficulties and expense involved in transporting bricks generally limited supplies to what could be produced locally. Canal and river navigation was available in some areas for the conveyance of bricks. For example, the opening of the Grand Junction Canal and its branches enabled the transport of bricks from new brickfields in adjacent districts to the vicinity of London after 1794 (Cox 1989, p. 11). But toll charges often were high and it appears that in many places they were not used extensively.[1] Although the railways provided an ever increasing network between various parts of the country by the mid-nineteenth century, rail transport costs for the carriage of bricks also were prohibitive. Dobson calculated the weight of bricks to be three and a half tons per thousand and reported that railway charges in 1850 were "2d. per ton per mile if under forty miles and 1 ¾ d. per mile if more than 40 miles", an expense that "more than doubled the value of a common brick compared with the price at the yard" (Dobson Part 1 1850, p. 114). Alan Cox also stated that in Bedfordshire the carriage of bricks only five miles from the kiln added 14s. onto a price of 34s. per thousand bricks, an increase of over forty percent (Cox 1979, p. 31). Consequently, it was necessary to locate brickworks as close as possible to the source of demand rather than bring the finished products from any great distance.

The structure of the traditional brickmaking industry developed in response to these factors. It was made up of a large number of relatively small works dispersed throughout the country with concentrations around urban areas. Studies of regional brickmaking industries show that small enterprises rather than large-scale works were predominant until the end of the nineteenth century. Expansion of the industry when necessary was accomplished by an increase in the number of small works rather than a fundamental change in the size of individual firms (Bowley 1960, p. 59-60; Samuel 1977, p. 25). For example, one study of brickmaking in the South-East Midlands reported that in 1831 an average of 5.9 brickmakers were employed by 103 brickworks. By 1851 the average number of employees had risen to only 7.8 but the number of works had more than doubled (Collier 1966, p. 69). Other studies have shown a similarly small number of brickfield workers per field in other regions. An examination of trade directories in Oxfordshire for 1861 indicated that the 69 brickfields operating in that county employed fewer than five labourers each (Bond, Gosling and Rhodes 1980, p. 17). And a comparison of the census data for 1871 and Ordnance Survey maps of Bedfordshire from the same period revealed that 332 brickfield workers were employed by 65 works, or an average of just over five workers per field (Cox 1979, p. 34-35).

The system adopted for the organization of work in the traditional brickmaking industry was particularly suited to small-scale, temporary enterprises with low capital investment. In most areas the brickfield owner hired a brickmaster at a price per thousand bricks to superintend the site and take full responsibility for the output of the operations. He in turn contracted with moulders to temper, mould and hack the bricks. Each moulder then hired his own "gang" of subsidiary labourers and acted as their employer. In some parts of the country only men and youths were hired for these jobs, but in other places the moulder hired family members, including women and children, to increase his own profits. This was prevalent particularly in areas where adult male workers were required for larger industries such as mining or iron works (BPP Factory and Workshops Act 1876, p. 690; Dobson Part 1 1850, p. 90; BPP Childrens' Employment Commission 1966, p. 142). The contract system was advantageous for several reasons. It encouraged entry into the industry and allowed for absentee ownership of the works by reducing overhead expenditures and the need for direct supervision of the workforce. Also, it was not necessary for the proprietor to have brickmaking knowledge or skills, and his own financial risks were minimized because they were shared with his subcontractors. Finally, it allowed the brickmaster to take on only the number of gangs actually needed to realistically meet the current requirements of the local markets (Littler 1982, p. 126-7; Pollard 1965, p. 38; Samuel 1977, p. 33).

The most important characteristic of the established system was its flexibility which enabled the industry to adapt to a wide range of physical and climatic conditions and to respond to regional differences or periodic changes in the consumption of bricks. In many parts of the country the traditional brickmaking system continued virtually unchanged throughout the nineteenth century and even into the early twentieth century. This raises an important question about the appearance of mechanical brickmaking devices in the late eighteenth and early nineteenth centuries. What stimulated the search for alternative methods of production? This question usually is answered by referring to the enormous increase in the demand for bricks during these decades.

2.2.
The Introduction of Brickmaking Innovations: Problems and Incentives

The population of England and Wales more than doubled between 1801 and 1851. More importantly, large numbers of workers migrated from predominantly agricultural areas to rapidly growing urban centres in search of better employment opportunities.[2] Concentrations of population in these centres created an unprecedented need for new dwellings, and early nineteenth century census records show substantial increases in the housing stock of many cities (Powell 1980, p.10). The demand for new housing was often tied to the prosperity of regional industries and a rise in industrial investment. For instance, booms in the textile industries of Lancashire and Yorkshire during the first half of the century stimulated the building of large numbers of mills and factories in the early 1820's, the mid-1830's, and again after 1850. These periods of building activity were followed by peaks in residential construction as newly recruited factory workers required housing (Lewis 1965, p.79, 89 and 221).[3] In areas of the country with insufficient supplies of building stone, brick was used increasingly to supply these urban building booms.

Government excise revenue accounts detailing the number of bricks charged with duty each year from 1784 until the tax was abolished in 1850 have been analysed in several studies to measure both levels of building activity throughout the country and trade activity within the brickmaking industry (Shannon 1934, p.300-318; Cairncross and Weber 1956, p.283-297). These statistics show not only periodic fluctuations and regional variations in brick production, but also a steady increase in the consumption of bricks in the first half of the century. For example, the number of taxed bricks in England and Wales rose from over 608 million in 1800 to more than 1462 million in 1849 (Shannon 1934, p.316-17). Similarly, bricks charged with duty in Scotland showed an increase from nearly sixteen million to over forty-one million during the same period (Cairncross and Weber 1956, p.296-7). According to Shannon, these figures represent a rate of increase one-third greater than the rate of population growth. The dominant upward trend in the demand for bricks before mid-century placed constant if cyclical pressure on the industry to increase production.

Changes in demand resulting from population growth are frequently linked with the emergence of new technology designed to expand an industry's productive capacity. However, many authors agree that demand factors alone are not sufficient to explain why innovations appeared at particular times, why they took quite specific forms and why certain production processes became the focus of intense inventive activity (Von Tunzelmann 1981, p.143-163; Rosenberg 1969, p.1-24; Bruland 1982, p.91-121). To answer these questions it is necessary to isolate and examine the special problems developing within the industry as a result of changing demand that technical innovations were expected to solve. The precise nature of these problems directed inventors towards specific solutions and decisively shaped the emerging new technology.

Increases in the demand for bricks in the early nineteenth century merely exposed and focused attention on several shortcomings within the traditional brickmaking system that imposed restraints on the ability of brickmakers in particular locations to increase productivity. Supplies in most areas were always uncertain due to the possibility of work stoppages or damage to the bricks caused by unfavourable weather conditions. The seasonal nature of the work and high transport costs placed unavoidable limits on the overall quantity of bricks available in a given area. This often led to shortages and consequent price rises and fluctuations which both consumers and brick manufacturers had learned to expect and apparently accepted. But the vastly increased requirements of burgeoning urban centres intensified these difficulties and created other equally vexing problems. Good quality surface clays were gradually depleted around the largest cities. Manufacturers were forced to establish works at greater distances from urban building sites or to use inferior clay deposits which required more time and greater care in their preparation (The Builder 1875, p. 717; Cox 1989, p. 11). One author reported that by mid-century builders in London had to purchase bricks from works as much as one hundred miles away (Chamberlain 1856, p. 491). Both of these expedients raised the brickmakers' costs and ultimately the price of bricks in areas where they were most in demand.

These problems were compounded and further restrictions were inflicted upon manufacturers when excise duties were levied on bricks and tiles. The tax was originally imposed by William Pitt in 1784, along with a similar duty on seabourne shipments of stone and slate, in order to repay debts incurred by the American War for Independence. But whereas taxes on stone and slate were eventually repealed (in 1823 and 1831 respectively), the brick duties were continually amended and increased. From the original tax of 2s. 6d. per thousand, the amount had doubled by 1802 with 5s. 10d. charged per thousand on ordinary bricks and 12s. 10d. for polished bricks (24 Geo. III. c. 24. and 45 Geo. III. c. 30.). In 1839 the Commission on Excise Inquiry repealed the previous acts and replaced them with new duties containing exact specifications relating to their collection and payment (2 & 3 Vic. c. 24.). The new acts placed a duty of 5s. 10d. on all bricks not exceeding 150 cubic inches and 10s. on bricks over that size. Each brick manufacturer was required by law to register with the excise officer in his district who then was allowed to enter the brickfield at any time to inspect and count the bricks while they were drying. In addition, the act stated that "all bricks whilst drying shall be placed in such a manner that the officer may readily and securely take an account of them; penalty for placing the bricks irregularly, £50." (2 & 3 Vic.c.24. Clause viii). All bricks found to be burned before being charged with duty also were subject to a fine of £50. While computing the duty to be paid, ten per cent was automatically allowed for bricks that were subsequently damaged.

An immediate effect of the duties was a substantial increase in the price of bricks. The regulations that were intended to facilitate the administration of the act also placed particular hardships on the manufacturers. The precise requirements for arranging the bricks while drying may have assisted the excise officers in their calculations, but they also had the effect in many cases of hindering production. During the campaign to repeal the duties in the 1840's, one author commented: "Even when the officers visit the works once a day, the inconveniences and loss to the operative at work are ever recurring. They are bound to lay their moulded clay down on certain spaces, and on those only, from which they must not remove the pieces until account had been taken of them for duty. Nor must they lay more on those given spaces than the officer allows; if full, they must stop work" (The Builder 1849, p.449). There were attempts to evade these restrictions despite the risk of penalty. One brickmaker described how sometimes false floors to conceal bricks were made in the drying sheds, but they were discovered frequently by a surprise visit by the excise official who then ordered the brickfield owner to forfeit the fine (Wescombe 1893, p.3).

The imposition of the excise duties may suggest a reason for the sudden appearance of brickmaking innovations at the end of the eighteenth century. The growth in the demand for bricks was a gradual and cyclical process that occurred over many decades and slowly exposed inherent weaknesses in the operation of the traditional brickmaking system that prevented expansion and regulation of the industry's output in many locations. But the imposition of the tax in 1784, as a sudden externally applied constraint, may have forced at least some brickmakers to begin the search for cost reducing technological solutions to many of their problems.

Innovations were introduced subsequently in several manufacturing processes before the mid-nineteenth century in an effort to expand productivity and lower operating costs. For example, various devices were adopted to facilitate the preparation of inferior or difficult clays in places where easily accessible deposits of purer clays were disappearing. It is likely that reserves of good quality plastic clays and natural marls (that is, earth containing naturally occurring amounts of lime) were exhausted in the vicinity of London by the mid-eighteenth century. In order to make the remaining available clay suitable for brickmaking, it was necessary to mix it with other substances to prevent shrinking or cracking of the bricks while they were burned (Dobson Part 1 1850, p. 17; Rivington 1879, p. 88-91). Pug mills were invented on the Continent as early as the seventeenth century (Hammond 1981, p. 5) and it is probable that by the mid-eighteenth century they were used in the London brickfields to temper clay mixtures consisting of brick earth, ground chalk slurry and sifted domestic refuse.[4] The mill was a wooden tub with horizontal knives or blades attached to a revolving central shaft and activated by a horse harnessed to an attached beam. The knives cut and kneaded the materials as it was thrown in at the top and forced it out at the bottom as an homogenous paste (Figure 2.1.).

Pug mills were faster and more efficient than older methods of tempering which required labourers to tread over the wet clay with their feet and turn it with picks and shovels. In other locations, stony clays containing quantities of pebbles or pieces of ironstone, as in clays from the coal measures, had to be soaked in wash-mills to free them from unwanted lumps before they were usable for brickmaking. Similarly, the hard marly clays found in the Midland districts required grinding mills with sets of cast iron rollers to crush the chunks of chalk or limestone they contained and bring them to a workable state of plasticity.

Efficient crushing devices, called Cornish rolls, were available after 1804 for this purpose (Noble 1853, p. 746). Edward Dobson warned in 1850: "If a small piece of limestone, no bigger than a pea, is allowed to remain in the clay, it will destroy any brick into which it finds its way" (Dobson Part 1 1850, p. 22; Rivington 1879, p. 89).

Several improvements in kilns and drying sheds also were introduced which attempted to speed up these stages of the operation or reduce the costs involved. One inventor suggested a system for drying bricks using waste heat from the kiln, while another brickmaker reduced the drying time to twenty-four hours by passing green bricks through a steam-heated tunnel on rolling trays (Noble 1953, p. 761; The Builder 1852, p. 385 and 800). Bricks traditionally were fired in a variety of kilns ranging from the open clamps or clamp kilns in southern brickfields to the widely used Scotch kilns and the regional Suffolk kilns or Newcastle kilns (Hammond 1977, p. 171-192). All of these were intermittent kilns working on the updraught principle. The bricks were arranged with a series of connecting spaces or flues that allowed the heat to circulate upwards from fires lit at the bottom. Clamps took from two to six weeks to burn thoroughly, while a fully loaded Scotch kiln could be fired only once every three weeks (Rivington 1879, p. 96 and 99). To avoid these lengthy delays, there appeared in the early 1840's multi-chambered kilns that rotated the heat from one chamber to the next so that bricks were burned continuously (British Patent No. 11, 155, 1847, Thomas Ainslie; The Builder 1846, p. 585). Although they were a major improvement over earlier methods of firing and provided a means for significantly increasingly the production of bricks, kilns of this type were large, complex and required a much greater financial investment than the owners of many small-scale works were willing or able to make. Consequently, continuous kilns were not widely adopted until after 1862 when the famous Hoffman kiln was imported from Austria to this country (Hammond 1981, p. 24).

The most prevalent innovations in brickmaking, according to the patent statistics, were mechanical devices for moulding the clay. One author reported that a total of 131 patents for clayworking improvements were granted in Britain by 1850 (Hobhouse 1971, p. 308). Of these, approximately eighty-three were machines for actually shaping the bricks or tiles as opposed to methods for mixing, grinding, drying or burning (Woodcroft 1854, p. 101-103; Appendix A). Why was inventive effort concentrated on this particular aspect of brick manufacture rather than on other processes? The large number of patents for brickmaking machines suggests that the task of moulding the bricks was considered by many to be the most important step in the entire operation as well as the most problematic in terms of expanding and regulating production.

The "Brick and Tile Making Machine" patented in 1741 by William Bailey of Taunton was the first recorded invention in Britain for mechanically forming bricks (British Patent No. 575, 1741). Like other early machines, this was a moulding apparatus that essentially imitated the procedures of hand moulding but at a greater speed. Bailey's invention consisted of three parts -- a separate mill for tempering the clay in advance of moulding; a brass or iron mould containing five or six bricks that was filled with clay, levelled by a large roller, and afterwards compressed by a stamper or plunger; and a screen to sprinkle soft sand over the empty mould and the roller to prepare them for the repeat motion of the machine. Each part of Bailey's machine was analogous to a step in the hand moulding process. In traditional hand brickmaking, the thoroughly tempered clay was carried in lumps from the pugmill to the moulders' tables where it was shaped into bricks by one of two methods depending on the characteristics of the local clay and on regional traditions. In "pallet-moulding" (or "sand-stock moulding"), sand was sprinkled first into a wooden- or brass-lined mould box, often divided into several sections, before the clay was thrown in with considerable force and pressed into the corners. The excess was scraped off the top with a "strike" and the finished bricks were turned out onto a pallet board and wheeled away to the drying sheds while the mould was sanded again and made ready for use. In the less common "slop moulding", the mould box was dipped in water before it received the clay. After striking, the entire mould containing the bricks was carried to the drying floor while a new mould was dipped in water and the process was repeated (Dobson Part 1, p. 27-30; Lloyd 1925, p. 29-38).

Moulders traditionally were considered the most skilled workers in the brickfield. Humphrey Chamberlain stated that this was based on "the knack with which he throws or drops the soft clay into the mould, so as to fill up every corner" (Chamberlain 1856, p. 490).[5] Hand moulding undoubtedly required accuracy, speed and a great deal of strength to keep up the necessary movements for a ten to thirteen hour day. However, the abilities of the other brickmaking labourers were equally crucial to the success of the operations. The temperer, who supervised the preparation of the clay, needed both knowledge and judgement to bring the paste to the optimum consistency. In southern fields the job of the soiler, who regulated the addition of ashes to the clay mixture, was thought by some to be the most important position. According to one source, "half an inch more or less to the foot of earth will either fuse the bricks and run them together into huge lumps called 'burrs', or will cause them not to be burnt enough to acquire the vitrification on the surface..." (Architectural Publication Society Vol. 1, p. 138). Even the supposedly unskilled "walk-flatter" (also known as wall-flatter or wheeler) played an important part in the moulding operations. This was the person who brought the clay in brick-sized lumps from the pug mill to the moulding table. One brickfield proprietor reported that this seemingly simple task "required great practise and nicety to give such a wedge-like form to each lump of clay as that the moulder can with one throw force it equally into all parts of the mould" (BPP Childrens' Employment Commission 1866, p. 103). Another brickmaster commented on the importance of burning: "There is more skill wanted in burning bricks than in any other part belonging to it" (BPP Manchester Outrages Inquiry 1867-68, p. 238). The hand brickmaking process, therefore, relied technically on an interdependence of skills rather than on the inherent superiority of the moulder's abilities.

The importance of the moulder in the brickmaking operations was founded principally upon his socially central position as "gang" leader. The subcontract system established a set of relationships based on work control and craft consciousness that were firmly entrenched within the industry. The moulders were engaged by the master brickmakers for a price per thousand bricks and then they chose the other members of their work groups. Thus they controlled access to all other jobs in the gang and the opportunity for others to acquire brickmaking skills. With this power they maintained the exclusiveness of their own positions and the strict heirarchy of the jobs beneath them. This is reflected in the distribution of wages paid to the gang members.[6] For example, in 1866 a total payment of 4s.4d. to the gang leader was distributed as follows: 7d. together to the pug boy, the pusher out and the barrow loader (usually children), 4d. to the walk flatter, 1s. each to the temperer and off-bearer (who removed the moulded bricks from the moulding table), and 1s.5d. to the moulder (BPP Childrens' Employment Commission 1866, p.138 and 140).[7] The moulders also controlled the pace of the work and the number of hours worked each day by the entire gang. One brickmaster stated: "The hours for day workers are from 6am to 6pm, but the moulder is paid by the thousand...so they please themselves. I have often known them to work from 4am to 9pm at the height of summer, so long indeed as the moulder can see to put a brick into the mould" (BPP Childrens' Employment Commission 1866, p.137; BPP Factory and Workshops Act 1876, p.366).

Despite its many advantages to the industry, the major drawback of the subcontract system was that the rate and quantity of output was totally in the hands of a highly independent workforce. By the nineteenth century, brickmaking labourers had acquired a reputation for being a particularly undisciplined, undependable and unruly group of workers. Mr. W.H. Lord, reporting to a Parliamentary Commission in 1866, stated: "In truth it is to the irregular and intemperate habits of the labourers, skilled and unskilled, that all the mischief of the brickfields is owing...Very often the whole gang is at a standstill because one of the men, the temperer, the off-bearer, or the moulder chooses to stay away" (BPP

Childrens' Employment Commission 1866, p. 130; Ward 1885-85, p. 34). Other evidence described how undisciplined work habits often caused extreme fluctuations in output: "Some moulders make 50,000 a week and more;...that is no doubt exceptional, but 40,000 a week is not at all out of the way. Sometimes you see they fall to 18,000, 10,000, and 8,000; when so small a weekly number is general you may attribute it to bad weather, but it is far more frequently caused by their being off 'on the drink' or for some amusement" (BPP Childrens' Employment Commission 1866, p. 136). Such practices seriously restricted attempts by brickfield owners to expand or regulate production in their fields. This was most obvious in enterprises that had introduced innovations to intensify other processes such as grinding, tempering or drying. As mechanical grinding and pugging devices produced regular quantities of tempered clay ready for moulding and artificial drying techniques rapidly prepared the raw bricks for burning, potential imbalances between these operations and the moulding process were created by the unpredictable output of the moulders and their gangs.

Attempts by brickmasters to interfere with the accustomed work practices in order to alter aspects of the production process frequently met with resistance. Permanent trade associations among brickmakers were uncommon in the first half of the nineteenth century because of the seasonal nature of the occupation. But there were isolated informal trade clubs in some parts of the country to which only the skilled moulders were admitted. R. W. Postgate, for example, cited an "uncertain number" in the outskirts of London and a dozen around Manchester (Postgate 1923, p. 246). These developed into active but loosely organized craft unions, in Liverpool as early as 1840 and in Manchester and Oldham after 1846, whose principle aim was to ensure that brickmakers maintained traditional control over the organization and conditions of their work. These issues were the cause of increasing local combinations by brickmakers during the 1840's and 50's as market pressures compelled many brickmasters to initiate cost-cutting changes or attempt to gain greater control over rates of output. For example, Richard Price described the riots by Liverpool brickmakers in 1840 when brickmasters in the area tried to introduce larger-sized moulds in the fields. The union not only demanded the right to determine the dimensions of the moulds, but also insisted that all moulds "must be branded with their lodgemark" (Price 1975, p. 114). A similar attempt by masters near Altrincham to increase the size of the moulds while continuing to pay the same wages also led to a turnout of the men and the intimidation of one of the "offenders" by a contingent of local brickmakers (The Builder 1851, p. 281).

Another incident of labour unrest occurred in 1843 when the Manchester Brickmakers' Operative Association was involved in attacks on the yard of local brickmasters, Messrs. Pauling and Henfrey, although the exact cause of this disagreement is uncertain. At least one report of this event noted the relationship so often described during the nineteenth century between industrial conflict and the introduction of new technology. The Builder, in reviewing an early brickmaking machine, commented on "a strange outbreak and conflict in Manchester among the brickmakers" and went on to say, "many will look upon the ingenious inventions which we now give a description and illustration of as a fitting visitation, they will argue from the labourers' outbreak to the brickmaking machine, as from cause to effect, and assign for the stimulus of invention the imposed necessity arising out of this rebellious conduct of the brickmakers" (The Builder 1843, p. 195 and 200).

The disruptive effects of industrial struggles provided a major inducement for the invention of many labour-saving mechanical devices during the nineteenth century.[8] The most famous example, described at length by authors such as Andrew Ure, Karl Marx and Samuel Smiles, was Richard Roberts' self-acting mule invented in 1825 as a consequence of strikes by skilled cotton spinners in Manchester (Bruland 1982, p. 97-104). Other accounts attribute the invention of Roberts' jacquard punching machine to a combination of workers constructing the Conway Tubular Bridge in 1848, and the patenting of William Fairbairn's riveting machine in 1837 to a strike by the boiler makers at his Manchester works (Smiles 1863, p.271; Fairbairn 1878, p.73). In writing his autobiography, Fairbairn stated: "The introduction of new machinery and the self-acting principle owed much of their efficacy and ingenuity to the system of strikes, which compelled the employers of labour to fall back upon their own resources and to execute, by machinery and new inventions, work which was formerly done by hand" (Fairbairn 1878, p.419-20).

Unfortunately, accounts of the events leading to the invention of specific brickmaking machines have not been recorded or have not survived. However, it is known that the intention of many early machine inventors was to gain independence from the skilled brickmaking labourers. In his patent of 1741, William Bailey claimed, "the whole work may be completed without touching the clay with the hands or feet of the labourers, and *any person* may be fully instructed in half an hour to work the engine..." (British Patent No. 575, 1741; my emphasis). It is significant that Bailey's machine, the first patented in this country, was designed to supercede all of the jobs traditionally done by the moulder and his gang. Whether impelled by the frequent lack of discipline or an increase in labour conflicts, the expectation of expanded production with a reduced reliance on skilled labour was one reason often cited by inventors and promoters to encourage the adoption of brickmaking machines. While recommending his newly patented machine, James Hunt told a group of civil engineers that in operating the device "all the persons employed were common labourers; professed brickmakers were thus not required" (Proceedings of the Institution of Civil Engineers 1843, p.150). Another entrepreneur, Humphrey Chamberlain, also suggested: "In brickmaking by machinery, we should employ as little labour as possible, but should give the machine the raw materials and take away the manufactured articles without any intermediate labour" (Chamberlain 1856, p.495).[9]

This chapter has considered some of the production problems experienced by the brickmaking industry as a result of rising demand that stimulated the invention of mechanical brickmaking devices in the late eighteenth and early nineteenth centuries.

Once inventive activity was initiated, there were other factors outside the industry itself that were influential in determining the form and ultimate success of these machines. One important factor was the response of brick consumers towards the new technology. The following chapter will examine the concerns and attitudes of the architectural profession with regards to clay products and the impact these attitudes had on the development of brickmaking machinery during these decades.

NOTES

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1. One study revealed that tolls on the River Nene at mid-century ranged from 1s.5d. per ton per mile for a journey of ten miles to 75d. per ton per mile for twelve miles (Collier 1966, p.78 and 93).

2. For example, Manchester increased in population by 40.4 per cent between 1811 and 1821 and by another 47.2 per cent in the following decade. Liverpool similarly grew by 43.6 per cent and Leeds by 47.2 percent during the same period (Ashworth 1960 p.9).

3. Lewis' building cycle theory explains how changes in population, credit factors and "stochastic events", such as wars or droughts, together created fluctuations in the rate of building activity.

4. Ashes or cinders were mixed with brick earth in London fields as early as the 1730's. In burning the bricks, the ashes increased the temperature so that a molecular change or vitrification occurred causing the finished products to be solid and impervious to the weather. The custom of adding chalk slurry to make an artificial malm was a later development and was said to be the patented invention of a brickmaker near London (Architectural Publication Society Vol. 1, p.138; Lloyd 1925, p.37).

5. See also Searle (1911, p.54) for the skill required in hand brickmaking.

6. The price per thousand bricks paid to the moulders fluctuated only slightly during most of the nineteenth century. Noble (1836) reported the following amounts in London: 4s.6d. in 1823; 3s.9d. in 1835; and 4s. in 1836. According to Dobson, in 1850 the rate remained at 4s. in London while in Nottingham it rose to 4s.4d. and in Staffordshire to 4s.6d. (Dobson Part 1 1850, p.91; Part 2, p.44 and 92). The London fields experienced a similar rise to 4s.4d. in 1854 (The Builder 1854, p.502). The range of payments in Kent brickfields considerably broadened in 1865 from 4s.4d. up to 6s.6d. in one location (BPP Childrens' Employment Commission

1866, p. 138 and 140).

7. Richard Price reported that by 1873 the Manchester brickmakers' unions had driven up wages sufficiently for the moulders and temperers to demand 2s. 4d. each per thousand bricks and the wheelers (or walk flatters) 2s. 3d. each (Price 1975, p. 110-132).

8. For a general discussion of this theme and a review of nineteenth century literature on the topic see Rosenberg (1969, p. 12-17). For recent studies that substantiate these claims see Bruland (1982) and Lazonick (1979).

9. See also The Builder (1847, p. 451) for similar claims made in behalf of a machine by William Hodson.

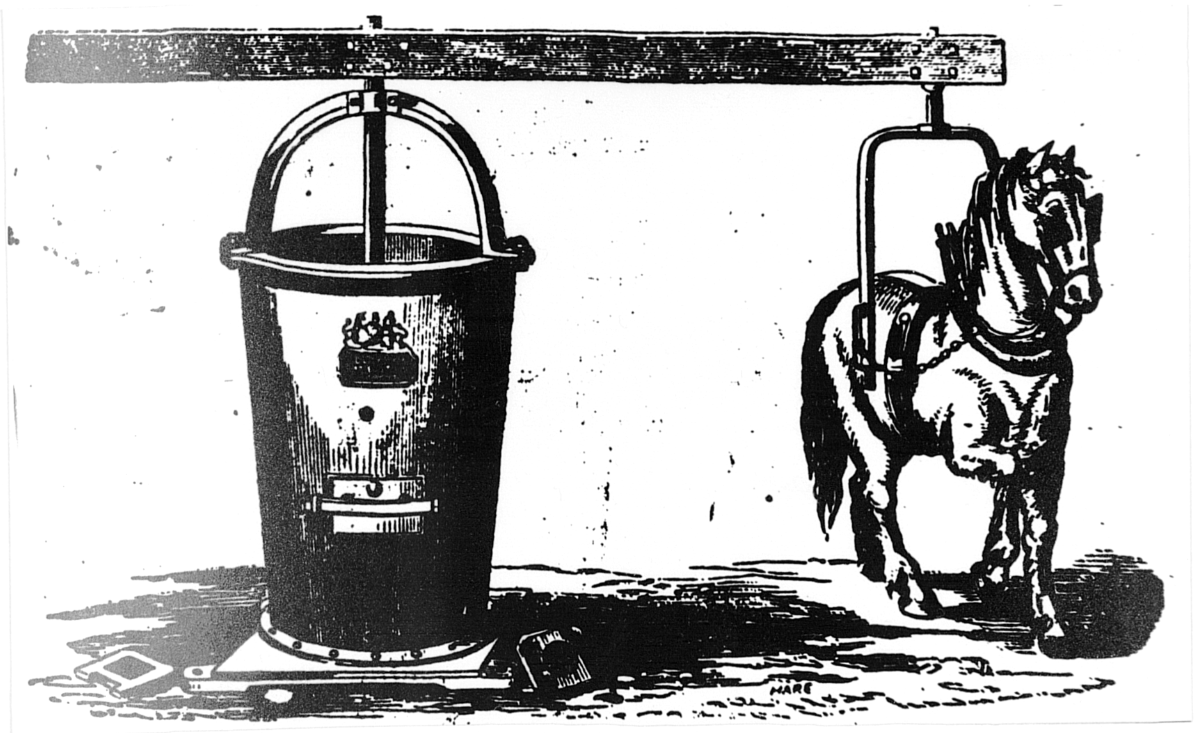

Figure 2.1. Horse-driven pug mill.
[From Emile Bourry, A Treatise on Ceramic Industries (1901) p. 279]

CHAPTER THREE

THE ARCHITECTURAL PROFESSION: CHANGING ATTITUDES TOWARDS BRICK

3.1. Architects and the Quality of Brick

Architects, as consumers of bricks, played an important role in stimulating the development of brickmaking machinery by their almost universal condemnation of inferior bricks and brickwork, especially those found in the vicinity of London. Beginning in the 1830's and throughout the century there were repeated comments in the architectural press condemning the decline in the quality of bricks and the lowering of bricklayers' skills. "The brickwork to be found in the neighbourhood of London, east, west, north and south, is truly disgraceful: unworkmanlike, unsubstantial, deceptive, dangerous", was a typical judgement (The Builder 1847, p.597). In support of this opinion there were frequent descriptions of walls being "blown-up" with three-quarter inch mortar joints, unfilled cavities in each course from improper bonding, "small pieces being inserted where whole bricks should have been used", insufficient cementing, and the lack of adequate tying of the inner and outer layers of brickwork leaving some walls out of perpendicular (The Builder 1844, p.67). Furthermore, it was said that "irregular masses of brick run together in the kiln, known as 'burrs', are often used for cheapness sake, especially in the lower parts of buildings, and having no solid bed, materially lessen the strength of the walls" (The Builder 1847, p.597).

This general lowering of bricklaying skills from a very high level of craftsmanship during the previous century did not occur suddenly.[1] Various reasons were suggested for the gradual decline. One was the development of competitive tendering and speculative building (The Architectural Magazine 1838, p.414; The Builder 1845, p.193; 1847, p.597). These were the result of fundamental changes in organization that gradually were introduced into the building industry during the second half of the eighteenth century. Previously, building projects were under the direct control and supervision of a landowner or his appointed architect or surveyor. Contracts were made with master craftsmen for different aspects of the construction and payment was made on the basis of "measure and value", that is, by measuring the amount of labour and materials consumed in the building and assigning each a fixed value plus a mark-up (Thompson 1968, Chapter 4). By the end of the eighteenth century a new system developed alongside the traditional organization whereby a contract for a pre-agreed lump sum was arranged with an intermediate person responsible for the entire building project. This was sometimes a master craftsman or builder who contracted with a developer or landowner to construct a number of houses for the speculative market and in turn arranged subcontracts with other masters in the various trades. Or it may have been a master builder who competed for a "contract in gross" to erect a large public building and maintained his own staff of workers from all trades (Cooney 1955, p. 167-76; Hobhouse 1971, p. 7-15; Powell 1980, p. 29-31).[2]

The emergence of new methods of contracting profoundly affected the traditional position of skilled craftmen in the building process and ultimately the level of craftsmanship. Large-scale master builders like Thomas Cubitt set up their own workshops and hired a predominantly permanent labour force under the supervision of a foreman for each of the trades. This undermined the advancement incentives and craft pride inherent in the traditional apprenticeship system and trade organization. Smaller firms, headed by a master craftsman or builder, often worked to strict contract deadlines and operated within extremely small profit margins. These firms had every incentive to reduce their costs by hiring less-skilled workmen and using inferior building materials. A leading article in The Builder in 1847 admitted: "The men themselves are scarcely to blame: they have not had fair play. There are few apparent inducements for good work or superior skill; rapidity or bad work are what their masters have desired, and the result is that men capable of executing good work are with difficulty to be found" (The Builder 1847, p. 597).

Another frequently cited cause of shoddy brickwork was the deplorable condition of the bricks themselves. Joseph Lockwood, a contributor to The Builder, commented: "The great falling-off of the quality of modern bricks is a very probable cause of the decadence of the art of bricklaying, which has sunk from a high degree of perfection to its present miserable condition." Poor quality bricks frequently were attributed to the careless way they were manufactured. "One great cause of the inferiority of bricks is the unwarrantable haste in which they are made", stated Lockwood (The Builder 1845, p. 137). In attempting to speed up operations in areas of high demand, some brickmakers were tempted to cut corners in some processes that ultimately seriously affected the outcome of the bricks. For example, it was reported that in many London fields the clay was no longer left to weather over the winter months, but was merely dug from the ground, layered with breeze (domestic coal ashes), passed quickly through the pug mill and taken immediately to the moulders' tables. In other cases too much breeze was added to the clay which enabled the bricks to burn more quickly in the clamps, but also increased the risk of over-burning and distortion. Similarly, there was a temptation to add large amounts of chalk that had not been properly ground and mixed causing one observer to comment, "I have seen bricks as carelessly made with respect to the use of chalk, that on dropping one of them, it would break to pieces and exhibit the chalk in large solid lumps" (The Builder 1845, p. 136-37). Reports such as these convinced many architects that negligence in preparing the clay and moulding the bricks was responsible for the "rotten, soft, and porous things so commonly used in situations where they ought never to have been permitted" (The Builder 1845, p. 183). They also helped reinforce the prevalent belief that the major source of deficiencies in the brickmaking industry was the irresponsible behaviour of the moulders and their gangs.

Poor quality bricks, however, also were the result of natural factors such as differences in the characteristics of the clay used by manufacturers and accidents that occurred during the process of burning. From the end of the eighteenth century bricks made in the southern counties and supplied to the London market were classified under three main types. These were malm bricks, made from a mixture of clay and ground chalk in imitation of the superior marl clays which contained a large amount of natural carbonate of lime; washed bricks made of clay washed in a wash mill to remove unwanted stones and with perhaps a small amount of malm added; and common bricks made of unwashed and usually unscreened clay with nothing added to improve its quality (Dobson Part 2 1850, p. 37; Rivington 1879, p. 105).

The method of clamp burning in southern fields produced additional subdivisions in the types of bricks according to where they were placed in the clamp and how they were affected by the fire. For example, the best and most expensive bricks, called "cutters" or "malms", were made of well-mixed malm earth and evenly burned. "Seconds" and "paviours" also were good quality, hard-burnt bricks, but they were slightly uneven in colour or had small blemishes on their surfaces. "Shippers" and "stocks" were either misshapen by accidents in the fire or more blemished than the others, but they were suitable for most ordinary work. Finally, "grizzles" and "place" bricks were underburnt and soft and were suitable only for inside work or garden walls, although cost-cutting builders often used them for other purposes. Washed bricks were categorized in corresponding qualities from "bright fronts" through "washed stocks", "hard stocks" (which were used primarily for pavings and footings), and the underburnt "place" bricks. The third category included "common stock" bricks, basically sound but with an irregular surface which was not suitable for facings, "rough stocks" which were hard burnt but extremely uneven in shape and colour because of the stones left in them, and the cheapest in price, the "common place" bricks (Dobson Part 2 1850, p. 37-38; Rivington 1879, p. 105).

When kilns were used instead of clamps, the classification was not as extensive because the bricks were relatively equally burned. Here the various qualities depended more on the selection and preparation of the clay. "Front bricks", for example, were made of carefully selected, finely ground clay, "rubbers" were run through a wash mill and mixed with sand, while "common bricks" were made of clay as it came out of the ground with little preparation other than tempering with water (Dobson Part 1 1850, p.57-58). Most other variations came from the arrangement of the bricks in the kiln. Those nearest the fire became vitrified and blackened, while mottled or striped colouring was the result of the bricks resting upon each other, thus allowing some surfaces to be only partially exposed to the heat (Rivington 1879, p.111).

This was a considerably larger variety of bricks than had been available up to the end of the eighteenth century.[3] The most likely explanation for the growing choice of bricks was the restrictions imposed by the excise duties (The Builder 1850, p.97). Brickmakers generally felt that the ten per cent rebate for damaged bricks allowed by the law was insufficient compensation for the actual numbers of bricks destroyed or blemished after being counted. Consequently, they attempted to sell all the bricks they made, including those that were imperfect, in order to gain a return at least equal to the tax they had paid. This flooded the market with extremely cheap, bad quality bricks which prior to the tax may not have been sold, but because of the increase in demand were certain to find a buyer. Many architects believed that as long as there was this enormous variety in the quality of bricks available and, therefore, an equal variety in prices, then inferior brickwork was inevitable. George Godwin, who later became the prestigious editor of The Builder, contributed to The Architectural Magazine in 1838: "The terms place bricks and stock bricks are merely disguises; they are but other words for *bad* bricks and *better* bricks; and one might reasonably suppose that no person would knowingly use bad naterials to effect a trifling temporary savings when better might be obtained and, therefore, that place bricks would never be used. Unfortunately, however, the reverse is so frequently the case" (Godwin 1838, p.413).

Godwin went on to point out another important reason for the gradual decline in bricklaying skills and the persistent use of bad quality bricks. This was the fashion for rendering exterior brick surfaces with stucco or other patent cements and plasters, "which naturally induces the men to do their work carelessly, knowing it will be covered, and engenders bad habits" (Godwin 1838, p.414). According to John Summerson, it is difficult to determine precisely when rendering brickwork became a commonly accepted building practice. Frank Kelsall noted that lime and sand compositions were long established vernacular materials in the south-east of England and in Scotland. But in imitating Inigo Jones and Palladio, the English Palladians bestowed respectability upon stucco for polite architecture (Kelsall 1989, p.18). As early as 1766 John Gwynne's London and Westminster Improved recommended stucco as an appropriate remedy for the "mean appearance" of bricks used in public buildings. Except for isolated examples, however, it was not used extensively for houses in the metropolis until Nash began his Regent's Park building programme in 1812 (Summerson 1978, p.129-30).

Stucco was chosen presumably because it was a cheap imitation of the stone used in better buildings (Summerson 1978, p.130; Cruickshank and Wyld 1975, p.192). Beginning in the eighteenth century walls of a sufficient thickness were frequently built with two layers of different quality materials. Buildings faced on the outside with costly Bath or Portland stone often had a backing of ordinary bricks. Similarly, brick structures were sometimes fronted with good quality facing bricks in Flemish bond because of its neat appearance while the inside consisted of place bricks bonded in the stronger and more economical Old English (Hammond 1903, p.5-6; The Builder 1844, p.67).[4] Early nineteenth century speculative builders, looking for ways to cut costs and finding a ready supply of cheap bricks, built the entire wall of inferior materials and substituted stucco for the more expensive facing products. Rather than being merely an architectural fashion, stucco rendering became a necessary expedient to protect poor quality brick surfaces from the action of the atmosphere.

3.2.

Professional Integrity and Brickmaking Innovations

The condemnation of inferior bricks and brickwork was linked frequently to another more widespread debate within the profession concerning the important issue of the position and status of the architect in the increasingly diversified building industry.[5] For most of the eighteenth century the occupational role of the architect was performed by two groups. At the top were a handful of talented amateurs who, because of their scholarly knowledge of past or foreign architectural styles, were called upon by elite patrons to prepare plans and elevations and supervise the construction of a small number of important or costly commissions. Below these were master craftsmen whose exceptional skills and experience qualified them to design and construct the vast majority of other buildings erected. While building craftsmen traditionally drew upon architectural conventions rooted in vernacular traditions, the socially exclusive role of the top architects depended upon their ability to provide refined and historically accurate designs that reflected the taste and discrimination of their cultured patrons (Kaye 1960, p.66).

In the early nineteenth century the demand for large country houses and monumental public buildings continued to provide prestigious commissions for a small group of highly esteemed architects.[6] The enormous growth in population, however, significantly expanded the need for other types of structures such as working class housing, factories, and buildings for the service sector like schools, hospitals, town halls and theatres. The responsibility for designing and supervising the construction of many of these new buildings was taken over increasingly by master builders, developers or engineers. These were entirely new occupational groups that had emerged when competitive contracting was introduced. The designs for new buildings, even speculative housing developments, often were prepared by persons calling themselves architects. However, they may have been the products of draughtsmen employed in the offices of large building or engineering firms or the "bread and butter" work of questionably-trained "architects" also practicing as surveyors, measurers or builders (Saint 1983, p. 60, n. 21; Trowell 1982). As the demand for architectural services increased and the range of patronage broadened, the number of architectural practitioners likewise grew but with varying degrees of quality and integrity. The problem was, as Andrew Saint put it, "the profession had expanded to meet the demand for new types of building in an entirely unregulated way, while the station which architects were to occupy within the growing, fragmenting building industry was still obscure" (Saint 1983, p. 61).

Uncertainty about the architect's professional position also undermined his traditional influence in matters of taste and design. Many practitioners with dubious training and abilities responded to the demand by middle class patrons for buildings with obvious architectural pretentions by resorting to an indiscriminate borrowing of architectural forms with easily identifiable symbolic associations. Stylistic conventions that once signalled the superior status and good taste of upper class patrons were diffused to all levels of architectural production. This occurred at a time when many top architects also began to feel the constraints imposed by years of careful study and emulation of historic architectural styles. Some, like George Wightwick, believed the only creative challenge left for architects was to recombine and refine the formal elements of the past: "The present age is an age of selection and adaptation; and it must rest its greatness on the perfect character of its combinations. Unable to improve upon the splendid individualities of the past, we are left to reclassify and re-employ them within outlines of improved grace..." (Wightwick 1835, p. 344).

The often arbitrary and inappropriate application of antique architectural forms to all types and classes of buildings, however, provided the basis for harsh criticism of the profession in popular journals, particularly during the 1820's and 30's (Kindler 1974, p. 22-37). Many observers felt that architecture had sunk to a state of "servile and monotonous imitation" or self-indulgent novelty and both, according to Roger Kindler, were "the undesirable extremes of the spectrum of possible relationships to the past..." (Kindler 1974, p.24). The only alternative acceptable to the critics was "originality" that did not copy but also did not stray too far from tradition, and this was an almost impossibly narrow ideal. By the 1840's many architects found themselves both socially and artistically in an awkward predicament. They were socially uncertain because of their precarious role in the changing organization of the building industry and frustrated artistically by their inability to find a satisfactory creative solution to the dilemma of architectural style (Crook 1989, Chapter 1).

Two separate developments, one dealing with professional organization and the other with design, attempted to redefine the architect's principle area of expertise and return the profession to its former social standing. The first was the founding of professional societies like the Architectural Society in 1831 and the Institute of British Architects in 1834 whose aims, stated in an "Address of the Institute of British Architects" in July of that year, included "establishing an uniformity and respectability of practice in the profession" (Kaye 1960, p.80). To secure an authoritative position for architects in relation to both the building industry and to other professions it was necessary to develop a recognized body of architectural knowledge and to establish a strict code of ethics that were clearly distinct from the skills and commercial practices of the other building trades. From the beginning the Institute excluded all other building practitioners including surveyors and master builders. It also adopted rules of conduct that disqualified members for "measuring and valuing works on behalf of builders,...receiving any pecuniary consideration or emolument from tradesmen,...and having an interest or participation in any trade or contract connected with building" (<u>Prospectus for the formation of a society to be called the Institution of British Architects</u> 1834, in Kaye 1974, p.77).

Assisted by the architectural press, recently established to disseminate information throughout the profession, Institute architects used these exceptional standards to differentiate themselves from ordinary building tradesmen and to emphasize their superior position within the building industry. They were particularly eager to dissociate themselves from the questionable methods used by many developers and speculative builders who they believed were responsible for perpetuating the use of inferior building materials and bad building practices which often led to the collapse of structures and loss of life. A leading article in The Builder declared: "As bad bricks can be obtained for less than good bricks, so long as houses built of the former will sell as readily as if the better had been used, especially if bedizened with a little compo...builders for the market will continue in their present course." The article went on to suggest: "If in all cases an architect or other competent person were called in previously to the purchase to examine the house...those who have practiced the "cutting" system would find it necessary to mend their ways and build better" (The Builder 1851, p. 749). The condemnation of poor quality bricks and brickwork was thus often used as part of an ethical argument by architects to define and enhance their own professional standing.

Moral objectives also were behind the architects' concern about the miserable working conditions found in many brickfields which often were linked with the inferiority of the bricks produced. One author commented: "Brute labour and the brute intellect which too frequently accompanies it, is not to be coveted as an element in the social constitution of this extraordinary country. Frequently have our hearts bled to see the degrading labour to which the brickfield has subjected our species, and most revolting of all to see women put to the drudgery of horses and engines; little children too, who in a country like this should be at school, disguised past recognition in the mixed sweat and plasterings of clay and mud which encumbered their attenuated frames..." (The Builder 1843, p. 193). Revelations of abuses in the textile and mining industries reported by the Childrens' Employment Commissions during the 1830's and 40's exerted a great deal of influence on public opinion (Saville 1973). Some architects, striving for middle class and professional respectability, joined in the chorus of horror and moral outrage at the existence of such conditions. Although the brickfields were not investigated until the 1860's, most of the profession would have agreed with Richard Prosser when he wrote about the brickmaking industry in 1850: "Improvements in the quality and conveniences of this manufacture are intimately connected with the moral, intellectual and physical conditions of society" (Dobson Part 1 1850, p. 113).

Middle class social consciousness had not yet extended to the approval of state intervention but instead looked to philanthropy and economic self-interest to solve society's problems. Writing in The Architectural Magazine in 1838, George Godwin encouraged members of the profession to take responsibility for the materials they used and become more knowledgable about the manufacture of bricks by visiting the local brickyards (Godwin 1838, p. 414). Some architects did play an active role in efforts to repeal the excise duties in the 1840's and many others were strongly in favour of its removel and anticipated remarkable changes in the quality of bricks once the law was amended (The Builder 1846, p. 71; 1850, p. 97). But there is little evidence that others became directly involved with attempts to improve brickmaking methods. Most architects, not personally familiar with the problems faced by the brickmaking industry, were easily convinced by inventors and promoters of brickmaking machines that the adoption of machinery would achieve the desired results.

From the mid-1830's the newly organized architectural profession and the architectural press enthusiastically supported the development of brickmaking machines. An article in The Builder, describing a recently patented model in 1843, stated: "We really consider the discovery of this excellent principle to be of the utmost importance to the building world" (The Builder 1843, p. 195). There were some who argued that the introduction of machinery would restore dignity and integrity to the manufacture of bricks and, consequently, raise the quality of the finished products. According to one observer, "the labour of hand brickmaking was of the most servile kind...anything that would supplant that kind of labour and allow a man to turn his attention to more enobling objects was deserving of the highest consideration" (Chamberlain 1856, p.495). Machine promoters who were anxious to gain the support of the architectural profession also highlighted claims that machine-made bricks were better than hand-made bricks. The Mechanics Magazine stated that bricks made by White's machine had "more solidity than bricks formed by hand" (1841, p.370), while James Hunt reported to the Institution of Civil Engineers (whose membership at that time also included many architects) that the primary objective of his recently patented machine was "to produce stronger and better-shaped bricks of more uniform quality than those made by hand moulding" (Proceedings of the Institution of Civil Engineers 1843, p.150). In the absence of experience to prove otherwise, many architects were willing to accept these assertions and encourage the adoption of brickmaking machinery like the editor of The Builder who wrote in 1852: "We scarcely anticipate that bricks will be made more cheaply by machine than by hand, but we may have them *better* for the same cost" (The Builder 1852, p.385, my emphasis).

3.3.
Architectural Reforms and Attitudes Towards Brick

Quality and integrity in the manufacture and use of building materials was a major concern of another group of architects who attempted to restore dignity and prominance to the profession by reforming the basic principles of architectural design. Dissatisfaction with a system of design that was preoccupied primarily with applied decoration and the imitation of past architectural styles led some to suggest that architectural form should be more closely related to contemporary needs and structural expression (The Architectural Magazine 1835, p.382). A.W.N. Pugin was undoubtedly the most famous and influential proponent of this new approach.[7] Derived from his thorough study of English medieval buildings, Pugin's writings were based on the conviction that all architecture was a reflection of the moral and spiritual condition of the society to which it belonged. A devout Roman Catholic convert, he hoped not only to reform architecture, but also eventually to bring about a religious revitalization of society by introducing Gothic principles of design into current architectural practice. Moving beyond the mere superficial application of medieval decorative elements, Pugin addressed fundamental constructive issues and suggested new theories based on the concepts of honesty and propriety in design. These principles had a profound impact on attitudes towards brick construction and ultimately on improvements in the manufacture of bricks.

In True Principles of Pointed or Christian Architecture, published in 1841, Pugin wrote: "Designs should be adapted to the material in which they are executed" (Pugin 1841, p. 1). This meant that the special properties and aesthetic qualities of each building material should be revealed in the construction of a building. This theme was developed further by the Cambridge Camden Society (later the Ecclesiological Society), a Protestant reform group with a special interest in church architecture. The Society's publications protested against all forms of architectural deception or sham, including imitations of one material by another such as cement masquerading as stone or attempts to conceal poor quality materials by the use of white-wash or stucco.[8] The following edict appeared in The Ecclesiologist in 1842: "Now we never objected to Parker's or any other cement on the score of durability...We protested, and must still protest, against it on much higher grounds; namely, that the offering to God materials which profess to be better than they are, and would fain to be taken for that which they are not, involves a kind of hypocrisy from which we cannot but shrink" (The Ecclesiologist 1842, p. 209).

Equally important to the early proponents of Gothic design principles was the belief in propriety or suitability in the use of materials. Again in True Principle Pugin wrote: "The external and internal appearance of an edifice should be illustrative of, and in accordance with, the purpose for which it is destined" (Pugin 1841, p.50). Propriety in architecture was expressed by a variety of methods in accordance with traditional social or ecclesiastical hierarchies. Scale, symbolic ornament, and even the choice of materials had a meaning or level of significance within the hierarchy. For example, stone was usually considered the most beautiful and, hence, the most respected building material. The majority of architects probably agreed with George Gilbert Scott when he wrote: "In buildings of the most dignified class, I cannot help strongly holding that wrought stone is the only proper material" (Scott 1858 p,94). Brick, on the other hand, was believed to be a humble material, traditionally best suited "for the general purposes of constructing walls" (Nicholson's New Practical Builder 1823, p.105), but not acceptable for buildings of architectural importance. In a directive to church builders, published in 1841, the Cambridge Camden Society went so far as to say: "Brick...should never be used: white certainly is worse than red, and red than black, but to settle the precedency in such miserable materials is worse than useless" (Cambridge Camden Society 1841, p.9).

The strictures opposed to brick were in part a reaction against the "Commissioners' Churches", built during the decade after the Church Building Act of 1818. Many of these were constructed for the sake of economy with pale London stock bricks (Summerson 1978, p.212-232). Pugin described them in Contrasts as a "meagre, miserable display of architectural skill..." (Pugin 1836, p.49). Similarly, most Gothic revival architects detested London's flat rows of Georgian brick houses which they considered dull and monotonous. Again Scott wrote: "It is quite clear that there is little inherent beauty in brick *per se*. If we doubt this, one glance at a London street will bring conviction" (Scott 1858, p.98). Yet despite these prejudices, the full implications of the principles of honesty and propriety in construction could not be avoided for long with regards to brick.

Pugin first set the example by employing brick for building projects that were restricted by limited funding such as his church of St. Wilfreds, Hulme, and St. Chad's Cathedral, Birmingham, both designed in 1839. His own house, St. Marie's Grange, built in 1835, was also of this material as were several of his Catholic convents and other secular works (Stanton 1971, p. 160-163). Brick was chosen by two other architects approved by the Ecclesiological Society in 1847 for large churches in the colonies, R.C. Carpenter for Colombo Cathedral and William Butterfield for the Cathedral at Adelaide. The Ecclesiologist, reversing its earlier edict, cautiously concurred that "brick is by no means a proscribed material for church building" (1847, p. 146). Two years later the influential art critic, John Ruskin, added his authoritative approval to the use of brick. In The Seven Lamps of Architecture, although maintaining his preference for stone construction, Ruskin nevertheless conceded: "In flat countries, far from any quarry of stone, cast brick may be legitimately, and most successfully used..." (Ruskin 1865, p. 45). These statements mark the beginning of a decided change in attitude towards brick and its acceptance as a material worthy of serious consideration for the best architectural productions.

Gothic revival architects were faced next with the problem of how best to treat brick. As always, The Ecclesiologist offered guidance: "Brick should be treated on a large scale; the architecture should be designed in bold and broad masses" (1847, p. 146). Both Pugin and the Ecclesiological architects greatly admired the boldness and textural variety of irregular stone surfaces as opposed to the smooth, square-cut courses of ashlar. The major difficulty with brickwork was its uniformity and its multiplication of regular lines which to these architects made it seem particularly lifeless. One way to minimize this regularity was to eliminate all other straight lines on the brick surface, such as string courses and quoins, and emphasize the strength of the building's mass and contour. Ruskin also believed that magnitude and "one bounding line from base to coping", dramatic and unbroken, conferred "power and majesty" on a brick building (Ruskin 1865, p. 61-2). But many agreed with the Ecclesiologists that "large masses of unrelieved bricks are most insipid and ugly" (The Ecclesiologist 1847, p. 147).

The problem was how to vary expanses of plain brick walling without interrupting the simple massive outlines of the building. One solution was to throw the facade into planes on different levels in order to create strong contrasts of light and shade. This was accomplished with the use of broad protruding chimneys and substantial buttresses or by separating and informally clustering the masses under sharply angled roofs. Both of these expedients were part of the formula adopted by Pugin for many of his early brick buildings like the church of St. Augustine's, Kenilworth, built in 1841 (Stanton 1971, p. 162). According to Ruskin, "after size and weight, the Power of architecture may be said to depend on the quantity (whether measured in space or intenseness) of its shadows" (Ruskin 1865, p. 69). A second alternative visually interrupted the flat brick surfaces with bands or patterns of vivid contrasting colours and shallow moulded or incised decoration. This was a method also recommended by Ruskin who admired the flat geometrical patterns on the medieval palaces and churches of Northern Italy. William Butterfield's remarkable design in 1849 for All Saint's Margaret Street, London, a richly decorated red brick structure, banded and diapered with darker, vitrified brick, boldly demonstrated the possibilites of this treatment.[9]

This church also illustrated the Gothic revivalists' preference for red bricks rather than the grey- or cream-coloured bricks that were the common material used in London for ordinary buildings since the middle of the eighteenth century. Pale bricks had been popular partly for aesthetic reasons. One building manual stated in 1823: "The grey stockbricks, made in the neighbourhood of London, harmonize much better with the colour both of stone and paint, and by persons of refined judgement are much preferred" (Nicholson's New Practical Builder 1823 p. 106).[10] It is equally likely that the taste for pale bricks was acquired out of necessity as the exhaustion of nearby clay deposits resulted in the opening of new brickfields in Kent along the Medway Valley where the brick earth naturally burned to these colours (Lloyd 1925, p. 58). The renewed interest in red bricks in the early nineteenth century was part of a growing appreciation for architectural colour, or "constructional polychromy", that developed alongside the other Gothic revival principles of structural expression.

Inspiration for the use of red brick was provided by numerous antiquarian scholarly studies of various decorative architectural styles that were published during this period. These ranged from descriptions of the red brick buildings in Northern Germany and the finely moulded and carved brick details in sixteenth and seventeenth century English brick houses to illustrations of ornamental Arab architecture and the polychromatic medieval churches of the Mediterranean. In 1855 George E. Street published an account of his travels on the Continent in which he admiringly described the vivid Gothic brickwork in North Italy and illustrated the most effective ways to create contrasts of colour in brick buildings. In arguing for constructional polychromy, he said: "Our buildings are, in nine cases out of ten, cold, colourless, insipid academical studies, and our people have no conception of the necessity of obtaining rich colour, and no sufficient love for it when successfully obtained. The task and duty of architects at the present is mainly that of awakening and then satisfying this feeling; and one of the best and most ready vehicles for doing this exists, no doubt, in the rich-coloured brick so easily manufactured in this country, which, if properly used, may become so effective and admirable a material" (Street 1874, p. 400).

There were those who recognized that this bold Gothic treatment of red brick required both skillful handling and good quality materials. Scott observed that brickwork "depends for good looks... more than most materials do, on the skill with which it is used, and in the absence of such skill its colour is too strong and obtrusive to permit it to be harmless, but, on the contrary, renders it - like all other strong colours inartistically applied - offensive, while the very same cause makes its value the greater when used aright" (Scott 1858, p. 99). Street also commented that "there is no sort of work which so much requires skillful handling or which is so liable to degenerate into vulgarity" (Street 1874, p. 399). Similarly, The Builder cautioned that the widespread introduction of machine-made moulded bricks would bring with it "ornaments fearfully misplaced" by less able or inexperienced practitioners (The Builder 1850, p.391). The greater difficulty, however, in terms of the future development of Gothic revival brick architecture was the fact that good quality coloured bricks (both red and black) were not available in all parts of the country.

The decision to employ red bricks in London was a particularly costly choice because sound bricks of this colour were not obtainable from local brickyards. The colour of bricks depended upon three variable factors: the composition of the clay, the intensity of the heat and the amount of air they were exposed to during burning. The presence of iron oxide in different proportions in the clay was responsible for the various shades of red in bricks produced in many parts of the country. In London fields, however, an artificial flux of ground chalk was added to prevent the clay shrinking or cracking during drying and burning and to produce a stronger body in the bricks. This flux also chemically combined with the iron oxide to produce colours ranging from light yellow to grey (Dobson Part 2 1850, p.19; Rivington 1879, p.89-91). Underburning and exposure to air also changed the colour of the bricks, especially those burned in clamps.

Clamps were constructed in such a way that as the fuel at the bottom was consumed, each neck of brick would slide down towards the middle so that air was prevented from entering the centre of the mass and affecting the colour of the bricks (Architectural Publication Society Vol.1, p.139). Those on the outside of the clamps, the soft, porous "place" bricks, often were red because they had received inadequate or uneven heat during burning or because they were in constant contact with the air. According to one source: "Great care is required in burning bricks to produce them of a good uniform pale yellow colour, which is the favourite of the London architects, for if they are burnt too rapidly in contact with a free supply of atmospheric air, they are liable to be of a dingy red colour colour alternating into a coarse dusky brown"(The Builder 1845, p.137). It is not surprising, then, that many London architects preferred the light coloured stock bricks. In the local brickfields a red brick was an imperfectly burnt, inferior brick.

Those wishing to experiment with polychromatic effects had to bring in coloured bricks from other locations adding considerably to their expense. This was illustrated by the bricks chosen by William Butterfield for All Saints, Margaret Street, all of which were transported from outside the area, and according to Eastlake, their quality made the church "more expensive than stone" (Eastlake 1970, p. 252). These included black bricks from Cowbridge in South Wales which cost the enormous sum of £4. per thousand (Gwilt 1867, p. 527), causing Street to comment later: "I rather regret the unnecessary goodness (as it seems to me) of the bricks in this noble work" (The Church Builder 1863, p. 17 quoted in Thompson 1971, p. 149).[11] While this expense may have been excessive, it was not uncommon, even in the decades after 1850. Hand moulded bricks from the area around Fareham in Hampshire were frequently used by London architects. These were hand dressed or polished and carefully burned in small oven kilns to a uniform deep red colour. The cost of these preparations and transport to London meant that Fareham red bricks were reserved for use as face bricks only in superior buildings.[12]

The priority given to colour and quality by the leading Gothic revival architects, despite the difficulty and expense in obtaining these materials, was expressed by G. E. Street when he advised: "Before, for economy's sake, we determine to sacrifice the colour of our work, and to use those detestable-looking dirty yellow bricks in which London so much indulges, we ought to consider whether, by some economy in other respects, we may not save enough to allow the use of the best kind of red brick for the general face of our wall" (Street 1874, p. 399). Many of the architects within this small, exclusive circle were fortunate in that their aesthetic choices were supported by a handful of well-to-do, devout High Church benefactors. Paul Thompson pointed out that Butterfield "worked with the best when he could (not a wholly economic choice)" and "outside London he always preferred the best local bricks" (Thompson 1971, p. 149-50). But for most ordinary architectural commissions, the expense incurred by the use of high quality red bricks in the metropolis was undoubtedly prohibitive.

Interest in Gothic design principles gained momentum and spread throughout the country after 1850, stimulated particularly by Ruskin's popular books. One writer commented: "The preponderance of feeling in favour of the Gothic is both decided and very influential" (The Building News 1858, p. 645). Away from London, especially in places where local clay deposits produced naturally coloured red bricks, the transition to the Gothic style and constructional polychromy was relatively smooth. In Manchester during the 1840's and 50's, Edward Walters and J.E. Gregan combined red bricks with stone trimmings in their designs for offices and warehouses adapted from Charles Barry's popular Italian palazzo style.[13] These were closely followed by experiments in the polychromatic Venetian Gothic style, inspired by the writings of Ruskin and Street, and introduced by Alfred Waterhouse in his Fryer and Binyon warehouse (1856) and the Manchester Assize Courts (1859), followed by Thomas Worthington's Hulme Baths in 1859-60 (Stewart 1956; Pass 1985, p. 87).

Despite a decided change of taste that conferred respectability upon red brick construction and encouraged the use of more vibrantly coloured materials, red brick buildings were rare in the vicinity of London prior to the late 1860's.[14] The reticence of many London architects to adopt coloured bricks probably can be attributed to economy and integrity rather than to aesthetic conservatism. This situation undoubtedly contributed to some of the feelings of frustration within the profession and the consequent expressions of dissatisfaction with the output of the brickmaking industry. In 1850 the editor of The Builder stated: "There appears to be considerable anxiety throughout the country to effect improvements in the manufacture of bricks, and treat it artistically" (The Builder 1850, p. 97). The first brickmaking machine had been invented over one hundred years before and yet by mid-century architects still were looking forward to anticipated improvements in the colour, quality and decorative potential of bricks that they hoped would result from the mechanization of the brickmaking industry. The following chapter will examine the machines themselves and ask why, after a century of inventive activity, this had not been accomplished.

NOTES

1. According to Ronald Brunskill and Alec Clifton-Taylor, the finest period of English brick architecture, both artistically and technically speaking, was between 1660 and 1760 (Brunskill and Clifton-Taylor 1977, p. 29).

2. For the variety in the size of firms and the contracts undertaken see Dyos (1968, p. 631-690).

3. Nathaniel Lloyd stated that in the mid-eighteenth century builders had a choice of grey stocks for facing bricks, red stocks for rubbed and gauged trimmings, and perhaps two qualities of place bricks for ordinary work (Lloyd 1925, p. 36-37).

4. For an explanation of the various types of brick bonding see Brian (1972, p. 11-15) and Brunskill and Clifton-Taylor (1977, p. 68-73).

5. For the history of the architectural profession in England see Colvin (1978, p. 18-41); Crook (1969); Jenkins (1961); Kaye (1960); and particularly Saint (1983).

6. See Crook (1969, p. 71) for the survival of aristocratic patronage in the early Victorian period.

7. For Pugin see Stanton (1971), including her extensive bibliography on the architect's life and works. For an evaluation of Pugin's writings and influence see Eastlake (1970), MacLeod (1971), and Pevsner (1972).

8. For the history of this group see White (1962).

9. See Muthesius (1972) for a discussion of these characteristics and other buildings by Butterfield, William White, George E. Street and G. F. Bodley.

10. Cruickshank and Wyld (1975, p. 178-191) discuss the use of bricks in London during the eighteenth century. See also Cox (1989).

11. Compare the price of these bricks with others quoted by Dobson in 1850: ordinary blue bricks from Staffordshire, £1. 8s.; best red bricks from Suffolk, from 30s. to £2.; red front bricks

from Nottingham, £1.13s., and polished red front bricks from Nottingham, £3. (Dobson Part 1 1850, p.91 and 101; Part 2 1850, p.95).

12. For example, Fareham reds were used by Henry Curry for St. Thomas' Hospital, 1868 (Rivington 1879, p.108) and by Hnery Cole for the Albert Hall and The South Kensington Museum (Cox 1989, p.14).

13. See Walter's Silas Schwabe warehouse, 1845 (Dixon and Muthesius 1978, p.127). John Archer described the local brick in Manchester as "a soft golden-orange colour and of great regularity" (Archer 1985, p.5).

14. Isolated exceptions included the library at Loncoln's Inn built in 1843-5 by the Hardwicks; St. Giles-in-the Fields National Schools by E.M. Barry, 1860; commercial premises in West Smithfield by G. Somers Clarke, 1860; and a handful of churches including Street's St. James the Less, Westminster, 1859 and John Pearson's St. Peter's, Vauxhall, 1863-5.

CHAPTER FOUR

MOULDING AND PRESSING MACHINES, 1741 to 1850

4.1. Moulding Machines

The earliest mechanical devices for moulding bricks and tiles were not radically new inventions. They were closely patterned after familiar hand moulding techniques and utilized simple, existing technology. Most machines were extensions of the operations of the pug mill, a prevalent feature in many brickyards. In preparing the clay for hand moulding it was well-mixed with water to make a soft paste that was easy for the moulders to manipulate. The first machines continued to use clay of this consistency. In many early machines the paste was delivered directly from a mill mounted above a table into an arrangement of moulds underneath (British Patent No. 3103, 1808, William Stewart; No. 5036, 1824, William Leaky; No. 5246, 1825, George Henry Lyne and Thomas Staniford; and No. 8956, 1841, Andrew McNab).

To provide more control over the flow of clay being propelled into the moulds, some machines had a separate hopper or cylinder, sometimes called a "dod". The clay was fed into the hopper either directly from the pug mill or by hand. In some cases the cylinder was fitted with a mechanical apparatus for squeezing out the material. For example, the second machine patented in this country, by Francis Farquharson in 1798, had a weight on a pulley elevated above an open hopper which fell onto the clay and forced it into the moulds (British Patent No. 2215, 179; No. 4507, 1820, Lemuel Wright). By 1820 other solutions were devised for feeding the moulds. One employed a piston in the hopper activated by a hand crank or a lever (British Patent No. 4482, 1820, John Shaw; No. 5086, 1825, Edward Lees and George Harrison; No. 5166, 1825, Alexander Galloway). Another used a screw to provide continuous pressure on the contents of the hopper which allowed an uninterrupted flow of clay into the moulds (British Patent No. 3685, 1813, Joseph Hamilton).

In addition to one of these methods for feeding the moulds, a feature in most machines was a sliding metal bar or wire to remove the superfluous clay from the top of the mould, similar to the action of "striking" in hand brickmaking. Less common in early machines, but sometimes included, was an apparatus to compress the soft clay into the corners of the mould and to force out pockets of air, again in imitation of hand moulding. This was usually a piston-operated plunger, although in some machines a roller performed this function. A great deal more ingenuity and experimentation was exhibited by inventors in the special arrangements of the mould boxes and the methods devised for extracting the bricks once moulded. These were aspects of a machine's operation that especially determined its speed and the quantity of bricks it was able to produce. The arrangements of the moulds in early patents tended to fall into one of four general categories: circular moulding tables, sliding mould frames, moulds attached to an endless chain, or moulds inserted into vertical wheels. Similarly, in removing the bricks from the moulds, one of three methods was usually employed: the mould itself would move up or down releasing the brick, a piston would push the brick either up or down out of the box, or a hinged portion of the mould would open allowing the brick to slide out or be removed by hand.

In 1798 Francis Farquharson of Birmingham was the first in this country to suggest a revolving circular table carrying up to twenty moulds. Each mould was filled successively by a charger as the table slowly revolved and once filled each box was pulled off by a curved iron hook then emptied and sanded by hand. A single mould box with two brick-sized compartments fit into one of ten slots around the circumference of the table. A similar circular table with three apertures to hold the mould boxes was patented by Thomas Gilbert in 1811. Gilbert's moulds were hinged frames holding six bricks, each brick resting on a pallet board, and by opening the hinge after the mould was filled, the bricks and pallets together were removed by hand (British Patent No. 3473, 1811). In Edward Jones' patent of 1835, a series of moulds were arranged on a circular table and were described as "having within each of them a piston by which the brick or other article depending on the shape of the mould when formed or moulded are forced from the mould..." (British Patent No. 6875, 1835, p. 2; Figure 4.1.). One element of novelty in this machine was the inclined track upon which the table rested that activated the pistons within each mould. Jones also claimed novelty for the small pallet in each mould box that enabled the brick to be lifted up out of the machine and carried away without damage. This also was the basis of Gilbert's patent in 1811 but neither were really a novel feature as pallets had been an essential part of the traditional technique for hand moulding stock bricks, the "stock" or pallet being simply a small board used to retain the shape of the brick (Lloyd 1925, p. 34-35).

The second part of Jones' patent consisted of a small rectangular frame to hold the hand-fed mould boxes. Pistons compressed the clay in each box and then held the moulded bricks down onto a table while the boxes lifted allowing them to be removed, each on a separate pallet (Figure 4.2.). This was a simpler version of a machine patented in 1825 by George Henry Lyne and Thomas Staniford that had a two-sided sliding mould frame which moved back and forth under a large pug mill (British Patent No. 5246, 1825; Figure 4.3.). Andrew Ure reported that the mould resembled "an ordinary sash window in its form, being divided into rectangular compartments (15 are proposed in each) of the dimensions of the intended bricks" (Ure 1839, p. 187). The mould frame was open at the top and bottom and rested on a flat board. Once filled, the clay was compressed by plungers and the entire frame was raised by a lever while the moulded bricks, still on the board, were pushed down onto a truck and wheeled away.'

Apparently this was a popular method still used in machines patented in the 1840's. Andrew McNab, an engineer from Paisley, described his machine of 1841: "A sliding frame beneath the bottom of the mill contains two moulds, so arranged that whilst one of them is under one of the openings in the bottom of the mill receiving the clay, the other is outside the mill delivering its brick" (Mechanics Magazine 1841, p. 253). Similarly, Robert Cook and Andrew Cuningham entered the details of a machine with "a sliding frame, containing two moulds, applied to each side of a common pug mill" (Mechanics Magazine 1841, p. 300). The only difference between the two machines was that in one a piston pushed the bricks out of the moulds, while in the other a boy removed the mould boxes and emptied the bricks onto a pallet while another mould was being filled (See also British Patent No. 9610, 1843, Joseph Kirby and No. 9751, 1843, Thomas Forsyth).

Yet another arrangement of the moulds in early machines was a circulating endless chain, first suggested by William Stewart in 1808 (British Patent No. 3101). Stewart's mould boxes, each holding four bricks, were attached to a continuous chain moving along a table beneath the pug mill. As each mould arrived at the end of the table it turned upside down and discharged its bricks into the hands of a workman.[2] Many of these elements were combined yet again in a "novel arrangement" patented in 1825 by Edward Lees, a publican, and George Harrison, a brickmaker, both from Little Thurrock in Essex. A wooden pug mill fed the clay into a cast iron box which was fitted with a piston to push the substance into a series of moulds on an endless chain. After being filled and the excess clay cut off, the moulds were made to lift up and the bricks, resting on separate wooden pallets, were removed (British Patent No. 5086, 1825). Further improvements were made in 1829 by John Cowdroy when he proposed jointed cast iron moulds suspended by rollers in a frame and operated by a crank. When the moulds were filled and pressed, their upper surfaces were smoothed by a sliding strike and the sides opposite the joints opened on a hinge and ejected the bricks (British Patent No. 5866, 1829).

A fourth category of moulding machines arranged the moulds in vertically revolving wheels. The specification submitted by Henry Devenoge in 1830 divided two large wheels into cells, each the size of a brick. The cells were filled from the top by a hopper and the clay was compressed by the action of the two wheels rolling across each other as they revolved in opposite directions. The bricks were supposed to be discharged simply by falling out as each cell reached the bottom of the wheel's revolution (British Patent No. 5937, 1830). A similar patent dated 1832 improved the method of extracting the bricks by means of pistons sliding on rods behind each cell and fixed to the rims of the wheels (British Patent No. 6257, 832, John J. Clark, John Nash and John Longbottom; Figure 4. 4.).

Occasionally other innovative solutions were suggested, such as the inverted moulding machine patented in 1825. Alexander Galloway, an engineer from London, described a complicated machine with a two-layered revolving table. The clay was passed from a hopper through holes in both sections of the table into a pump below. As the table began to revolve, the pump was lined up with an inverted mould box attached to the upper layer of the table and a piston forced the clay upwards through an aperture in the lower part of the table and into the mould. As the tables revolved yet again a discharging plate passed over the filled mould and forced the bricks downwards through a second aperture in the lower table where they were removed from the machine (British Patent No. 5166, 1825). In another patent granted in 1826 to William Choice and Robert Gibson, a pug mill deposited the clay on a revolving plate, upon which a mould box was made to fall and thus become filled from the underside. The mould then passed over a polishing wheel which smoothed the bottom before being emptied of its brick by a weight falling from above (British Patent No. 5353, 1826).

An examination of patent specifications for moulding machines prior to 1850 shows that most were various combinations of the same basic elements and mechanical operations closely following techniques used in hand brickmaking. These machines were similar to devices patented in other countries during the same period. In particular, there was considerable inventive activity in the United States where ninety-three patents for clayworking devices were registered by 1847 (Purcell 1968, p. 19-27). Undoubtedly a free interchange of ideas and techniques existed between the two countries through descriptions in scientific publications, first-hand observations by travellers, and the patenting of foreign machines in both countries.

As an example, Frances Farquharson's moulding machine with its circular table, dated 1798, may have been patterned after a machine patented in the United States in 1794 by Apollos Kinsley of Connecticut. Farquharson stated that he was patenting "a method and machine for making bricks and tiles used in foreign parts" (British Patent No. 2215, 1798). In a letter to Thomas Jefferson, then in charge of patent procedures as United States Secretary of State, Kinsley described a machine with a revolving horizontal table carrying moulds which were successively filled by a weight falling on an iron plate in a charger suspended over the table (Purcell 1968, p. 23). Kinsley's first patent for a brickmaking machine had been granted the previous year and this device also was patented in Britain in 1800 by Isaac Sanford, formerly of Hartford, Connecticut, but then residing in Covent Garden. The machine consisted of a wooden pug mill with blades to cut the clay and a screw at the bottom to force the substance into moulds holding either two or four bricks. The moulds were sanded by hand on a platform mounted at the side of the machine and then they were made to travel under the mill along a table composed of friction rollers mounted on a frame (British Patent No. 2368, 1800; Figure 4.5.).[3]

Other American machines were described in journals on this side of the Atlantic in the early nineteenth century. The Bulletin de la Société d'Encouragement pour l'Industrie Nationale illustrated a machine operating in extensive brickworks near Washington D.C. in 1819 (Vol. XVIII, p. 361-66). In this machine a hopper filled a series of moulds arranged on a revolving table while a charger with a cast iron cap compressed the clay. The moulds were then emptied by a piston which pushed the bricks down onto a receiving table. This appeared six years before any British patent suggested the use of a piston for pushing bricks out of their moulds. Another machine, the "Ohio Brick Striker", patented by Ebenezer Duty and Daniel W. Duty of Geaugo County, Ohio, was noticed in Newton's London Journal of Arts and Science in 1829. The journal stated that "this machine is too complex for a short description, its principle parts are a hopper to contain the compost, a lever to force the same down into the mould under the hopper, and a carriage and lever by which the mould is forced under the striker." It was said that the machine was given a trial in England but "was not found to answer the expectation of the inventors" (Vol. 3 1829, p. 107).

The enormous variety and experimentation found in patents for brickmaking machines during the first half of the nineteenth century indicates that no single mechanical solution had yet emerged that was obviously superior to others. It also suggests that certain aspects of the brickmaking operations were far more difficult to mechanize than others, in particular the processes of compressing the clay and ejecting the finished bricks. This was because there were serious technical problems to overcome in attempting to mould wet clay with machinery. The greatest difficulty was with the substance sticking to parts of the machine. In imitating the actions of hand moulders, it was necessary to exert sufficient pressure on the clay so that the corners of the mould were filled and unwanted air was expelled, but not so much that it adhered to the metal or wooden surfaces. Apparently this was very difficult to achieve. In most machines that delivered the brick earth directly from the pug mill or a hopper, the traditional methods of sanding or wetting the mould boxes were adequate protection against sticking. In many cases, however, the pressure on the clay in these machines was not sufficient to fill the corners of the mould because of the friction encountered while it moved along the sanded surfaces (Ward 1885, p. 31). Thus it became necessary to include rollers or plungers to compress the substance more thoroughly into the moulds. But according to one patentee, "one great inconvenience resulting from the use of this description of machine is the great liability of the clay to adhere to the plunger, and when such is the case it is very likely to strain or derange some parts of the machine" (British Patent No. 10,506, 1845, Thomas Middleton).

Some inventors attempted to overcome this problem by including ingenious mechanical devices for removing the excess clay from the pressing plates or rollers. For example, Thomas Middleton attached a scraping apparatus "to scrape and clean the plunger every time it rises" (British Patent No. 10,506, 1845). Others suggested different methods for lubricating these elements. Henry Clayton's machine had a metal frame covered with an oil-saturated cloth that entered the mould and lubricated it prior to each filling with clay (British Patent No. 10,132, 1844). Similarly, in William Percy's patent two years later, grooves in the piston used to eject the bricks were filled with a material saturated in oil. Each time a brick was pushed out, the piston simultaneously oiled the inner surfaces of the mould (British Patent No. 11,256, 1846).[4] Still other inventors recommended heat to prevent adhesion of the clay. The patent for a vertical wheel machine by Messrs. Clark, Nash and Longbottom described a method for subjecting the clay in the moulds to "red-hot irons to expel superfluous moisture" (British Patent No. 6257, 1832). These solutions were not entirely successful and inventors struggled with the problem for several more years. In 1857 Robert and James Porter patented a highly complicated arrangement of moulds with removable bottoms, each fitted with "a sponge, sand and oiling apparatus for lubricating the brick mould and facilitating the easy delivery of the brick" (British Patent No. 2601, 1857; <u>The Builder</u> 1858, p. 593).

Another major difficulty encountered when using soft, wet clay of the same consistency as that used by hand moulders was that the bricks were frequently misshapen by the action of the machine removing them from their moulds. Each of the various methods employed for automatically ejecting the bricks had problems to contend with. In some machines a hinged section of the mould box simply opened to allow the bricks to slide out onto a movable surface that carried them away. Machine makers and users soon found that this surface too required protection against sticking and it was sometimes made of moleskin or leather for this purpose. James Hart's machine, patented in 1848, went further and lifted the moulded bricks onto an endless cloth band "kept wet by brushes dipped in water" (British Patent No. 12,311, 1848). Another method used to eject the bricks was to push them out of their moulds with a piston, but this often produced a concavity on one side of the brick because of excessive pressure on the clay or because it adhered to the piston's metal surface. In other machines the mould box moved up or down leaving the bricks standing on a pallet board or a piston pushed the pallet holding the bricks up out of the mould, thus avoiding contact with the clay. The use of a pallet considerably reduced the risk of damage to the bricks, but according to one source, in both cases the portion of the clay first released from the pressure of the mould tended to expand causing one end or side of the brick to be thicker than the others. Chamberlain stated that at least one machine maker had attempted to remedy this by providing an apparatus to slice off the uneven portion (Chamberlain 1856, p. 495).

Even when hand labour was used to empty the moulds, soft clay bricks were distorted easily after being carried away from the machine. Hand moulders were able to compensate for this distortion sometimes by making one side of the brick smaller to allow for settling during the initial drying time. It was possible to adapt the mould boxes used with machinery in a similar way. In 1843 Thomas Forsyth claimed a "unique construction and application of a counteracting curved surface to the moulds, by which the bricks are rendered more perfect in form" (British Patent No. 9751, 1843). But according to one brickmaker, the speed of the machine undermined this careful system: "As the machine turns out six bricks at a time, there is the constant danger of the barrow loader placing the bricks so that the off-bearer would have the wrong side of the brick presented to him" (BPP Childrens' Employment Commission 1866, p. 137). These technical difficulties were added to the many other unavoidable problems inherent in brickmaking with soft, wet clay, such as the vulnerability of the newly moulded bricks to damage during the lengthy drying period and loss due to shrinking or cracking during burning.

By the mid-nineteenth century brickmaking machinery had been in existence in Britain for over one hundred years. Various shortcomings within the brickmaking industry had pointed to the need for technical solutions to serious production problems. A large number of brickmaking innovations were introduced and patent statistics show that the majority of these were mechanical devices for moulding bricks and tiles. Many of the machines invented, if not entirely perfected, offered at least potential solutions to the industry's problems. Furthermore, similar moulding machines had been adopted in America, sometimes on quite a large scale, thus demonstrating their apparent success.[5] But in this country there were objections to a variety of technical problems, many of which remained unsolved well into the second half of the century.

The most likely explanation for the slow technical development of moulding machines seems to be the small number of machines actually in operation in British brickfields prior to 1850. The few patentees who stated their occupations as brick or tile manufacturers may have operated prototypes of their machines in their own works, for example, George Harrison, a brickmaker from Little Thurrock in Essex (British Patent No. 5086, 1825) and John Nash, tile and brick manufacturer from Market Rasen, Lincolnshire (British Patent No. 6257, 1832). But there are only isolated references to others suggesting that most moulding machines were not given a sufficient trial in this country to provide an adequate evaluation of their capabilities or to allow for rapid modifications or improvements in design.

One obvious reason for the avoidance in adoption of these machines was the existence of the excise duties on bricks. The minimum compensation of ten per cent for ruined bricks was potentially discouraging to brickmakers wishing to try out new moulding machinery. During the campaign to abolish the duties in the 1840's one writer commented: "All experimentalists who attempt new modes of making bricks, should their bricks on first experiment turn out bad, suffer not only the loss of such failure in the ordinary way but have to pay a tax to the Government for making the attempt" (The Builder 1846, p. 71; Chamberlain 1856, p. 493). One revealing example of how extensive the loss could be as a result of imperfect machinery was the experience of the Middlesbrough Owners who established a brick and tile yard in Cargo Fleet Lane in 1839 with two newly invented machines by John Richardson of Hutton

Rudby. There are no details available pertaining to the machines, but it was stated that for the first two years of operation, out of 1,326,798 machine-made bricks for which excise duty was paid, 402,766 were failures (Lillie 1968, p.69). Clearly the use of untried machinery entailed a great financial risk. Most brick manufacturers during the nineteenth century were not in a position to sustain such losses. The prevalent attitude was that expressed by one observer in 1856: "It is only to be expected that brickmakers would hold back from adopting machinery until they were convinced it was of a perfect character and could be depended upon in all respects" (Chamberlain 1856, p.500). Faced with a choice between an unpredictable workforce or what was seen to be a technically imperfect machine, it seems most brickmasters before 1850 opted for the status quo. Without a period of trial and user feed-back, there was little opportunity for further development of moulding machinery despite the enthusiasm of the inventors.

4.2. Pressing Machines

Soft clay moulding machinery was not sufficiently developed by 1850 to make a significant impact on levels of production within the brickmaking industry. Technical problems and the restrictions of the excise duties discouraged the widespread adoption of these machines. Pressing machines, on the other hand, were invented to provide a substitute for the costly and laborious methods previously used to manufacture specially finished facing bricks. In the traditional hand processes of dressing and polishing, a moulded and partially dried brick was either beaten with an iron-tipped, wedge-shaped tool called a dresser to correct its irregular shape and sharpen its arrises, or it was polished on a cast iron plate to smooth its surfaces. Dobson reported that "this process is only gone through with the very best bricks, and its cost is such that it is not employed to any great extent" (Dobson Part 1 1850, p.73 and 83). Polished and dressed bricks were expensive not only because of the labour intensive techniques used to make them, but also because until 1839 they were taxed with double the amount of duty than ordinary bricks, that is, 12s. 10d. per thousand compared with 5s. 10d. for common bricks. This provided a strong incentive for brickmakers to find a more economical method for producing well-shaped, smoothly finished facing bricks without resorting to the heavily taxed hand processes.

Samuel Miller's "seconding machine", patented in 1801, was designed for this purpose. Like hand methods, it worked with previously moulded, semi-dried bricks and tiles. The patentee described its operation: "The principle of the machine is founded upon securing five sides of the parallelogram during the time the operator forces down the piston or square block on the sixth by the power of the lever. It may be effected by the screw and fly or any other mechanical contrivance" (British Patent No. 2543, 1801). According to Miller, the purpose of the machine was to "give a greater correctness to bricks as well as giving their surface a firmness for better resisting the damp."[6]

One of the best known pressing machines was that patented in 1830 by Samuel Roscoe Bakewell, a brick manufacturer then residing in Whiskin Street, St. James, Clerkenwell. His patent included an improved method for grinding and mixing clay using grinding stones in a pit, a "peculiar construction of hand mould", and the press (British Patent No. 5985, 1830). Apparently Bakewell spent some time in the southern United States where he observed brickworks in Tennessee and Louisiana. Clay mills he had seen in New Orleans were the source for his patented mill and it is probable that his press was similarly inspired by an American machine. In 1834 Bakewell published a pamphlet entitled <u>Observations on Building and Brickmaking, Etc...,</u> in which he outlined his views on the best methods for manufacturing bricks and provided a justification for his inventions. Like others of his day, Bakewell deplored the inferior quality of bricks made in some parts of the country, calling them "rough, ugly, soft, misshapen lumps of burnt clay (hardly deserving the name of bricks) full of hollows, fissures and protuberances..." (Bakewell 1934, p. 13). He was convinced that the principle causes of poor quality bricks were defective tempering of the clay, which he thought "ought to be performed more than doubly what is usual", and using clay that was too soft. He proposed to work the clay thoroughly but at the same time to keep it as dry as possible because, as he stated, "the stiffer the clay the better the bricks will retain their shape in drying and firing and they will be less porous when burnt" (Bakewell 1834, p. 14-15). His special hand mould was designed to enable the moulder to work clay of an unusually strong consistency and the press was intended to further shape the finished bricks and give them more solidity. Like Miller's seconding machine, Bakewell's press was extremely simple in its construction and operation (Figure 4.6.). The semi-dried bricks were dusted with sand, placed in a covered mould box and subjected to pressure claimed to be more than two tons by a piston activated by a series of hand-operated levers. Alternative mechanical arrangements to effect the movement of the piston were suggested, one involving a toothed metal rack and another a toothed wheel.

Bakewell was especially ambitious in promoting his inventions, announcing machine demonstrations in the newspapers of various cities. In 1832 it was reported that he had "made arrangements with several respectable individuals to form a company under the title of 'The Leicester Patent Brick Company' for the purpose of introducing improvements in brickmaking into Leicester during the ensuing spring" (The Leicester Chronicle 3 October 1832, quoted in Bakewell 1834, p. 26). Subsequent notices reported that presses had been installed in brickfields in other parts of the country, including the yard of Samuel Grocock in Leicester, in Salford by brickmaker Henry Brownbill, in Stafford at the works of Daniel Glover, a brick and tile manufacturer from Hanford, and in London by William Rhodes of Hackney Road (Bakewell 1834, p. 22 and 26; Architectural Magazine 1835, p. 93). William Rhodes was one of the London brickmakers visited by Edward Dobson to obtain material for writing his treatise on brickmaking in 1850 (Dobson Part 2 1850, p. 41).

Bakewell's pamphlet was reviewed by both the Mechanics

Magazine (September 1834) and the Architectural Magazine, and while the grinding mill was barely noticed by these periodicals, the brick press received particular attention. Bricks finished by the machine were praised for their great strength, durability and beauty which one journal said "must far exceed anything hitherto to be met with in this country" (Architectural Magazine 1834, p. 312). Ten years after the original patent was granted, a memorandum was filed in the Patent Office by John Manning of Leicester, acting in Bakewell's behalf, disclaiming the grinding mill and the hand mould, as they had "not in practice proved to be useful", leaving only the press covered by patent protection because "it had become of great value" (British Patent No. 5986, 1830, "Manning's Disclaimer to Bakewell's Specification", 1840 p. 2).

Other machines like Miller's and Bakewell's were patented or introduced before mid-century (British Patent No. 7391, 1837, Richard Roe; No. 10,020, 1844, William Basford; and No. 10,152, 1844, William Hodson). At least one other company, the Architectural Tile Company, was organized to manufacture roofing and facing tiles with "Dampier's patent concentric press machine". This machine was a combination re-press and punching device. Thin slabs of "leather-hard" clay were simultaneously compressed and cut into decorative, moulded shapes by means of "iron dies and cutting frames" under a pressure of from ten to twenty tons. The company claimed, "being pressed in a partially dried state, they are less liable to mutilation or shrinkage after being made" (Prospectus and Descriptive Statement of the Architectural Tile Company 1847).[7]

Pressing machines were integrated easily into most brickyards (Figure 4.7.). Because they were small and hand-operated by only one attendant, they complemented traditional work practices rather than superceded them. They also were simply constructed, performed only a single mechanical function and worked with partially dried clay bricks rather than with lumps of sticky, wet clay. Consequently, pressing machines were not plagued by the serious technical problems encountered by the larger and more complicated moulding machinery. Most importantly, they were capable of considerably increasing the output of good quality facing bricks and thus lowering their cost. It appears they were widely adopted by 1850 when Dobson remarked that "machine-pressed bricks can be produced much cheaper than those dressed by hand, and there is little inducement to employ the latter process" (Dobson Part 1 1850, p. 74).

Nevertheless, brickmakers reported some undesirable side effects in the bricks after they were pressed by these machines. Although pressed bricks had the same smooth faces and sharp edges as those dressed by hand, they also were much denser and heavier. Practical experience with the machines had revealed some problems with drying and burning the bricks after pressing. Because of their greater density, the drying time was much longer than for ordinary bricks. Pressing forced the moisture remaining in the external surfaces of the bricks to their centres where it was condensed. Thus, frequently the surfaces became dry too quickly and had a tendency to scale off before they could be burned. Similarly, if too much moisture remained in the centres of the bricks, it was said that they were liable to crack and then explode during burning from a build-up of steam. Added to this, Dobson observed that in some machines, either from poor construction or over-use, the piston cover did not fit tighly over the mould causing an unsightly raised edge all around the bricks (Dobson Part 1 1850, p. 31).

Building professionals, many of whom were deeply dissatisfied with the overall quality of brick production, were uncertain and sometimes divided in their response to bricks pressed by machinery. In the first place, they did not agree about the desirability of increased density. Some believed that a dense texture and extra weight produced a harder brick that was stronger and less affected by the weather. George Godwin, writing in the Architectural Magazine said: "The heavier a brick is when dry...the better it is, the more solid, the more impervious to water" (Godwin 1838, p. 43). Similarly, in a discussion on brickmaking at the Institution of Civil Engineers in 1843, one contributor said he believed that "light bricks were generally porous, and that when they were used for building external walls the moisture soon penetrated; this was not the case with dense bricks, and if they were generally made more compact, thin walls would resist damp as well as thick ones." On the other hand, another participant stated that in his experience, the surface of pressed bricks were often found to scale off upon exposure to frost leaving them even more vulnerable to the absorption of moisture." Others wondered "whether builders would not consider them objectionable from their great weight", and whether mortar would not fail to adhere to their smooth surfaces (Proceedings of the Institution of Civil Engineers 1843, p.149-152). This was a frequent complaint, as one writer explained: "These bricks, being made so perfectly square, have very close joints, and thus present a very small surface to the action of the atmosphere" (Transactions of the Yorkshire Agricultural Society 1845, p.26). One solution to this problem was to press the bricks, as Bakewell's machine did, with a "frog" or an indented surface on the bedded sides to make a key for additional mortar.[8]

There also was disagreement among architects and engineers about the strength of pressed bricks. One engineer commented that members of his profession "generally preferred dense bricks as their works required strength." But others, including the architect Charles Fowler, cautioned that density was not necessarily synonomous with strength and that increased weight should not be an index of quality (Proceedings of the Institution of Civil Engineers 1843, p.153). This uncertainty pointed to the need for systematic testing to determine the crushing strength of machine pressed bricks. Although brick arches and beams had been tested previously in 1837 by Mark Brunel and in 1841 by Thomas Cubitt (Architectural Publication Society Vol.1, p.142-43), one of the first experiments to test the resistance to crushing of single bricks was carried out by Cubitt at his Thames Bank brickworks in 1847. A variety of commonly available bricks were placed between two parallel metal plates and subjected to pressure by means of an hydraulic press. The results were reported in The Builder. A superior washed stock brick, hand-made, yielded to a weight of 36 tons, while a kiln-burnt machine-pressed brick bore a pressure of 60 tons without injury (The Builder 1847, p.537).[9] The results of

Cubitt's experiments undoubtedly reassured many building professionals of the superior strength and quality of bricks pressed by machinery.

Initially, architects admired and praised the visual qualities of pressed bricks and welcomed them as a great improvement over many hand-made products. In the mid-1830's, Loudon wrote in the Architectural Magazine that walls constructed with Bakewell's pressed bricks would be "more handsome and more durable than any brick wall heretofor erected" (1834, p.312). This was primarily because of their exceptional smoothness and narrow joints. The smooth finish of pressed bricks was appreciated because it made them more impermeable to the atmosphere and thus maintained the colour and clean appearance of brick walls. These were particularly important characteristics in London where porous materials like soft bricks and stones rapidly absorbed the dirt and smoke of the urban environment and, according to Scott, "render[ed] the whole building a gloomy, light-absorbing mass" (Scott 1858, p.106). G.E. Street recognized this when he wrote in 1850: "In a town such as London I should use brick...simply on account of its superior smoothness and evenness of surface" (The Ecclesiologist 1850, p.229).

Machine prssed bricks, however, did not fit comfortably with the increasingly popular beliefs of the Gothic revival architects and theoreticians. An important part of Ruskin's ethical argument was that the value of a moulded material like brick was in the human labour used to make it, and he strongly disapproved of machines applied to the fashioning of any material (Ruskin 1865, p.45). In Remarks on Secular and Domestic Architecture, Scott was surprisingly specific about the way bricks ought to be made. He believed slop-moulding, in which the mould was first dipped in water before it received the clay, resulted in "a crude, earthenware surface to the bricks", whereas a sand-moulded brick burned to a "beautiful bloom." He particularly disliked pressed bricks for their shiny evenness: "That extreme smoothness produced by pressing is not usually pleasing, and the thin joints which accompany it are much to the contrary" (Scott

1858, p. 102). These characteristics conflicted with the Gothicists' appreciation for surface texture and irregularity. Paul Thompson stated that Butterfield always preferred the rough textures and uneven colours of the best hand-made bricks and "he never favoured the cheap, mass-produced bricks" (Thompson 1971, p. 150).[10] These opinions were probably not shared by the majority of ordinary architects at mid-century, however, most of whom would have been grateful for a reduction in the price of facing bricks which resulted from the widespread use of pressing machines.

Inspired by the early success of pressing machines, some inventors experimented with the possibility of combining the processes of moulding and pressing in one operation. By submitting raw clay to a greater amount of pressure in the mould, they hoped to extract unwanted moisture while smoothly finishing and shaping the bricks. As early as 1828, William Mencke suggested a machine that consisted of a hydraulic press to lift and firmly hold the boxes containing the brick earth and a screw press, activated by a lever, to firmly press the moulds. When the pressing action was completed, the moulds remained stationary while the bricks sitting on boards were lowered and removed (British Patent No. 5681, 1828; Figure 4.8.). Other machines for pressing single bricks from raw clay were patented or manufactured before mid-century. One of these, an unpatented machine made by a Mr. Russell of Seaton Ross, was awarded a prize at the Yorkshire Agricultural Society exhibition in 1845. The press was described in the Society's journal: "It consists of a strong wooden frame, on which an iron box is placed, of the exact dimensions of the brick; into this the clay (well-pugged) is placed, and the upper lid of the box is strongly pressed down, by means of a long iron lever, the man at work bringing his whole weight to bear upon it..." (Transactions of the Yorkshire Agricultural Society 1845, p. 26).

Most wet clay presses, such as that manufactured by John Whitehead, were similar to re-presses, that is, they were simply constructed mechanisms totally hand-operated by a single attendant (Figure 4.9.; See also British Patent No. 10, 188, 1844, Henry Holmes). Because they worked with wet clay rather than semi-dried bricks, they probably experienced the same technical difficulties as the larger, more automatic moulding machines. Similarly, it is unlikely that they were able to avoid retention of moisture in the finished bricks and the attendant problems with drying and burning.

One possible solution to these problems was to eliminate the water from the clay before it was placed in the machine. In 1838 Francis Charles Parry and Charles De Lavaleye stated that the objective of their invention was "to manufacture the bricks from the clay *as dug from the ground* by means of great pressure effected by machinery...by which pressure the form of the brick is more effectually preserved and it may be exposed to the fire sooner by reason of the moisture being forced out" (British Patent No. 7551, 1838; my emphasis). This clearly was a departure from previous clayworking methods. Traditionally, the brick earth was well-mixed with water to make it more pliable and easily handled by the moulders, after which the moisture was evaporated from the bricks before they were burned. Water added to the clay extended the length of the drying time and also increased the potential for contraction or distortion of the finished bricks. Reducing the moisture content not only shortened the drying time, but also minimized the risk of damage to the drying green bricks.

In 1839, in his Dictionary of Arts, Manufacture and Mines, Andrew Ure described an American machine which he said could mould 30,000 bricks in a twelve hour day. More significantly, he reported that "the bricks are so dry when discharged from their moulds as to be ready for immediate burning." Ure went on to state that a M. Mollerat in France also attempted to mould bricks using condensed pulverised clay in an hydraulic press, but the process had proved to be too tedious and costly (Ure 1839, p. 185). Perhaps as a result of these descriptions Richard Prosser, a civil engineer from Birmingham, began to experiment with a clayworking process using dry clay and in 1840 obtained a patent for making small objects such as buttons from dried Staffordshire brick earth. Prosser not only used ordinary clay without the addition of water but, if necessary, he further evaporated the moisture out of it in a slip kiln until it was of the appropriate dryness. He then ground the clay to a fine powder, placed it in a metal mould and subjected it to a pressure of about 200 pounds to the square inch. In addition to these small articles, the inventor explained that he intended to make larger items such as bricks and tiles with greater speed than any other process and with "almost any degree of excellence in point of design given them", i.e., decoration. (British Patent No. 8540 1840).[11] Another patent by William Betts and William Taylor in 1843 had the object of "making or producing bricks, tiles, etc. from clay which is in a much drier and harder state than that in which it is generally employed." The intention of this patent was the same as Prosser's although instead of using a fine clay powder, lumps of very stiffly tempered earth, cut roughly to the size of a brick, were placed in the machine (British Patent No. 9659, 1843; No. 12,454, 1848, Thomas Snowdon).

As well as possessing the smoothness, regularity and sharpness of outline found in ordinary pressed bricks and tiles, objects made by the dry clay process generally required no further drying and could be taken directly to the kiln. The potential advantage of this system in eliminating many of the deficiencies in the traditional brickmaking industry were apparent. There was, unfortunately, a great deal of scepticism about dry clay pressing. Initial discussions by architects and engineers were entangled with the debate about density in ordinary pressed bricks. At a discussion in 1843 it was claimed in support of the process that a dry clay pressed tile would shrink only one-eighth of an inch after burning and a nine inch stock brick was capable of sustaining a crushing pressure of ninety tons (<u>Proceedings of the Institution of Civil Engineers</u> 1843, p. 149). In 1850, Dobson also made an attempt to distinguish Prosser's dry clay method from other pressing machines by stating, "it is a common but erroneous notion that articles made by Mr. Prosser's process are denser than similar articles made in the common way; the reverse is the fact" (Dobson Part 1 1850, p. 31). Despite this encouragement, there was little more than curiosity about the dry clay system for brickmaking. It received its most extensive development in the manufacture of decorative tiles, where it was frequently called dust pressing.

The tile manufacturer, Herbert Minton, immediately recognized the potential of the new process for mass producing decorative wall tiles and within a few months of Prosser's patent he had installed seven presses at his works in Stoke. By the time architects and engineers were beginning to debate the suitability of the method for the manufacture of bricks, sixty-two presses were being successfully operated by Minton (Barnard 1972, p. 16).

One very important obstacle prevented brickmakers from adopting dry clay pressing machines before mid-century. Once again the restrictions imposed by the excise duties on bricks were particularly discouraging to those improvements that significantly altered traditional methods of brickmaking. The mechanized dry clay process was unique in that it eliminated the difficult period of drying required by wet moulded bricks. As one inventor put it, "any machine that can make bricks or tiles from clay in a partially dry state may be worked throughout the whole or at any rate the greatest portion of the winter" (British Patent No. 9659, 1843). The advantages of the system were obvious -- a lengthened brickmaking season would guarantee a continuous supply of bricks to meet any demand and a great deal of the damage incurred during drying would be reduced. But in obviating the need for drying these machines were completely outside the established structure imposed by the excise legislation. The rigid regulations requiring the arrangement and counting of the bricks at a particular place and only during the drying period virtually restricted all further developments of this mechanized method until after 1850 when the tax was repealed. There was continuing interest and debate about the dry clay process, especially as accounts of the success of American machines appeared regularly in the British press (The Builder 1845, p. 449; 1852, p. 385; Proceedings of the Institution of Mechanical Engineers 1853, p. 148-51; Whitworth 1854, p. 103). But even preliminary trails of the method for making bricks were delayed in this country for at least a decade as a result of the obstacles imposed by the tax on bricks.

NOTES

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1. There is some confusion about the spelling of one of the names in this patent. Ure in 1839 and Woodcroft in 1854 spelled the name "Stainford" while the patent, as printed by the Patent Office in 1857, spelled it "Staniford". It is likely the latter is a printing error.

2. A variation of this method was proposed by William Leaky in 1824 (British Patent No. 5036).

3. Sanford credited Kinsley with the invention of the machine.

4. In 1853 Henry Clayton petitioned the court against Percy for infringement of his patent. Percy, a machine maker from Manchester, defended himself by attempting to disclaim the novelty of Clayton's machine and showing its similarity to several other patents. Although Percy's machine did resemble Clayton's in it basic processes, there were some differences, notably in its more sophisticated method for lubricating the mould box and the manner of applying motive power. Despite these distinctions, the jury returned a verdict in favour of Clayton and Percy had to withdraw his patent (The Builder 1853, p. 491).

5. Moulding machines were the prevalent method of mechanized brickmaking in the United States throughout the nineteenth century and into the early years of this century (Bowley 1960, p. 63, n. 1).

6. John Woodforde incorrectly states that machines for re-pressing bricks date from the 1870's (Woodforde 1976, p. 115).

7. There was no patent registered under the name Dampier.

8. Frogs were made in hand-moulded bricks from the end of the seventeenth century (Cox 1979, p. 24).

9. Additional tests to compare the rates of absorption and retention of moisture in various types of bricks were not undertaken until the 1860's (See Chapter Eight).

10. Thompson further speculated that Butterfield's

increasing use of coloured bands, chequers and diapers in the late 1850's and 60's was a reaction to the growing uniformity of bricks resulting from the introduciton of various mechanical processes such as wire-cutting and the "stiff-plastic" method. Actually the stiff-plastic process was not fully developed in the late 50's and certainly not widely adopted, while wire-cut bricks were seldom used for facing bricks. See Chapters Five and Seven for the development of these two brickmaking methods. It is more likely that Butterfield was reacting against the growing use of brick presses to finish facing bricks.

11. For a description of Prosser's method see also Dobson (Part 1 1850, p.31) and Barnard (1972, p.48-49).

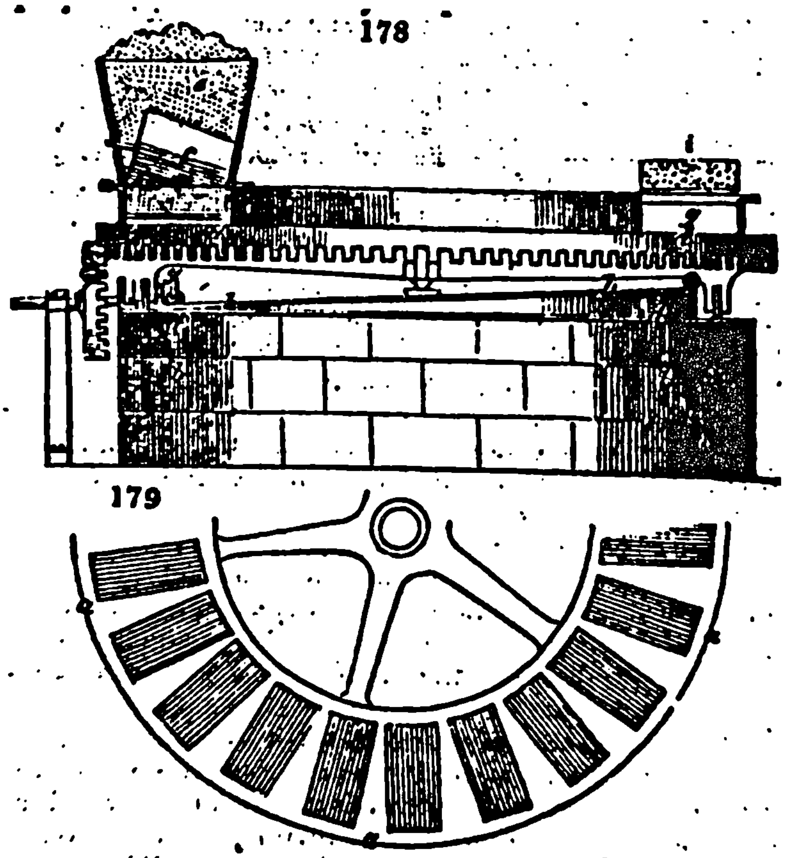


Figure 4.1. Brickmaking machine patented by Edward Jones, British Patent No. 6876, 1835, Part I.
[From Andrew Ure, A Dictionary of Arts, Manufactures and Mines (1839) p. 186]

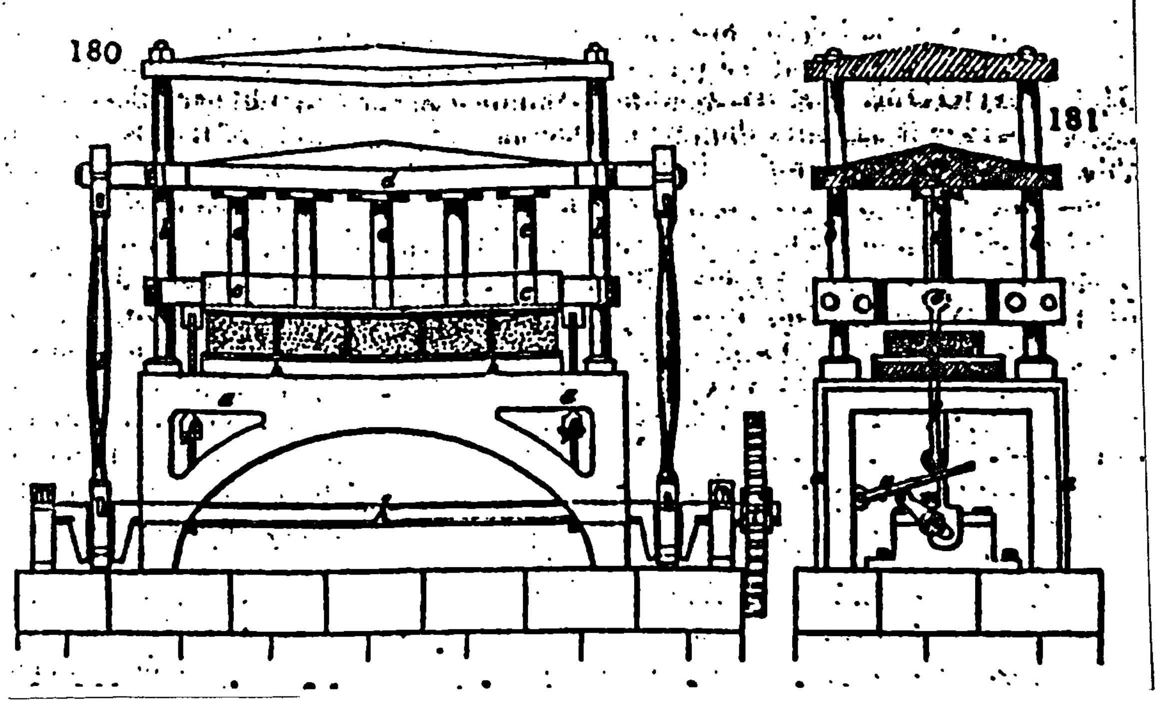


Figure 4.2. Brickmaking machine patented by Edward Jones, British Patent No. 6876, 1835, Part II.
[From Andrew Ure, A Dictionary of Arts, Manufactures and Mines (1835) p. 188]

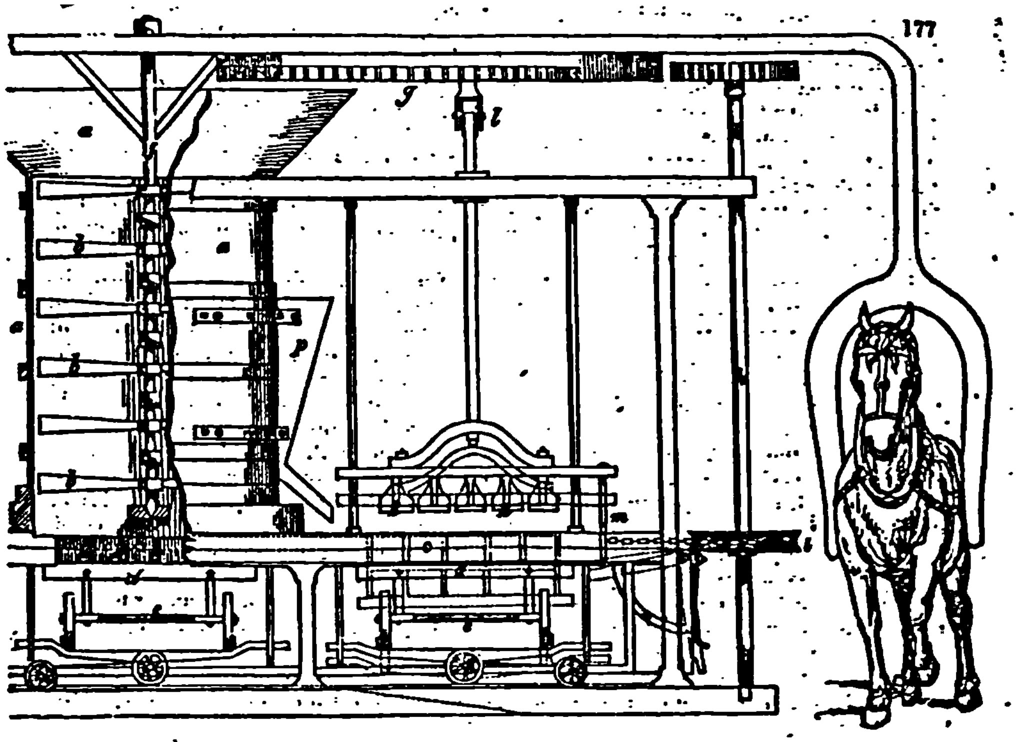


Figure 4.3. Brickmaking machine patented by Thomas Staniford (or Stainford) and George Henry Lyne, British Patent No. 5246, 1825. [From Andrew Ure, A Dictionary of Arts, Manufactures and Mines (1835) p. 186]

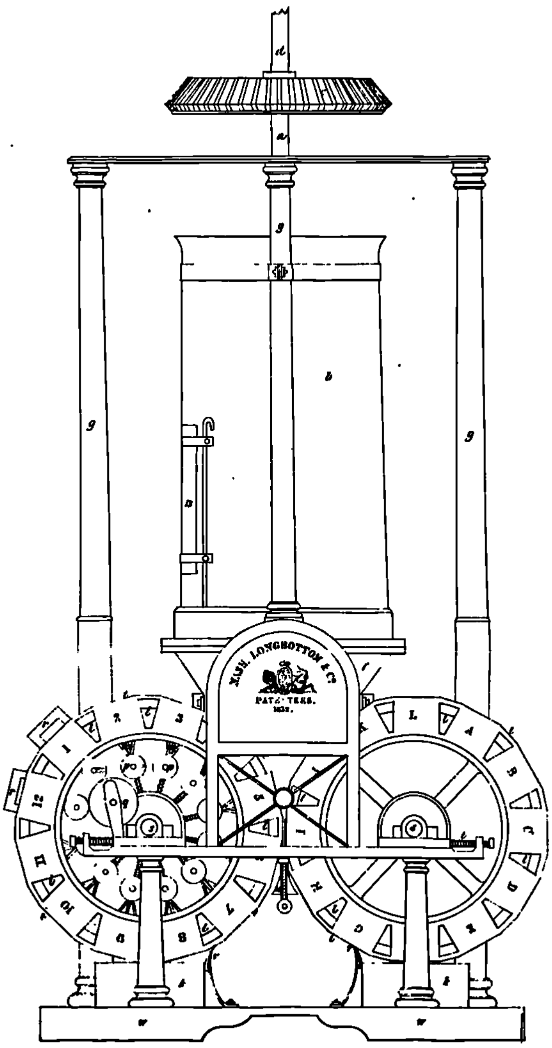


FIG. 2.

Figure 4.4. Vertical wheel moulding machine, British Patent No. 6257, 1832, John J. Clark, John Nash and John Longbottom. [Drawing enrolled with patent]

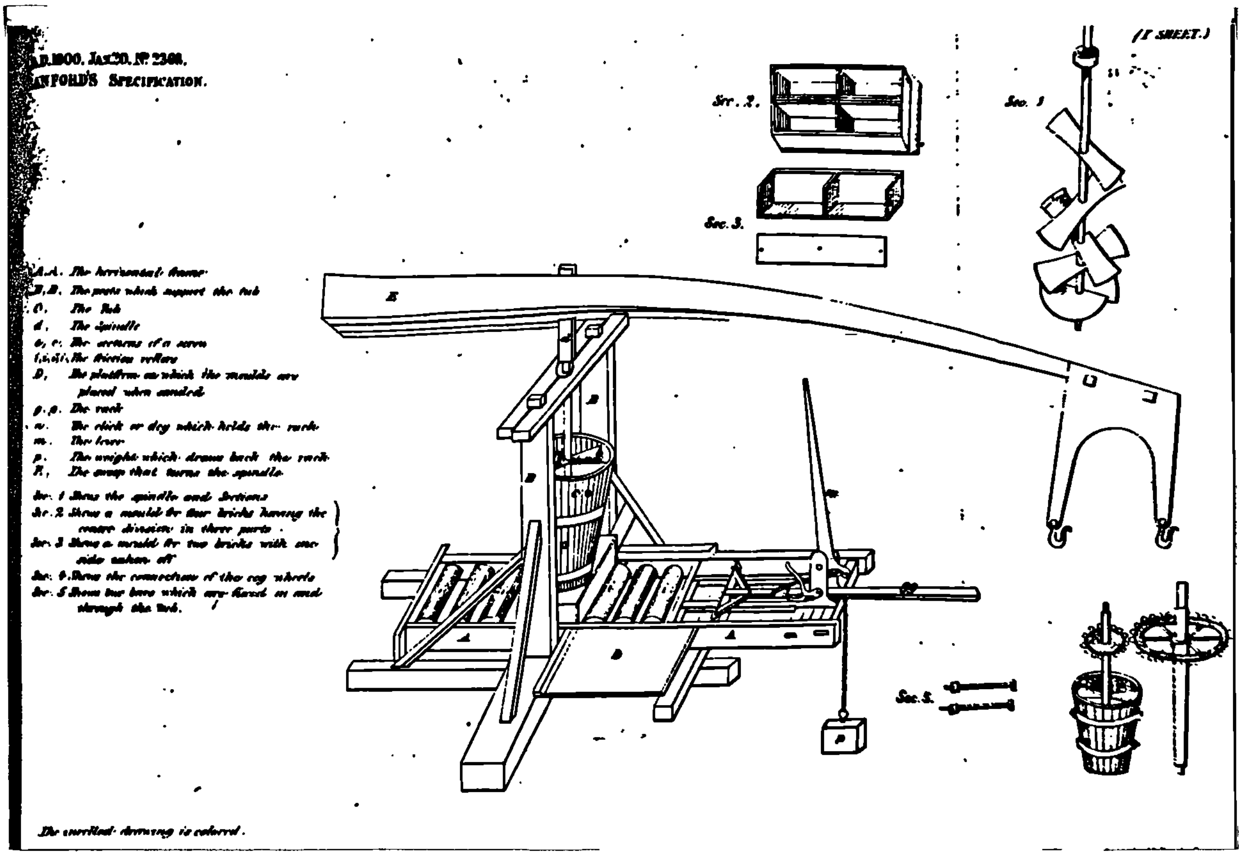


Figure 4.5. Machine invented by Apollos Kinsley of Hartford, Connecticut, U.S.A., patented by Isaac Sanford, British Patent No.2368, 1800.
[Drawing enrolled with patent]

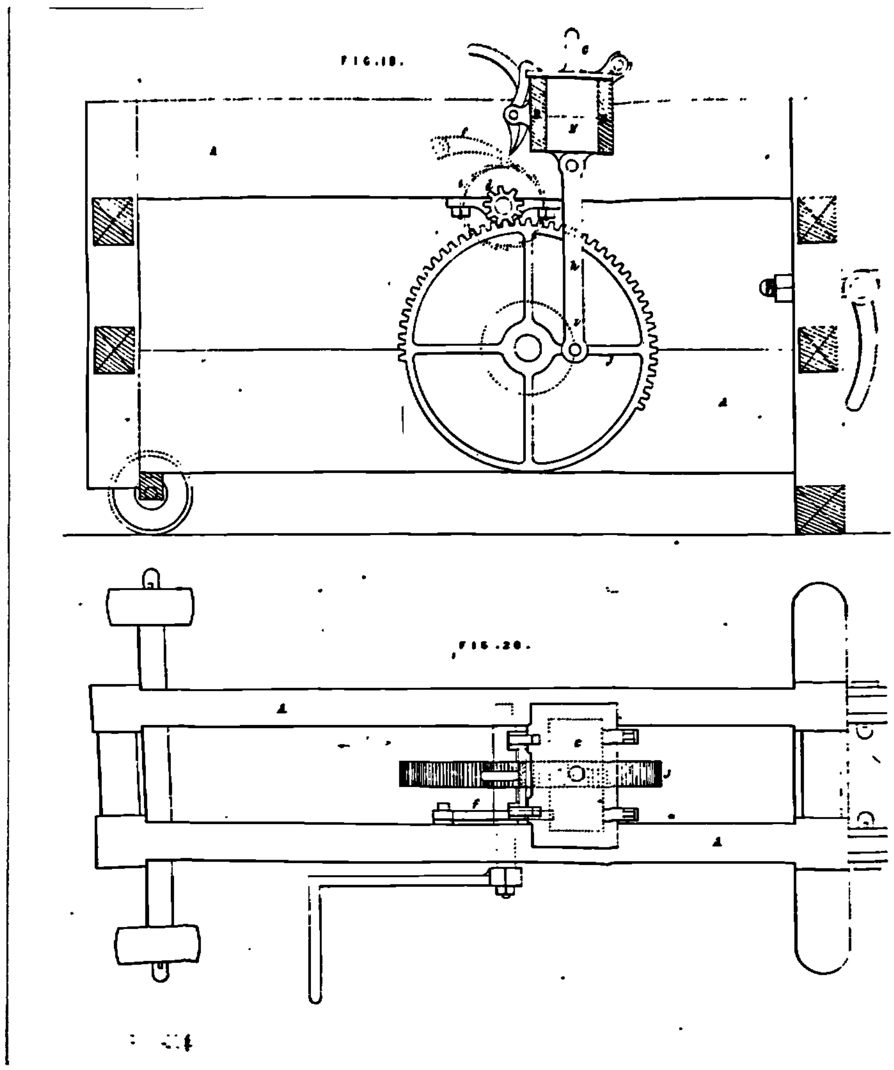


Figure 4.6. Brick press by Samuel Roscoe Bakewell, British Patent No. 5985, 1830. Top, side view; Bottom, top view.
[Drawing enrolled with patent]

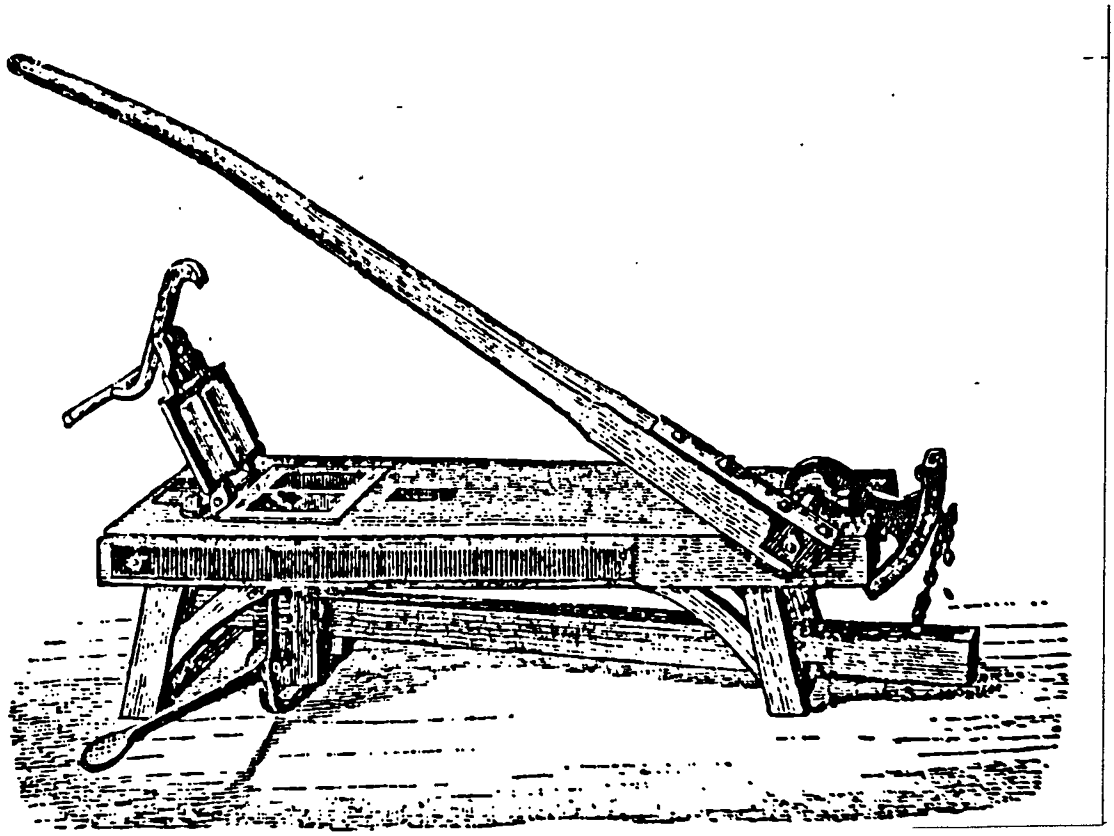


Figure 4.7. Early lever-operated brick press.
[From Emile Bourry, A Treatise on Ceramic Industries (1901) p.288]

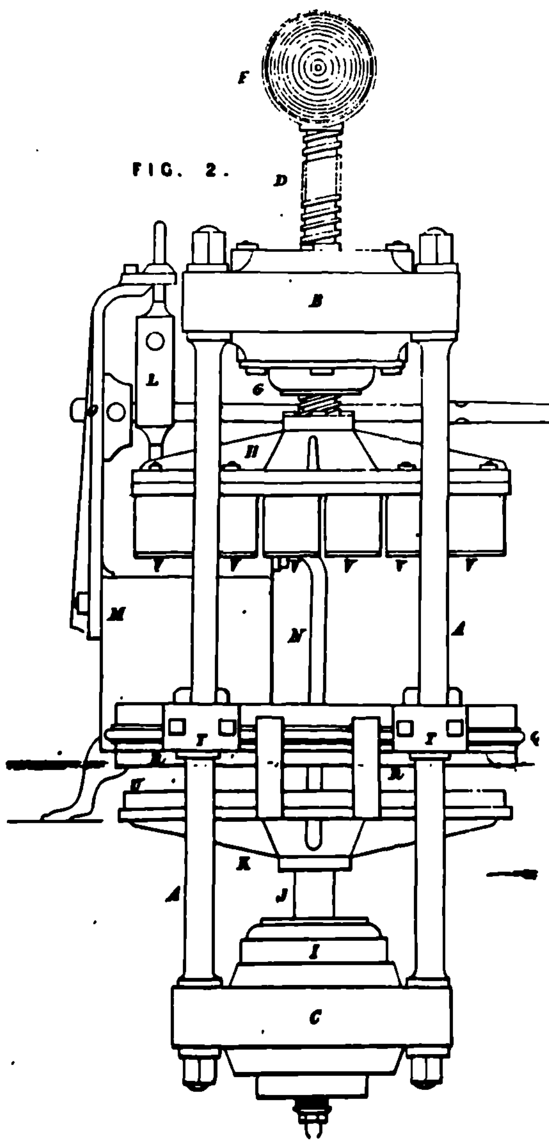


Figure 4.8. Hydraulic brick press by William Mencke, British Patent No.5681, 1828.
[Drawing enrolled with patent]

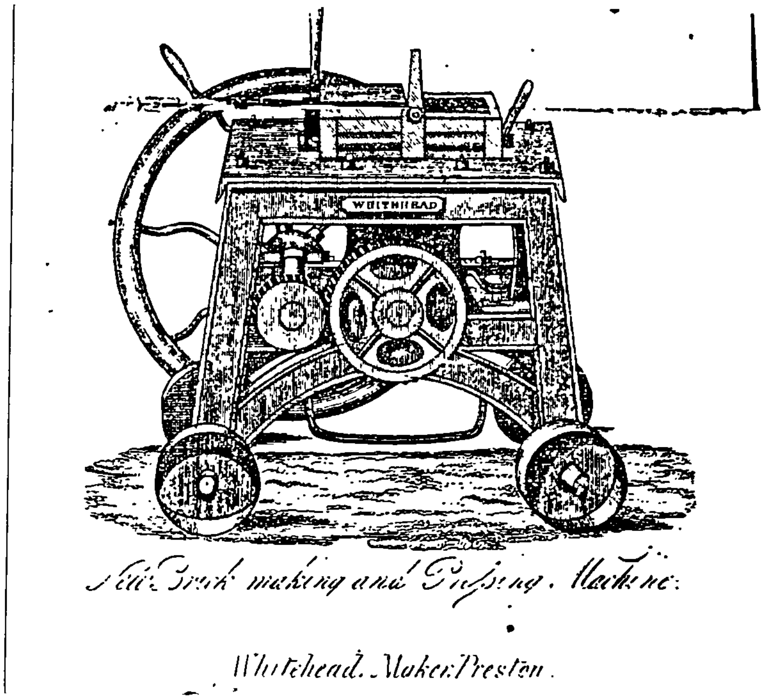


Figure 4.9. Brickmaking and pressing machine, John Whitehead, manufacturer.
[From John Whitehead's Trade Catalogue, 1851]

CHAPTER FIVE

EXTRUSION MACHINERY IN THE 1840'S

5.1.
Agricultural Drainage and Tilemaking

The rigid regulations of the excise duties on ordinary bricks discouraged experiments with machinery in most brickyards prior to 1850. Without the opportunity to test their clayworking machines in actual brickmaking situations, inventors were unable to identify or correct design defects or imperfections. But this opportunity came eventually from the agricultural sector as the growing interest in draining argricultural lands created a lucrative market for machinery capable of manufacturing large quantities of drainage tiles and pipes. Moulding and pressing machines failed to meet the needs of these new tilemaking consumers. Instead, an entirely different process for making hollow clay goods was invented and developed which surpassed the moulding method in performance and popularity and ultimately became the predominant clayworking method in this country.

The need for effective underdrainage of heavy clay soil farm land had been recognized from the end of the eighteenth century. This need was emphasized during the agricultural depression between 1813 and 1836 when many clay soil farms were either abandoned or extremely undercultivated (Ernle 1912, p.362-3). Stiff clay soils produced smaller harvests during a shorter growing season and at greater cost and effort than the lighter more porous soils. Various systems of drainage were proposed by agricultural engineers and drainage specialists who wrote widely-read treatises on the subject (Smith 1831; Stephens 1848). The importance of this effort was acknowledged as early as 1794 when excise duties on bricks and tiles "for the sole purpose of draining wet and marshy land" were removed (7 Geo. IV.c.49.s.3.). Bricks or tiles for land dainage were to be clearly stamped or moulded with the word "drain" and their use for any other purpose was subject to a penalty of £50.

Further encouragment was offered in the 1840's when several acts were passed in Parliament providing funds for permanent drainage improvements on landed estates. The Public Money Drainage Act of 1846 authorized the Treasury to advance public money to landowners, up to two million pounds in Britain and one million in Ireland, to be administered by the Enclosure Commissioners. A second act followed in 1850. The Private Money Drainage Act of 1849 was formulated to extend the protection of public administration to landowners who chose to borrow from one of the private drainage companies.[1] Throughout these years large sums of money were spent on making thousands of acres of farm land agriculturally profitable.

The foundation of the Royal Agricultural Society of England (hereafter RASE) in 1838 and the publication of its popular journal edited by Philip Pusey were instrumental in fostering a general interest in land drainage. Pusey estimated in 1841 that there were "probably at least 10,000,000 acres in England which required to be tile-drained, perhaps many more" (Journal of the Royal Agricultural Society 1841, p. 103, hereafter JRASE). Many articles appeared in the journal discussing the various methods of drainage and Pusey himself campaigned actively for passage of the drainage acts (Spring 1963, p. 139-148). The ancient method of drainage, first practiced in Essex and Suffolk and emulated elsewhere, was called thorough drainage (or thorow). A trench from two to two and a half feet deep was cut at intervals along the field and the bottom was filled with boughs, peat or twisted straw and then covered over with earth. A more lasting solution was to fill the trenches with stones before covering, but increasingly clay tiles and pipes, which were lighter and more permanent, were preferred where they could be obtained (JRASE 1843, p. 23-44).

Drainage tiles were moulded by hand in a process similar to hand-moulding bricks and often were made in the same small brickyard in rural locations. Where the demand for bricks was great, as in urban areas, the manufacture was carried on in separate yards with tileries specializing in a large number of hollow clay products (Dobson Part 1 1850, p. 43; Part 2 1850, p. 51). Preparation of the clay for tilemaking was similar to that for brickmaking although the clay itself was often stronger and the pug mill used for mixing it differed slightly from common brick earth mills, particularly in London tileries. Drainage tiles were considered the coarsest class of earthenware in consequence of the rough treatment they received and the fact that they were buried in the soil.

Tiles were made in a variety of shapes, the most popular being the large semi-circular tunnel tile, the smaller U-shaped tile with a flat "sole", and the cylindrical pipe tile. For each of these there was an appropriately sized rectangular flat mould from about one-half to one inch deep and a specially shaped bender or "horse" which gave the tile its curved shape. Tunnel tile moulds could be as large as 18 inches by 15½ inches while drain tiles for use with flat soles ranged from 13½ inches by 11 inches to 13½ inches by 7½ inches. The following description of drainage tilemaking by hand at the *Foddestone Brickyard on the Stow Hall* Estate in Norfolk appeared in the first volume of the JRASE: "In the process of making tiles, the moulder fills and strikes the mould, takes it off the stock, and lays it on the bender; an attendant boy presses it to the bender, dips his hands in water and washes and smooths the tile, then carries it on the bender, and places it on the shelves...where it dries by a thorough draft...; when they are dry enough to move without damage they are placed one upon another on the hakes or piles in the shade till placed in the kilns" (Wiggins 1840, p. 352).

Pipe tiles were made in a slightly different way. After moulding the clay to the required size, it was wrapped around a wooden cylindrical drum. The edges were closed, the surfaces were smoothed, and sometimes a flange was formed entirely by hand as the drum revolved, just as in pottery work (Dobson Part 1 1850, p. 109). This method was partially mechanized at least as early as 1725 when William Edwards obtained a patent for an "engine" to turn a potter's wheel fitted with a plug of wood for the purpose of making pipes. He claimed that "one wheel could turn off fifteen or twenty dozen pipes in a day" (British Patent No. 480, 1725). Pipe tiles usually were made from twelve to eighteen inches in length and their diameter could vary from three inches to over sixteen inches, each pipe being priced according to the size of the bore. In the Staffordshire potteries at mid-century, a hand-made pipe tile without a socket was sold for 1d. per inch of bore (Dobson Part 1 1850, p. 109). Priced in such a way, hand-made pipe tiles were totally outside the means of many farmers, although they provided a far superior method of draining agricultural land. It was reported that one farmer could consume as many as 520,000 tiles to drain his land, and Philip Pusey commented that the "high price of draining tiles is almost prohibitory of draining" (JRASE 1841, p. 93 and 103).

There was enormous variety in the prices of hand-made drainage tiles in different parts of the country. Small tiles without soles were sold in Norfolk at 25s. per thousand in 1840 while in Gloucestershire and Somersetshire they sold for 40s.. Two years later in the Isle of Wight they cost as much as 55s. per thousand priced at the yard. The price of tiles was based on the cost of labour and the coal for burning which varied greatly throughout the country. Added to the high cost of the pipes and tiles themselves was often the cost of cartage from the nearest brickyard to sometimes quite distant rural areas where they were used. This generally also entailed a large number wasted due to breakage, a loss calculated to be from ten to twenty per cent of the total (Stephens 1848, p. 141). Much of the discussion about tile drainage in the agricultural press centred on the best means for reducing the price of tiles and, consequently, the cost per acre of drainage. This and the incentive to increase the availability of clay drainage tiles, encouraged by the advantages of public funding for drainage schemes, directed the attention of many tilemakers to the possibility of adopting machinery for their manufacture.

Most machines invented for moulding bricks, whether for soft or dry clay, were adapted for making tiles simply by changing the size and shape of the mould boxes. One machine devised solely for making tiles, however, was patented in 1833 by Robert Beart of Godmanchester (British Patent No. 6738). Beart's tile machine was a simple variation of the usual moulding machine. A pug mill was suspended on a large wooden frame above two moulds that were attached to a circular cross-frame revolving on a spindle, each mould coming successively under the opening of the mill to be filled. Attached to the underside of each mould was a piston activated by a screw and a series of toothed wheels which, when turned by a pair of handles, pushed the clay up out of the box. Rather than turning it completely out, however, Beart proposed to have a workman cut off the top inch of the clay protruding out of the mould with an instrument shaped like a rolling pin with a wire stretched across one side. After one tile was sliced off, the handle was turned again to push up another inch of clay and so on until the mould was emptied. It was still necessary to lay the tiles over a bender to shape them just as in hand moulding.

Edward Crocker, steward to the Sixth Duke of Bedford, installed one of Beart's machines at the Duke's kiln at Husborne Crawley in 1833. It isn't entirely clear if this was one of his first patented machines or a simplified version that was manufactured later and illustrated in the Journal of the RASE in 1841. Beart's original patent had allowed for several variations, for example, the elimination of the pug mill and the substitution of a rack bar for the screw. The much smaller machine illustrated in 1841 included these variations and, in addition, was reduced to one hand-fed mould box instead of two. It also had a spring stop mechanism to lock the piston in place while the tile was cut off, whereas such an apparatus did not appear in either of his patents of 1833 or 1834 (Figure 5.1.; JRASE 1841, p. 98; Cox 1979, p. 37-38).[2] Apparently the experience gained from having his machines used in various brick and tile yards in the area allowed Beart to make the necessary changes to adapt them to local needs and to ensure their successful operation (Cox 1979, p. 38; Ransome Collection TR RAN P1/A2).

It is possible improvements were made when he contracted with the agricultural implement makers, Ransomes of Ipswich, to manufacture the machine. In 1843 the RASE awarded a medal to Ransomes for "a Beart's brick machine improved by a Mr. A. Stickney of Ridgemont, Holderness" (JRASE 1843, p.369). Beart's machine was found in practice to turn out 2000 tiles a day, a great increase over hand-made products. Although he claimed it would reduce the price of tiles and soles to between 28s. and 32s. per thousand, the estate records showed that at Crawley the combined price was 38s. per thousand (Cox 1979, p.38). It appears that despite increasing the kiln's output, the machine was not able to supply the growing demand for drainage tiles in the vicinity. The Duke subsequently began to look around at other machines to increase production still further at this site (Cox 1979, p.39).

Another apparatus for making tiles that received some exposure in the Journal of the RASE was the "machine" invented by William Irving in 1841. This device was merely a wooden box with its sides hinged to a table into which a workman pressed the clay. A bar with wires attached to one side was drawn across the clay cutting it into sixteen tiles "like the leaves of a book standing up." The sides of the box were then let down and the flat tiles were removed one by one and bent on a horse (British Patent No.9165, 1841; JRASE 1842, Parts 2 and 3 p.398-400). Irving's invention was one of those tested by the Duke of Bedford at Crawley to assist Beart's machine but, unfortunately, the wires continually broke and the apparatus had to be returned. Apparently other tilemakers in the area who tried the device had the same problem (Cox 1979, p.39).[3] It soon became obvious that machinery for moulding tiles in imitation of hand-moulding methods, requiring a separate process for bending, could not compete in speed or output with newly invented extrusion machines that produced already bent tiles in one operation.

5.2.

The Introduction of Extrusion Machines

Extrusion machinery was based on an entirely different principle for forming bricks and tiles. A column or bar of clay was forced through an appropriately shaped aperture at the mouth of a large container and then cut to the desired size. The form and size of the column was determined simply by the configuration of the die through which the clay was extruded. This was an iron plate with the shape of the tile or pipe cut out of its centre and attached by screws across the opening of the container. It is not difficult to imagine how this machine may have evolved from the use of a hopper and piston to control the flow of clay into the moulds in many early moulding machines.

A toolmaker named Johann George Deyerlein, residing in Cockspur Street, London, appears to have been the first person to patent the process in this country in 1810. Deyerlein particularly specified that the clay should not be made so wet as was usual for moulding bricks and tiles so the finished products would not lose their shape while being removed from the machine. His invention consisted of two hoppers, each having an orifice with seven holes capable of forming seven bars of clay at the same time. A piston pressed the clay out of each hopper alternately and the seven bars thus extruded were placed on a movable barrow where they were cut by hand into four bricks each with a wire cutter. A variety of special mouthpieces was suggested for making tubes, mouldings and pipes of different shapes (British Patent No.3319, 1810). From this patent a large number of machines subsequently was developed by other inventors. These differed from each other in the placement of the hopper (either vertically or horizontally), the position and design of the orifice or die plate (either at the bottom or at the sides of the hopper), and in the means for squeezing the clay through the shaped dies (with a piston, the blades of a pug mill, or a series or rollers).

The simplest arrangement for a piston-operated machine was a horizontal box with a single action piston to force the clay out of the moulding orifice placed at one end. Machines like these were limited in speed because as the hopper was emptied, the operation came to a complete stop while the piston was drawn back and the box reloaded with clay. For this reason they came to be called "stupids" (British Patent No. 4138, 1817 William Busk and Robert Harvey). Faster in operation were machines like Deyerlein's with reciprocating pistons forcing the clay first out of one cylinder and then the other. Richard Weller's machine, patented in 1845, had two cylinders, one at each end of the machine, both holding a piston activated by a lever. The machine's most unique feature was the way it was filled. When one cylinder was emptied it swung from a horizontal to an upright position to enable it to be filled while the other was engaged in making tiles (British Patent No. 10,577, 1845). Another machine designed and patented by Frederick Ransome and John Warren similarly had two horizontal containers with dies at their outer ends and doors on top to recieve the clay. A continuously rotating pinion in the centre of the machine caused the pistons in each cylinder to move alternately in opposite directions, thus forcing out the clay (British Patent No. 11,282, 1846).

A variation on this type was a machine by John Hatcher of Benenden, Kent that apparently was not patented. The clay was thrown into one of two vertical cylinders and placed under a stationary piston which extruded a length of pipes or tiles onto an endless belt where they were cut by hand. When one cylinder was emptied the other moved beneath the piston and the process was repeated (Figure 5.2.). Yet another arrangement was the machine patented by William Worby in 1844. Three small vertical cylinders were attached to the sides of an ordinary pug mill to receive the clay. Each cylinder contained a piston attached by a rod to a wheel above the mill. A crossbar worked by a horse caused a roller to run along the edge of the wheel depressing each piston in turn and pushing the clay out of the orifices at the bottom of the cylinders (British Patent No. 10,237, 1844).

Practical experiments with piston-operated extrusion machines in making drainage tiles during the 1840's revealed several technical problems. One serious disadvantage was the frequency with which they broke down from hardened clay or small stones getting lodged in moving parts or obstructing the die plate. Another objection was the air which was expelled by the piston along with the clay, sometimes with such force that it caused the tiles to be misshapen. One author complained, "a constant crackling and exploding noise is heard whilst the tiles are being protruded by the piston" (Stephens 1848, p. 143). To solve these problems, several machine makers began to include screening devices to intercept debris in the clay. Robert Beart's improved extrusion machine, patented in 1845, contained a grating across the end of a hollow piston that collected the stones while it was in motion. He also provided a valve in the top of the hopper to regulate the air around the piston (British Patent No. 10,636, 1845). Similarly, five years after his first patented machine, Henry Clayton began to include "slide air valves to the cylinders... new patented perforated metallic gratings... and all the internal cog work is cased over to prevent the clay and grit working into them" (JRASE 1849, p. 13).

A major disadvantage of piston operated machines was the sometimes lengthy delay while the piston was drawn back and the hopper refilled or, in the case of double-action machines, while the motion of the piston changed directions. Some inventors attempted to solve this problem by dispensing with the piston altogether and attaching the moulding orifices directly onto the underside of a large pug mill. Frederick Etheridge's "Patent Tile-Making Apparatus" was little more than an elevated pug mill with a series of dies along the bottom with mandrils attached to bend the clay as it emerged (British Patent No. 9538, 1842; see also No. 11,041, 1846, William Benson). Because the extrusion process required a stiffer clay than moulding machines, Henry Franklin proposed to substitute a large archimedean screw for the knives in the pug mill to submit the clay to greater pressure, thus enabling it to be forced out dies in the sides rather than underneath the mill (Figure 5.3.; British Patent No. 11,334, 1846). Like others of this type, Franklin claimed the great advantage of his machine was that it "combined the process of preparing the clay with the manufacture of the pipes" (<u>The Architect and Building Operative</u> 1849, p. 228; British Patent No. 8267, 1839, James White; <u>Mechanics Magazine</u> 1841, p. 370).

The die plates used by most extrusion machines caused another serious problem. As the stream of clay was forced out of the moulding orifice, the surfaces dragged against the stationary plate making jagged edges and rounding off the corners of the column of clay. This wasn't a major difficulty in the manufacture of rough drainage tiles, but it was later objectionable in the production of ordinary bricks. To avoid this problem another type of extrusion machine was invented using rollers or compressing cylinders to form the stream of clay. This was first suggested in 1830 when one inventor specified that the prism of clay extruded through a die should pass between a pair of rollers to dress its surfaces to the required shape and smoothness before it was received on a table to be cut (British Patent No. 5917, 1830, Ralph Stevenson). The next step was to eliminate the die completely and allow the rollers alone to shape the clay column. The Marquess of Tweeddale is usually credited with the invention of this method in 1836, but two years earlier a French brickmaker residing in London, John Baptiste Pleney, was granted a patent for a brickmaking machine that was a preliminary experiment with the process. Pleney proposed to place the brick earth on a movable bed or table where it was compressed under a series of rollers of descending sizes to the desired thickness. Vertically arranged wires along the sides trimmed the column to the appropriate width while another horizontal frame of wires cut it into bricks or tiles (British Patent No. 6701, 1834).

Tweeddale's machine was considerably more complex. A mass of tempered clay was fed by hand between two cast iron cylinders, one above the other, each covered with moleskin or leather to facilitate its movement and prevent sticking. The clay was compressed to the necessary thickness and width and then carried by an endless web over another cylinder that bent the slab to the curved form of a drainage tile. From there it was passed through two vertical rollers and a series of adjustable graduated hoops that further formed it to the required shape. At this point the movement of the clay was temporarily stopped and the column was cut into tile lengths by a wire stretched across a horseshoe-shaped frame suspended above the machine on a connecting rod (British Patent No. 7253, 1836; Figure 5.4.). For the manufacture of bricks the specification was slightly altered -- the distance between the two cylinders was increased, two smaller vertical rollers were placed in front of the large cylinders to control the width of the clay before it was compressed, and the bending cylinders were eliminated. Another patent by Tweeddale two years later made some alterations to the cutting apparatus and added a cistern to drop water on the tiles while they were being bent as they had a tendency to crack along their backs from the stiffness of the clay (British Patent No. 7757, 1838; Stephens 1848, p. 142).

Early trials of the inventor's tile machine in 1838 at the works of Dean and Henderson at East Fenton and George Reid at Ballencrieff in the East Lothian were highly successful (Tweeddale MSS, 9 May 1838 and 10 May 1838). But the brickmaking apparatus apparently encountered several failures at brickworks in the south of England and Tweeddale contemplated further improvements in the method of feeding the clay to the machine (Tweeddale MSS, 9 March 1839 and 11 March 1839). The following year he was involved in negotiations with James and Ogle Hunt to form a company to promote the machines. Recognizing some weaknesses in the machine for making bricks, James Hunt conferred with Robert Stephenson and I. K. Brunel about the problems and Tweeddale eventually was persuaded to allow the three of them to make the necessary alterations at Brunel's works at Chippenham. The improvements subsequently were patented in Hunt's own name in 1842 (British Patent No. 9243, 1842; Tweeddale MSS, 17 August 1839 and 13 Sept. 1839).

In the new patent, the principle of the original machine was retained, that is, leather covered rollers compressed and shaped the bricks. But instead of moving horizontally through the machine, the clay was passed vertically from a leather covered cast iron hopper mounted above and was cut by a wire stretched immediately below the cylinder. Both the clay and the surfaces of the rollers were kept moist by water dripping from a cistern through a series of channels behind the leather. Another improvement in the new patent was the provision of separate pallets running along an endless chain beneath the compressing cylinders to receive the bricks in place of Tweeddale's endless moleskin (Figure 5.5.). In promoting the new machine, James Hunt pointed out that the clay compressed between the rollers was noticeably denser and more durable than that extruded by a piston or a pug mill. This reduced the chance of tiles being broken during carriage (Hunt 1841, p. 149).

Other experiments with the use of rollers in extrusion machines were conducted by a Scottish farmer, John Ainslie. Ainslie's first patent in 1841 specified a large pair of rollers to crush the clay before it passed into a horizontal mill where it was forced by a double spiral screw out through a die. The die was actually a combined die and moulding chamber in the form of three curved tiles of descending sizes. Once shaped, the stream of clay moved forward to a special cutting apparatus consisting of two wires attached horizontally to a pair of continuously revolving chains allowing the tiles to be cut without stopping the movement of the machine (British Patent No. 8965, 1841; Figure 5.6.). By 1845, Ainslie seems to have dispensed with the screw and his second patented machine was said to be an "adaptation of Tweeddale's" having a pair of rollers to force the clay directly through the moulding chamber. He also altered his cutting apparatus introducing a compressed air piston to activate the wires (British Patent No. 10,481; Transactions of the Yorkshire Agricultural Society 1845, p. 26, hereafter TYAS). A year later Ainslie patented still further improvements, this time a smaller machine fed by hand from a separate pug mill. The patent specified "a series of rollers placed in such a position as to form the mould for the brick, and moving simultaneously in such manner that the bricks shall be formed by the revolutions" (British Patent No. 11,155, 1846).[4] The machine also was adapted to form a frog in the bricks either by a projection on the rollers or with a specially designed "lifter" that raised each brick and scouped out a hollow.

The sudden and decisive changes in machine design as seen in Ainslie's successive patents over five short years were not mere whims on the part of the inventor. As we shall see below, they illustrated the rapid stabilization in the form of extrusion machinery that occurred in the 1840's as a result of deliberate efforts by the Royal Agricultural Society of England to provide a forum for the exchange of information about new machines and for testing and evaluating machine performances.

5.3.

Agricultural Exhibitions and Competitions

The exhibitions of agricultural implements at the annual meetings of the Royal Agricultural Society of England provided the national exposure and opportunities for competition that were instrumental in directing the development of extrusion machines invented during the 1830's and 40's. Besides these national meetings, older established agricultural societies in many counties held their own local meetings and competitions each year to evaluate new machinery and advise prospective purchasers. [5] The first show sponsored by the RASE which included brick and tile machines was in 1842 at Derby where two were exhibited. The following year a prize of £10. was offered to the best machine at the meeting, but as no provision was made to test the capabilities of those entered, the judges were able only to award silver medals to four competitors (JRASE 1843, p.369). At the Shrewsbury meeting in 1845, eleven machine makers exhibited fourteen different machines and by 1848 in York, no fewer than thirty-four were shown (TYAS 1848, p.42). After that the number of competitors began to decline as more sophisticated methods were devised to test the machines and as particular manufacturers began to show a decided competitive advantage over the rest of the field.

The trials and judging of machines at the Society's exhibitions and subsequent critical reports in their journal were extremely important for two reasons. First, they helped to clarify for machine makers the requirements of the agricultural community, who were the primary consumers of brick and tile machinery prior to 1850. Second, they encouraged and rewarded the development of machines most suited to those needs. Two individuals were particularly important in this endeavour -- Philip Pusey, editor of the JRASE, and Josiah Parkes, consulting engineer to the Society, both of whom were regularly called upon to act as judges. The aims of the Society were clearly reflected in the types of machines chosen to receive the top prizes and commendations in their publications.

In stark contrast to the claims made by many early promoters that brick and tile machines reduced the reliance upon hand labour, the RASE gave the greatest encouragement to machinery that helped to create employment for unemployed farm labourers. In 1843, Philip Pusey remarked: "There is little doubt that the next winter will bring with it much want of employment for country labourers; but this evil may be remedied by landlords who will employ, in the lasting improvement of their own properties, those who stand unwillingly idle, only it is necessary that their stewards should exert themselves now and make preparations in time...a tilemachine should be procured in order that the tiles may be got ready for the season when they will be required" (JRASE 1843, p. 49). This statement represented the attitudes and values of the older rural social order -- the enlightened self-interest of the landed classes in the profitable improvement of their property and a benevolent paternalism towards the dependent landless labourers -- in contrast to the profit-seeking values of the new capitalist entrepreneurs. The development of tilemaking machinery over the next decade, however, clearly demonstrated the willingness and ability of machine manufacturers to adapt and accommodate to the demands of these customers.

Edward Dobson summarized the requirements of the market for tile machines: "They are most wanted precisely in situations where a brickyard would be an unprofitable speculation, viz. in the open country, and often in places where the cost of carriage from the nearest brickyard would virtually amount to a prohibition of their use. What is wanted, therefore, is a good and cheap method of making drain tiles without much plant and without erecting an expensive kiln as the works will not be required after sufficient tiles have been made to supply the immediate neighbourhood...making drain tiles a 'home manufacture' is, therefore, a subject which has much engaged the attention of agriculturalists during the last few years" (Dobson Part 1 1850, p.45). The needs of rural tilemakers did not necessarily call for the best practice technology. Two of the most technically sophisticated and complete roller extrusion machines, those invented by the Marquess of Tweeddale and John Ainslie, were criticized frequently early in the decade for being too large and because they required steam power to operate. Both subsequently were redesigned on a smaller scale suitable for the application of hand power. The Builder described how the unique requirements of the consumers caused Tweeddale's company to alter his original invention: "At first, these machines were contructed on a large scale...but by recent improvements, the apparatus is brought down to the power of a common labourer, not necessarily acquainted with the process of tilemaking, and it is thus made available in the drainage of private estates, where even only a moderate supply is required" (The Builder 1843, p.195).

Another early manufacturer significantly altered his machines to satisfy the needs of the market, but only after several years experience and the emergence of strong competition. Robert Beart, inventor of an early tile-moulding apparatus which included a horse-operated pug mill to feed the moulds, not only reduced the size of his original machine, but eventually patented a small hand-powered tilemaking device on the extrusion principle in 1845. By 1847 he admitted in a trade circular: "The patentee was the first in 1832 to introduce machinery for making draining tiles; and having from that period worked machines both by horse and hand power, the result of his experience is that small machines are best adapted for large as well as small works, and produce more uniform and better articles. The difficulties and confusion attendant upon a machine making from twelve to fifteen thousand per day are so great that he has given up working by horse power and has now, in each establishment, two small hand machines" (RASE Show Catalogue 1847).

Machinery was expected to be not only hand powered but also labour intensive. The number of men and boys required to operate each machine was always calculated and reported at the RASE exhibitions. In 1843 Tweeddale's modified hand powered machine was said to need "a man and a stout lad to work it and two boys to carry the tiles to the drying sheds." Etheredge's combined pug mill extrusion machine required "one man to fill the mill, two boys to cut off the pipes and place them on barrows, one man and a boy to wheel away and set them to dry on frames" (JRASE 1843, p.370-71). Most other machines manufactured during the decade were operated by three or four attendants.[5] . It is apparent that by 1840 machines were available that were capable of mechanized, large-scale brick and tile production, but the demand was not in that direction. Agricultural consumers wanted hand powered, labour intensive machinery and entrepreneurs were quick to respond.

Machines designed to maximize labour apparently did not encounter significant opposition or resistance from agricultural workmen. Alan Cox reported that in the 1830's the steward of the Sixth Duke of Bedford did not anticipate difficulties with the workers over the introduction of new machinery because he said, "it will no doubt be a means of giving scope for the employment of labour..."(Cox 1979, p.37). Similarly, F.W. Etheredge wrote in his prize essay on tilemaking in 1845: "Although machinery has reduced the price of the article, it has not been the means of throwing out of employment a single hand, but it has created not only labour for the poor by an immense increase in the consumption of tiles, but also a greater amount of produce for the farmer..." (Etheredge 1845, p.476-7). Nevertheless, new machinery was sometimes greeted with suspicion or indifference by country labourers because of its novelty or complication. One tilemaker reported that because of the savings he accrued by using a machine, he was able to increase the wages of his labourers "to put them in good humour with the instrument" (R. Garrett and Sons trade circular c.1847, p.3). Another writer commented on unspecified unfavourable circumstances an early Tweeddale machine had to overcome, "the parties employed being decidedly hostile to its success" (Tweedale MSS, 9 May 1838).

Some manufacturers were aware that it wasn't sufficient merely to find puchasers for their products. The success or failure of a machine often depended upon initial supervision in setting up the apparatus and in training the workforce to use it properly. For example, John Birnie, lessee of Tweeddale's patented machine, wrote to the inventor in 1839: "We shall never have justice done to the brick machinery until we can send people to the works under our own influence for instruction..." (Tweeddale MSS, 5 Sept. 1839). F.W. Etheredge also observed that the failure of machinery in some works could only be attributed to mismanagement: "The great evil is that the inventors of the machines do not make it imperative on puchasers to allow them to send a man to start them properly, for if the slightest difficulty is found by the workmen, the machines are condemned (as they are generally prejudiced against improvements) with only a few hours' trial" (Etheredge 1845, p.476).

The machines most highly praised by the agricultural societies were those with simple, sturdy construction and uncomplicated mechanical operations. A simply constructed machine was more likely to gain the acceptance of the workforce and less likely to experience breakdowns and stoppages of the work. The RASE summarized its aims: "The first requisite in an agricultural implement is efficiency, the second simplicity, and this last is scarcely less important than the first, inasmuch as simplicity is the very quality which ensures its being efficient in the hands of ordinary unskilled labourers, and at the same time affords the best guarantee for its being easy to repair when an accident does happen" (Thompson 1849, p.66).

Generally speaking, machines using rollers to extrude the clay, like those by Tweeddale, Hunt or Ainslie, were considered more reliable and less susceptible to damage. John Ainslie claimed in his company's publications that his machines were so simple in their construction that with common care they cannot get out of order, and any country mechanic can easily repair them" (The Ainslie Brick and Tile Machine Company c.1847, p.2). This was undoubtedly an important factor for machines set up in remote rural locations. Similarly, the engineer Robert Bridges, who made several of the Marquess of Tweeddale's first machines, wrote to the patentee assuring him of their successful operation despite the most difficult conditions: "The tile machine has been now working in different parts of the country and in circumstances most unfavourable. In every instance the charge of the machine has been committed to persons ignorant of their construction and unaccustomed to the management of machinery, and in most cases the clay has been prepared by common labourers equally ignorant of the method of preparing clay for making bricks and tiles...After undergoing such an ordeal it is quite ridiculous to talk of them being a failure" (Tweeddale MSS, 9 May 1838). The simplicity of Tweeddale's machines also was noted by the editor of The Builder when he remarked that they were "free from the usual objection of being intricate. They are, on the contrary, exceedingly easy in operation, portable and not liable to derangement" (The Builder 1843, p.195).

Pug mill extrusion machines likewise were believed to be less prone to mechanical failure as well as particularly easy to operate. Pug mills had a long history of use in many parts of the country and most brickmakers were familiar with their operations and confident of their reliability. Henry Franklin described the merits of this type of machine in 1849: "It is constructed entirely of iron, and is remarkably strong and simple, having no complexity of wheels, etc., which renders it so much less liable to wear and breakage. It is easily worked by one horse and three boys, requiring no practical experience to feed it, as the clay is simply thrown into it in a rough and unprepared state" (RASE 1849, p.93-4).

The attitude of the RASE towards piston-operated machines often was conflicting. On the one hand these machines were admired because they were considerably smaller, more portable and faster than most pug mill or roller extrusion machines. But they were also the most mechanically complicated and sensitive to mistreatment. Some of the objections to piston machines have already been mentioned, including the release of air from the piston chamber and the frequent obstruction of the die plates requiring the use of very carefully pugged and screened clay. Damage to these machines also was often caused by careless or inexperienced workers driving the piston too far forward and injuring the die plate or screening apparatus. The most diligent manufacturers of this type of machine tried to correct this shortcoming by including a stopping mechanism on the driving shaft to arrest the motion of the piston and avoid potential damage (RASE 1849, p.87 and 149).

The Society's judges were particularly critical of perpendicular piston machines which they considerd an inefficient and overly complex method of making tiles. There were several machines manufactured on this principle, the best known of which was by Henry Clayton (British Patent No.10,132, 1844; Figure 5.7.). Clayton's machine consisted of a stationary piston mounted in a strong iron frame with two swinging cylinders containing apertures for the dies at the bottom. The machine was unique in that the clay was first screened by passing it through the cylinder with a perforated grating at the bottom to catch the stones. Then, by replacing the grating with a die plate, the same cylinder was used to extrude the pipes or tiles. This method of screening was considered more thorough, although not as fast, as the wire or bar screens placed in front of the dies in most horizontal piston machines. The vertical method was also much better for making large diameter pipes as they were easily supported on a mandril immediately upon descending from the die and were less likely to become flattened by their own weight as in horizontal machines. Yet despite these apparent advantages, the RASE were adamant in their judgement against perpendicular machines.

In 1845 the judges simply pointed out that they preferred the horizontal principle for its convenience and economy of labour. At the York meeting in 1848, the opinion expressed was considerably more direct when it was stated in a summary of the competition:

"The writer cannot but think that Mr. Clayton would have done well to have discarded the vertical for the horizontal mode of delivery..." (YTAS 1848, p. 43). But Clayton was persistent in developing his machine. The following year the comments of the judges were really quite harsh: "This maker (Clayton) has displayed a vast deal of patience and ability in the endeavour to perfect an *erroneous system*.. it is at once apparent that the numerous clever contrivances by which his shifting cylinders are made as little objectionable as possible are yet proofs of the faulty nature of the original plan" (Thompson 1849, p. 66-67). The RASE strongly believed that loading the cylinders from an elevated position was inefficient as was the use of mandrils to receive the pipes or tiles after they were extruded.

These supposed "deficiences" did not seem to hamper the ability of Clayton's machine to produce a large quantity of good quality pipes. It was always one of the top competitors in exhibition trials. Despite repeated criticisms by the judges, it seemed always to be a commercially successful machine. Clayton attempted to pacify the judges by offering as an option a special horizontal extrusion chamber so the machine could be worked either vertically or horizontally. By the end of the following decade, however, he was manufacturing predominantly horizontal devices. Vertical machines by other manufacturers also apparently did not survive long after mid-century except in establishments undertaking the large-scale manufacture of sewer pipes, but it is difficult to assess whether this was because of customer preferences or bad publicity in the RASE journal. It is interesting to note, however, that even as late as the 1870's, either in response to some remaining demand by consumers or out of obstinance, Henry Clayton continued to offer for sale his "Combined Vertical and Horizontal Action Drain-Pipe and Tile Machine" little changed from that discouraged by the RASE judges twenty-five years earlier (Atlas Works. Henry Clayton, Son & Howlett 1871, p. 46; Figure 5.8.).

Economy of effort was another characteristic admired by the RASE judges. The prize-winner at the Shrewsbury meeting in 1845, a machine invented by Thomas Scragg, was praised because it was worked "with greater ease to the workmen than any other machine" (JRASE 1845). At the eighth annual meeting of the Yorkshire Agricultural Society at Beverley, John Anslie's machine, which did not win a prize, was criticized because "the force required to work it was too great for one man or two boys; and it had not even the assistance of a fly-wheel" (TYAS 1845 p. 26).[7] The RASE became increasingly concerned with this aspect of machine design during the decade.

In 1848 an attempt was made to determine more accurately the amount of hand power required to operate each machine. After preliminary trials, four competitors were given a final test in the following way: "...by allowing to each machine a number of turns of the winch, while the machine was producing tiles, so calculated that the power applied (the hand) should move through equal spaces, an account taken of the number of tiles produced" (TYAS 1848, p. 41). The machine patented by Richard Weller produced the largest number of tiles in this test but the judges objected to its operation by a lever bar because of the strain it put on the man working it and, consequently, awarded the prize to someone else. The following year, "Amos' machine for testing hand power", called a Prony brake or dynamometer, was introduced and applied to the top three competing machines, two of which, Whitehead's and Scragg's, were said to be so nearly balanced "that it would have been difficult to decide between them." On the basis of this test alone, the prize was given to Whitehead (TYAS 1849, p. 66; Constant 1983, p. 188-89).

The chief purpose of the RASE implement trials was to reward the machines that produced the greatest number of tiles or pipes in the most efficient manner. A comparison of the output of each competing machine was thus the most important aspect of the judging. Output could vary considerably, particularly in the early 1840's when the capabilities of the machines were only estimated or reported by contributors to the Society's journal. For example, in 1843 Etheredge's machine was said to produce 8000 tiles a day compared with 1800 one-inch pipes made by John Read's small machine (JRASE 1843, p. 371 and 374). The manufacturers of Hatcher's machine advertised in 1845 that it was capable of turning out 11,000 pipes in a ten-hour day, while Josiah Parkes claimed he had made more than 20,000 pipes a day with Scragg's machine (The Builder 1845, p.144; TYAS 1846, p.152). This enormous variety was not entirely the result of exaggerated claims by machine promoters. When the RASE engineer introduced his device for measuring hand power at the Norwich meeting in 1849, eight machines were given a trial of five minutes to determine the largest number of pipes each was capable of producing. The quantities ranged from 185 made by Whitehead's machine to 24 by Henry Franklin's screw-operated pug mill machine. The JRASE commended Franklin by saying, "the work was done in good style, but was not expeditious enough to answer" (TYAS 1849, p.66). By this time each of the top three competing machines, by Henry Clayton, John Whitehead and Thomas Scragg, produced over three times the quantities of the other exhibitors. All of these were double-action piston machines.

Quantities could be increased in various ways. The most obvious method was to multiply the number of openings in the die plate. Etheredge's vertical pug mill machine was exceptional in having eight die orifices, each die capable of forming two to four tiles. According to promotional literature, the machine was able to make from sixteen to thirty-two tiles at one time and the inventor stated he proposed to fix up to fifteen dies in the mill to increase its productive capacity still further (JRASE 1843, p.371). But as each length of pipe had to be supported on a hand held mandril, the actual capacity of the machine depended more upon the number of workmen available to receive the pipes. The die plates in early horizontal piston machines varied from one to seven openings, but by mid-century it was reported that Scragg's machine was fitted with a plate making eleven pipes of one-inch bore (TYAS 1846, p.153). The number of openings in the die plate was limited, however, by the capacity of the clay box and the strength of the piston to force the clay out through all of the openings simultaneously.

As the RASE continued to encourage the production of greater quantities of pipes and tiles, the size of the machines also was correspondingly enlarged. The capacity of the clay box in John Whitehead's first prize-winning machine was 3744 cubic inches, capable of making forty-eight two-inch tiles with one filling. In 1849, however, a new improved machine exhibited by this manufacturer had a box holding 6650 cubic inches of clay which could make seventy-five two-inch pipes or tiles (RASE 1949, p. 148-49). The enlarged capacity of the clay cylinder also required an increase in the length of the receiving table to hold the extruded pipes while they were cut. Whitehead devised a double table which enabled pipes on both surfaces to be cut simultaneously. However, as one author observed, "the practical limit to the number of lengths which can be cut at once is the distance to which the streams of clay can be propelled without losing their shape..." It was found in Whitehead's prize machine that for each two-inch opening of the die plate, five lengths of pipes, each length approximately thirteen inches, could be extruded without being distorted (<u>TYAS</u> 1848, p. 44; Figure 5. 9.).

It seems likely that the early aims of the RASE in encouraging small, portable tilemaking machinery were ultimately compromised by their increasing emphasis on greater productive capacity. Most machines eventually included wheels to make them portable, even many of the perpendicular machines like Henry Clayton's which were originally stationary. But by the end of the decade, great strength and durability, usually requiring heavy all-iron contruction, combined with increased size for the production of ever larger quantities of tiles were the qualities most often admired by the judges.

Finally, in their search for a "good and cheap" method for making drainage tiles, the price of machinery was frequently considered during RASE comptetitions and on several occasions the decision of the judges was influenced by a machine's low price. In the exhibition of implements at the Shrewsbury meeting in 1845, one of the reasons stated for awarding Scragg's machine the top prize over Henry Clayton's was that its cost was considerably less, including the dies (<u>TYAS</u> 1846, p. 152). In the same year, the low price of Charnock's machine was cited as a reason for awarding it the prize at the Yorkshire Argricultural Society competition at Beverley over the machine exhibitied by John Ainslie (TYAS 1845, p. 26).

Early in the decade there were vast differences in the prices of machines, from over £40. for a large pug mill or roller extrusion machine to £6. for a small single-action piston machine made of wood. As machine design became stabilized quite rapidly in the mid-1840's in response to consumer feed-back and competition, prices showed correspondingly less fluctuation. By the end of the decade, price differentials were an accurate indication of the size, complexity and durability of the machines available (See Appendix B). Thus, the small single-action piston machines were priced at the lower end of the scale, the larger double-action piston machines with their increased productive capacity were in the mid-range, and the more substantial pug mill machines and more reliable roller extrusion machines were priced at the upper end of the scale. Although the RASE continued to prefer the high-production, moderately-priced machines, the qualities of higher priced models often were recognized. In 1847 it was acknowledged: "The machine invented by Mr. Ainslie made pipes of better quality than any other in the yard...Its high price and the slowness of its action must prevent its coming into common use unless much improved, but it would be valuable to any one who was anxious to make a limited number of tiles of very superior quality, regardless of expense" (TYAS 1849, p. 68).[9]

5.4.

Manufacturing and Marketing Tilemaking Machinery

The growing interest in land drainage, along with financial opportunities available for land owners who wanted to invest in drainage schemes, provided the basis for a lucrative new market in drainage pipes and tiles and the machines for making them. A result of this was a significant increase in the numbers of patents granted for clayworking machinery during the 1840's and in the number of firms who began to manufacture and sell new machines. There was enormous variety in the size, financial investment, organization and marketing strategy of machine manufacturing firms during the period. Commercial factors such as these, rather than technical superiority, often determined the success or failure of particular machines in the market place.

Many of the earliest tilemaking machines were manufactured and sold by individual promoters with presumably limited financial backing. This restricted their ability to develop or publicize their products to any great extent. Many of these machines were not protected by patents, probably due mainly to the meagre resources of their inventors, but also because of the tenuous, speculative nature of many of these enterprises. For some, the agricultural exhibitions were their only exposure in the national market. Although few survived in competition with the larger or better financed manufacturers, it is not unlikely that many small independent machine makers achieved a modest success in various local markets.

John Read was an early machine promoter who acquired notoriety in the RASE for being the first person to recommend the use of cylindrical pipe tiles for land drainage as early as 1788 (JRASE 1843, p.273). Read originally experimented with hand-made pipes, but by 1843 he had developed machine-made pipes for which the Society awarded him a silver medal. The machine used by Read was a small upright iron cylinder in a wooden frame with a lever-operated piston. Said to cost no more than £6. or £7., it fulfilled precisely the general expectation that the production of drainage tiles should become a "home manufacture", i.e. it was inexpensive, portable, simply constructed and hand-operated. But shortly thereafter for unknown reasons Read discontinued its promotion and moved to London to manufacture stomach pumps and surgical equipment instead (JRASE 1843, p.372).

An equally short-lived venture was the machine made by Wm. Bullock Webster of Houndsdown, near Southampton, a "neighbouring argriculturalist" of Frederick Etheredge, patentee of a pug mill extrusion machine in 1842. Etheredge's machine was fairly successful and this seems to have inspired Webster to market his own hand-powered double-action piston model which was manufactured at the Waterloo Iron Works in Andover and exhibited at two RASE meetings in 1847 and 1848. Calling himself a drainage engineer, he promoted his "Patent Hand Pipe and Tile Machine" with a small two-sided trading card (Figure 5.10.; RASE Show Catalogues 1847). Webster did not actually patent the machine. The use of the word "patent" was a relatively common promotional method to make the public believe the product was unique or different from others. For some reason Webster was not confident enough about the machine to submit it to trials at the exhibitions and in 1848 he was severely reprimanded by the RASE :"Mr. Bullock Webster of Houndsdown exhibited a tile machine, but was not in a position to have it tried. As this is the second meeting of the Society at which the same thing has occurred...should Mr. Webster be found to shrink from competition a third time, it is possible that the judges would not permit the implement to be exhibited at all" (<u>TYAS</u> 1845, p.44-45). The machine was not shown again.

A second modestly promoted, unpatented machine was Swain's Registered Pipe and Tile Machine, exhibited at the Society's meeting in 1847 and also advertised with a small trade card illustrating the device in operation and including four testimonials (Figure 5.11.; RASE Show Catalogues 1847). It isn't known how long Swain manufactured the machine or the extent of its use. Another independent machine maker, a Mr. Charnock of Wakefield, succeeded in winning the prize at the Yorkshire Agricultural Society competition at Beverley in 1845. Charnock exhibited his small double-action piston machine again in 1847 but it was overshadowed by the "Utile" drain tile machine made by the engineering firm, Bradley and Company, also of Wakefield, and said to be "of the same principle as that shown by Mr. Charnock...but adapted to more power" (<u>TYAS</u> 1847, p.33).[9]

One of the most successful independent promoters was Thomas Scragg of Calvely, Cheshire. His employer, a Mr. Davenport, first showed Scragg's single-action piston machine to Josiah Parkes in 1843 and may also have provided some financial backing, although

Davenport's name was never officially connected with the enterprise (TYAS 1846, p. 153). Scragg exhibited his machine for the first time in 1845 at the Shrewsbury meeting where it was judged the best of fourteen competitors (Figure 5.12.). It received the top prize again at Newcastle-upon-Tyne in 1846. Although he seems to have engaged only in limited promotional activity, Scragg apparently was a shrewd entrepreneur who kept abreast of suggestions made by the RASE judges and ahead of improvements made by other machine makers (RASE Show Catalogues 1847). By 1848 the Society said: "Mr. Scragg has by his numerous improvements been mainly instrumental in developing the great capabilities of the horizontal mode of delivery" (TYAS 1848, p. 43). The following year he was awarded the large contract to supply the hollow bricks for Robert Rawlinson's roof over St. George's Hall, Liverpool, which gave him favourable publicity in the architectural press (The Builder 1850, p. 98; see Chapter 8).

Scragg continued to participate in RASE exhibitions and to win medals for his high quality machines, but by the early 1850's there were indications that he was being surpassed by the larger, more diversified firms who were able to return profits from the sale of other poducts into machine development and more extensive publicity. During this period of rapid change in tilemaking machinery, many independent manufacturers, unable to equal the significant improvements made by larger firms, withdrew from the national market. But there were often other small-scale entrepreneurs ready to take their places, frequently introducing unpatented new machines closely patterned after the most popular market leaders.[10]

Many of the machines marketed during the decade were manufactured by established engineering firms specializing in agricultural implements. In contrast to independent manufacturers, these firms had sufficient financial flexibility to develop and improve new products and to withstand the losses incurred by unsuccessful machines. They were also able to use their established reputations and recognized names to facilitate promotion of new machinery. These businesses acquired designs for machines in several ways -- by the direct purchase of patent rights, by a variety of licensing arrangements with inventors, or by in-house experimentation. One author concluded that for industry as a whole during this period, few established firms were willing to invest in the purchase or licensing of a new invention unless it offered the security of patent protection (Dutton 1984, Chapter 8). However, in the rapidly changing, speculative market for tilemaking machinery in the late 1840's this was not always the case as newly patented machines often were quickly superceded by other considerably improved models. It seems at least some of the large engineering firms were willing to risk experimentation with untried and unprotected new designs.

The important firm of J. R. and A. Ransome of Ipswich was one of the first to add tilemaking machines to its more traditional line of equipment. This decision was made at the end of the long agricultural depression during which Ransomes began to expand its production of non-agricultural machinery as a "buffer between the firm and the unpredictable fortunes of agriculture" (Grace and Phillips 1975, p. 3). In 1842 Ransomes purchased the rights to manufacture the pug mill extrusion machine invented by Frederick Etheredge (Figure 5.13.). As one of the first widely promoted machines, it was noticed by the RASE ("Mr. Etheredge has invented a machine, of which the well known house of Ransome at Ipswich think so highly that they have purchased the patent") and its operation at the tilery established by Etheredge at Eling was described in the Society's journal in 1843. If comments by the patentee can be relied upon, it must have been at least initially a financial success as it was reported there were "already sold above fifty machines of different sizes" (<u>JRASE</u> 1843, p. 48 and 372). But it was a high-priced, substantial apparatus requiring a horse to operate. RASE objections to the vertical mode of delivery as well as their encouragement of more portable horizontal machines after 1845 may quickly have undermined the early popularity of Etheredge's model.[11]

Ransomes also were involved with several other machines during this period, but the precise nature of these arrangements is not known. For example, William Worby, works manager in the agricultural division of the firm, patented a small three-chambered piston extrusion machine in 1844 (British Patent No. 10,237). Experiments leading to this invention may have been financed by the company and conducted at the firm's foundry as several years earlier R. G. Ransome had sought legal advice "concerning the rights of masters and workmen in inventing, developing and patenting unspecified machinery" (Ransome Collection CO 5/13). It isn't known if this particular machine was actually manufactured or sold by the company. The Ransome firm was listed, however, as one of two licensed manufacturers of Dampier's Concentric Press in literature by the Architectural Tile Company in 1847 (RASE Show Catalogues 1847). It also had some kind of agreement to manufacture a simple lever-operated brick moulding apparatus for a family member, Frederick Ransome, who acquired British patent rights in 1845 from its American inventor, Alfred Hall (British Patent No. 10,845; see Figure 6.2.). Although it was initially promoted by Frederick from his premises at Flint Wharf, Ipswich, during the 1850's Hall's machine was marketed exclusively by the Ransome firm primarily to export customers (Catalogue Illustre des Machines et Instrumens Fabrique par Ransomes et Sims, Juin 1859; Chamberlain 1856, p. 495; see Chapter Six). Despite their early and diverse experience with tilemaking machinery, Ransomes did not continue their involvement with these products for the home market after mid-century.

Richard Garrett and Son of Leiston in Suffolk acquired the rights, probably by purchase, to manufacture a machine patented in 1845 by Richard Weller, a brick and tile maker from near Dorking (Figure 5.14.; British Patent No. 10,577, 1845). This small horizontal piston machine won prizes at local Norfolk agricultural shows in 1845 and 1847 and an RASE award in 1846. But subsequently it was criticized by the RASE judges for its lever bar operation ("a very objectionable mode of applying hand power") and its unusual swinging cylinders that turned upwards to be filled with clay ("it takes up time and complicates the construction") (TYAS 1848, p. 48). The firm's established reputation for high quality products and the large number of differently shaped dies offered with the machine may have compensated for what the RASE believed was its questionable design. In 1847 the company's trade circular included two pages of testimonials from satisfied users in several counties (TYAS 1849, p. 67; RASE Show Catalogues 1847).

A large engineering firm in London owned by George Cottam and Samuel Hallen first manufactured tilemaking machinery in 1841 when they contracted to make ten machines for the Tweeddale Patent Drain Tile and Brick Company (Tweeddale MSS Abstracts of Agreement 1840). Three years later they acquired exclusive rights to manufacture and sell an unpatented machine by John Hatcher of Benenden, Kent. Claimed to be "by far the simplest and most economical machine that has hitherto been invented for the purpose of making drain and other tiles", nevertheless, it went unnoticed in RASE competitions. Besides the usual trade flier and several pages devoted to a description of the machine in their catalogue, Cottam and Hallen were one of the few firms to advertise in the architectural press during the period, placing a notice and illustration of the machine in The Builder in 1845 (p. 144). As this was an unpatented machine, it was pointed out in all promotion that there was no charge for patent or licensing fees, turning this to competitive advantage.

During the second half of the decade, many machine makers entered the market with unpatented new machines that were virtual copies of other successful models. For example, Barratt, Exall, and Andrewes of the Katesgrove Iron Works, Reading, manufactured a machine similar to that made by Cottam and Hallen with movable perpendicular cylinders and a stationary piston operated by a rack and wheel. This apparatus had a vertical delivery creating a rather awkward position for the workman cutting the tiles as he had to stand in a pit below the machine while the person operating the wheel above was required to stand on a stool (Figure 5.15.; RASE Show Catalogues 1847). The firm of John Holmes of Norwich introduced a new pipemaking machine at the RASE meeting in 1849 which was exhibited along with over one hundred other agricultural implements. Despite the judges objections to the principle, it was lever-operated with two vertical cylinders and a perpendicular delivery of the pipes (RASE 1849, p.78).

Late entry into the market became an advantage for John Whitehead, a machine maker from Preston. Whitehead's first tilemaking machine, a large yet portable single-action piston machine, was introduced in 1848 when it received the top prize at the RASE exhibition at York and again the following year at Norwich (Figure 5.16.). It was commended for its sturdy all-iron construction with double racks, its efficient cutting apparatus, and the large capacity of its clay box. The judges remarked: "Whitehead's prize machine is undoubtedly the most complete that has yet been exhibited." But they also recognized that "this maker commenced the business at a time when most of the practical difficulties of the manufacture had been surmounted by the ingenuity and perseverence of others, and that the excellence of his machine is chiefly the result of principles of construction previously in use." (TYAS 1848, p.42). Whitehead's initial success may have been built upon the experience of others, but his machines also were recognized for their "first-rate workmanship" and he later introduced improvements increasing their speed and productive capacity. After mid-century Whitehead's business expanded to become one of the best known firms specializing in high-quality, technically advanced clayworking devices.

A small number of machine manufacturers set up companies for the specific purpose of working particular patents for brick and tile machinery. These firms may have had the benefit of more extensive financial backing than most independent promoters and, unlike the diversified agricultural implement makers, all of their resources were available to direct towards improving and publicizing their tilemaking machines and subsidiary products. Consequently by mid-century machines by these firms were some of the most commercially successful in the marketplace. The earliest of these specialized companies, and the only one prior to 1850 which was granted legal corporate status by a private Act of Parliament was the Tweeddale Patent Drain Tile and Brick Company. In 1839 John R. Birnie began discussions with brick manufacturers

James and Ogle Hunt about the formation of a company to promote the brick and tile machine patented by the Marquess of Tweeddale in 1836. Birnie, along with two others, was a lessee of Tweeddale's patent and had been responsible for marketing the machine in England. By increasing the capital available for promotion, he believed the patent would " be brought into full effect several years earlier than can well be expected otherwise" (Tweeddale MS, 4 June 1839). Negotiations proceeded for several months while Birnie and his partners warned Tweeddale of impending competition and urged him to accept an offer from the Hunts. Finally, early in 1840, articles of agreement were finalized and in April an act to grant incorporation was passed by Parliament.[12]

Tweeddale transferred his patents to the company, whose shareholders were limited to the Hunt brothers, the engineer Robert Stephenson, and George Glyn, in return for £5,000 and 2s. for every 1000 feet of tiles produced by the machines under license (Tweeddale MSS Articles of Agreement, 1840). The intention of the company was to erect tile works on landed estates or to become tenents of already established works installing Tweeddale's machines. It also had the power to grant licenses to use the machines "if the consumption of an estate be small or the owner preferred manufacturing his own tiles or bricks." The fee for licensing was 4s. per 1000 tiles. In addition to the machines already set up prior to the company's formation, by 1841 there were works erected at twenty-one locations throughout the country as well as at the company's own site at Millbank in London (Tweeddale Patent Drain Tiles 1841). In response to early criticism about the large scale and power requirements of their machines, in 1843 the company offered a modified hand-powered version more in line with emerging consumer demands. Although the Tweeddale Patent Drain Tile and Brick Company did not participate in RASE exhibitions to promote their machines, by 1850 Dobson stated that the company's brickmaking device, by that time under John Hunt's patent, was one of the two most frequently adopted in the country (Dobson Part 1 1850, p.31).

The other most popular brick and tilemaking apparatus, according to Dobson, was Ainslie's machine. A farmer from the Lothian region of Scotland, Ainslie first patented a large steam-powered machine with a pair of rollers to crush the clay, a screw-operated extrusion chamber with dies and a unique continuous cutting frame. Ainslie apparently promoted it by himself (Civil Engineer and Architect's Journal 1842, p. 427). Criticism of the machine's large size and slow action caused him to patent modifications in 1845, eliminating the screw chamber, reducing its overall size and adapting it to hand power. At this point Ainslie apparently transferred his business interests to the Acton area of London and shortly thereafter a company was formed, presumably to finance and work his second patent. Literature for the Ainslie Brick and Tile Machine Company included the names of James Smith, chairman, Robert Scrivener, works manager, William Gordon, secretary, and George Howe, engineer.

In 1846 Ainslie patented still another improved machine along with a pug mill and an interconnecting system of kilns. Instead of extruding the clay through a die, the newest machine had four rollers, similar to Tweeddale's machine, for shaping the bricks or tiles (British Patent No. 11,115, 1846). The machine described in publicity by the newly formed company, however, was clearly Ainlsie's earlier patent: "The peculiarity of these machines is that a continuous stream of clay passes between the cylinders and presses through the dies in the most perfect manner..." (The Ainslie Brick and Tile Machine Company c. 1847; RASE 1849, p. 173). An illustration of the machine, now portable and much reduced in size from the original, shows what appear to be drain tiles emerging from a die plate (Figure 5. 17.).

Evidently, despite his association with this company, by mid-century Ainslie entered into other agreements to manufacture his subsequent patents. In 1850 at the RASE meeting at Exeter, it seems he had formed another enterprise with William B. Moffatt, a manure manufacturer from London. Listing his address as Perryhill, Sydenham, Kent, Ainslie and Moffatt exhibited samples of manure and Ainslie's newest tilemaking machines, "having a new mode of feeding, by the addition of one roller in connection with the other two", i.e. his patent of 1846 (RASE 1850, p.155). This raises a question of which machine patented by Ainslie did Dobson refer to as being popularly used for brickmaking prior to mid-century. In discussing the Ainslie machines improved by Thomas Cubitt and used at his large works at Burham on the Medway, Hermione Hobhouse illustrated the new roller machine patented in 1846, but cited an 1852 description of Cubitt's works in The Builder. This article clearly mentioned the clay moving through a die: "The clay passes through two rollers out of the pug mill, by which means the air is driven out...Oil runs in behind the die, to facilitate the passage of the clay through it" (The Builder 1852, p.285; Hobhouse 1971, p.313). This suggests that Ainslie's earlier patented machines rather than his roller extrusion machine were more commonly known and adopted.[13]

The commercial and competitive success of Henry Clayton was clearly the result of perseverence, specialization and enthusistic publicity. Listing his occupation as a plumber in his first patent in 1844, Clayton began to promote his machine, apparently successfully, from his premises at Upper Park Place, Dorest Square, London. By 1845 the judges at the RASE meeting at Shrewsbury remarked that "the reputation of Mr. Clayton's machine has been well merited and notoriously well established" (TYAS 1846, p.152). The disapproval by RASE judges of perpendicular extrusion machines has already been mentioned. Despite these repeated criticisms, Clayton's machines, which combined a particularly effective method for screening the clay along with an apparatus for shaping the tiles, were sufficiently popular that he defied the judge's opinions and persisted in developing and widely publicizing his process. The commercial response was such that the Society could not fail to recognize their popularity and it was admitted in 1848: "His very effective machines have been extensively patronized by the public" (TYAS 1848, p.43).

By that time Clayton had established himself as a specialist manufacturer of a variety of implements for land drainage and clayworking, including several versions of his hand-powered extrusion machines, a small moulding machine, pug mills, cast steel drainage tools, and an improved steel brick mould for hand brickmaking. He also offered for sale complete plans and working drawings for a brick and tile manufactory "upon an improved economical and systematic mode" (RASE 1849, p. 13-15). In the following decade Henry Clayton and Company continued to expand its range of brick and tilemaking equipment, demonstrating a keen awareness of the needs of the changing market, a determination to perfect the extrusion process and, equally importantly, a decided confidence and flair for self-promotion.

5.5.
The Diffusion of Clayworking Machinery

It is not possible to determine the full extent of the diffusion of clayworking machinery in quantitative terms with the incomplete information available. However, a random selection of Agricultural Society publications and various advertising testimonials can provide an impression of the geographical distribution of machines prior to 1850. The map in Figure 5.18. shows the locations of selected purchasers of eleven tilemaking machines for which information is available. The map is based on trade literature for machines by Robert Beart, the Marquess of Tweeddale, Richard Weller (Garrett and Son), John Ainslie, John Whitehead and for Swain's Registered Machine. In addition, isolated references to machines by John Read, F.W. Etheredge, Henry Clayton, John Hatcher and Thomas Scragg found in other published sources were used (See Appendix C).

One important feature of machine distribution should be acknowledged, that is, the rural character of most of the locations shown in the map. Purchasers of tilemaking machines in the 1840's bought them primarily for use on country estates or in small towns and villages. This implies that there was apparently little difficulty in supplying machines to rural locations. It also suggests that machinery was capable of working a variety of different clay types. Stephen Stannard, a brickmaker for the

Hon. H. W. Wilson of Kirby Cane, near Bungay, Suffolk, wrote to Garrett and Son in 1847: "Our earth is very stony, but by making use of your screen, it frees the earth from stones and makes good sound pipes and tiles." Similarly, Mr. J. Lee of Mereworth, near Maidstone, Kent, wrote to the same manufacturer: "My clay is a sort of blue marl, very stony, and it was some time before I could properly prepare it, but I have no hesitation in saying that when clay is free from stones, of a soapy nature, and used stiff it will make tiles of all descriptions, far superior to those made by hand" (Garrett and Son c. 1847, p. 4). A. E. Holden from Alston Hall, Derby also testified to the proficiency of a machine by John Whitehead which he said was successful in working the stiff, marly clay of that region. Later arguments about the unsuitability of machinery for working some clays must be studied with caution in the light of the acknowledged flexibility of these machines.

Admittedly, the fragmentary data we have used raises many more questions about the diffusion of machinery than it can possibly answer satisfactorily. It is useful primarily because it indicates that by 1850, when the tax on bricks was repealed, machinery capable of making bricks and tiles was spread relatively widely throughout the country rather than being restricted to particular locations. This suggests that many more areas were exposed to and had experience with clayworking devices at an earlier date than has been recognized previously.[14] The importance of this widespread early exposure to machinery for tilemaking must not be overlooked in terms of the knowledge and experience with mechanized processes that was acquired. Recognition of the seemingly generalized distribution of machines during this decade also provides an interesting perspective with which to examine the adoption of mechanized processes for common brickmaking after mid-century. As we shall see, in contrast to other countries, the extrusion process was sufficiently well-developed during the 1840's that it dominated the British brickmaking industry for most of the remaining century.

NOTES

1. These included the West of England and South Wales Land Drainage Company, 1848; General Land Drainage and Improvement Company, 1849; The Lands Improvement Company, 1853; and The Land Loan and Enfranchisement Company, 1860 (Spring 1963, p. 149-153 and 194).

2. Cox illustrated the later version of the machine and claimed this was the one used at Crawley. But he also stated, "Beart had agreed to put up one of his machines at Crawley for £60..." (p. 37). Only four years later, c. 1837, Beart was selling his smaller machine for just £12. There is no evidence that any early machines experienced such a drastic and rapid reduction in price, indictaing that the apparatus installed at Crawley may have been the larger and more complicated version with pug mill and two mould boxes according to Beart's first patent (See trade circular, Ransome Collection TR RAN P1/A2).

3. Several authors incorrectly credited Irving's "machine" with being the first to have a wire cutting device (Hudson 1972, p. 32; Woodforde 1976, p. 115). Actually Pleney's patent of 1834 (British Patent No. 6701) for an extrusion machine specified a frame of copper wires operated by a lever to cut the extruded slab of clay into bricks. There is no evidence that this machine was manufactured and sold, but subsequent machines of the same type, like Tweeddale's in 1836, also used a mechanically operated wire cutting device.

4. Note the similarity with Tweeddale's and Hunt's machines.

5. These included the Yorkshire Agricultural Society, the East Norfolk Agricultural Society, the United East and West Norfolk Society, among many others. Also, there were separate societies in Ireland and Scotland.

6. See tabulated statement of machine trials (TYAS 1849, p. 67)

7. This omission was remedied by Ainslie over the next three years.

8. It isn't entirely clear which of Ainslie's several patented machines this author was referring to. See Section 5.4. for Ainslie's business activities.

9. The history of the firm of Bradley and Craven does not mention this early extrusion machine. During the 1850's Bradley and Company began to experiment with grinding equipment and moulding and pressing machinery and they subsequently became well-known for machines of this type (Bradley and Craven Ltd. 1963).

10. See, for example, new machines introduced by Henry Curtis of Moorend & Hambrook, near Bristol (RASE 1850, Stand No.38), and James Hart of Southwark (RASE 1849 p.241, Stand No.129).

11. Unfortunately, manufacturing and sales records for tilemaking machines made by Ransomes in the 1840's have not survived amongst the company's extensive records. Per conversation with D.C. Phillips at the Institute of Agricultural History, Reading.

12. For a summary of the negotiations leading to the formation of the company see Dutton (1984, p.164-168).

13. Until the late 1850's when Chamberlain patented what he called a "rotating die" with four revolving sides, the word "die" commonly referred to a stationary die plate.

14. Raphael Samuel said that the "development of machinery in brickmaking was extraordinarily uneven, both as between different regions and in different departments of work" (Samuel 1977, p.44). Marian Bowley also stated that "serious adoption began in the late 'fifties and early 'sixties..." (Bowley 1960, p.64).

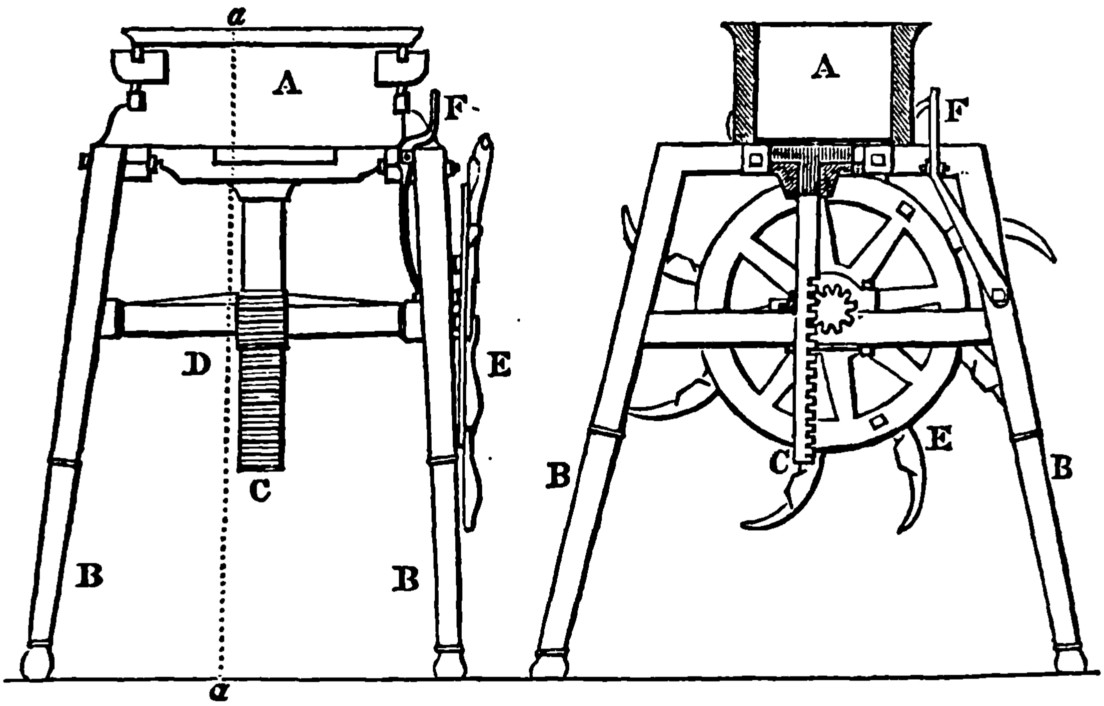


Figure 5.1. Tile-moulding machine invented and manufactured by Robert Beart, c. 1841.
[From Journal of the Royal Agricultural Society Vol. 2 1841, p. 98 and Robert Beart Trade Catalogue]

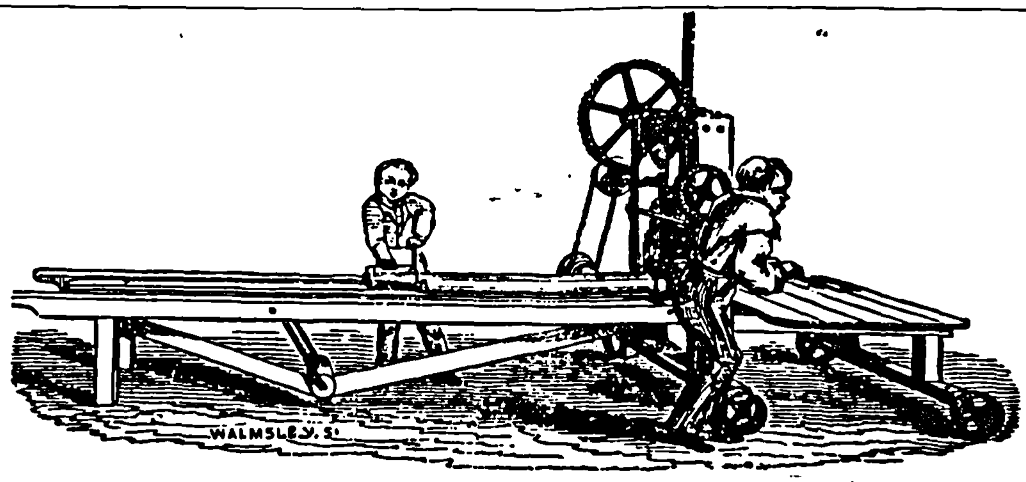


Figure 5.2. Unpatented tilemaking machine by John Hatcher of Benenden, Kent.
[From trade catalogue, Cottam and Hallen, Winsley Street, Oxford Street, London, June 1847]

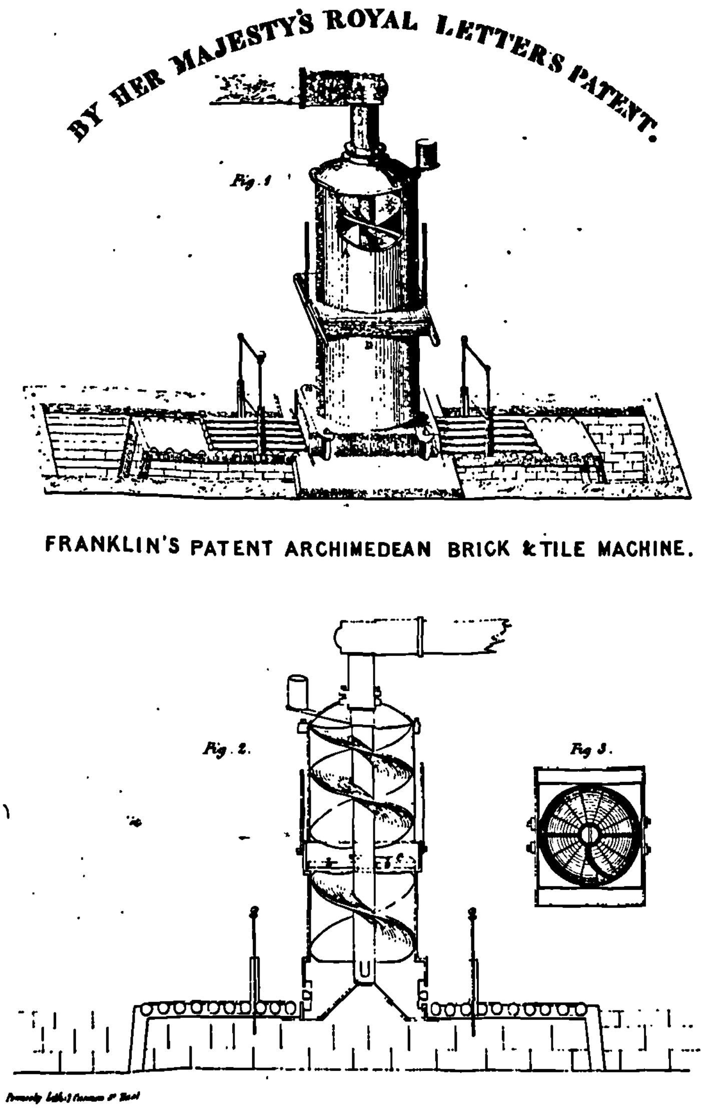


Figure 5.3. Franklin's Patent Archimedean Brick and Tile Machine
[From Henry Franklin Trade Catalogue, 1847]

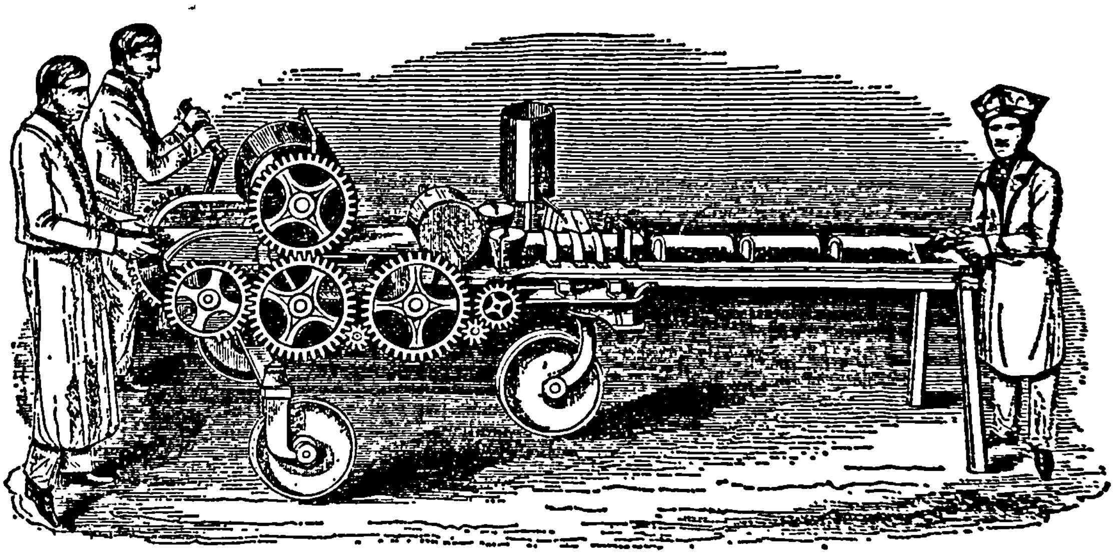


Figure 5.4. Tilemaking machine by the Marquess of Tweeddale, British Patent No. 7253, 1836.
[From The Builder Vol. 1 1843, p. 195]

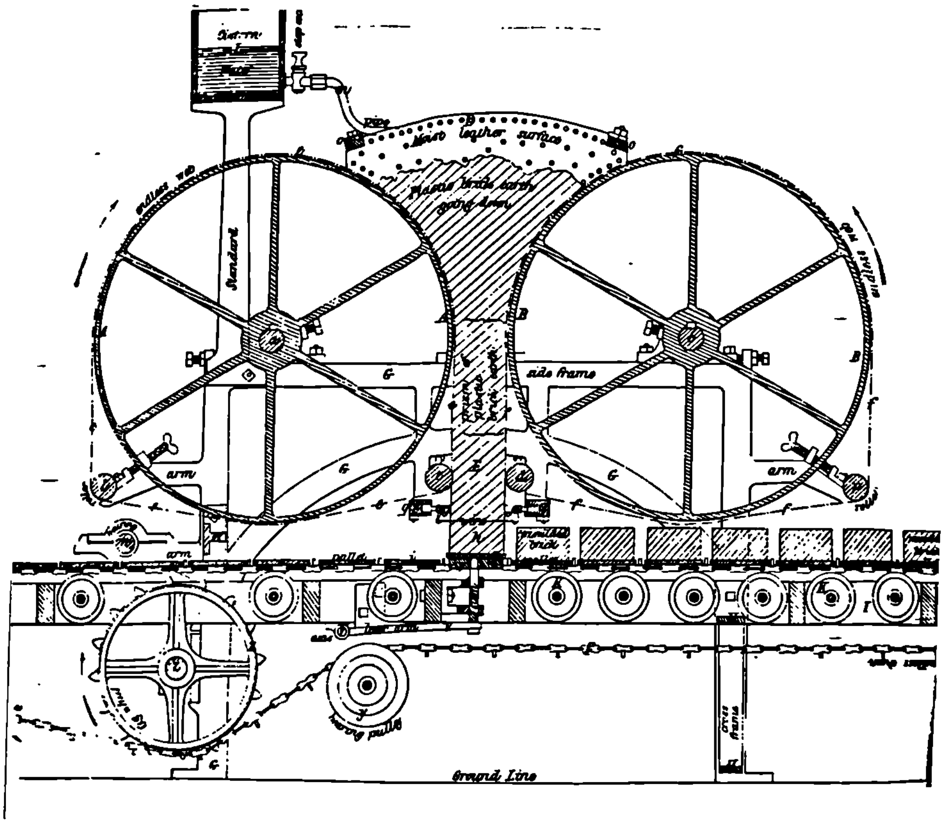


Figure 5.5. Hunt's improvement on Tweeddale's brickmaking machine, British Patent No. 9243, 1842.
[Drawing enrolled with patent]

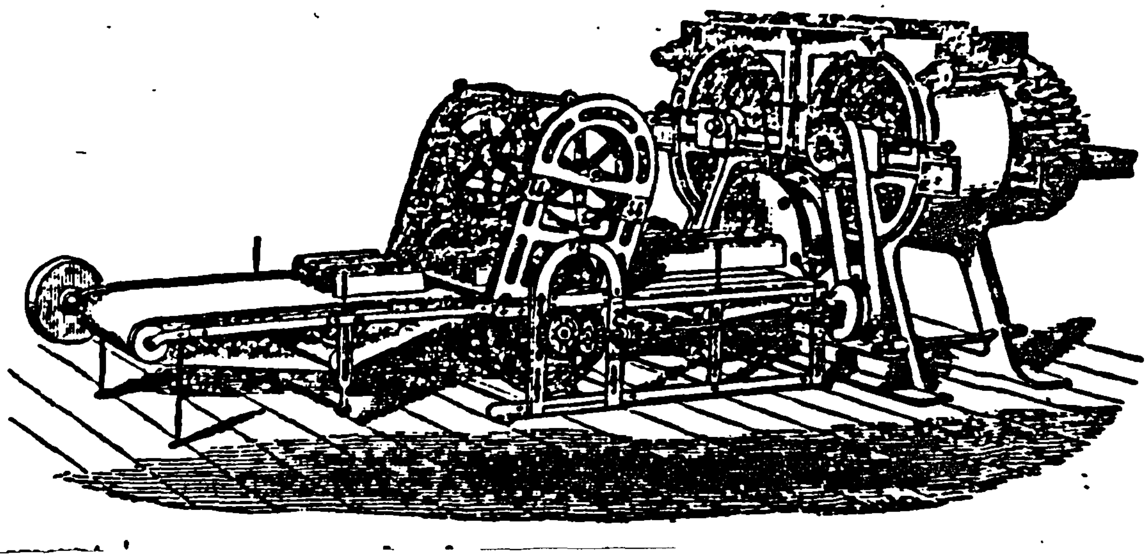


Figure 5.6. Brick and tile machine patented by John Ainslie, British Patent No. 8965, 1841.
[From Civil Engineer and Architect's Journal Vol. V 1842, p. 427]

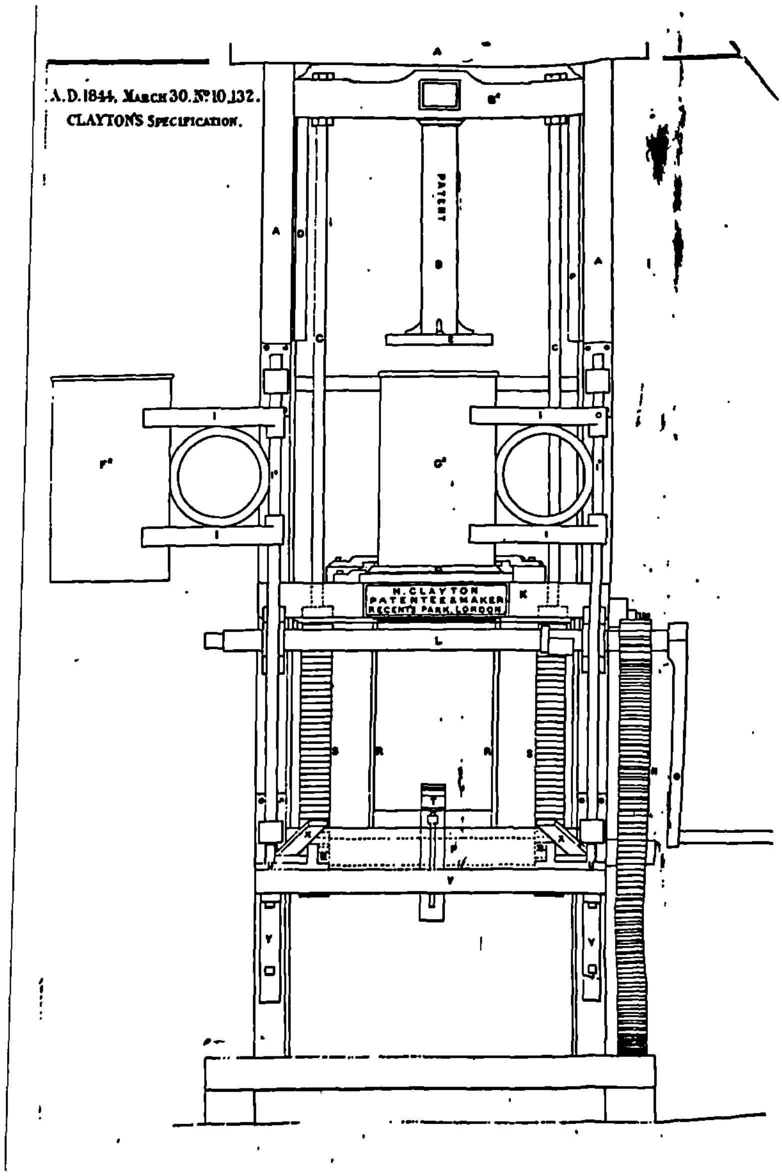
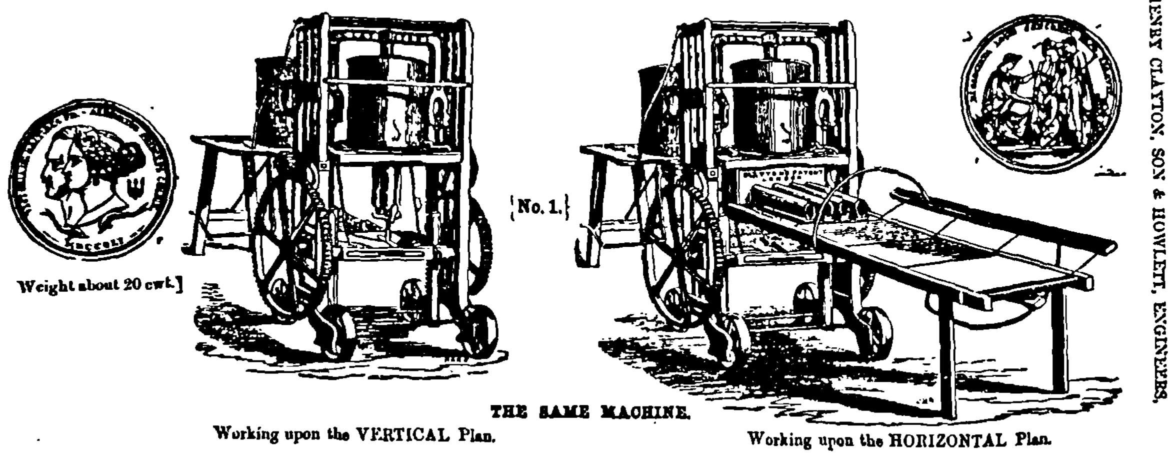


Figure 5.7. Henry Clayton's perpendicular piston machine, British Patent No. 10,132, 1844.
[Drawing enrolled with patent]

DRAIN-PIPE, TILE, & HOLLOW BRICK MACHINE,

Combining both the Vertical and Horizontal Action in the same Machine.



The above Machine is a Master Machine for the "*Screening Process*" especially, besides its general adaptability. It is fitted with two cylinders, attached by swing brackets (so that one cylinder is being filled while the other is being emptied); has strong double racks and wrought-iron pinions, and has the recent improvement and great practical advantage of **combining** both the Vertical and Horizontal modes of working **in the one Machine**. It is of great strength, simple in construction, worked easily by Hand-power; not subject to the delay or derangement incident to other forms or principles of machinery—especially for the Screening process; and will produce from 5,000 to 10,000 feet of Drain-Pipe, or from 5,000 to 7,000 *Hollow* Bricks per day. It was proved by the Dynanometer (at the Exeter Meeting, R.A.S.E., 1850) to be the most rapid, and to require the least working power (*consequently the best and most economical Hand-power Machine, in labour, extant*), as it required *7lbs. less power of draught*, and took 12 *less revolutions in each charge*, with the same given quantity of power; screened 154lbs. *more clay*; and made *considerably the greatest quantity of each size of large pipes* in the same allotted time.

Figure 5.8. Clayton's combined vertical and horizontal drain pipe, tile and hollow brick machine.
[From Atlas Works, Henry Clayton, Son and Howlett, 1871, p. 46]

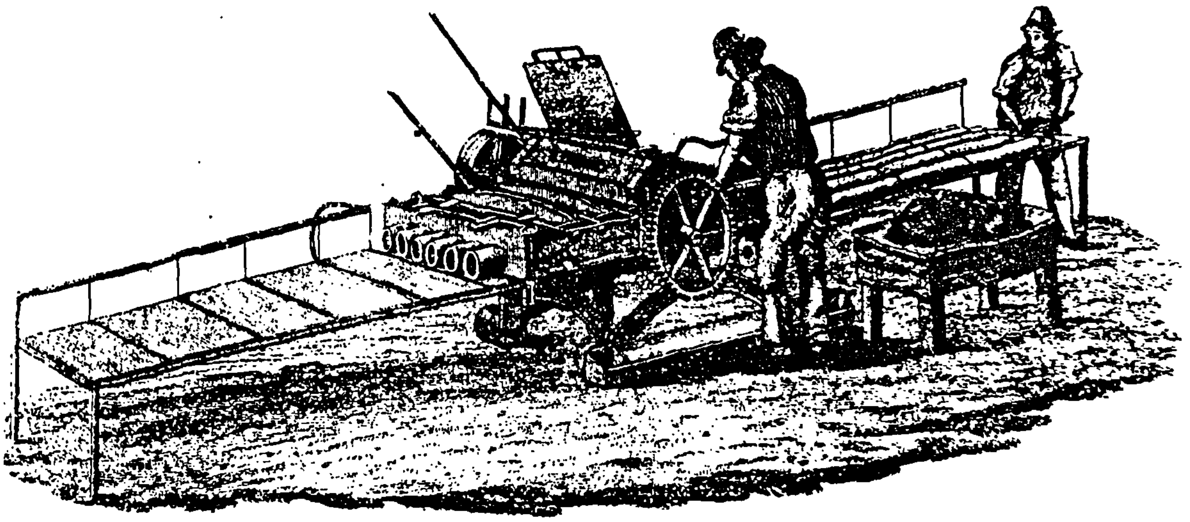
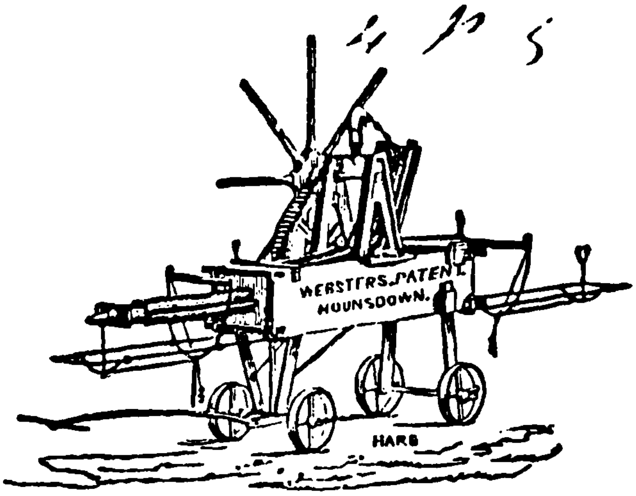


Figure 5.9. Whitehead's prize tilemaking machine, c. 1851.
[From John Whitehead's Trade Catalogue, 1851]

Figure 5.10. "Patent Hand Pipe & Tile Machine" by Wm. Bullock Webster, c. 1847.
[From trade card, c. 1847]



PATENT

HAND PIPE & TILE MACHINE,

INVENTED BY

WM. BULLOCK WEBSTER, ESQ.

Draining Engineer to Her Majesty,

OF HOUNSDOWN, NEAR SOUTHAMPTON,

AND

MANUFACTURED BY TASKER AND FOWLE,

OF

THE WATERLOO IRON WORKS, ANDOVER,

HANTS.

Price £25.

[See the other side.]

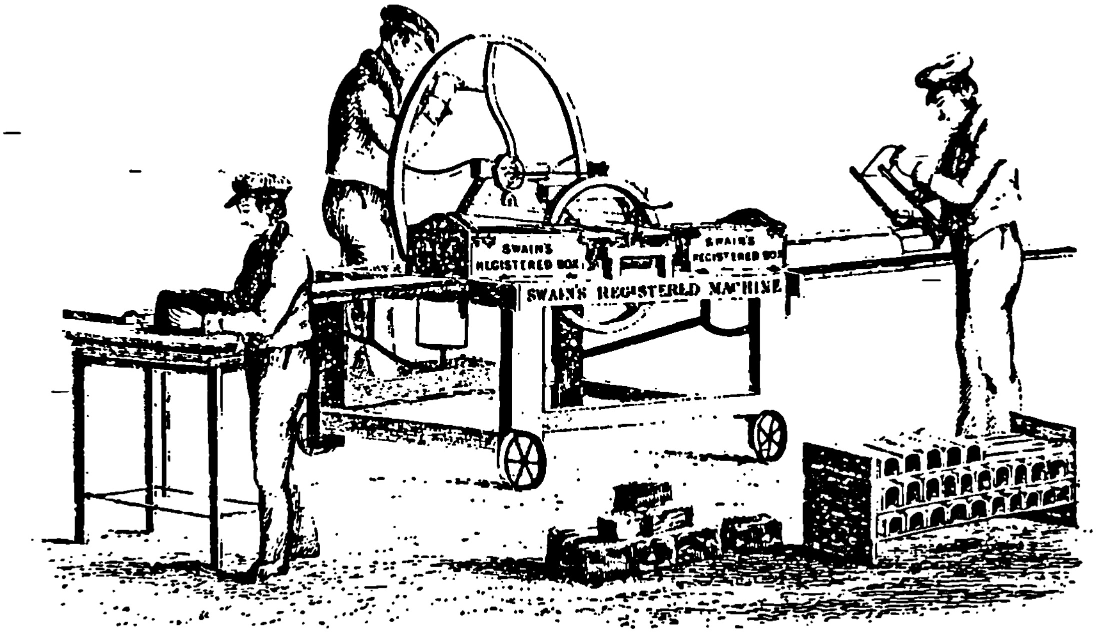
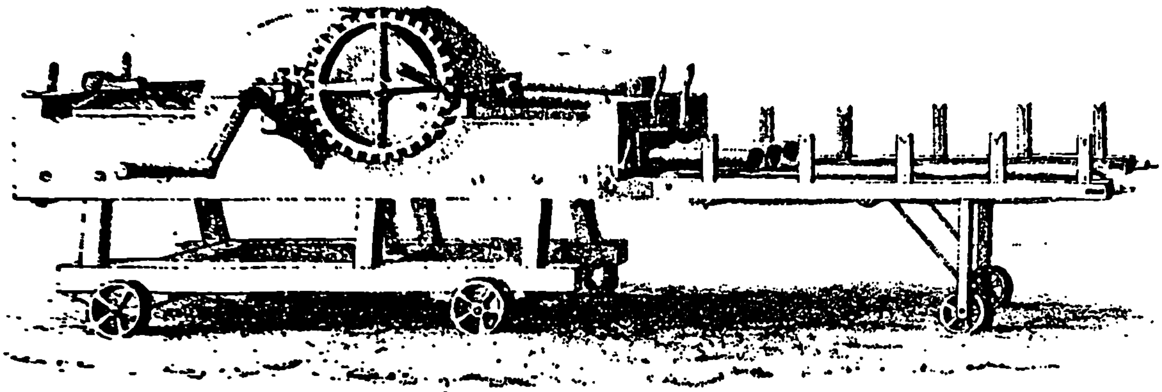


Figure 5.11. "Swain's Registered Pipe and Tile Machine", c. 1847.
[From trade card, c. 1847]



THOMAS SCRAGGS, IMPROVED TILE MACHINE.

To which the Prize of TWENTY POUNDS *was awarded by the Royal Agricultural Society of England at the Meeting at Shrewsbury and Newcastle Upon Tyne 1845 & 6.*

Figure 5.12. Thomas Scragg's unpatented tilemaking machine.
[From trade literature, c. 1847]

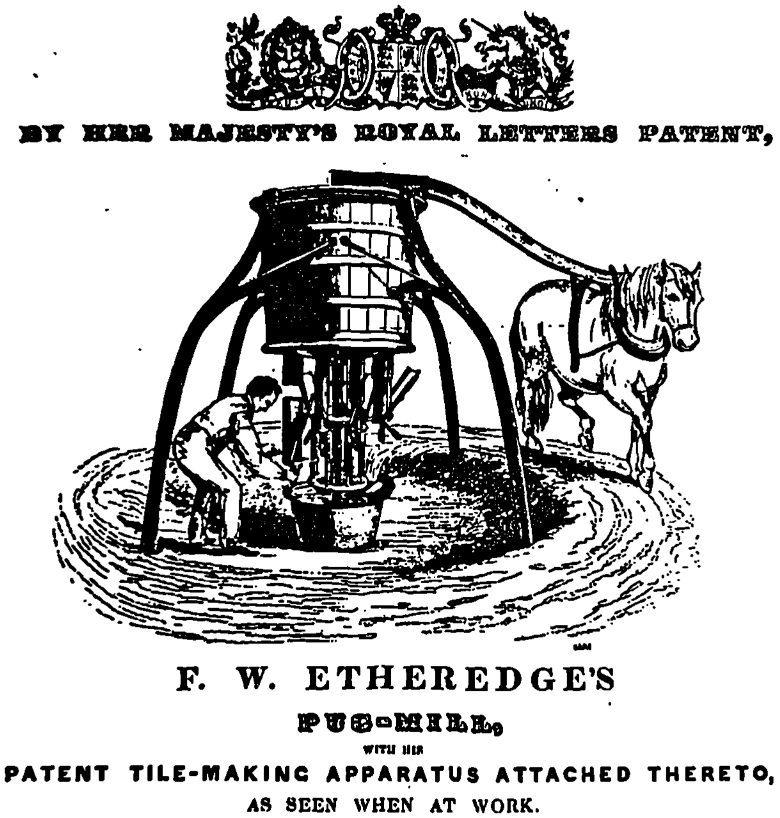


Figure 5.13. F.W. Etheredge's pug mill tilemaking machine manufactured by Ransomes of Ipswich.
[From trade literature, c.1847]

Figure 5.14. Pipe and tile machine patented by Richard Weller in 1845, manufactured by Richard Garrett and Son.
[From trade catalogue, c. 1847]

PATENT

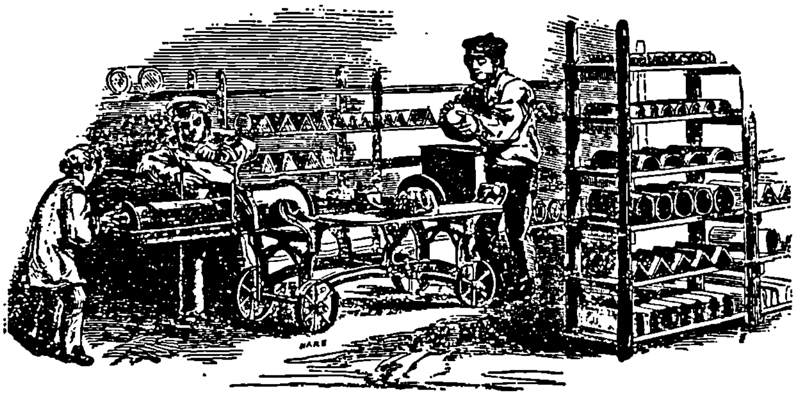
HAND PIPE AND TILE MACHINE,

Invented by Richard Weller, Capel, near Dorking, Surrey,

AND MANUFACTURED BY

R. GARRETT AND SON, LEISTON WORKS. SAXMUNDHAM,

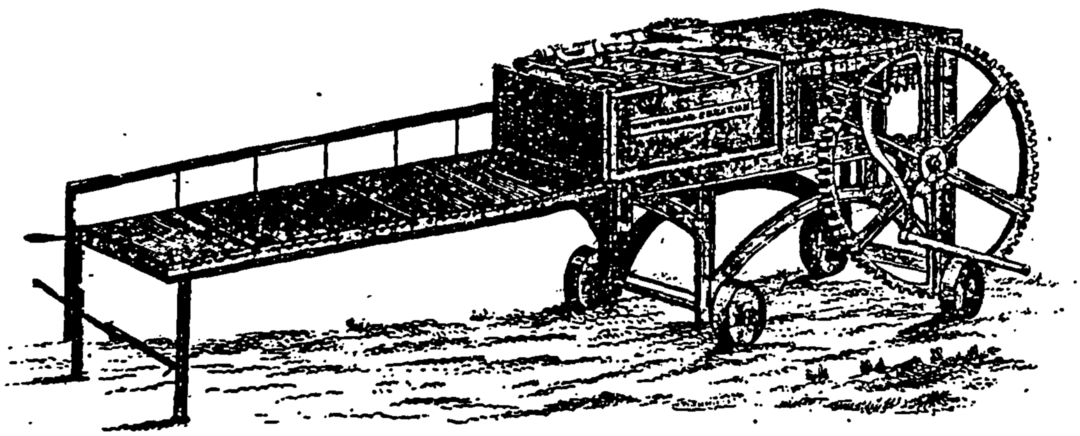
SUFFOLK.



The following Prizes have been awarded for this Machine.

The first Prize of the East Norfolk Agricultural Society, held at Norwich, September 10th, 1845.
The first Prize of the United East and West Norfolk Society, ditto June 18th, 1847
A Prize of £5. by the Royal Agricultural Society of England, at Newcastle on Tyne, July, 1846

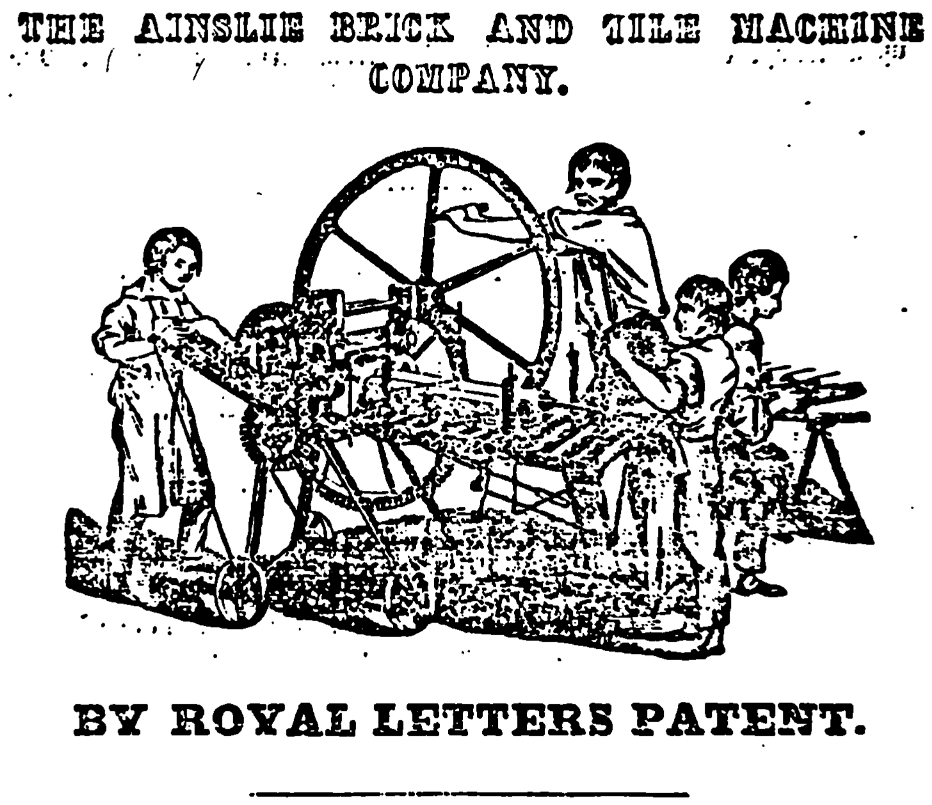
Figure 5.15. Tilemaking machine manufactured by Barratt, Exall, and Andrewes, Reading.
[From trade catalogue, c. 1847]



Improved Tile Machine.—No. 1. Whitehead. Maker. Preston.

Figure 5.16. Whitehead's first prize-winning tilemaking machine. [From John Whitehead's trade catalogue, 1851]

Figure 5.17. Brick and Tilemaking machine patented by John Ainslie, 1845.
[From The Ainslie Brick and Tile Machine Company 1847]



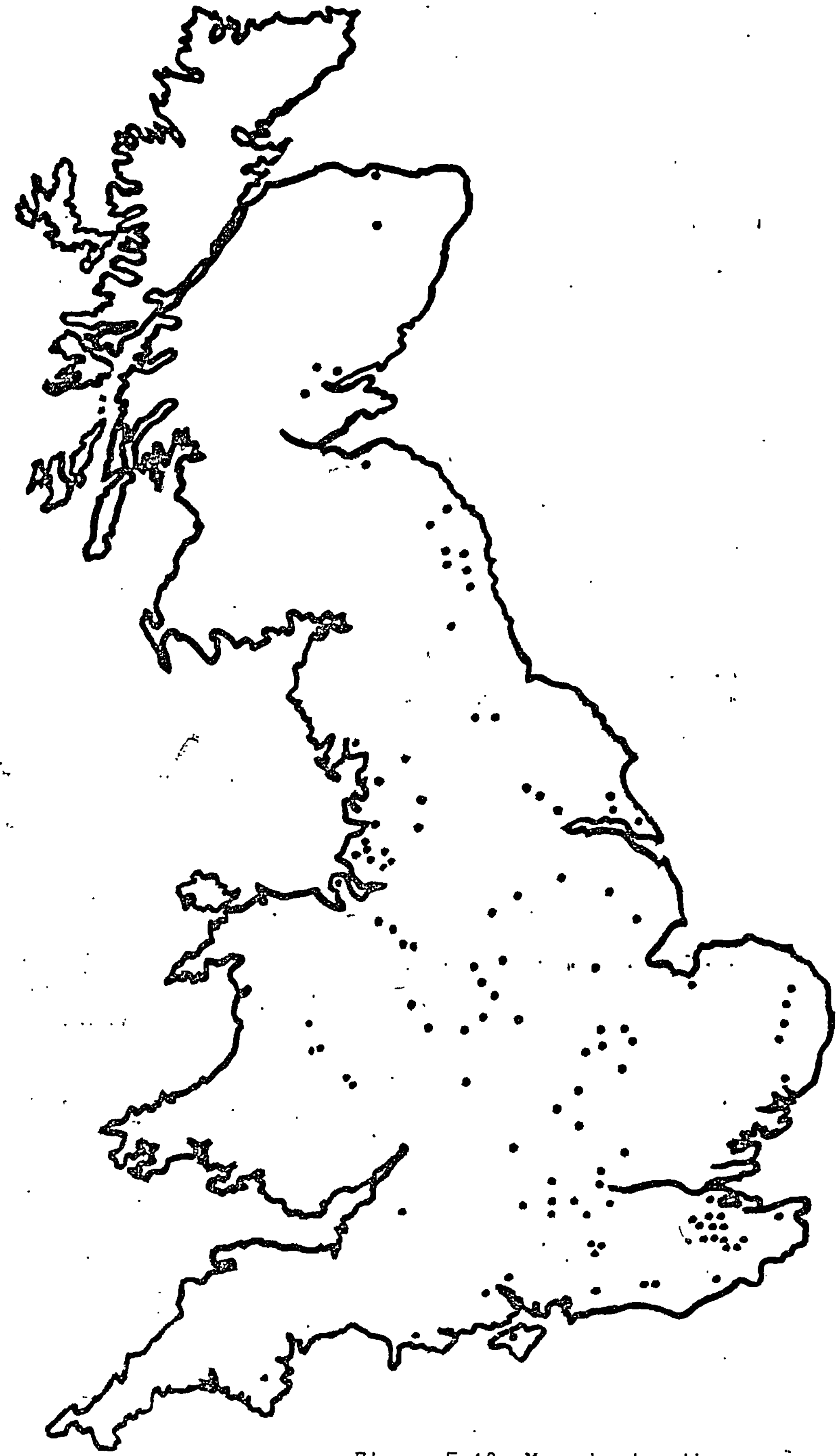


Figure 5.18. Map showing the locations of purchasers of selected tilemaking machines prior to 1850 (see page 137 and Appendix C).

CHAPTER SIX

EXPANDING MARKETS FOR MACHINERY

6.1.
Economic Growth and Patenting Activity

During the 1840's agricultural drainage provided the main stimulus for the rapid development of clayworking machinery. After several years of public agitation, Parliament repealed the excise duties on bricks in 1850 (13 and 14 Vic. c.9.). This removed a major obstacle to further experimentation with new machinery and provided an incentive for the widespread adoption of mechanized methods for brickmaking. The decades immediately following the repeal of the tax also saw an expansion of the market for machinery. This chapter will identify the sources of the demand for brickmaking machines after mid-century and will show how characteristics of the market not only influenced the rate of adoption of machinery, but also the direction of its development.

The repeal of the tax on bricks occurred at a particularly propitious time. From 1850 to 1873 Britain experienced a period of rising prices, expanding investments, mutiplying trade opportunities and marked economic growth that has been called the "Great Victorian Boom". A major participant in this period of prosperity was the building industry, comprising between twenty and thirty per cent of the total gross domestic fixed capital formation in the country (Church 1975, p.34). Rising incomes, rapid increases in population, continuing heavy migration to urban areas and active industrial investment all contributed to an unprecedented demand for new buildings.

As in the first half of the century, residential construction in the growing cities accounted for a large proportion of the substanital increase in building. Housebuilding, in turn, continued its dependence on expanding transport facilities to urban areas and the prosperity of regional industries. Plans for new or altered buildings submitted for the approval of local authorities under the Model Building Bye-Laws issued by the Central Board of Health after 1848 have provided researchers with data to construct indices of building activity for selected locations during the second half of the century (Aspinall and Whitehead 1980, p. 199-203). For example, A. K. Cairncross demonstrated the connection between fluctuations in shipbuilding and the demand for new housing in Glasgow after 1870 (Cairncross 1935, p. 4). Similarly, A. G. Kenwood pointed out the upswings in building in Middlesbrough during the 1850's and 60's, which peaked in the early 70's as a result of the rapid growth of the local iron industry (Kenwood 1963, p. 117). Although railway building was most active in the 1840's, after mid-century the impact on residential construction of economic activity resulting from expansion of the railways was significant in many cities. Various studies show substantial increases in the total volume of house building during the period, moving in a series of booms and slumps. According to J. Parry Lewis, house building in Britain fluctuated with a peak in the early 1850's, followed by a trough later in the decade, and thereafter steady growth until the early 1870's (Lewis 1965, p. 316-17 and Appendix 4).

While never approaching the volume of residential construction, there were increases in industrial building corresponding more closely to fluctuations in the trade cycle, but showing similar regional variations. For example, the expansion of the hosiery and lace trade between 1851 and 1857 stimulated the building of 154 factories and warehouses in Nottingham (Gorman 1980, p. 185). Similarly, based on the reports of factory inspectors from 1852 to 1857, Lewis estimated that 1,455 new factories and 338 additions were built in Lancashire as a result of investment in the textile industries (Lewis 1965, p. 89-95). More than ever before, the phenomenal growth in building activity during the third quarter of the nineteenth century exerted pressures on the brickmaking industry to expand its productive capabilities.

After the repeal of the tax on bricks in 1850, there was little interest in measuring levels of productivity in the industry. However, the few records that are available show an enormous increase in the manufacture of bricks after mid-century. The last quantification by government revenue agents in 1849 counted 1,462,767,154 bricks charged with duty. It wasn't until 1858 that another attempt was made to establish the volume of brick production. This was by Robert Hunt, Keeper of Mining Racords for the Geological Survey of Great Britain. The results, published in 1860, revealed a total of 2,503,004,600 bricks, tiles and pipes manufactured in England and Scotland, or an additional 1,000 million a year in less than a decade (Hunt 1860, Part 2; The Builder 1860, p. 761-2). Brick production clearly kept pace with the persistent demand for new buildings.

Following repeal of the excise duties on bricks, a substantial increase in the number of patents granted for brickmaking machinery was recorded. Between 1851 and 1873 approximately 364 patents were enrolled for machines capable of shaping bricks and tiles. Figure 6.1. is a graph showing the quantities and yearly distribution of brickmaking machine patents during this period. These statistics do not include patents for separate processes such as mixing or grinding the clay or for drying or burning the bricks. They do include those for improvements to parts of machines directly related to shaping the bricks such as cutting apparatus, dies, moulds, etc..[1]

It is tempting to attribute the rise in patenting activity to the repeal of the tax on bricks as do several authors (Chamberlain 1856, p. 493; Price 1975, p. 120). However, a comparison of the patents granted in other industries indicates that the sizeable increase in patented brickmaking machines was merely a reflection of an acceleration in overall patenting activity after mid-century. A lucrative economic climate stimulated new invention in all industries by increasing the potential for profits and, hence, the commercial value of patented new products. The flucuations in brickmaking patents were similar to patenting trends in other industries and, according to one author, corresponded to the rhythm of the trade cycle (Dutton 1984, p. 177). An exception to this was the particularly large number in 1853 which followed passage of the 1852 Patents Act. This act replaced the previously separate patents required for England, Scotland and Ireland by a single U.K. patent. The result was a great reduction in the cost of taking out a patent from nearly £400. down to £180.. The new law also stipulated that this fee could be paid in three instalments over the first seven years of patent protection (15 and 16 Victoria.c.83; Boehm and Silbertson 1967, p.29).

Several observations may be made about the patents for brickmaking machines after 1850. First, approximately 68 patents or almost twenty per cent of the total were granted to persons residing in other countries, primarily in France, Germany and the United States. It is doubtful that many of these inventions were manufactured or marketed extensively in Britain. Only a few examples have been identified. Peter Efferz, for instance, was originally an engraver from Prussia until he established a business in Manchester making machines based on two patents dated August 1855 (British Patent No.1970) and May 1857 (British Patent No.1451). Effertz took out several other British patents during the next ten years. Another isolated example was the inventor Augustus Morand from Brooklyn, New York who apparently moved to Leeds to go into business with Thomas Derham (British Patent No.325,1871). As earlier in the century the patenting of foreign machines in this country was primarily significant for the technical information that was made available to British inventors.

Second, some of the patents were granted only provisional protection and presumably lapsed after a period of time (from twelve to fifteen months) for failure to submit a complete specification (for example, British Patent No.1667, 1864; No.1077, 1864 and No.541, 1868; Boehm and Silbertson 1967, p.65).

Third, many machines protected by patents were designed to mould a variety of other substances such as peat, coal dust, or artificial stones, and were applicable only incidentally to moulding clay. Many of the vertical wheel moulding machines were developed for this purpose and probably were not promoted seriously for the manufacture of bricks (British Patent No.1053, 1857;

No. 1723, 1864 and No. 1627 1872).

Fourth, it is difficult to determine exactly how many patented machines were put into production and marketed to the public. As the size and technical complexity of machines increased, so did the development costs and the difficulties of manufacture. As Dutton pointed out, "convincing investors that they should invest in inventive activity was not easy, except perhaps where an invention was obviously valuable" (Dutton 1984, p. 169). The market for machinery after 1850, however, was relatively undefined and unstable and, consequently, it was extremely difficult to determine in advance the potential value of a new product.

Finally, the nature of the patents themselves illustrates the intense level of competition between inventors of brickmaking machines. A great many new patents consisted of only slight improvements upon previously patented machines. Prior to the Patent Act of 1872 the British patent system did not require an examination of novelty for a new patent, leaving such decisions to the courts (Machlup and Penrose 1950, p. 4). Thus, the emergence of patent infringement cases dealing with brickmaking machinery indicates an increase in competition and the growing commercial value of new machines. During the 1840's the pirating of designs was common and many machines on the market were either unpatented copies of older models or, if patented, were closely patterned after other machines. After 1850 some patentees began to use the courts, or threatened to use them, to defend the exclusivity and, therefore, the market value of their inventions. As litigation was expensive and the outcome not always predictable, an inventor's financial backing and realistic expectations of future profits were important factors in deciding to take legal action.[7]

Henry Clayton was one of the first patentees to take advantage of the courts to defend his inventions. In 1853 he successfully petitioned the court against William Percy for infringement of his patent for a combined three-process machine for making pipes, tiles and bricks (British Patent No. 10, 132, 1844). The alleged infringement centred on a modification to Clayton's popular extrusion machine which enabled it to perform the functions of a moulding machine. In stating his case, Clayton's council emphasized the originality of his three-part machine that screened the clay through a perforated metal grating, moulded and pressed the bricks and then pushed them onto an endless belt. A unique aspect of the machine was an apparatus that was dipped in oil to lubricate the mould box after each brick was discharged. The civil engineer, Charles May (formerly with Ransomes of Ipswich), the patent agent and engineer, William Carpmael, as well as several brick and tile manufacturers were called upon to testify for the plaintiff, particularly as to the substantial and valuable improvements made by Clayton's patent over previous machines.

William Percy, the accused infringer, was a machine maker from Manchester who was granted a patent in 1846 for various improved shapes of bricks and a moulding and pressing machine (British Patent No. 11,236). Percy called Benjamin Fothergill, a civil engineer from Manchester, as his principal witness, and he attempted to disclaim the novelty of Clayton's machine by showing its similarity to several other patents. Although Percy's machine did resemble Clayton's in its basic processes (as did many others), there were some differences, notably a more sophisticated apparatus for lubricating the mould boxes and another method for applying motive power. Despite these distinctions, the jury returned a verdict in favour of Clayton. In summing up, the Lord Chief Baron commended him for his careful and complete patent specifications (<u>The Builder</u> 1853, p. 491). The judgement, however, did not seem to deter Percy who continued to experiment with brickmaking machinery and took out additional patents over the next eighteen years (British Patent No. 350, 1855; No. 1732, 1858; No. 410, 1860 and No. 2389, 1870).

Following the favourable outcome of this case, there is evidence to suggest that Henry Clayton threatened a similar action against John Whitehead, another machine maker from Preston. Whitehead was one of Clayton's strongest competitors at RASE meetings in the late 1840's. The designs for his popular machines were mainly adaptations and improvements upon earlier less successful machines. As Whitehead did not patent his products at that time, Clayton's litigation seems to have been a joint action against the manufacturer and various users of his machines.[3]

Letters to Lord Wodehouse from George Forrester, steward of the Kimberley estate in Norfolk, who had purchased a Whitehead tilemaking machine in 1853 for the Kimberley brickyard, reveal some of the circumstances of the case. In March 1854 Forrester received a letter asking him to make himself liable for "a fortieth part" of the expenses of defending Whitehed in court. His correspondence to his employer, dated 3 April 1854, warrants quoting at length: "I am unable to give any particulars relating to Whitehead's tilemaking machine beyond those contained in the papers which I forwarded in my last letter. The number of persons who have purchased the machines in question is very considerable, every one of who [sic.], in case of Mr. Clayton obtaining a verdict, would be liable to be proceeded against for having used the machines...It appears to me to be a very unreasonable state of the law to make all purchasers and users of the machine liable to damages when the only person actually to blame must be the manufacturer himself. If Mr. Clayton should obtain a verdict in his favour it would be quite reasonable that he should receive a royalty for the future use of the machines, but in both cases Mr. Whitehead should be the only party liable to damages. I believe, however, that the law does not bear out my view of the case" (Wodehouse/Kimberley MSS KIM34/2). Precise details about the action are not known, but apparently it was settled before reaching the courts as there was no further reference to the matter in Forrester's correspondence.[4] The incident illustrates the lengths to which some manufacturers were willing to go to eliminate a rival in the increasingly competitive market for brickmaking machinery after mid-century.

An examination of the patents for brickmaking machines clearly shows that many inventors were working simultaneously on some of the same problems. Once the major technical processes were established, the market value of a new machine often was enhanced significantly by fairly subtle improvements or refinements.[5] Thus, the substantial increase in patents for brickmaking machines after

1850 does not necessarily indicate that rapid or dramatic progress was being made in machine development. A large number of patents may have been granted before a really significant and useful improvement appeared. Patenting activity at this time was equally a reflection of the easing of patenting laws and the general mood of optimism and expectation of profits among inventors in a prospering economy.

6.2.
Agricultural and International Markets

A noticeable characteristic of the market for clayworking machinery after 1850 was the sustained demand from the argicultural sector. The decade from 1853 to 1862 is often referred to as the "Golden Age" of English agriculture. Despite a decline in the agricultural workforce caused by urban migration, these prosperous years saw some of the highest yields ever recorded for many crops, a sharp rise in livestock prices and substantial profits for many farmers. This in turn generated previously unseen expenditures on the expansion of holdings, the construction of farm buildings, livestock development, land drainage and the purchase of machinery (Ernle 1912, p. 370-72).

Although substantially developed before mid-century, drainage tilemaking gained momentum during the fifties and sixties with many more estate owners and tenant farmers undertaking drainage schemes and purchasing new pipe and tilemaking machinery. Some agriculturalists, who invested in machinery during the 1840's, purchased additional machines during these years, often from several different manufacturers. A correspondent to Henry Clayton and Company in 1861 claimed to have used machines from four different firms in the previous fifteen years before buying Clayton's pipe and tile machine. Another tilemaker, Thomas Wilkes from Warwickshire, used a machine by Clayton for sixteen years, but acquired more during the 1850's (Henry Clayton and Company c. 1862). Accounts for the brickyard on the Kimberley estate in Norfolk, owned by Lord Wodehouse, show a similar expansion of use and experimentation with machinery from different manufacturers. In 1849 a tilemaking machine, presumably by the Ainslie Company, was purchased by the estate for £33.10s.. By 1853 another was added, this time Whitehead's drain tile machine costing £29.16s.6d.. Ten years later one of these, "an old tile machine", was sold for £2.18s. (Wodehouse/Kimberley MSS KIM 34/5 1849-50; 33/4 1852-53 and 33/4 1859-60).[6]

The requirements for agricultural tilemaking were consistent throughout the period and, consequently, the form of machinery, as developed during the the 1840's, remained relatively the same. Machine manufacturers continued to produce a selection of small, labour-intensive extrusion machines which they exhibited at the ever-popular annual shows of the agricultural societies. After repeal of the excise duties these small machines also frequently were used for the local production of small quantities of building bricks. Some manufacturers like Edward Page and Company of the Victoria Iron Works, Bedford, specialized in portable, hand-powered machines for agricultural use. The larger more diversified firms, such as Bulmer and Sharp of Middlesborough, also offered at least one small brick and tile machine in their range of products (Figure 6.2.; Clark 1862, p.254; Henry Clayton and Company c.1862).

The demand for these small machines was greatly increased by the expansion of international trade. During the third quarter of the nineteenth century, a growing proportion of British engineering goods was exported to overseas markets. Agricultural implement makers, in particular, grew rapidly in the decades after the Great Exhibition as a result of export trading (Grace and Phillips 1975, p.5; Whitehead 1964, p.74). Following the example of these firms, several specialized brick machine manufacturers looked to international markets as a source of new profits or to boost unpredictable sales at home.

A succession of international exhibitions provided the opportunity for firms to promote their products and attract overseas customers. Sending machinery to an exhibition involved a considerable expense for the entrepreneur who incurred not only transport costs, but also the costs of labour to erect and staff displays and to dismantle and return the unsold machines. British brick machine manufacturers apparently enjoyed a competitive dominance at the exhibitions throughout the 1850's and 60's that sufficiently offset this large expenditure. At the Paris Exhibition of 1867, for example, T.C. Archer reported that "the only exhibitors of machinery for making bricks and drainage tiles...are to be found in the British section" (British Sessional Papers 1867-68, p. 109). These included several machines by Henry Clayton, John Whitehead's "two-cylinder machine", Gregg's brick presses and Peter Bawden's moulding machines. Clayton was especially successful at the major exhibitions, winning medals at Amsterdam in 1853, the Universal Exposition of Paris in 1855 and the Royal Exposition of Vienna in 1857 (Henry Clayton and Company c.1862; Mechanics Magazine 1856, p. 107).

Many firms supplied machinery to non-industrialized European countries. In 1859 Henry Clayton secured a lucrative contract in Russia. According to The Builder, in that year he obtained "special privileges from the Russian government for the establishment of very extensive brick manufactories in St. Petersburg and Moscow" (The Builder 1859, p. 482). Like many of the agricultural implement makers, Clayton had agents in Moscow, the Netherlands and possibly in other countries to facilitate sales.[7] By 1862, the year of the London Exhibition, Clayton's trade literature contained a large number of testimonial letters from overseas purchasers. Customers had written from Germany, Switzerland, Belgium, Norway, France, Austria, Hungary and the Netherlands. Clayton sent machines to the Russian Government Mines in Siberia and to the estates of the Grand Duke Nicolai. He also supplied brick and tile machinery, mills, steam engines and sawing machines to other European nobles for use on their estates. It was reported that the Counts Nicholas, Paul and Maurice Esterhazy of Hungary purchased a total of forty-four machines between 1855 and 1862 (Henry Clayton and Company c.1862).

Another reliable source of customers for machine manufacturers was the British colonies. Tilemaking machines were used on colonial agricultural estates and simple brickmaking machines provided materials for major military or public works projects like railway construction. In 1851 the Mechanics Magazine reported that Lt. Col. Cantley of the Royal Corps of Engineers bought machines to send out to India where they were used to make the hundred million bricks required for engineering works at Roorkee (Mechanics Magazine 1851, p. 193-4). Apparently good quality building bricks were extremely high priced and difficult to obtain in India. T. Roger Smith, a Fellow of the RIBA, stated in 1868 that "native bricks are very dear and small, being thin like Roman bricks, they are mostly defective...The fact is that good materials and fuel for brickmaking are both equally scarce" (Smith 1867-68, p. 204). For the project, Cantley selected machines by the Ainlsie Company, but they were not capable of handling the local clay: "The bricks were all torn at the edges and broader at the bottom than at the top." He then purchased Hall's machines, manufactured by the Ransome firm in Ipswich. These "succeeded admirably" in turning out the requisite number of bricks and greatly rduced the cost of the construction (Mechanics Magazine 1851, p. 194).[51] Other companies reported sales in the colonies. Henry Clayton sent a shipment of machines to Ceylon for large government works in that country and to South America for railway construction (Mechanics Magazine 1857, p. 518). Also, one of the first successful dry clay brickmaking machines made in this country by Platt Bros. & Co. of Oldham was shipped to a customer in India (Proceedings of the Institution of Mechanical Engineers 1859, p. 50).

Henry Clayton apparently sold the same extensive range of products to overseas customers as he did to those at home (Figure 6.3.). Some of the agricultural implement makers, on the other hand, developed special products aimed particularly at the needs of the export market. Hall's brickmaking machine was one of the products selected by Ransomes of Ipswich for the colonial and overseas trade. Invented in 1845 by Alfred Hall of the United States, Ransomes demonstrated the machine in 1851 at the Great Exhibition (The Illustrated London Journal 1851). But by 1856, Chamberlain remarked that "although largely used in America, it did not become general here" (Chamberlain 1856, p. 495). Apparently the firm withdrew the machine from the home market and promoted it exclusively abroad. It was included in some of Ransomes' foreign language publications (Catalogue Illustré des Machines et Instrumens Fabrique par Ransomes et Sims, Juin 1859).

Hall's machine resembled many of the soft clay moulding machines invented during the first half of the century (Figure 6.4.). As we have seen, these had a large container, usually a pug mill, to mix the clay and propel it into an arrangement of moulds moving beneath an opening in the hopper. A stamper, plunger, or roller then compressed the clay in the boxes and the bricks were discharged either by hand or by one of several mechanical methods. During the 1840's when extrusion machines were being developed for agricultural tilemaking, a variety of brick moulding machines also were patented, but they were introduced only after repeal of the tax on bricks. One of these, a machine patented in 1848 by James Hart an engineer from Southwark, was a complete brickmaking system with a washing mill, compressing rollers, a pug mill and moulds arranged on an endless chain (British Patent No. 12,211, 1848). Driven either by steam or by two horses, capable of producing nearly 20,000 bricks a day, and priced at £187., this comprehensive machine stood out from the other smaller and less expensive hand-operated tilemaking machines at the RASE meeting at Norwich in 1849 (RASE 1849, p. 241). Thomas Middleton, also an engineer from Southwark, patented a soft clay moulding machine in 1845 with an hydraulic press to regulate the compression of the clay in the moulds (British Patent No. 10,506, 1845).

In 1854, another machine patented in both America and Europe by its inventors, Sands and Cummings of New York, was introduced in England by Nourse and Company of Cornhill. This was a large pug mill with combined screw blades and cutting knives to mix the clay which was then forced into a frame containing six moulds. A similar machine, manufactured by Peter Bawden and Company of Nottinghill was first patented in Canada where it won the top prize at the 1860 Montreal Exhibition and was selected to provide bricks for the Parliament buildings in Ottawa. Bawden's machine was described as "a box about four feet square by six feet high, in the center whereof a vertical iron shaft, armed with blades on the Archimedean screw principle is turned by horse power, mixing and thoroughly kneading the clay, which is thrown in at the top and delivered at the base in moulds of bricks complete" (The Builder 1864, p.531).

Some British brickmakers adopted these machines after mid-century, but frequently expressed dissatisfaction with the bricks they produced. J.&.S. Williams, Richardson and Company of Shepherd's Bush purchased six of Bawden's moulding machines. All of the pug mills were powered by horse, but the pressing, striking off and emptying of the moulds was done by hand for five of the machines, while only one delivered the bricks automatically. R.M. Smythe, the owner of two brickfields in the vicinity of Heston, also tried Bawden's machines. Smythe stated that he preferred hand moulding because the machines were unable to make the bricks level: "The brick tends to thicken at the lower sides after the off bearer has put it in the hacks" (BPP Childrens Employment Commission 1866, p.137). This was only one of several difficulties encountered by brickmakers when attempting to mould soft clay mechanically. Wet clay bricks were most liable to be misshapen while being removed from the moulds and carried off. In machines with automatic ejection, the mould box moved up or down leaving the brick standing on a pallet. In others a hinged section of the box opened to allow the brick to slide out. As we have seen, it was reported that the portion of the brick first released from the pressure of the mould expanded, causing one end or side to be thicker than the others.[9] Machines using pistons to push the bricks up out of the mould sometimes produced a concavity on one side from the clay adhering to the metal surface of the piston.

Emptying the moulds by hand was less damaging to the bricks, but the soft clay still was easily distorted after being carried away from the machine. Hand moulders were able to compensate for this distortion by making one side of the brick smaller to allow for settling during its initial drying time. The mould boxes for machines could be adapted similarly. But according to R.M. Smythe, the speed of the machine undermined this improvement: "As the machine turns out six bricks at a time, there is the constant danger of the barrow loader placing the brick so that the off-bearer would have the wrong side of the brick presented to him" (BPP Childrens Employment Commssion 1866, p.137). According to other brickmakers, emptying a machine by hand also considerably reduced the overall speed and efficiency of its operation. Humphrey Chamberlain estimated that "in making 15,000 bricks a day, and calculating the moulds to weigh 4 lbs. each...we have to employ the extra manual labour of taking off, and again feeding on the machine (two removals) rather more than 53½ tons of iron, while the whole weight of the clay for the day's work is not more than 75 tons" (Chamberlain 1856, p.495). These difficulties were added to problems already inherent in making bricks with wet clay, that is, the vulnerability of the newly moulded bricks to damage during the lengthy drying period and loss due to shrinking or cracking during burning.

Wet clay moulding machines seemed like a safe and familiar choice for brickmakers contemplating the adoption of machinery after mid-century because of their similarity to hand brickmaking. Many moulding machines were only slightly more complicated than the ordinary pug mills used for tempering clay in most brickyards and they offered the benefit of combining the two processes in one apparatus. But they required thoroughly mixed, soft clay and thus were limited somewhat in the range of clay types that could be used in them. Dissatisfaction with the quality of products made by these machines may have prevented their widespread acceptance in this country. Overseas customers, on the other hand, preferred this brickmaking method to the extrusion process, which was more familiar to British brickmakers, and thus found wet clay moulding machines completely satisfactory.

By the mid-1870's competition from foreign manufacturing firms strenghtened. Many overseas manufacturers specialized in soft clay moulding machines and moved ahead of British firms in developing this process. There was a sharp increase after 1870 in the number of non-British manufacturers demonstrating brickmaking machines at the major exhibitions. This increase was made more apparent by the declining participation of British machine makers. In their report on brickmaking machinery at the Vienna Exhibition in 1873, Maw and Dudge observed a falling-off in British exhibitors: "We missed from the collection some of the best known and most largely used machines." A relative newcomer, Thomas Derham of Leeds, exhibited the only power driven machine in the British section while Edward Page and Company of Bedford again demonstrated their small hand-powered extrusion machines (Maw and Dudge 1874, p.382).[19] In contrast to the British displays, there were extensive steam-powered exhibits by American manufacturers including C.A. Winn of Pennsylvania and German machines by J.Schmerber, Edward Laeis and Company, Sachsenberg Bros., C. Schlickeyser and Hertel Eisengresserin und Maschinen fabrik Gesellschaft. There also were two machines by Austrian manufacturers, Springer and Stern and Louis Henrici. Missing altogether were the most successful British machine makers from the previous two decades such as Henry Clayton and John Whitehead. It is possible that these firms and others withdrew from the international exhibitions because declining overseas sales no longer compensated for the enormous expenses they incurred by participating (Elbaum and Lazonick 1986).

As we have seen, one possible reason for declining sales may have been a divergence in brickmaking techniques between Britain and other European countries. The lack of interest in British machinery by Dutch brickmakers illustrates this point. According to one report, all bricks in Holland were cheaply made by hand prior to the late 1860's when brickmakers began to experiment with mechanical processes. At first British extrusion machines were tried, but the jagged edges left by the cutting wired were greatly disliked. Other types of machinery, like dry clay presses also were tried, but the Dutch brickmakers thought they were too large and too costly to purchase and operate. Moreover, they still preferred to add large quantities of water to their clay which they believed improved the strength and durability of their bricks.

Consequently, brickmakers in the Netherlands looked to other sources like the United States for soft clay moulding machinery which was the prevalent technique used in North· America. In addition, simple inexpensive moulding machines requiring little motive power other than hand labour were manufactured locally and widely adopted because they were more compatible with traditional brickmaking methods (The Builder 1875, p. 194).

Export trading was an important source of profit and growth for some British brick machine makers during the 1850's and 60's. The success of these companies in overseas markets may account for the continued success of certain products like hand-operated extrusion machines or soft clay moulding machines that were otherwise thought to be unsuitable to the needs of British brickmakers. Promoting machines in overseas markets was expensive, however, and with the appearance of strong foreign competition, profits became increasingly uncertain. Hence, machine makers focused their attention on the problems experienced by the brickmaking industry at home and gradually pushed machine development in new directions.

6.3.
The Formation of Brickmaking Companies

The repeal of the excise duties on bricks removed a major obstacle to the development of brickmaking machines and encouraged some brickmakers to experiment with mechanized methods. An equally important incentive appeared in the mid-1850's when a series of acts regulating the formation of companies and granting limited liability created new opportunities for British brick manufacturers to establish large-scale operations and invest in machinery. [11] The earliest move towards reform came in 1844 when the Joint Stock Companies Registration and Regulation Act was passed. This act provided for incorporation by a simple two-part process consisting of, first, a provisional registration to allow the company to promote itself and, second, a completed registration which granted full incorporation. The Limited Liability Act of 1855 and the Joint Stock Companies Act of 1856 followed. These offered limited liability to newly incorporated companies and reduced the number of persons required to register a "memorandum of association" (Shannon 1931, p. 272-74).

As a result of granting limited liability to joint stock companies, there was an enormous increase in the number of companies formed after 1855. Statistics show that up to 1856 only eleven companies existed for the purpose of manufacturing bricks, tiles and pottery. But between 1856 and 1865 sixty-one new limited companies were added.[12] The large increase in the number of new companies formed during these decades may be somewhat misleading as many were abortive. This means there was no record of the company after its initial registration, indicating an immediate failure to promote the enterprise or to collect the necessary capital. Shannon estimated that about thirty-six per cent of all companies formed between 1856 and 1865 were unsuccessful in this way. Out of the sixty-one new companies organized for working clay in the ten years after 1865, twenty registrations or nearly one-third were abortive. During the next decade forty-two out of 181 were in this category. Among these may have been the London Brick Making Company which registered provisionally in July 1853 but submitted no further communication to the Registrar (Public Record Office, hereafter PRO, BT41 379/2150).[13] Another apparently abortive company was the Brick, Tile and Pipe Steam Manufactory registered in February 1869 "for the manufacturing by steam power and hand labour of bricks, tiles, pipes and all and any other articles that are usually or can be made or manufactured for building or draining purposes." This registration also was not completed (PRO BT31 1448/4301).

Other companies had only a short existence of three years or less, suggesting they were speculative, fraudulent or simply too badly managed to survive. Some of these may have been a type of speculative activity in which companies were formed not as serious enterprises, but so they could be wound-up immediately allowing the promoters, often including lawyers and accountants, to profit by the winding-up process (Todd 1932, p. 66-67). The short life of other new companies may have been the result of fraud or malpractice by the directors. One such company was the Patent Face Brick Making Company Limited, registered in August 1858 "for the making of bricks by machinery or otherwise." All shares were taken up by members of three families. The company reported a summary of capital and shares in 1861, but by 1864 the Registrar was notified that "the secretary of the Patent Face Brick Making Company is dead, that a Director has absconded with the Company's money, and that the said company has been defunct for some time past..." (PRO BT31 355/1295).

Most of the clayworking companies registered under the new acts were formed to manufacture bricks by machinery or to work a specific brick machine patent. High-production mechanized brickmaking required a considerably greater capital outlay than works using hand methods, not only to purchase the machines but also to erect adequate buildings to house the operations and to pay for additional fuel consumed by the machines.[14] Some genuine enterprises took advantage of the opportunity to jointly invest in high-priced brickmaking plant and to establish large mechanized brickworks. But the great number of abortive and failed companies clearly reflects both the high level of optimism among promoters and the risky nature of large-scale brickmaking ventures at that time. A statement by the Patent and Common Brick and Tile Company Limited in its registration in 1854 summarized the optimism and faith in machinery held by many companies: "Various meetings have been held for the purpose of taking into consideration the vast increase in the demand for stock and other bricks in and around the metropolis and other improving places and the great insufficiency of the supply and also the power of manufacturing by machinery and steam power...an unlimited supply of stock and common bricks and tiles of superior quality to any that can be produced by ordinary means..." (PRO BT41 540/2959).[15]

Surviving records of new joint stock companies indicate that many, while not necessarily of a speculative or fraudulent nature, were neither profitable nor long-lived. Other statistics by Shannon show that of the clayworking companies fully registered between 1856 and 1874, thiry-nine per cent were wound up within ten years of being formed. These figures are slightly higher than the percentages for companies in all industries combined (Shannon 1933, p. 302 and 308). Companies wound up compulsorily because of liabilities accounted for a full one-fourth of all companies registered. It appears also that the proportion of insolvencies increased throughout the period. These businesses may have been the victims of general downward trends in the economy or of increasing competition within the brickmaking industry. But Shannon supports the view that "companies which so failed, failed from fraud or gross mismanagement amounting to fraud" (Shannon 1933, p. 295).

A small number of new companies were wound up for the purpose of reforming because they were sold, amalgamated or reconstructed. A much greater number, seventeen per cent of companies formed, were dissolved voluntarily suggesting only an earlier recognition of impending failure. For example, the Arley Pottery and Fire Brick Company was formed in March 1857 with works situated at Upper Arley near Bewdley in Staffordshire. Subscribers included the clayworking engineer Humphrey Chamberlain (it is possible that machines patented by Chamberlain were used by the company), the bankers Samuel and H. E. Gurney, and one of the few architects known to have been involved in a brickmaking enterprise during the period, Henry Baker.[16] The company submitted a summary of shares in 1858 and again in 1859 and 1860, but it was voluntarily wound up in August of that year presumably due to losses incurred (PRO BT31 25/131).

The precise circumstances leading to the demise of these businesses are obscure because for most of them the only surviving records are the formal reports sent to the Registrar of Joint Stock Companies. Additional information, however, is known about two companies set up to manufacture machine-made bricks in the city of Manchester. The Lancashire Brick and Tile Company was registered in October 1862 "for the manufacture of bricks and tiles and other articles made from clay by means of a machine of which Charles

Hadfield and William Alfred Attkins are the patentees..." (PRO BT31 677/2882). The patent referred to, dated 6 June 1860, was for a vertical wheel moulding machine subsequently manufactured by the engineering firm of Farmer and Broughton of Salford (British Patent No. 1391, 1860). The Builder announced in November that "after careful testing (by pressure and otherwise), the bricks made by the machines of the Lancashire Brick and Tile Company were found superior to others" and the company recieved the contract to supply both common and facing bricks for the new gaol attached to the Manchester Assize Courts, designed by Alfred Waterhouse. Although the company had its own works in Cheetwood Lane in Manchester, the magistrates decided to erect one of the machines near the courts to utilize clay on the building site (The Builder 1862, p. 843). It was reported later, however, that the facing bricks produced by the machine were of such poor quality that eventually another machine was substituted. According to George Burton, a bricklayer on the job, "the bricks were so inferior that they could not put them to the face; they are not put to the face, they are put at the interior of the walls" (BPP Manchester Outrages Inquiry 1867-68, p. 871).

The Lancashire Brick and Tile Company was one of only four brickmaking companies in the vicinity using machinery and they became the object of intimidation and violence by the trade unionists in labour disputes that were later investigated by the Royal Commission on Trades Unions in 1867. For example, in 1862, just prior to the formation of the joint stock company, the roof of the engine house at the Cheetwood Lane works was blown off and on another occasion the water in the steam boiler reservoir was secretly let out so that when the fire was lit it would blow up. The company's managing directors, Attkins and Hadfield, also reported that in 1863 a bottle of combustibles was thrown through a window at the site , bolts and nuts were dropped in between the toothed wheels of the machine to cause a breakdown, and bricks made by the company were spoiled repeatedly in the night (BPP Manchester Outrages Inquiry 1867-68, p. 805-6; Price 1975, p. 110-132). The company was able ultimately to find only two or three customers for their products because of fear of retributions by the unions, and in 1865 they stopped operating (Price 1975, p. 127, n. 28; PRO BT31 677/2883).

A second joint stock company, The Patent Machine Brick and Tile Company Limited, was registered in June 1860 to produce machine-made bricks in the city of Manchester (PRO BT31 481/1883). This company established works on Lord Derby's land adjacent to the Assize Courts and became known as Grundy and Company, presumably after John Grundy, a company director and principal shareholder (BPP Trades Unions Commission 1867, p. 230). The machine installed at the works was a dry clay press manufactured by Platt Brothers and Company from Oldham. When the machines by Attkins and Hadfield failed to make suitable bricks to face the new gaol, the contractor bought bricks from Grundy and Company and from an identical machine operating in the city by the Ardwick Brickmaking Company (BPP Manchester Outrages Inquiry 1867-68, p. 871). This brought both companies into conflict with the unions in protracted labour disputes at the prison building site. A strike originating with the bricklayers' labourers over the unfair hiring of a gang leader soon spread to other trades. The contractor on the job, under great pressure to complete the building in time for the July assizes, proceeded to hire non-union workers to finish on schedule. But the trade unionists retaliated by intimidating those who worked at the site by blocking the delivery of supplies from building materials merchants under their control and by prohibiting the use of machine-made bricks on other jobs in the city involving union workers.

They further attempted to persecute the architect, Alfred Waterhouse, by threatening to suspend work at his other Manchester building sites if he did not take their side in the dispute and dismiss the offending foreman. According to Edmund Ashworth, chairman of the committee for building the Assize Courts, "it was not until Mr. Waterhouse had published a circumstantial account of the strike, and thus prepared the way for severe criticism by the press on the line of action adopted by the men, that the bricklayers at length gave way and allowed their masters to resume their contracts" (BPP Trades Unions Commission 1967, p. 230). The unionists, however, did not give up their boycott of machine-made bricks. "After the new gaol ceased to require so many machine-made bricks, the machine company (Grundy and Company) could not get a sale for their bricks and with a strong combination against them on the part of the bricklayers and brickmakers, they had to give up" (BPP Trades Unions Commssion 1867, p. 230). In August 1866 notice was given that the Patent Brick and Tile Company Limited would be voluntarily wound up and in 1869 this was completed (PRO BT31 481/1883). During the time they were supplying machine-made bricks for the gaol, the Ardwick Brickmaking Company also had supplies at their yard destroyed and their machine damaged from objects being thrown in it. A former manager in the company testified that the losses due to damage were so heavy that the owner, Mr. Marsden, also was forced to give up his business (BPP Manchester Outrages Inquiry 1867-68, p. 144).

The failure of machine brickmaking concerns in Manchester has received a great deal of attention from historians because of the details revealed in the Royal Commission inquiries. It must be acknowledged that the particular circumstances leading to their demise were not typical of the experiences of companies in other parts of the country. Their lack of success, however, was not unique. In a study of Manchester trade directories, Richard Price found that the survival rate of brickmakers in the area, including those involved in hand brickmaking enterprises, was extremely low. Fewer than one-fourth of all brickmaking firms operating between 1853 and the early 1880's lasted more than five years (Price 1975, p. 117). This study and those by Shannon of joint stock companies clearly show the general instability of the brickmaking industry during this period of economic expansion. The greater capital investment required by large-scale mechanized works and, to some extent, the instability of the machines themselves made these companies much more vulnerable than others to the uncertainties of the marketplace.

There were, on the other hand, a few very successful and durable large machine brickmaking enterprises established in the decades after mid-century. Not all of these were incorporated. The Builder remarked in 1852 that "companies have been formed in the most eligible localities that could be selected for the purpose of manufacturing bricks in steam factories by a new patent process" (The Builder 1852, p. 800). The patent was by Robert Beart for a complete brickmaking system including clay preparation and extrusion machinery, drying stoves and kilns. Beart established large works at Arlesey along the Great Northern Line, sending a substantial proportion of his annual production to the London area. In 1877 he formed Beart's Patent Brick Company and by 1880 he merged with the adjoining Arlesey Brick Company and opened an office in London. Only at the end of the century was the firm incorporated (Cox 1979, p. 44, 45 and 70). Another company, also apparently formed to work Beart's patents, was Edward Gripper and Company with three establishments near Nottingham, at Carlton, Basford, and a forty-six acre site at Mapperley (The Builder 1852, p. 800; Church 1966, p. 229). In 1867 Gripper amalgamated with another brickmaker named William Burgass to form the Nottingham Patent Brick Company and purchased new machines using the "semi-dry" process (Gorman 1980, p. 185-86). This company provided most of the sixty million bricks for George Gilbert Scott's Midland Grand Hotel at St. Pancras Station (Simmons 1968, p. 53).

The Burham Brick, Pottery and Cement Company Limited was formed in 1859 to purchase works that had been established by Thomas Cubitt in 1853 at Burham on the Medway. The company purchased all the buildings and machinery used by Cubitt including seventeen Ainslie brickmaking machines ("improved by Cubitt"), pug mills, washmills and steam engines totalling 220 horse-power to operate the works (The Builder 1859, p. 655; Hobhouse 1971, p. 311-13). By 1861 another brickmaking machine by Henry Clayton, several of his "Patent Rotary Orifice Dies" and brick presses also were added (Henry Clayton and Company c. 1862). In 1866 it was reported that 577 persons were working for the company, some of whom gave evidence about working conditions to the Commission on the Employment of Children (BPP Childrens Employment Commission 1866, p. 141). All of the property belonging to the company was sold again in 1871 and a new joint stock company was registered in December of that year which lasted until it was voluntarily wound up in 1900 (PRO BT31 1670/5913). Other references to the company throughout the period indicate that it remained one of the country's major brick producers (Rivington 1879, p. 107 and 109).

The immediate response to passage of the new company legislation in the decades after 1850 was a high level of expectation and speculation in machine brickmaking. But investing in a joint stock company to promote large-scale mechanized brickworks was fraught with risk and uncertainty. Although there was a substantial increase in new registrations, the failure rate of companies was high and only a small number became well-established, profitable enterprises. P.L. Payne estimated that by the end of the period "joint stock companies accounted for at most between five and ten per cent of the total number of important business organizations" (Payne 1985, p. 19). Evidence suggests that the demand for high-production brickmaking machinery was concentrated in a very small number of large-scale businesses.[17] For most of the century, the British brickmaking industry was dominated by small firms whose special needs greatly influenced the technical development of brickmaking machinery.

6.4.
Expansion of the British Brickmaking Industry

Vast increases in the demand for bricks after 1850 placed enormous pressure on the brickmaking industry in England and Scotland to expand its productivity. The industry responded to this demand by mutiplying the number of small-scale brickworks dispersed throughout the country. Unfortunately, there are few reliable statistics to document this expansion. In 1858 Robert Hunt counted the number of works in each county for the Geological Survey of Great Britain and reported a total of over 1,400 (Hunt 1860; Bevan 1876, p. 164). Fifteen years later, after passage of the Factory Act Extension Act of 1871 which brought small brickfields previously defined as workshops under the jurisdiction of the factory inspectors, the number of fields reported in 1873 was 1,739. Most of the factory inspectors' reports indicate the prevalence of small enterprises in the brickmaking industry. For example, sub-inspector Whymper stated in 1873: "In my sub-division, as in other parts of England, brickfields are scattered about here and there, though they are found principally in the neighbourhoods of towns. They are for the most part small..." (BPP Factory Inspectors Reports 1873, p.14). Additional evidence given to the Select Committee on the Factory and Workshop Acts in 1876 substantiated this observation. Inspector G.H.L. Rickards cited only two brickworks in the vicinity of Leeds sufficiently large to be subject to factory regulations (over fifty employees), while there were thirty defined as workshops (under fifty employees). Similarly, J.H. Bignold, sub-inspector of factories in Cheshire and North Wales, reported that all the brickworks in Cheshire were workshops and only seven near Buckley were considered factories. Sub-inspector W.O. Meade-King stated that he knew of only one factory brickyard among many small workshops in his district around Manchester (BPP Factory and Workshop Acts 1876, p.423, 467 and 492). This dominance of small-scale, local producers in the brickmaking industry for most of the nineteenth century undoubtedly influenced the technical choices made by manufacturers in developing new brickmaking machinery.

Other factors which were equally important in helping to direct the development of machinery into quite specific forms after 1850 were the availability of labour and the composition of the workforce. Economic historians have pointed out that the relative abundance and low cost of labour in Britain during most of the nineteenth century profoundly affected the pattern of technical progress in many British industries (Aldcroft and Richardson 1969, p.174-79).[19] According to this argument, as long as there was a plentiful and cheap labour supply, then producers were able to function profitably despite their apparent small scale and the persistence of handicraft methods. Aldcroft and Richardson further concluded that "cheap labour probably constituted the greatest barrier to the adoption of mechanisation and new techniques" (Aldcroft and Richardson 1969, p. 176). Evidence suggests that this was particularly true in the brickmaking industry.

In 1876 G. Phillips Bevan stated that "the manufacture of bricks and draining tiles employs a very large population thoughout the kingdom and perhaps gives more steady occupation (albeit it a 'season' one) than almost any trade." But attempts to calculate the number of brickfield workers based on census reports were hampered by the fact that the census was taken in March before the large number of summer workers was hired and thus reflected only the permanent winter workforce. Nevertheless, Bevan observed that "brickmaking is eminently a juvenile employment." According to statistics he consulted, out of a total of 36,249 males employed in the industry, 21,278 were under the age of 25 years. Of 2,530 females, 2,248 were under that age (Bevan 1876, p. 155).

Investigators for the Commission on Childrens Employment in 1866 also were unable to arrive at accurate figures for the number of persons employed because of the nature of the subcontract system of hiring brickfield labour and the refusal of many "gang" members to answer the inspectors' questions. Nevertheless, in reporting to the Commission on the brickfields in the vicinity of London, H. W. Lord counted the number of gangs working in the West Middlesex district and, based on his own observations, estimated that over half of gang members were under eighteen years of age and about half of those under eighteen were also under thirteen years old (BPP Childrens Employment Commission 1866, p. 127). The employment of children was encouraged by the low wages they received in contrast to adult workers and by the fact that many parents were eager to push their offspring into paid occupation to add to the family income.[19] As George Skey, the owner of a brickworks at Wilnecote near Tamworth, explained to a Parliamentary Select Committee: "Really it was a kindness to the people to give their children an opportunity of working early, and also it would gradually break them into the new business" (BPP Factory and Worshop Acts 1876, Question 6581).

Bevan's statistics indicated that there were very few women employed in the brickfields, but the census figures he used may not have reflected the influx of female workers for short periods during the summer months (Samuel 1977, p. 4). Brickmasters in various parts of the country held different opinions about the hiring of women. There were some who believed, like the manager of the Aylesford Pottery Company in 1866, that "a brickfield is certainly not a proper place for a young woman to work in" (BPP Factory and Workshop Acts 1876, p. 142). On the other hand, in many places women moulders were in great demand because other industries, such as iron works or coal mines, absorbed most of the male workforce. Many of these fields also contained the hard marly or stony clays that necessitated a large capital investment in heavy grinding machinery to make the available material suitable for brickmaking. These enterprises more than others may have tried to avoid further investment in machinery by relying on cheaper female labour to make the bricks by hand (BPP Factory and Workshop Acts 1876, p. 148).

In some locations women were preferred because of their reliability or because it was thought they were more skilled at moulding. Mr. G. K. Harrison, proprietor of the Stourbridge Lye Brickworks and chairman of the Stourbridge Fire-Brickmasters' Association, stated: "Women are much neater in the hand, they can make a brick often better than men, because they manipulate it readily. There is not so much trouble with them; they do not stop off two or three days at a time as the men do" (BPP Factory and Workshop Acts 1876, Question 5627; BPP Childrens Employment Commission 1866, p. 138). In most cases, however, women and children were hired in the brickmaking industry to lower operating costs and thereby avoid the expense of puchasing labour-saving mechanical devices (Habakkuk 1967, p. 141-42). By the early 1870's, however, government intervention made this increasingly difficult.

In 1866 an article in The Quarterly Review summarized the reports of the Commissioners appointed to inquire into the employent of children: "One of the greatest abuses of juvenile labour that we have met with occurs in the manufacture of bricks. The employment itself is not unhealthy, inasmuch as it is carried on in the open air, but when the strength of children is overtaxed, and the hours of work are excessive, the injury to health becomes very marked" (The Quarterly Review 1866, p. 365). The Childrens Employment Commission of 1866 investigated all of the non-factory trades employing children that were not already regulated by legislation. The detailed revelations of its reports incited great public indignation about the treatment of brickyard children and the harmful effects on young girls employed in the fields. George Smith, a brickmaster from near Leicester, wrote an emotional plea for public protection of children in the industry (Smith 1867). In 1870 The Builder stated: "We feel strongly that girls should not be employed in brick and tile yards on any account, as the work is entirely unfit for them. To see girls engaged in such works, and at such unreasonable hours, mixed up with boys of the roughest class, must convey to the mind some idea of the sort of wives, with such training, they will make, and the kind of influence they will eventually bring to bear on society" (The Builder 1870, p. 585). In the following year governmental control was extended to include brick and tile yards (34 and 35 Victoria 1971 [194] II p. 49). Women and children under the age of ten years were not allowed to work in any brickfield and the employment of youths was severely restricted and regulated.

According to Raphael Samuel, this legislation "undermined the whole system of labour recruitment" in the industry (Samuel 1977, p. 93). Evidence does indeed suggest that some brickyard owners were forced to adopt machinery because of these restrictions. But this was by no means a universal response. Positive effects of the new law were not immediately forthcoming because of the difficulties of enforcement. Five years after it was passed, brickfield owner George Skey testified that "the last two or three years there has been such a great scarcity of juvenile labour that I felt it necessary to put up machinery..." But H. J. and Charles Major, brick, tile and pottery manufacturers at Bridgewater near Taunton, admitted: "We have put up a lot of machinery at a very large cost to get rid as far as possible of those small children, but we cannot do without them entirely." It seems this was the prevalent attitude. Even George Smith admitted that in his district in Leicestershire machinery was not substituted generally for juvenile labour except in the largest works (BPP Factory and Workshop Acts 1876, Questions 6581, 6606, 9314 and 13,977).

In the late 1870's children still were used extensively for many brickyard tasks -- according to Smith, sometimes four boys attended each moulder, three to carry the clay to the table and one to carry off the finished bricks. The factory inspector for the Manchester district stated that "a large number" of children were employed in the brick trade there, primarily to help draw the clay up from the pit where it was mixed or to carry off from the moulders tables. In Essex and Suffolk brickmakers even continued the "inhuman practise of putting boys, naked to their legs and arms, to tread on cold clay when saturated with water, for hours at a time" (BPP Factory and Workshop Acts 1876, Question 7257, 7298, 8721 and Vol. XXIX Part I, p.30-1).[20] The owners of brickyards were required to post notices of the law. Some brickmasters' associations attempted to enforce the regulations, for example, by fining members for allowing work by children or youths after 6 P.M..[21] But most brickmasters were not willing to assume resonsibility for hiring workers directly, and through the subcontract system the employment of juveniles, particularly boys and youths, persisted.

For most of the nineteenth century, the British brickmaking industry was dominated by small-scale, local producers who relied on an abundance of low paid workers, especially children, to avoid heavy capital investment and, at the same time, to maintain profits in an increasingly competitive market. Despite governmental intervention in 1871 that attempted to control the hiring of child and female labour, juvenile employment persisted for several decades. In attempting to satisfy the needs of these producers, many machine makers developed and marketed brickmaking machinery that was small-scaled, versatile, inexpensive and labour-intensive. These semi-automatic machines allowed brickyard owners to intensify certain areas of production while continuing to utilize the readily available, inexpensive juvenile labour for peripheral tasks. The following chapter will examine in greater detail the technical evolution of two different types of machines. It will show how the requirements of machine users profoundly influenced specific technical choices made by machine manufacturers and, consequently, the direction of machine development during the second half of the nineteenth century.

NOTES

1. For a comparison of patents in previous decades see Appendix A.

2. See Dutton (1984, Chapters 4 and 9) for a discussion of the changing interpretation of patent law in the courts and its effect on the value of patents.

3. By 1854 this must have been a sizeable number. See a partial listing of Whitehead's customers in Appendix B.

4. Also, there are no published accounts of the case. Per conversation with Mary O'Regan, Leeds Law Library.

5. One author suggested that such differentiation was a characteristic feature of British business during this period. P.L. Payne stated that in the face of growing competition, many firms were able to survive only by "increasing specialization designed to exploit marginal differences in quality or design, and by creating the impression that the differences were greater than they were in reality" (Payne 1985, p.41).

6. The first machine is presumed to be an Ainslie machine as in the following year drain pipe dies were bought from the Ainslie Tile Company (Kimberley MSS, KIM 29/2 1850-52). My thanks to Robin Lucas for this source.

7. Ransomes of Ipswich established several branch warehouses or agencies to handle European trade, principally in Eastern Europe. Garrett's also had representatives in India, France, and Russia as well as an office in Pesth. Other large companies established factories on the Continent, such as Clayton and Shuttleworth at Vienna in 1857 and Robey of Lincoln at Pesth in the same year (Saul 1970, p.153; Grace and Phillips 1975, p.6; Whitehead 1964, p.74)

8. The bricks on this project were reportedly only one-third the customary price of bricks on the market in Bengal and one-eighth of the cost near Calcutta.

9. At least one machine, that used by the London Brick

Company, was fitted with an apparatus to slice off this uneven side (Chamberlain 1856, p. 495).

10. Another source also noted the appearance of a large pug mill extrusion machine shown by Rushton and Proctor, an agricultural engineering firm from Lincoln, and a dry clay moulding machine by Bradley and Craven of Wakefield (Journal of the Society of Arts 1874).

11. Prior to this, large partnerships and companies were discouraged by imprecise and complex partnership laws. These were characterized by a confusing definition of what constituted a partner, by an absence of legal arbitration between partners in dispute, by overwhelming difficulties in legal proceedings with third parties and, in the case of companies, the need for a costly charter of incorporation granted by Parliament.

12. For comparison, during this same time 65 companies were formed to manufacture specialized engineering products, 65 for paper and printing, 41 for shipbuilding, 18 for lead manufacture and 157 for cotton manufacture. From 1865 to 1874, a further 181 companies were registered for the manufacture of clay or cement products (Shannon 1932, p. 396-423; 1933, p. 290-316)

13. This company may have reformed later with a slightly different name. Humphrey Chamberlain mentioned the machines used by the "London Company" in his address to the Society of Arts in 1856. This should not be confused with the London Brick Company established by J. C. Hill to manufacture Fletton Bricks at the end of the century.

14. For example, when Mr. R. White set up a large mechanized enterprise near Grimethorpe in Yorkshire in 1868, his capital investment was £5,000. to erect a large brickmaking machine by Bradley and Craven of Wakefield and a new Hoffman kiln to ensure continuous operation of the works (The Builder 1868, p. 82).

15. This company was formed originally in 1853 under the name Patent Waterproof Brick and Tile Company to work a patent granted in 1851 to John Workman for waterproofing bricks and tiles by means of a solution baked into the clay at a high temperature. Apparently the company was unable to collect enough capital and it

was reorganized in 1854 under the new name. One of its subscribers was James Hart, an engineer and brick machine maker from Southwark. It is possible that Hart's machines were adopted by the new company as well as Workman's waterproofing process (Civil Engineer and Architect's Journal 1852, p.112; The Builder 1852, p.385; British Patent No.12,311, 1848).

16. Baker had been a Fellow of the RIBA since 1855 and was responsible for designing the Gurney banks.

17. In his study of the brickmaking industry in the South East Midlands after 1800, Collier reported that out of 231 brickworks operating in 1851, only four were incorporated companies and by 1881 that number had risen to only 18 (Collier 1966, p.127).

18. There is extensive literature on this subject, much of it intended to compare the industrial performance and technical development of Britain and the United States. See particularly Habakkuk (1967); More (1980); Rosenberg (1969) and Saul (1970).

19. The testimony of George Blenkinsopp, factory inspector, in 1876 stated: "That is why they employ smaller ones, because a small one comes in as an addition, probably at a very small wage" (BPP Factory and Workshop Acts 1876, Question 4844).

20. See also testimony of Thomas Cotthurst and William Symons of Bridgewater (Questions 13,687-94); Robert McLean Smyth of Cowley (Question 3498); and A.C. Pillner of Newport (Questions 14,359-61). Statistics show that for the whole of British industry during this period there was only a 9.2% drop in the number of boys occupied and a 5.4% reduction in the employment of girls between 1871 and 1881 (Porter 1912, p.24).

21. This was reported by C.G.W. Hoare, sub-inspector for Salford, Pendleton, Farnworth, Bury and Heywood district. It is interesting to note, however, that fines were not imposed for employing children full-time (BPP Factory and Workshop Acts 1876, Questions 14,355 and 9933).

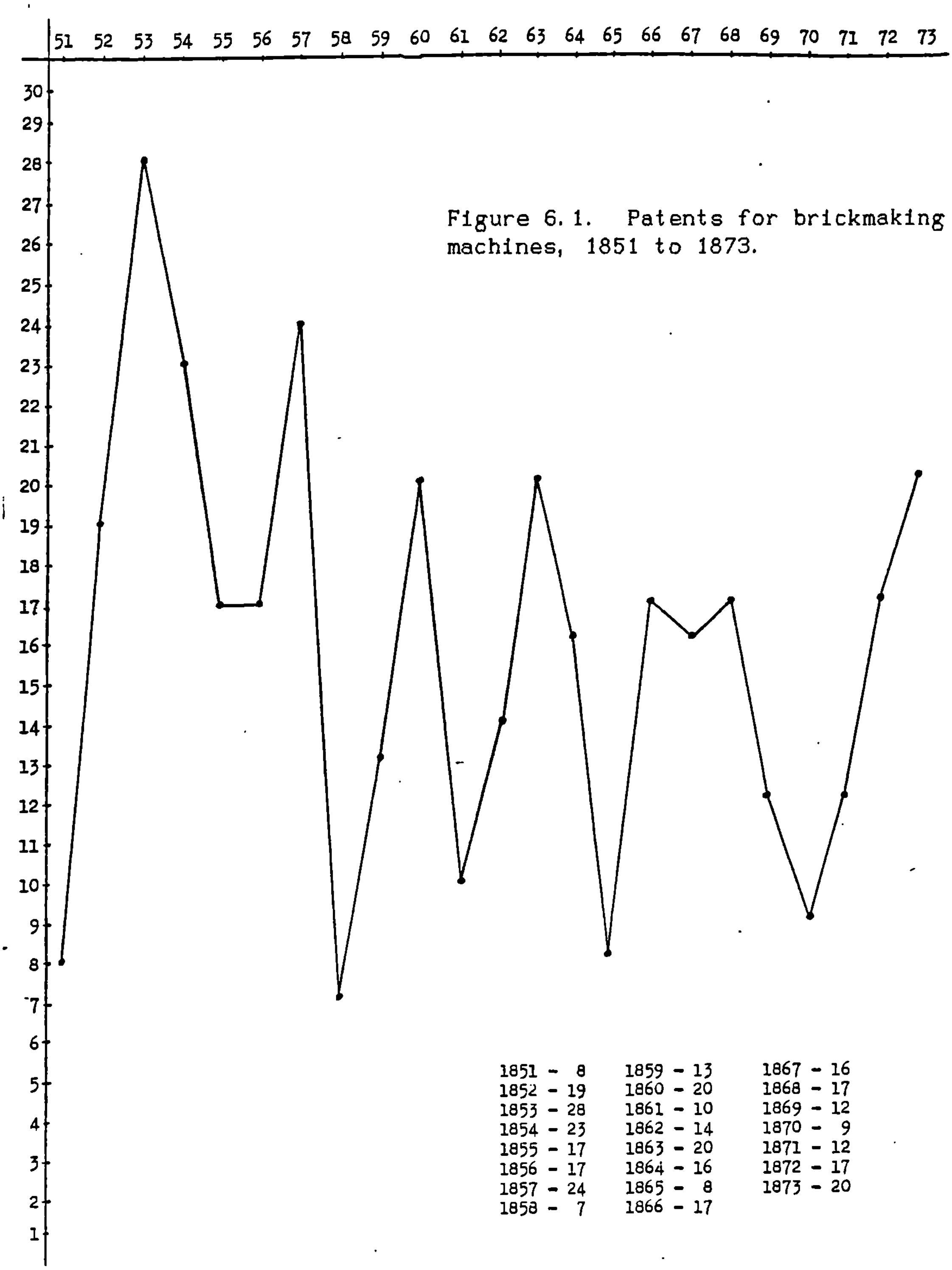
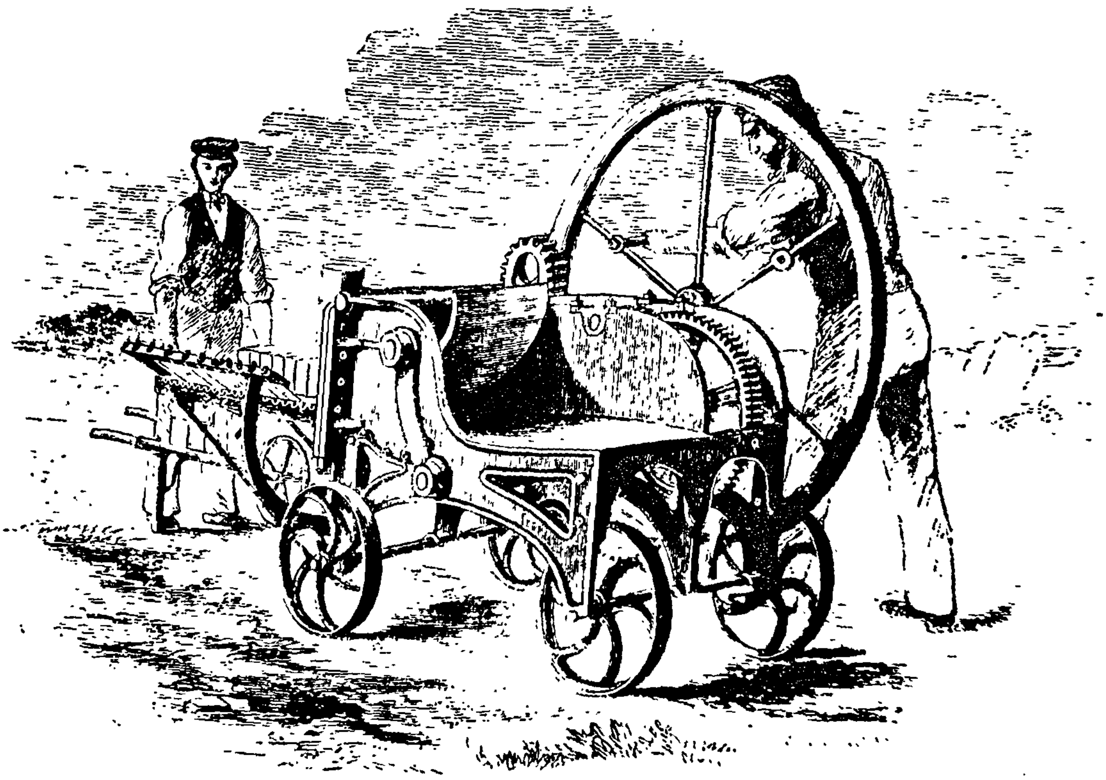


Figure 6.1. Patents for brickmaking machines, 1851 to 1873.

1851 - 8	1859 - 13	1867 - 16
1852 - 19	1860 - 20	1868 - 17
1853 - 28	1861 - 10	1869 - 12
1854 - 23	1862 - 14	1870 - 9
1855 - 17	1863 - 20	1871 - 12
1856 - 17	1864 - 16	1872 - 17
1857 - 24	1865 - 8	1873 - 20
1858 - 7	1866 - 17	

Figure 6.2. Bulmer and Sharp's hand-powered brick- and tilemaking machine, 1862.
[From D.K. Clark, The Exhibited Machinery of 1862, Etc. (1864) p.255]



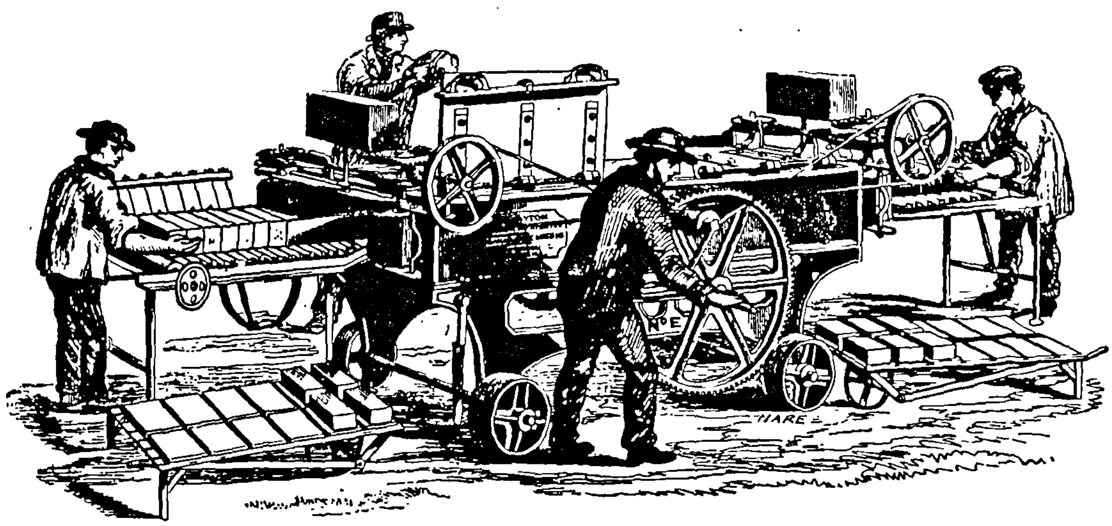


Figure 6.3. Clayton's "No. E" General Purpose Brick and Tile Machine.
[From Henry Clayton, Son and Howlett trade catalogue, 1871]

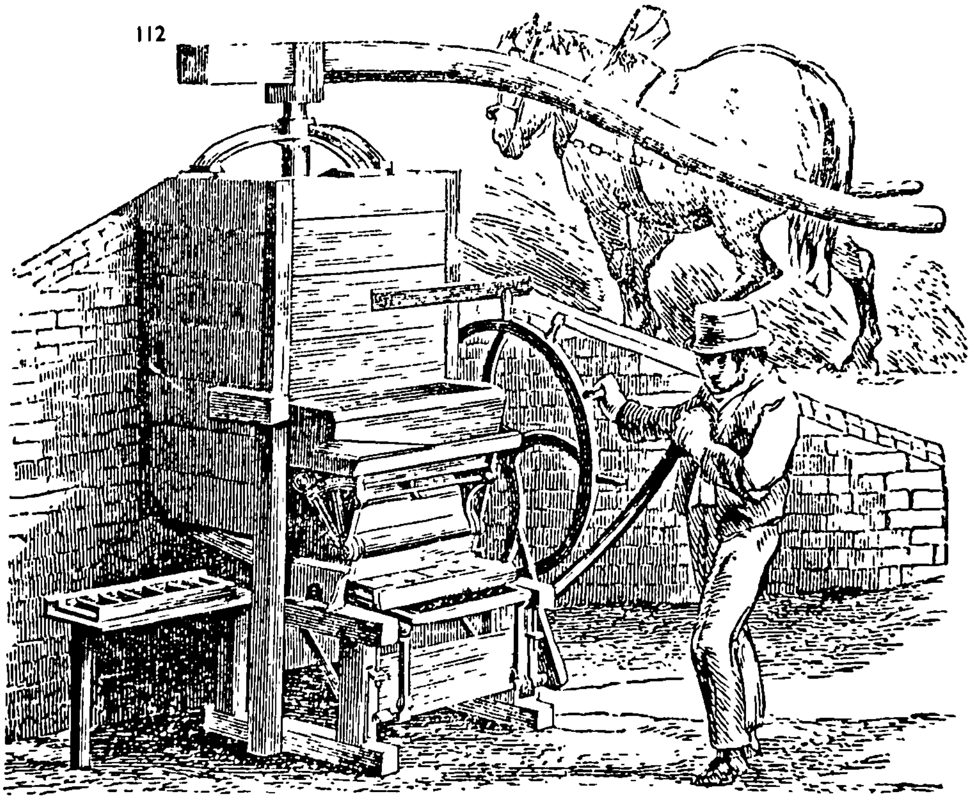


Figure 6.4. Hall's patent brick-moulding machine, British Patent No. 10,845, 1845, Frederick Ransome, Assignee.
[From Catalogue Illustré des Machines et Instrumens Fabrique par Ransomes et Sims, Juin 1859 and John Woodforde, Bricks to Build a House (1976)]

CHAPTER SEVEN

BRICKMAKING MACHINES AFTER MID-CENTURY

7.1.
Extrusion Machinery and Brick Production

Market factors can provide only a general explanation for machine development after 1850. Other, more pointed, questions also need to be asked concerning why the various types of mechanically produced bricks possessed quite different physical characteristics and why particular mechanical processes were favoured more than others. To answer these questions we need to look at some of the specific design choices faced by manufacturers in developing new machinery and to consider the variety of technical solutions available to them. More importantly, we need to examine problems or issues that surfaced about particular aspects of machine design or function. These often emerged within the "consumption junction" as controversies or imperatives surrounding the productive capabilities of specific machines or the quality of machine-made products.

In order to convince brick manufacturers that they should adopt mechanized processes, machine makers had to demonstrate two things. One was that brickmaking machinery would significantly reduce operating costs and increase production beyond the capabilities of hand methods. The second was that machines could produce bricks of a quality equal to or better than hand moulded products using most available types of clay. In 1856 Humphrey Chamberlain, an inventor and "consulting clayworking engineeer", described what he believed were the most desirable characteristics of a successful machine. He thought the machine should pug the clay and shape the bricks automatically at great speed and with no cessation of motion. Furthermore, it should be portable, consume a minimum of power and not use any manual labour except for feeding the pug mill and hacking the finished bricks (Chamberlain 1856, p. 496). This was in many respects a very different apparatus from the small, mechanically simple and labour intensive machines widely available for drainage tilemaking at mid-century.

As a result of Royal Agricultural Society competitions and extensive use in agricultural drainage schemes during the 1840's, extrusion machinery was more fully developed than any other clayworking process. The increasingly high output of these machines, their widespread use, and the resulting familiarity with the process amongst manufacturers of clay products favoured their adoption for common brickmaking after repeal of the excise duties on bricks in 1850. Despite their suitability for tilemaking, however, extrusion machinery, as developed during the previous decade, could not be applied directly to the manufacture of bricks. For one thing, the production of ordinary bricks used a much greater volume of clay compared with hollow pipes and tiles and this posed a serious problem in converting these devices to brickmaking. Tilemaking machines were limited in both size and speed when handling larger amounts of clay. Although there had been a trend towards bigger hoppers at the end of the 1840's, these were very quickly emptied when manufacturing solid bricks, each containing 150 cubic inches of clay. Hand feeding from a separate mill to keep the container supplied with material also proved to be a very slow process.

In addition, the clay mixture used with extrusion machinery tended to be stiffer than that used with moulding machines and the amount of pressure required to extrude a solid brick-sized column of paste was much greater than for tilemaking. Most ordinary piston-operated machines lacked the necessary strength, and their speed was further restricted by their intermittent action. Also, tilemaking machines were extremely sensitive to the quality of the clay used, needing a thoroughly tempered substance to prevent damage to working parts. With larger amounts moving through the machine, careful preparation was more important than ever.

To increase the output and speed of extrusion machines for the production of common bricks it was necessary to make two modifications. First, the clay receptacles had to be enlarged and, second, a method for feeding the clay continuously into the extrusion chamber had to be devised. In many machines manufactured during the 1850's this was accomplished by attaching the extrusion cylinder directly onto a pug mill to provide a constant supply of clay (Figure 7.1.). Henry Clayton remarked at the Society of Arts discussion on brickmaking in 1856: "A machine for making bricks must be of a large character to be beneficial; the first and most indispensable part of brickmaking was that the clay should be effectually prepared, and as they were aware, clay could not be handled in a small space... hence, the machine must necessarily be large." Clayton went on to say that "the clay ought to be put in by barrow or truck; it should then be carried continuously forward as was done in the ordinary pug mill..." (Chamberlain 1856, p.499).

Earlier pug mill extrusion machines were condemned by the RASE judges during the 1840's because they were too large and clumsy for the requirements of drainage tilemaking. But by 1860 Clayton's "Univeral or A1" machine had a ramp leading to the top of a large pug mill for the workmen to wheel up barrows of raw earth and empty into the machine (Figure 7.2.). In 1859 a machine patented by Joseph Eccles, said to be twelve feet long by nine feet wide, mechanically delivered the clay from where it was dug to the mill by a series of wagons moving along an inclined tramway (British Patent No.836, 1859; The Builder 1861, p.291). This was also the system used to keep the machines constantly supplied at the Aylesford and Burham Brick Works: "The clay is brought up an incline to a staging by the engine that drives the machine" (BPP Childrens Employment Commission 1866, p.141).

Unfortunately, combining the pugging and extrusion operations in this way introduced several attendant problems. In the first place, increasing the overall size of the machines obviously conflicted with the ideal of portability. Chamberlain maintained that machines "should be portable in order to save labour in carry off" (Chamberlain 1856, p.496). Earlier machines had to be portable so that the soft clay pipes or tiles could be removed and placed immediately in the sheds or hacks to dry without incurring damage by being carted away. Instead, the machine itself was wheeled around the sheds. With large, stationary machines it was crucial that the clay be as stiff as possible so the bricks were firm enough that they would not lose their shape before drying. The knife blades in ordinary pug mills, however, often were not adequate to mix and consolidate the stiffer clay compositions thoroughly. Imperfect amalgamations produced weak, defective bricks with cracks and laminations (Searle 1931, p. 134).

As a result, some machine makers resorted to a screw rather than ordinary blades in the pug mill to provide a stronger and more consistent pressure on the clay. This was suggested by John Ainslie in his first patented machine in 1841 (British Patent No. 8965), although by 1845 he apparently eliminated it in favour of a smaller hand-fed piston-operated device to meet the needs of the tilemaking market. Another early machine maker, Henry Franklin, also adopted an archimedean screw in his large pug mill machine in 1846, but in RASE competitions it was found to be too slow compared with other double-action piston machines. Although some brickmakers claimed that screws caused the finished bricks to have circular fractures in them, this seemed to be a popular solution to the problem of mixing and propelling stiff clay mixtures. For example, the machine manufactured by the firm of Randell and Saunders from near Bath had an extrusion cylinder with a double screw (The Builder 1851, p. 310). This must have been similar to the device patented in 1861 and improved in 1862 by Peter Effertz in which the clay was mixed in a hopper by a "combination of screws" (British Patent No. 2211, 1861; No. 3303, 1862; The Builder 1862, p. 324). Chamberlain's patent of 1853 also had a screw in the pug mill "but with the addition of knives on the thread of the screw" to ensure thorough mixing (British Patent No. 2591, 1853; Chamberlain 1856, p. 494).

Another remedy for the difficulty of blending stiff clay was to position a pair of rollers between the pugging cylinder and the die to further consolidate the material before it was extruded. This, too, was a previous solution, the basis for John Ainslie's second patent in 1845 (British Patent No. 10,481). According to company publicity, this method "prevented the air bubbles caused by the piston machines" and allowed for the "more perfect mixing of the clay" (RASE 1949, p. 173). Two other machine inventors adopted a similar arrangement, J.F. Porter in 1855 (British Patent No. 240) and Charles Fletcher in 1857 (British Patent No. 1737; The Builder 1858, p. 400). Over a period of five years, Samuel B. Wright and Henry Green of Rugby developed a process that eliminated the die altogether and relied on a pair of rollers to compress together separate streams of clay converging from three screw-operated pug mills (Figure 7.3.). The purpose was to apply outer layers of finely textured and coloured clay to a coarser clay body (British Patent No. 1626, 1855; No. 2958, 1857; and No. 1089, 1860; The Builder 1858, p. 540). The similarity of this process to earlier machines patented by the Marquess of Tweeddale in 1836 and James Hunt in 1842 is obvious.[7]

As we have seen, in many parts of the country brickmakers were forced to used inferior or difficult clay deposits that required a variety of mechanical devices to prepare the material adequately for tempering and mixing. During the 1840's several users of small tilemaking machines reported success in working the difficult hard marls or stony clays found in some regions. One of the most frequently heard complaints about extrusion machinery after mid-century, however, was that it was unable to manufacture usable bricks with all types of clay. In many cases, machines that had been completely adequate for tilemaking, failed when attempts were made to convert them to brickmaking (Chamberlain 1856, p. 493). Many machine makers were convinced that extrusion machinery was mechanically correct and feasible for brickmaking, but that it failed in practice because of the difficulties encountered in working particularly hard clays in various regions of the country. In 1852 The Builder stated: "It is scarcely necessary to remark that all clays will not suit brick machines" (The Builder 1852, p. 800). Robert Beart, an experienced brick manufacturer and machine inventor, also commented in 1856 that brick machinery "must be adapted to the peculiar clay it had to work. Clays varying in different localities required different arrangements of machinery for its working; and upon some clays, or mixed substances of which bricks were made, no machinery had up to the present time been brought to bear" (Chamberlain, 1856 p. 497).

Many brick manufacturers justified their hesitation in adopting machinery by claiming that brickmaking machines were unable to work the clay in their particular districts. For example, one brickmaster stated in 1856 that "it is very doubtful whether any of the machines yet invented, however well they suit the blue galt(sp.) of the Medway Valley, are adapted for working the London clay" (BPP Childrens Employment Commission 1866, p. 142). Similarly, H. J. and Charles Major, brick manufacturers from Bridgewater, reported to a Parliamentary Commission in 1876: "I might say that the material that we have to deal with in Bridgewater is very different to anything I have seen in the Midland Counties or in the North... The material at Bridgewater is aluminous and of a very tenacious character so that it cannot be worked by the same machinery as is used in many other districts." Brickfield owners from the West Midlands, however, said the same about their clay: "Brickmaking machines are of very little use in this district as our bricks are all made of marl...", stated one manufacturer from Oldbury near Birmingham (BPP Factory and Workshop Acts 1876, p. 48).[2]

The response of machine manufacturers, beginning in the late 1850's, was to add various combinations of clay preparation devices to extrusion machines to enable them to handle a variety of clays with different characteristics. The most common accessory was a crushing mill. Machines then were identified as four-, three-, two- or one-process machines depending on the number of preparatory functions they performed in addition to shaping the bricks (Bale 1890, p. 62). Thus, Henry Clayton's "Universal or A1" machine was called a three-process machine because "it combined in itself the three processes of crushing, pugging and brickmaking" (Figure 7.4.; Henry Clayton and Company c. 1862). Joseph Eccles' four-process machine, patented in 1859, added a hopper with sets of knives or "agitators" to cut the clay into small pieces before it was passed through the crushing rollers to grind down the hard lumps. From there the clay moved into a screw-operated pug mill and out through the dies (British Patent No. 836, 1859; The Builder 1861, p. 291). Another large multi-process machine was patented in 1870 by George Wright. This combined a four-roller crushing mill, a pug mill with four dies and four pairs of moulding rollers to control the shape of the clay columns extruded from the dies. Like many other machines, the crushing apparatus in Wright's patent consisted of one pair of toothed rollers to break up the clay roughly and a second set of smooth rollers, each driven at different speeds, to produce a rubbing and crushing action (British Patent No. 1272, 1870; Bale 1890, p. 92).

One of the principle aims of machine manufacturers during the second half of the century was to extend the clay-working capacities of brickmaking machinery by increasing the number of clay preparation choices available to customers. It was not uncommon for a single manufacturer to offer machines in a wide range of sizes and with a variety of options, including up to three sets of crushing rollers, expression rollers, grinding mills and, later, grinding pans and sets of trough mixers for the hardest materials (Figures 7.5. and 7.6.; Searle 1931, p. 135-143). In the 1860's and 70's, Henry Clayton invited prospective purchasers to send seven or eight cwt. of clay to be tested by the company "stating the nature and extent of their requirements" prior to selecting the appropriate machine. Clayton's range included three sizes of hand-fed machines powered by hand, horse or steam (Figure 7.7. and 7.8.); two-process machines "adapted to the working of certain kinds of clay for which the vertical method of pugging is preferable" (Figure 7.9.); three-process machines with one pair of crushing rollers "for all ordinary qualities of clay, or of marls or mixed earths"; and machines with double crushing rollers "adapted to the using of stoney clays, hard unsoakable marls or an admixture of earths" (Henry Clayton and Company c. 1862; Builders' Trade Circular 1869, p. 13).

So far this chapter has considered two important trends in the technical development of extrusion machinery after 1850. One was an increase in the size of the machines, especially the receptacles for holding the clay. This rendered the previous idea of portability impossible and by 1870 many machines were heavy, permanent fixtures firmly bolted to a strong iron plate or masonry foundation and weighing up to eleven tons (Henry Clayton, Son and Howlett c.1872, p.21). A second trend was an extention in the versatility of the extrusion method by providing customers with every possible combination of preliminary clayworking devices. These were attached to the standard extrusion chamber and enabled the machines to work even the most difficult brick earths. Many manufacturers offered a wide range of machines, from the smallest hand-operated tilemaking apparatus to large, complicated double-delivery machines suitable for large-scale brickmaking. Both of these developments were aimed at substantially reducing the operating costs of brickmakers and increasing the productive capabilities of the machines. Several attendant problems, however, relating particularly to the quality of brick products, had to be overcome before extrusion machinery could gain widespread acceptance for ordinary brickmaking.

7.2.
Extrusion Machines and Brick Quality

Increasing the overall size, strength and versatility of extrusion machines were important improvements designed to increase brick production and lower brick prices. New clay preparation functions encouraged a far wider distribution of machinery than in previous decades and, in many cases, greatly improved their performance. However, the quality of extruded wire-cut bricks remained a problem for many years. One author commented in 1867 that bricks made by the extrusion process were "considerably cheaper than hand-made bricks whenever there is a sufficient demand to keep the machine constantly employed; but the quality of the bricks is not in many cases superior to that of hand-moulded bricks, and it leaves much to be desired" (Engineering 1867, p.197). Despite significant improvements in machine design, architects frequently expressed dissatisfaction with machine-made brick products. In 1857 the editor of The Builder lamented: "The general object of all new machinery has not been to make [bricks] well, but to make them cheaper" (The Builder 1857, p. 528). Another author commented vaguely that "brickmaking machines are not what they should be" (The Builder 1861, p. 52).

Most extrusion machines had great difficulty maintaining an accurate and consistent shape in the clay column after it was extruded and while the bricks were being cut. The shape of the bricks was controlled by three main components of the machine: the die, the cutting apparatus and, to some extent, the process adopted for removing the bricks from the machine. Of these, the die was undoubtedly the most important element in determining the ultimate form of the products (Ward 1885, p. 11). In early tilemaking machines, a column of clay was extruded from a die plate containing a hole shaped like the end of a tile or hollow pipe. It was then cut by a single wire or a series of widely spaced wires along its length. Production was intensified by multiplying the number of openings in the plate and, hence, increasing the number of clay columns. With an increase in the number of columns, however, it was difficult to ensure that all were extruded at the same speed and with the same pressure from each of the apertures simultaneously. Unevenly extruded streams of clay meant that there was always a quantity of wasted clay at the ends after the tiles were cut.

When these machines were converted to making ordinary bricks this became an even greater problem because of the larger volume of clay used. The solution adopted by most machine makers by the mid-1850's was a die containing only one aperture with the dimensions ten by five inches, or the size and shape of a brick lying on its side. The wires of the cutting frame were spaced approximately 3 ¼ inches apart. This narrow spacing allowed as many bricks as possible to be cut in one operation to compensate for the loss in the number of clay streams. It also ensured that the rough surfaces left by the wires cutting through the clay were on the bedding sides of the bricks rather than on the exposed faces, thus providing a key for the mortar while at the same time preserving a smooth external appearance. This apparatus was called a "cross-cut" die (The Builder 1855, p. 371; Bourry 1901, p. 283). In passing through this fifty square inch opening, however, the solid stream of clay travelled fastest where it was least impeded, that is, in its centre while the outer surfaces were exposed to the friction of the fixed die. The greater speed of the clay moving through the middle did not exert enough pressure to push the remainder of the substance into the corners of the die. This produced imperfectly shaped bricks with rounded or ragged edges. The clay was said to be so jagged sometimes that the bricks would eventually split along these blemish lines (Chamberlain 1856, p. 498).

Robert Beart addressed this problem as early as 1845 when he patented a system for extruding bricks which were perforated with twenty-four round or hexagonal holes (British Patent No. 10,636, 1845). Beart achieved this by hanging a series of cores or tongues within the die. In passing these cores the clay met with friction throughout its mass and thus travelled at a uniform speed, pushing the material solidly into the corners of the die. Besides improving the shape of the clay column, the perforations also reduced the quantity of clay in each brick making it lighter and exposing more of its surface to evaporation in drying and burning. The bricks still suffered from jagged edges because of contact with the stationary surface of the die until Beart adopted the double "water die" patented in 1853 by John Heritage (British Patent No. 1921, 1853). This patent solved the problem by lubricating the clay on its passage through the die. The paste was roughly formed to the shape of a brick by the first section of the die and then it was passed through a container of water to smooth its jagged surfaces before being pressed through a second smaller die which further consolidated its shape (Chamberlain 1856, p. 496).[3]

Other machine inventors working at the same time attempted to reduce the friction around the edges of the clay by means of movable rollers. Henry Chamberlain patented a machine that extruded the clay through a stationary die approximately one inch larger in each direction than an ordinary brick and with rounded corners to facilitate its passage. The paste then passed between four moleskin covered rollers that compressed the column to the appropriate size and shape while simultaneously giving it sharp arrises and clean surfaces (British Patent No. 259, 1853; The Builder 1856, p. 22). Henry Clayton claimed to have experimented with this method but rejected it as "he found it requisite to have some friction upon the sides of the die" (Chamberlain 1856, p. 499).[4] Clayton's "Patent Rotary Orifice Die" retained only the fixed upper and lower edges of the die plate but replaced the two sides with rotating rollers to sharpen the angles of the clay column as water dripped from a cistern above to smooth its surfaces (Figure 7.10.; Builders' Trade Circular 1869, p. 13). This die was frequently mentioned in the technical press as being the most advanced solution to the problem then available. It is difficult to determine in retrospect whether its popularity was actually due to its technical superiority or to Clayton's exceptional skill in marketing the device. As well as being a much advertised feature on all of Clayton's machines, the "Patent Rotary Orifice Die" also was sold separately and could be attached to any other extrusion machine on the market. For example, several of Clayton's dies apparently were purchased by the Burham Brick, Pottery and Cement Company around 1861 and attached to some of their seventeen Ainslie brickmaking machines (Henry Clayton and Company c. 1862).

There was little further inventive activity connected with the design of extrusion dies until several improvements were patented in the late 1860's and early 1870's. The most important of these used a liquid lubricant to correct distortion in the clay column. In 1867 Charles Murray patented a die that eventually rivalled the popularity of Clayton's. This apparatus was made of four separate adjustable pieces, two of which were covered with moleskin having vertical grooves underneath through which water was continuously flushed in different quantities depending upon the consistency of the clay being used. Although Murray claimed that the die offered the advantage of versatility, according to one author it actually was best suited only to mild and loamy clays

(British Patent No. 2158, 1867; Ward 1885, p. 15; Bale 1890, p. 230).

A rather more complicated solution was proposed in 1868 by Jonathan Pinfold of Rugby "with the object of equalizing the speed of the clay at its centre and ends on its passage through the die" (British Patent No. 2111, 1868). Pinfold believed that the die by itself was not responsible for impeding the movement of the clay, but that this occurred all along its progress through the machine after leaving the pug mill. In his machine, manufactured at the Warwickshire Iron Works, the clay was fed from the mill through a pair of compressing rollers and into a compressing chamber before reaching the die (Post Office Directory of Trade 1870, p. 56). Pinfold's solution to the problem of differential speed was a series of cheeks lubricated by water pressure to ease the paste from the rollers to the die. The die itself was lined with brass and angled "so as to minimize the effect as much as possible of the difference of travel between the ends and middle of the stream of clay" (Bale 1890, p. 230).

In reviewing the progress of extrusion machine dies in 1890, M. Powis Bale observed: "Although a great deal of ingenuity has been expended in making dies of various forms, none can be pronounced as the best under all circumstances and for all kinds of clay" (Bale 1890, p. 230). Ultimately, improvements in extrusion machine dies during the nineteenth century were not able to raise the quality of extruded bricks up to the standards anticipated by many brick consumers. The makers of extrusion machinery were faced with a dilemma in that attempts to solve the problems of quality frequently conflicted with or modified the goal of increasing the productive capacity of the machines. This predicament is best illustrated by the development of the cutting table, the design of which was crucial in establishing a balance between quality and quantity in extrusion machinery.

The mechanism used for cutting the columns of clay and the method employed for removing the bricks were equally important in determining not only the accuracy and quality of the finished bricks, but also the overall speed of the machines. In tilemaking before mid-century several streams of clay were extruded from the die onto an endless belt or onto pallet boards travelling across a long table. In some cases, the motion of the clay columns was stopped at short intervals to allow a single wire to be drawn through one length of pipes or tiles which were then quickly removed for drying while the machine pushed out the next length of clay. Alternatively, the streams moved several feet onto the table before the action of the machine ceased and a series of wires, mounted in a frame on one side of the table, was pulled down or across the clay by an attendant dividing the columns into several lengths of tiles. These were then removed individually and the motion of the machine was resumed.

When extrusion machines were converted to ordinary brickmaking, these methods of cutting created several problems. The added weight of the clay in solid bricks often caused the endless belts to wear out quickly. Also, handling separate pallet boards became increasingly cumbersome and tedious for the workmen. Besides the obvious limitation on output caused by the intermittent motion of the machine, the speed of production was further dependent upon the skill of the attendant in pressing the wires through the clay. If the attendant was rushed there was a chance that he would not make a clean or square cut. But if the work was slowed down to allow for accuracy then, according to one source, "the advantage of the machine was lost" (Chamberlain 1856, p. 496). More importantly, the return motion of the wires through the clay column frequently tore the edges of the bricks making them both unsightly and weak. Yet despite these problems, machine makers retained this method of cutting after mid-century. Clearly, however, there was a need for improvements to prevent delays and increase the speed of the operation, to minimize handling, and to reduce potential damage to the bricks due to friction with the table and cutting wires.

Some manufacturers believed that output could be increased and better quality bricks produced with a single wire so long as the action of the machine was not stopped during the cutting process. Their efforts were concentrated on developing fully automatic, continuous cutting devices. Several machine patents proposed self-acting wires which moved back and forth across the clay column or up and down in a chopping motion. In many cases, as in the machine by Peter Efferz patented in 1862, the wires cut the column not straight across, but at a compensating angle proportionate to the velocity of the clay (British Patent No. 2335, 1862; The Builder 1862, p. 324). In Humphrey Chamberlain's machine, patented in 1853, the wire was put in motion and regulated by gearing connected to the pug mill and die so that it was in continuous movement with the action of the clay. Chamberlain claimed that this arrangement allowed the machine to produce 2,000 bricks per hour in contrast to the usual 8,000 to 10,000 per day made by hand moulders (The Builder 1856, p. 22; Chamberlain 1856, p. 500). But this arrangement was not entirely successful and further improvements were patented, in 1860 by H. T. Green and S. B. Wright (British Patent No. 1089), and in 1864 by John Slater (British Patent No. 1865), among others.

These solutions were similar to the rapid developments being made with American extrusion machinery. In the early part of the century, moulding and pressing were the predominant techniques of mechanized brickmaking in the United States. Extrusion machinery was only introduced during the 1850's when land drainage was first undertaken on a large scale in that country.[5] Apparently the process was adapted very quickly to the needs of American brick and tile mamufacturers and by the mid-1860's examples of large American extrusion machines were patented in this country. The first of these, by Cyrus Chambers from Philadelphia, Pennsylvania, had a large conically-shaped horizontal pug mill, a tapered mouthpiece with a lubricated die, and a self-acting pivoting knife that travelled with the clay column and squarely cut the bricks lengthwise as in tilemaking machines (British Patent No. 2879, 1864). Later improvements included a series of revolving discs or a vertical cutting wheel with seven arms carrying wires that was mounted above the moving clay and cut off the bricks as it revolved (Figure 7.11.; Bale 1890, p. 300). It was said that these devices were capable of cutting two hundred bricks per minute although, because of other limitations, the actual output of

American machines was only about 4,000 bricks per hour (Bourry 1901, p. 287).

There is no indication that any of these methods were emulated by British machine makers. Instead, after mid-century attempts were made to improve the more familiar hand-operated, multiple-wire cutting tables (Figure 7.12.). For example, in some machines the wire cutting frame was made to reciprocate by the attendant who first drew it through the clay in one direction, then immediately drew it back in the opposite direction through the advancing column. This produced an intermittent rhythm and was meant to speed up the operations. But the success of this method depended upon the clay being extruded at a constant speed and the attendant drawing the wires at the same rate. Apparently this co-ordination between man and machine was very difficult to achieve.[6] Another attempted improvement replaced the endless webs on which the stream of clay travelled with small rollers set into the top of the cutting table to facilitate its movement. Also some machines were made with shields or clamps to hold the clay in place while it was being cut, a small advance over previous tables which required the workman to support the columns by hand as he was cutting.

Unfortunately, these refinements did not appreciably alter the overall speed of the cutting tables or entirely eliminate distortion in the finished bricks. Effective solutions continued to elude manufacturers until well into the 1860's when, according to patent statistics, there was a marked increase in inventive activity centred on this problem. There was also intensive competition among machine makers to be the first to invent a workable solution. This is illustrated by an important patent infringement case initiated by Charles Henry Murray in the early 1870's against Henry Clayton, Francis Howlett (Clayton's business partner) and an employee, Joseph Burdett (The Law Times 1872, p. 110-115).

In 1866 Murray was granted two patents, one in April with Matthew Jennings for an extrusion brickmaking machine (British Patent No. 1057) and another in June for an improved cutting apparatus (British Patent No. 1581). In Murray's cutting table, a length of clay equal to twelve bricks was cut off by a single preliminary wire and advanced onto a movable, oiled, zinc-covered surface. The outer edge of the table, acting as a resisting plate, was used to push the clay column forward against a series of wires fixed to a stationary frame. The bricks then were transferred onto a loose board which allowed them to be removed all at the same time. With this improvement not only were a larger number of bricks cut in one operation, but also they were removed much more quickly and without excess handling so that the operation was virtually continuous (<u>The Law Times</u> 1872, p. 112).

Clayton apparently immediately recognized the value of Murray's invention and began to experiment with a similar apparatus at his establishment in London. In 1868 Joseph Burdett, "an assistant in Clayton's works" acting in his behalf, patented a new extrusion machine with a cutting table incorporating essentially the same principles and mechanical arrangements as Murray's (British Patent No. 2767, 1868). A year later, Clayton began manufacturing his "Patent Self-Delivering Table" which differed from Murray's only in the method used for oiling the table surface (<u>Builders' Trade Circular</u> 1869, p. 131). At this point Charles Murray initiated legal proceedings. Clayton's defense rested on claims of prior anticipation and prior use of the principles involved in his patent. He had been working for some time on the problem of continuous cutting and had acquired rights to a patent granted in 1863 to Julius Gustav Dahlke for "improvements in machinery for cutting clay, etc." which was based on a machine invented by Gottfried Sachsenberg of Germany (British Patent No. 49, 1863). Although this machine was substantially different from Murray's and found to be unsuitable, additional experimentation led to an improved cutting apparatus which was patented in April 1868 by Thomas Dixcie, another of Clayton's employees (British Patent No. 1194).

Evidence at the hearing described Dixcie's patent as a machine "in which the clay is cut by lateral motion of wires as it proceeds along a belt or succession or rollers, and the bricks are then delivered one by one at the end of the machine" (<u>The Law Times</u> 1872, p. 113). This arrangement also was essentially different from Murray's cutting table, but Clayton claimed that Dixcie's implement anticipated the Burdett patent, which in turn was the alledged infringer. In its first hearing, the Vice Chancellor dismissed Murray's case stating that each individual element of his machine and cutting table had been used before and, therefore, lacked novelty. But Murray subsequently appealed the decision and in its second hearing the previous judgement was overturned.

Lord Justice James sustained Murray's assertions about the refinement and utility of his invention by stating that the patent specification was a claim for an entire machine or arrangement of parts rather than a claim to any one part. He further concluded that Clayton had failed to make a case for prior anticipation of Murray's machine in any of his patents and that the machine patented by Burdett was indeed "a mere alteration of the plaintiff's for the purpose of evading the plaintiff's patent." The following point of law was put forward in the judgement: "A combination of common elementary mechanical materials in such a manner as to produce a result previously attained by other mechanical arrangements may be the subject of a valid patent, provided the result be of a better or more useful kind or be produced in a more expeditious or more economical manner" (<u>The Law Times</u> 1872, p. 110).

Charles Murray's perceptions about the value of his patent, which prompted him to defend it so vigorously in court, proved to be accurate. By 1885 it was stated that most of the cutting tables then in use were based on his invention (Ward 1885, p. 141). Other improvements were patented at that time by J. D. Pinfold who suggested mounting the whole table on wheels and rails so that it could travel along with the moving stream of clay while the attendant pushed through the wires. It was claimed that this would eliminate the waste at one end of the column and make the cutting process even more continuous. Although several manufacturers adopted this device (Figure 7. 13.), writers around the turn of the century observed that Murray's cutting implement was still the most widely used with extrusion machinery (Bale 1890, p. 301; Bourry 1901, p. 287; Searle 1915, p. 75).

As we have seen, after 1850 extrusion machine makers were concerned with two specific areas of machine development. One was increasing the speed and output of the machinery and the other was improving the quality of machine-made products. Unfortunately, technical problems relating to the extrusion and cutting of the clay column continually undermined attempts by manufacturers to increase the productive capabilities of their machines. Persistent distortion, jagged edges and heaviness in wire-cut bricks led to intense inventive activity focused on the cutting implement and the extrusion die. The design of the cutting table in particular was critical in correlating the output of the machine with the quality of the finished bricks. Fully automatic continuous cutting devices, like those used in the United States, were capable of considerably increasing the production of extruded bricks. But machine makers in Britain, responding to the needs of a brickmaking industry which relied heavily on an abundant and relatively cheap work force, continued to manufacture the slower, hand-operated, mutiple-wire cutting tables. This choice effectively restricted the potential output of the machines and, because of limitations in their design, they continued to produce ragged, imperfect bricks. Brick consumers apparently tolerated this situation because at the same time other types of machinery were being developed that promised to produce the visually perfect bricks architects demanded for building facades.

7.3.
The Development of Pressing Machines

During the 1850's, while extrusion machinery was rapidly developing the capabilities necessary for the large-scale production of common bricks, machines for manufacturing bricks from dry clay were still in an experimental stage. Dry clay pressing machines had been the subject of much interest and discussion before mid-century, but little practical experience was acquired in applying the method to ordinary brickmaking.[7] Dry clay presses, however, were used extensively during this period in North America. Various descriptions of American dry clay machines appeared in the British press. For example, as early as 1845 a publication in this country reprinted a report in the Franklin Journal which described a new patent granted in America to Benjamin H. Brown for moulding and pressing clay "as it is taken from the bank". This was a simple machine, not unlike those for moulding plastic clay, but with the addition of toothed rollers which finely cut and ground the dry earth before it was conducted to the moulds (The Builder 1845, p. 449). More importantly, the same journal noticed a British patent taken out by two other Americans, Woodworth and Mower, in 1852. This machine introduced the combined mechanical processes that later became essential components of all successful dry or semi-dry clay machines in this country.[8] These included the use of a second percussion for ensuring that the substance was thoroughly compressed into the moulds and an apparatus for lifting the clay lump between strikes of the piston to allow compressed air to escape (The Builder 1852, p. 385 and 538).

American dry clay machines also were described by Joseph Whitworth in his special report to Parliament on the New York Industrial Exhibition in 1854. According to Whitworth, at one brickyard in New York sun-dried clay was ground thoroughly by rollers before being dropped into the moulds of a machine where it was pressed by cam-operated rams fixed in a heavy frame above the moulding table. This pressing was repeated and then the bricks were compressed yet again from the top and bottom by revolving cams to complete the process. He described a similar machine operating near Washington, D.C. which "had been in use for sixteen years" and made "about 1800 bricks per hour from dry clay by compression only" (BPP New York Industrial Exhibition 1854, p. 120). Another American dry clay pressing machine, invented by Mr. Culbertson of Philadelphia, was described to the Institution of Mechanical Engineers in 1853. Acting on clay "taken direct from the bank", the moulds passed twice under a pressing cylinder which applied pressure that was "gradual and continuous, allowing the air to escape freely as the clay is forced into the mould" (Proceedings of the Institution of Mechanical Engineers 1853, p. 149). By 1856, Humphrey Chamberlain stated that "the dry clay American machine is about the best example of this class" (Chamberlain 1856, p. 494).

British inventors eventually patented other machines for moulding dry clay, but apparently not until they were certain that excise duties on bricks would be removed. One early British patent was by Thomas Snowdon, an engineer from London, for a pressing machine for granular clay or artificial fuel which had levers to drive two rams into covered moulds (British Patent No. 12,454, 1849). Two patents in 1855 and 1856 were granted to John Roberts for a machine capable of turning the "coarsest material" into pressed bricks by means of a roller weighing up to ten tons which passed over a series of cast iron moulds containing the earth (British Patent No. 2813, 1855; No. 1261, 1856; The Builder 1857, p. 32). Also exhibited in 1857 at the Highland Agricultural Society show was a machine, patented by Gabriel Arthur, "with the novel purpose of making bricks and tiles from common earth by pressure" (British Patent No. 1091, 1857; The Builder 1857, p. 488).[9] These machines seemed to be technically less sophisticated than American models and there is no evidence that any were developed further.

Proponents of the dry clay method were keen to point out the potential advantages of the process. First, the need for drying the newly moulded bricks was eliminated because they could be taken from the machine directly to the kiln for burning. In addition, there was little wastage of materials with this process because the drier consistency of the earth reduced the possibility of distortion or destruction of the bricks prior to burning. Finally, it was claimed that bricks made by the dry clay process had sharper edges, more accurate shapes, and exceptional hardness, "almost as smooth and dense as polished marble" according to one source (The Builder 1852, p. 385; Fothergill 1959, p. 45; Clark 1864, p. 254).

On the other hand, during the discussion on brickmaking at the Society of Arts in 1856, Humphrey Chamberlain speculated that dry clay presses would not come into general use because they consumed an enormous amount of power, they were expensive (some dry clay machines cost more than £1400), and he believed the process was not suitable for many clays found in this country. Chamberlain also pointed out that "breakage with this large machinery is very serious, and of too frequent occurrence" (Chamberlain 1856, p. 494). The civil engineer, Charles May, concurred and observed that "it would not pay to evaporate the moisture from the clay by artificial means, and they had not a sufficient continuation of dry weather to do it, as was the case in America." May also reported that a brickmaker at Hanwell near Banbury tried manufacturing bricks from dry clay, but abandoned the enterprise because the machine employed failed to compress the powdered clay completely into the corners of the moulds (Chamberlain 1856, p. 498).

In another discussion at the Institution of Mechanical Engineers at the end of the decade, similar doubts were raised about the dry clay process. W. A. Adams referred to "softness at the edges" of some dry clay machine-made bricks he had used several years earlier to construct a chimney which "were soon found to suffer from the weather." Another participant remarked that this was because the moulds in these machines were too quickly worn from the grit contained in the dry powdered earth. Charles May thought this wear and tear on the machines would considerably raise the cost of manufacture by as much as 5s. per thousand and prevent brickmakers from "producing dry clay bricks for a moderate price in the long run, though they might do so for a short time after first starting." He also suggested that the most serious defect in dry clay bricks was the difficulty in burning them sufficiently: "They appeared to require considerably more burning than wet-made bricks in order to render them equally hard and strong." May's scepticism was in part based on practical experience as he himself had been granted a patent for a dry clay machine in 1853 (British Patent No. 1797; Chamberlain 1856, p. 498). He was convinced that "in the manufacture of dry clay bricks there were great practical difficulties to be overcome, which had in most cases proved much greater than they appeared at first in the application of machinery to the manufacture" (Fothergill 1859, p. 46-48).

At the same meeting, the engineering firm of Platt Brothers and Company of Oldham demonstrated a model of a machine which they believed alleviated many of these problems. This was a large brickmaking system based on an American machine that was used in the United States for fourteen years before it was purchased and improved by John Platt (BPP Select Committee on Scientific Instruction 1867-68, Ques. 5761; Burn 1931, p. 302). The machine was so extensive that the firm was unable to display its operation at the International Exhibition of 1862 and instead sent samples of bricks manufactured at their brickworks near the Hartford Ironworks at Oldham (Clark 1864, p. 256). In the system described to the Institution of Mechanical Engineers by the engineer Benjamin Fothergill, the clay was first dried in a large shed by an arrangement of flues running under the floor. It was then taken by an elevator to a revolving pulverising machine where the lumps were pounded by a series of cast iron crushers and pressed through an inclined screen which blocked any stones or other hard substances from moving on to the pressing apparatus. From the pulveriser the clay was delivered by a spout to the hopper of the brick press where a measured amount was discharged into a series of four moulds and compressed twice by cam-operated rams heated by steam to prevent adhesion of the clay to their faces. Finally, the bricks were subjected to a third pressing from above which was counteracted by a simultaneous upward pressure by pistons placed beneath the moulds. These pistons continued to push the finished bricks to the top of the moulds where they were removed by hand.

According to Fothergill, careful preparation of the brick earth distinguished this system from all other dry clay machinery: "The machine ensured that nothing but clay was put into the bricks, and all stones were entirely separated by the action of the pulveriser without any force being spent in crushing them, the clay being supplied to the moulds in a thoroughly uniform state for all bricks." Furthermore, he maintained that bricks made by the system were hard throughout and did not suffer from weak arrises because of the unique third pressing by which they were made "to slide through the moulds whilst the severe pressure of the cams is taking place, which gives a fine polished surface to the sides of the bricks, and ensures the angles being all filled up completely square." William Richardson, a representative of the company, pointed out that in most previous dry clay machines "the pressure had been applied on one side only; but in that mode of manufacture it was found that the bricks could not be made equally hard and sound on the underside, and an advantage was gained in the present machine by the pressure being applied simultaneously both above and below." In addition, strain or injury to the moulds was negligible because they were constructed with movable plates made from case-hardened wrought iron. The cost of wear and tear was estimated at only 1s. per thousand bricks (Fothergill 1859, p. 47 and 49).

In the early 1860's various improvements and additions were made to Platt's clay preparation machinery. First, a drying chamber was introduced. This was a thirty-five feet long inclined cylinder rotated by friction rollers on a longitudinal shaft. A blast of hot air, drawn from the kiln and forced through the chamber by a fan, dried the clay as it circulated through a series of rotating shelves (Clark 1864, p. 256). But the company stated they had learned from experience that "the clay must not be brought into the [pressing] machine in its heated state, since the hot moulded bricks, when exposed to the atmosphere, lost their coherence in cooling, cracked and twisted by unequal contraction, and were unfit for use." Thus, another addition to the process was a cooling chamber similar in every respect to the drying cylinder except that a blast of cold air gradually reduced the temperature of the clay.

Finally, according to the firm, the process of converting the clay into a slightly moist powder was the most difficult aspect of the dry clay brickmaking process. Consequently, after the material left the pulveriser and cooling chamber it was put through another disintegrator with a revolving disc that further broke it up by centrifugal action. The aim was to reduce the clay to the exact degree of dryness without allowing it to lose all coherence, and to maintain that consistency throughout. The optimum proportion of moisture was said to be from six to eight per cent (Searle 1931, p. 293). But as late as 1885 one source reported that most dry clay brickmaking machines failed to achieve this consistency: "Even though all the clay be delivered from the pan-mill equally moist, some of it, owing to its being ground overnight or to rolling to the outside of the heap, gets drier than the rest. Thus, the measurement of the clay in the moulds wants perpetually adjusting, and at best the bricks must vary in quality" (Ward 1885, p. 9). Platt's claimed they could produce 20,000 perfectly shaped bricks each day by this method, of a quality which made them "particularly suitable for facing the outer walls of superior classes of buildings" (Engineering 1867, p. 197). When facing bricks made by a wet clay moulding machine proved unsatisfactory for facing the new Strangeways gaol in Manchester by Alfred Waterhouse in 1866, a dry clay press made by Platt Brothers and Company was substituted and succeeded in turning out 8,000,000 "very good square bricks" for the project (BPP Trades Unions Commission 1867, p. 61).

Several other inventors attempted to overcome the problems associated with the dry clay process after mid-century.[10] One of the most commercially successful was the manufacturing firm, Bradley and Craven of Wakefield, who patented a new machine in 1859 (British Patent No. 155, 1859). To enable the firm to experiment with shale deposits prevalent in the district, they opened brickworks next to the Roundwood Colliery and installed a grinding mill, elevators, a screen and their new machine (Figure 7.14.; Bradley and Craven Limited 1963, p. 79). The firm engaged Humphrey Chamberlain to act as their selling agent despite the fact that only three years earlier, in his Society of Arts Prize Essay on brickmaking, he had expressed scepticism about the dry clay process (Chamberlain 1856, p. 494).

A clayworking engineer, Chamberlain lived at Kempsey near Worcester and, together with Messrs. Mansell and Elliott, had an agency at 16 Cornhill in the City of London (Bradley and Craven Limited 1963, p. 75). He described to The Builder the lengthy experiments by the firm which led to the patenting of the new machine and particularly the difficulties encountered in expelling the air from the clay while in the moulds. If the air was not discharged completely there appeared "a series of laminated cracks on the face of the bricks, caused by the expansion of the air on being released from pressure" (The Builder 1859, p. 508). Like the Platt Brothers' system, Bradley and Craven's machine compressed the pulverised clay by three distinct pressing operations to ensure all the air escaped. The first pressure was produced when a piston, attached to the adjustable bottom of the mould, moved along a gradual incline pushing the clay firmly against a covering plate. The second and third pressings were achieved by plungers placed on opposite sides of the machine above the moulds and operated by eccentrics attached to an overhead shaft. The firm claimed the pressure could be regulated to produce bricks of different densities, and the machine would work equally well with dry or dampened clay if a portion of sand was added to the brick earth.[11]

Although Chamberlain continued his collaboration with Bradley and Craven for over twenty years, he also established his own brickworks in Barnsley and developed an improved dry clay brickmaking machine which he patented and perfected during the late-1860's. He proposed to press the bricks first in one part of the machine and then to deliver them, "by a self-acting cage", to a second press so "the confined air is expelled and the density equalized" (British Patent No. 77, 1865; No. 541, 1868; and No. 3507, 1876, F. Chamberlain). According to one source, this was a substantial advancement: "It increases the cost slightly, but the brick is of superior quality, partly owing to plenty of time being allowed for the air to escape, and partly also because the press-mould can be kept in much better order than the machine-moulds, as the latter bear the brunt of the work." Three Chamberlain machines were installed at the Kent Brick and Tile Company at Pluckley Station near Ashford, Kent by Henry Ward, but he reported that "though they did good work, [they] were complicated and needed much repair" (Ward 1885, p. 9 and 12). A similar machine, manufactured later by Bradley and Craven, was greatly enlarged to resist the strain inflicted upon it, and was said by another source in 1890 to produce bricks "of excellent quality" (Bale 1890, p. 442).

Machine experiments by the Platt Brothers, Bradley and Craven and Henry Chamberlain succeeded in overcoming many of the problems encountered in the manufacture of bricks with dry clay. Various grinding mills and mixers reduced the brick earth to a reasonably consistent texture and moisture content while multiple pressings from both top and bottom ensured uniform density and the complete expulsion of air in the moulded bricks.[12] In addition the machines themselves were enlarged and strengthened to prevent excessive wear and tear or breakage. One remaining problem was the length of time required to burn dry clay bricks which, because of the nature of the material, was greater than for bricks which were made from clay mixed with water and later dried before firing. According to Alfred Searle, the dry clay process was only effective "when the bricks contain[ed] sufficient vitrifiable material or 'bond' to bind the particles firmly together" during a prolonged period of burning (Searle 1931, p. 293). This required enormous quantities of coal for firing the kilns, thereby considerably raising the price of the finished bricks. As early as 1859 one member of the Institution of Mechanical Engineers suggested that "it might be worth considering whether some mixture of lime or other alkali with the clay might be employed advantageously to aid in the burning by causing the bricks to vitrify at a lower temperature" (Fothergill 1859, p. 51). But this also was an unwelcome additional expense. An economic solution to the problem eluded brickmakers until the discovery in the Oxford Clay Vale of brick earth with a high natural carbonaceous content which proved to be the ideal material for dry clay brickmaking (or the semi-dry process as it was also known).

The development of the Fletton brickmaking industry has been thoroughly researched and described by Richard Hillier in his book, <u>Clay that Burns</u> (Hillier 1981). Sometime around 1880 one of the small brickmaking firms leasing land on the Fletton Lodge Estate near Peterborough (probably the Hempstead Brothers) experimented with making bricks from a strata of shaley Lower

Oxford Clay discovered immediately below a bed of plastic surface clay. Because this material had a naturally low moisture content, it was particularly suited to grinding and pressing by semi-dry brickmaking machinery which the firm had installed by 1882.[13] A unique feature of the clay was that when it was heated to 400 degrees Centigrade it produced combustible gases that ignited and burned the bricks to a temperature of 1,050 degrees requiring only a relatively small amount of finely ground coal to regulate the firing (Hillier 1981, p.17). In addition to these material advantages, the brickworks of the Oxford Clay Vale were situated along the railway line between the Midlands coalfields and London, thus facilitating the acquisition of fuel and the transport of bricks to major markets in the south (Healey and Rawston 1955, p.47). Although they continued to manufacture bricks by a plastic process (with Murray's machines), by the end of the decade the extensive adoption of semi-dry process machinery enabled the Peterborough brickfields to produce jointly one hundred thousand pressed bricks each day (The Building News 1889, p.532).

By 1890 several firms were manufacturing machinery for the semi-dry process based on the principles developed by the Platt Brothers and Bradley and Craven. The earliest machines used by the Hempstead Brothers at Peterborough were by Scholefields of Leeds and Thomas C. Fawcett, but "by 1900 all the main producers of fletton bricks had adopted Whittaker's brickmaking machinery" (Hillier 1981, p.19 and 25). Manufactured by Christopher Whittaker and Company of Accrington, they were designed especially for making bricks from hard substances like slate debris, fireclay and ground shale (Figure 7.15.). The powdered material was subjected to two separate pressings of approximately thirty tons each with a slight pause between to allow the air to escape. Like earlier machines, the pistons were heated by steam to prevent adhesion of the clay, and they produced from 12 to 16 bricks per minute (Ward 1885, p.12; Bale 1890, p.443; Hillier 1981, p.32). William Johnson of Castleton Foundry, Leeds also manufactured a massive machine for making bricks from difficult clays or refactory materials (Figure 7.16.). Johnson's machine offered four distinct pressings to ensure that air was thoroughly expelled. A pressing head first dropped on the filled mould boxes to render them completely and densely packed with powdered clay. It then dropped a second time where it remained in the moulds while two additional powerful pressures were given to complete the process (Bale 1890 p. 535).

Despite the extraordinary success of the semi-dry process in the Peterborough brickfields, it was not widely adopted elsewhere because it was not compatible with other types of clays. One contemporary author wrote, "all clays can be manufactured into plastic bricks, but only a small portion of them can be made into semi-dry bricks" (Ward 1885, p. 8). Alfred Searle observed that "many attempts to use the semi-dry process failed because the material was unsuitable" (Searle 1931, p. 293). Except for shales and some marls, most clays were far too damp to move easily through the perforations of the grinding mill or they clogged the feeding mechanism and would not drop into the moulds. Enlarging the size of the perforations allowed unground lumps or pebbles to pass through which lessened the quality of the bricks, while the addition of ashes or burnt ballast to the clay or artificial drying increased the overall costs of production (Ward 1885, p. 8). Some inventors recognized the need for an alternative method that would produce smooth, perfectly shaped facing bricks using the more common damp or plastic clays.

A new brickmaking process was developed eventually which combined the plastic and semi-dry systems. This was called at first the "semi-plastic" method, but later it became known as the "stiff-plastic" process. According to Searle "the stiff plastic process owes its name to the fact that the bricks appear to have been made of plastic material, though they are stiffer and stronger than most bricks made by a plastic process." Clay such as loams, some boulder clays and shales were ground "to the consistency of freshly dug garden soil" and sifted as in the semi-dry process. If the material was too dry it was then mixed with a quantity of water to achieve a moisture content of between seven and eighteen per cent and moulded under considerable pressure (Searle 1931, p. 251; Collier 1966, p. 107).

It is difficult to identify exactly when the stiff-plastic process was invented because, as we have seen, many early dry clay brickmaking machines were developed to work with clay "as dug from the ground" (See section 4.2.). One of these was the "Patent Solid Brick Machine" patented in 1857 by Joseph Pimlott Oates, a surgeon from Erdington near Birmingham (British Patent No. 730, 1857; Noble 1953, p. 755). In Oates' machine clay was brought directly from the pit and macerated in a large cast iron hopper with a compound screw (Figure 7.17.). It was then propelled down a narrow shaft to a pressing chamber where it was driven with great force into two moulds. Extending horizontally from this chamber was a safety pipe which allowed the clay, which was fed continuously into the chamber, to escape as each mould was filled and levelled, thus preventing undue strain on the machine.

Describing its operation to the Institution of Mechanical Engineers in 1859, John Clift pointed out that because the moulds were supplied with a continuous stream of clay at a constant pressure, they were "thoroughly filled with a uniform density of clay throughout, without requiring any sudden excessive pressure that would cause the brick to be denser on the outside than in the centre" or damage the machine (Proceedings of the Institution of Mechanical Engineers 1859, p. 254). In addition to the simplicity and durability of Oates' machines, they also dispensed with expensive procedures for pre-drying and pulverising the clay as with dry or semi-dry process machines and the need for drying newly moulded bricks before burning as in the plastic brickmaking process. Sold by the firm of Oates and Baylie of Stourbridge, fourteen of the machines were in operation throughout the country by 1859 including one at the Blaenavon Iron Works in Wales, two at the Oldbury Brick Works, one at the Cobham works of Messrs. Peto and Betts, and two at the works of Messrs. Kirk and Parry, contractors for Fort Elson, constructed between Southampton and Gosport (The Builder 1858, p. 235; 1865, p. 700; Laxton's Builder's Price Book 1869, p. 76).

In developing the stiff-plastic process, features were borrowed from both semi-dry and plastic machines. For example, William Wilson patented a machine in 1859 in which dry pulverized clay was first ground by edge runners and sifted as in the semi-dry process. It was then moistened by the condensation of steam in a rotating cylinder, and pressed by upper and lower plungers with a hydraulic buffer interposed between the brick mould and the compressing ram (British Patent No. 1903, 1859; Clark 1864, p. 255). A similar machine was patented by Julius Frederick Moore Pollock in 1866 (British Patent No. 2195) and improved in 1869 (British Patent No. 2911). Pollock's machine, which also ground then moistened the clay, was manufactured by the firm of Pollock, Laing, & Powley of Leeds in three sizes which produced either 1,000, 2,000, or 4,000 pressed bricks per hour (The Builder 1870 p. 604).

Elements from the extrusion process also were adopted by some machine makers. A traditional technique used in many brickyards prior to mid-century was to shape the bricks by extrusion machines and then press them one by one in separate hand presses to achieve the desired finish. These small presses were substitutes for earlier hand methods of dressing and polishing facing bricks (see section 4.2.). Experiments with machinery beginning in the late 1850's combined these two processes. In one example patented in 1857 by Thomas Rowcliffe of London, the clay was first crushed and screened, then pugged in an ordinary mill, and extruded through a special moulding orifice containing small horizontal rollers to compress and lubricate the material. Finally, the bricks were transferred by a movable frame to steel-lined boxes where they were pressed "by two indent rollers and a disc crank, acting upon a rack lever or quick screw motion" (British Patent No. 2837, 1857, p. 2). In J. Gillespie's patent of 1871 the clay was "preliminarily kneaded in an extrusion machine and cut up into lumps" before being pressed or finished in ordinary moulds (British Patent No. 2429, 1871). In 1871 William Nichols of Leeds and William Batley of Rotherham improved the mechanism for delivering extruded cylindrical lengths of clay to the press (British Patent No. 967, 1871). This device was used in the machine patented by Batley in 1873. It consisted of a large horizontal pugging cylinder "with an opening or hopper at or near each end for feeding in the clay" which was then "forced out through one or more openings at or near the centre." The cylindrically-shaped clay streams were cut into brick-sized pieces and carried by an endless band to the pressing portion of the machine (British Patent No. 242, 1873, p. 2-4).[14]

Other machine makers chose to form the rough clot of clay in a simple moulding apparatus, but used a more powerful compressor than earlier moulding machines (Searle 1915, p. 78). Two different types of machines were developed. In one the rough bricks were moulded in the recesses of a revolving vertical drum, after which they were ejected onto a revolving table where they were deposited into moulds and pressed (British Patent No. 2636, 1864, Joshua Heap and Thomas Jolley; Bourry 1901, p. 290). An example of this type was the Fawcett stiff-plastic machine (Figure 7.18.). Another class formed the clots in a horizontal rotary table like that manufactured by Bradley and Craven of Wakefield who claimed to have originated this type of machine (Figure 7.19.; Searle 1931, p. 274). Moulds fitted into the table rotated intermittently beneath a pug mill and received the clay. As the table rotated again the rough bricks were pushed out of the moulds and transferred to the pressing boxes where they were consolidated (Ward 1885, p. 16-17; Bale 1890, p. 442).

Ordinary brick products made by the stiff-plastic process could be made into superior facing bricks by being taken directly from the machine to a separate re-press for a final pressing (Searle 1931, p. 283). Often these were attached to the larger machine and were virtually identical to earlier re-presses except that they were connected to the main power source rather than hand-operated (British Patent No. 2155, 1871, M. Richardson). Several contemporary sources commented on the excellent quality of bricks made by the stiff-plastic process (Bale 1890, p. 442). Mr. J. W. Hill observed in 1885: "The direction in which machinists of the present day were progressing was that of the semi-plastic [stiff-plastic] process, the happy medium between the hand-made and the semi-dry processes" (Ward 1885, p. 37). According to Noble, the design of stiff-plastic machinery remained unchanged well into the twentieth century (Noble 1953, p. 755).

Dry clay pressing machines, like extrusion machinery after mid-century, developed in response to the requirements and special characteristics of the British brickmaking industry. There was not just one perfect way to design a brickmaking machine. A variety of technical options was available to machine manufacturers. Design decisions were made to solve specific problems with machine function and to harmonize with various materials and the skills and established patterns of work within the industry. In making these decisions, both machine manufacturers and brickmakers were constantly aware of the expectations of brick consumers. Ultimately, the suitability of brick products to meet the needs of consumers in the building industry determined the success or failure of particular machines or mechanized processes. Architects, in particular, were greatly concerned about the price, quality and appearance of clay products. The following chapter will examine the attitudes of architects towards machine-made bricks after mid-century and consider their efforts to establish professional standards and influence aspects of brick production.

NOTES

1. The validity of both Tweeddale's and Hunt's patents would have expired by 1860.

2. See also testimony by G.K. Harrison from Stourbridge: "There is no machinery at present can make bricks from the clay of this district as well as the hand can make them" (BPP Factory and Workshop Acts 1976, Question 5,613).

3. Note the similarity of this invention to Tweeddale's machine of 1836 that bent a slab of clay to the shape of a drainage tile over a cylinder while water dripped on it from an elevated cistern. The machine then pushed the slab through graduated hoops to finish its formation. By 1850 the fourteen year protection of Tweeddale's patent had expired. Another patent adopting cores for this purpose was by John Francis Porter (British Patent No. 240, 1855).

4. According to Clayton, Chamberlain stole the idea while, as a consulting clayworking engineer, he was under license to sell Clayton's machines and knew of his experiments.

5. Henry French's Farm Drainage, published in New York in 1859, described many of the tilemaking machines reviewed in the 1840's by the Journal of the Royal Agricultural Society, providing inspiration and models for American machine makers. Two very simple American devices, by John Daines of Birmingham, Michigan and Pratt and Brothers of New York also were illustrated (French 1859 p.205-210). There is no evidence that British machines were actually sold in America during this period.

6. Chamberlain reported that machines made by the Ainslie Company and Porter, Hind, and Porter of Carlisle had tables of this type (Chamberlain 1856 p.496).

7. In Britain dry clay presses patented by Richard Prosser and Herbert Minton, among others, were used successfully in the potteries for manufacturing some items such as buttons and small tiles, but brickmakers showed little interest in the method (See

section 4.2.).

8. Terms used to describe dry clay manufacturing processes are the source of potential confusion when researching nineteenth century pressing machines. Some authors used interchangeably the terms "dry" and "semi-dry" to mean clay "as dug from the ground" (Proceedings of the Institution of Mechanical Engineers 1853 p.149; Chamberlain 1856 p.494). Others distinguished between "dry" clay which was artificially dried before pressing and "semi-dry" clay which was used without the moisture removed. Moreover, later in the century another process was introduced which used "damp dust" or clay partially softened by steam or small amounts of water to achieve a higher moisture content. This process eventually was called the "stiff-plastic" process, but during part of the century it was used interchangeably with the term "semi-plastic" (The Builder 1861 p.795; Clark 1864 p.255; Ward 1885 p.8).

9. See also British Patent No.2060, 1853, Weston Grimshaw and Ellis Rowland; No.2484, 1857, Joseph Lewis; No.647, 1857, Thomas Burstall (The Builder 1855 p.50).

10. See British Patents No.1490, 1855, William Woodcock; No.948, 1856, James Nasmyth and Herbert Minton; No.1589, 1856, A.L.S. Chenot and E.C.A. Chenot; No.2071, 1856, Thomas Burstall; No.605, 1857, William Smith, James and Joseph Cadman; No.1091, 1857, Gabriel Arthur; No.1980, 1857, Charles Barlow; No.2484, 1857, Joseph Lewis; No.1732, 1858, William Percy; No.473, 1864, Auguste Julliene; No.2195, 1866 and No.2911, 1869, Julius Pollock.

11. The firm was awarded medals at the Royal Agricultural Society exhibitions in 1859 and 1862 and at the Yorkshire Agricultural Society show in 1860. In 1868 one of the machines was installed at a large brickworks owned by Mr. R. White near Grimethorpe (Bradley and Craven Limited 1963 p.7; The Builder 1868 p.87).

12. According to Searle, "it is a mistake to press from both top and bottom simultaneously, as this invariably leaves a weak centre or granulated seam in the brick where the pressures meet each other. This defect has been overcome, however, in nearly all of the presses used today by pressing first from the top to a

point beyond centre, then from the bottom to a point beyond the centre, the upper plunger still remaining on the brick while the lower pressure is taking place, thus expelling the air through the air-holes in the plunger plates" (Searle 1931 p. 307).

13. Collier stated that the ideal moisture content for semi-dry brickmaking was less than eight per cent but that clay with as high as fifteen per cent could be used successfully (Collier 1966 p. 116).

14. Searle stated that "a cylindrical clot has mechanical advantages in that it can be rolled from one machine to another" (Searle 1931, p. 273).

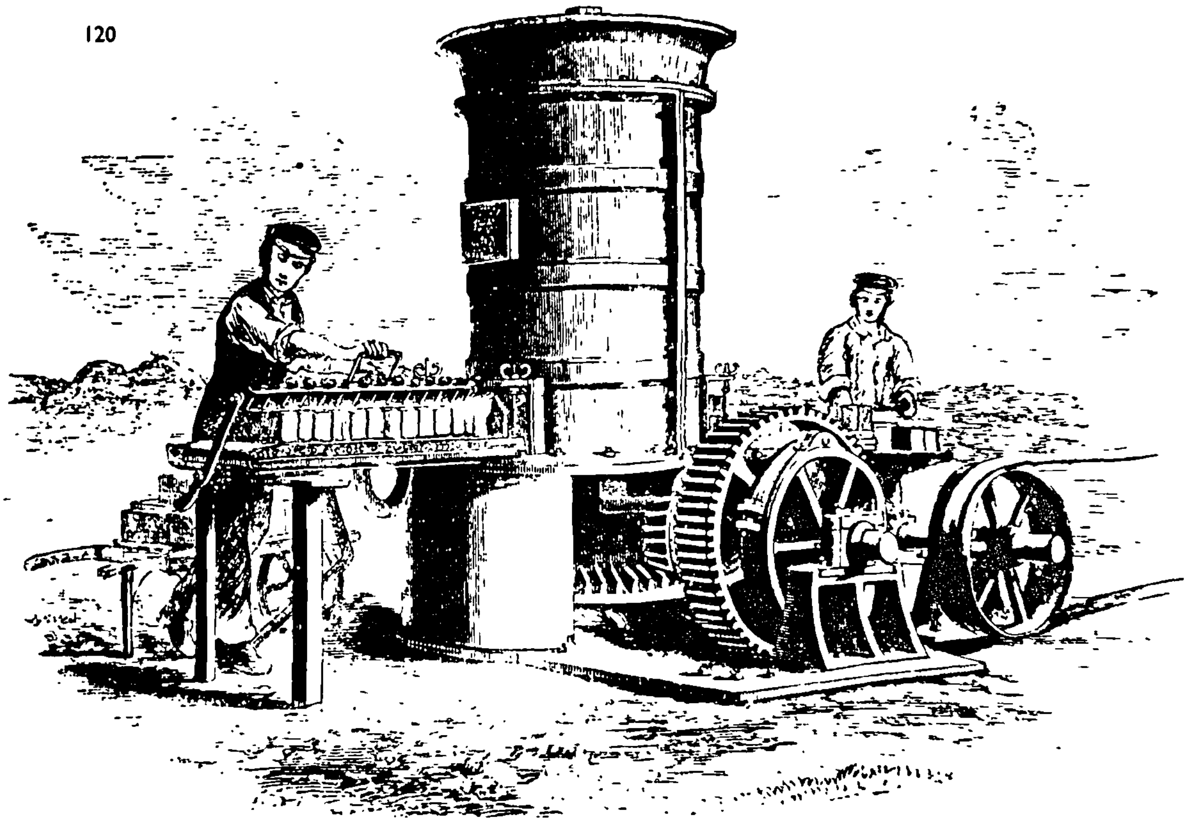


Figure 7.1. Extrusion brickmaking machine attached to a pug mill, Bulmer and Sharp, manufacturer, c.1860.
[From John Woodforde, Bricks to Build a House (1976)]

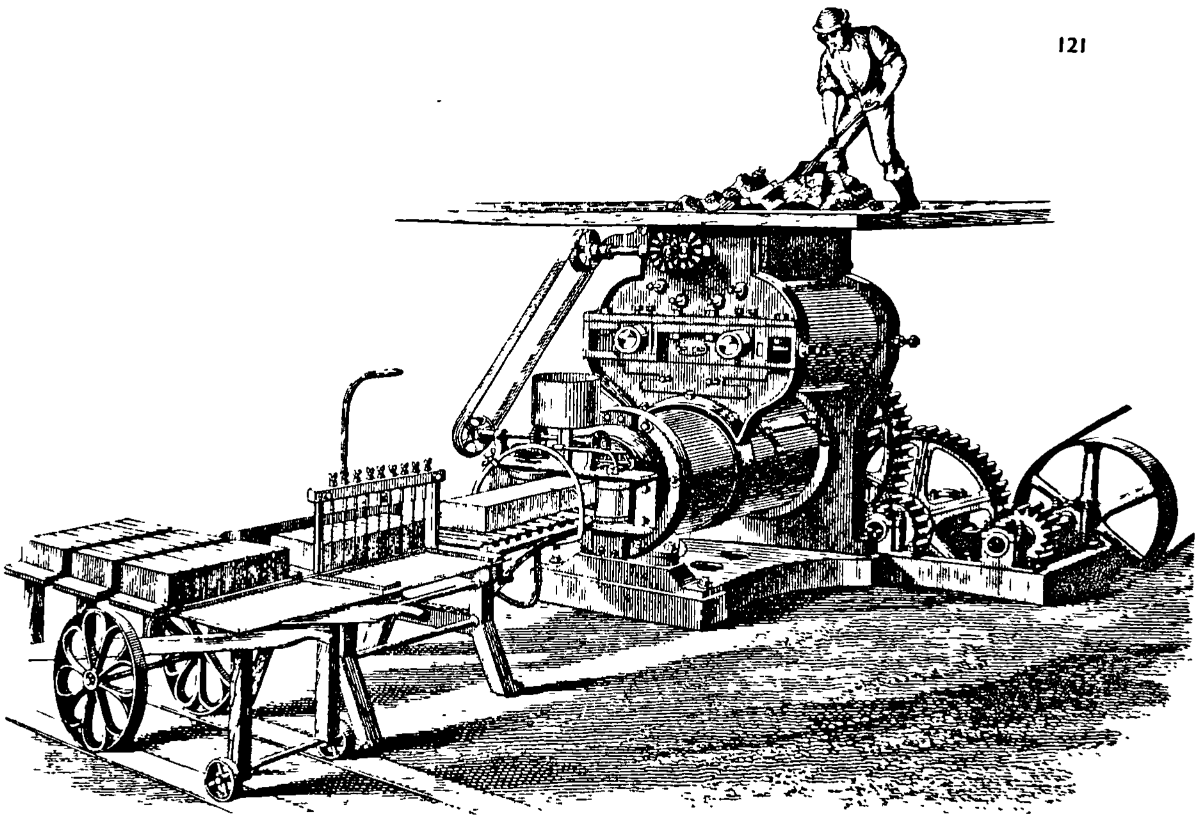
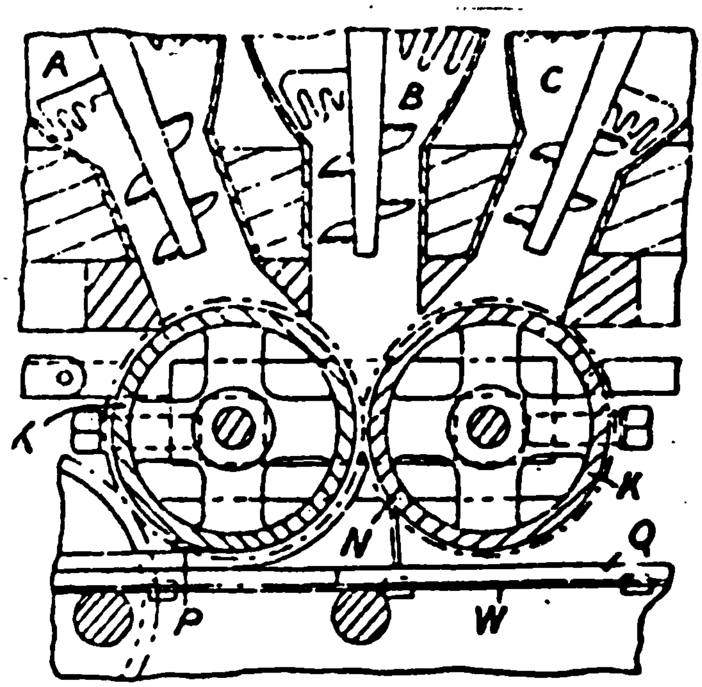


Figure 7.2. Ramp-loaded brickmaking machine by Henry Clayton, c. 1860.
[From John Woodforde, Bricks to Build a House (1976)]

Figure 7.3. Extrusion machine patented by S.B. Wright and H.T. Green, British Patent No. 1089, 1860. A, B, and C, pug mills; K, compression rollers; N and P, scrapers; Q and W, boards on an endless belt to carry finished products away (see page 6).
[Drawing enrolled with patent]



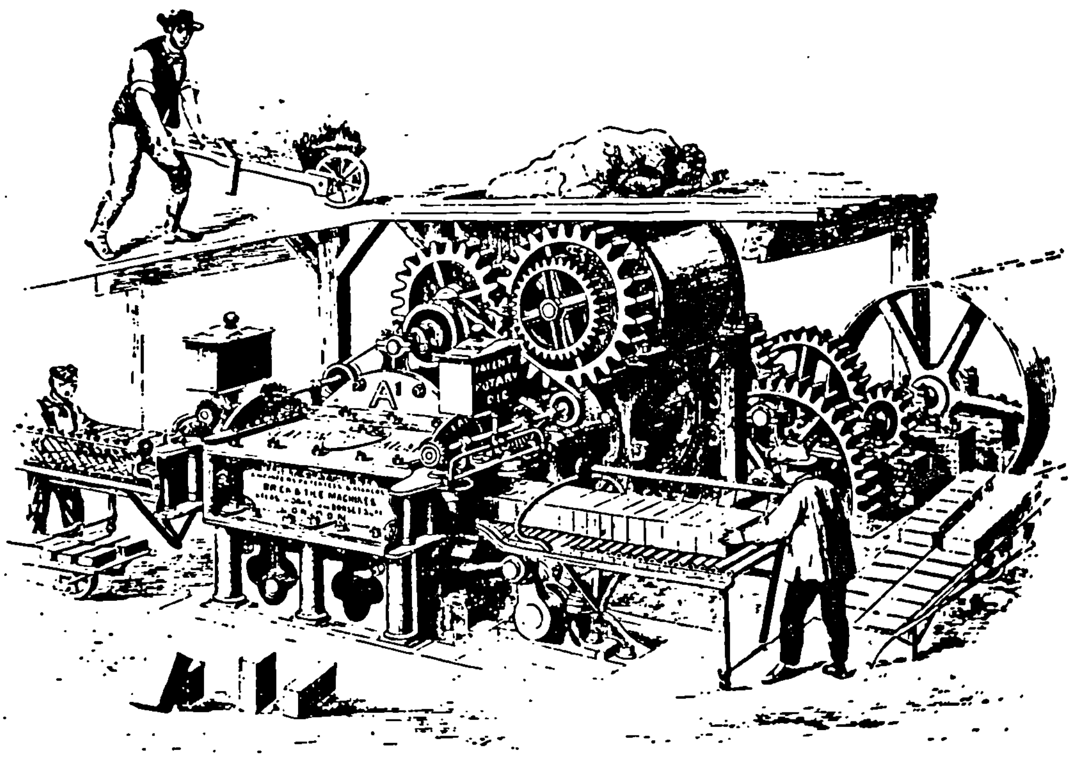
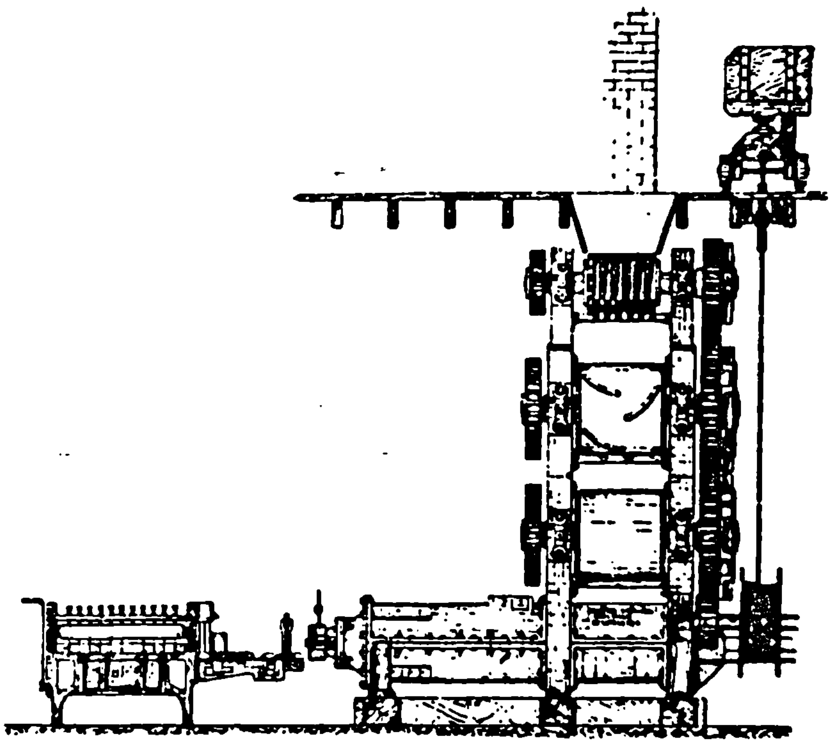


Figure 7.4. Henry Clayton's Universal "A 1" Combined Three-Process Brick Machine.
[From Henry Clayton and Company trade catalogue c.1862]

Figure 7.5. Extrusion brickmaking plant with three sets of crushing rolls, pug mill, die and cutting table.
[From Alfred Searle, Modern Brickmaking (1931) p. 138]



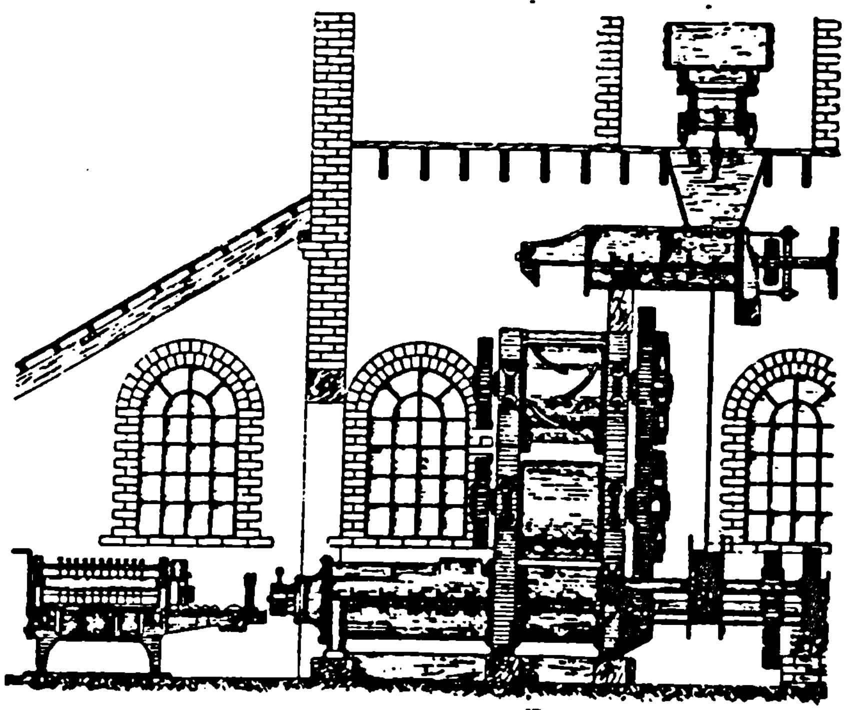


Figure 7.6. Extrusion brickmaking plant with feeder or trough mixer, two sets of crushing rolls, pug mill, die and cutting table. [From Alfred Searle, Modern Brickmaking (1931) p. 139]

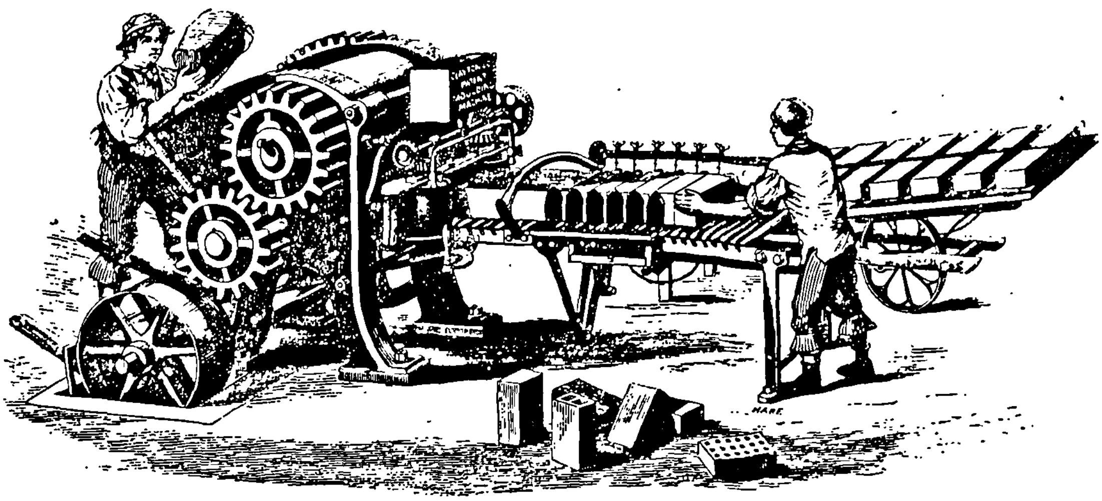


Figure 7.7. Henry Clayton's One-Process Brickmaking Machine.
[From Henry Clayton, Son & Howlett, Atlas Works (1871) p. 30]

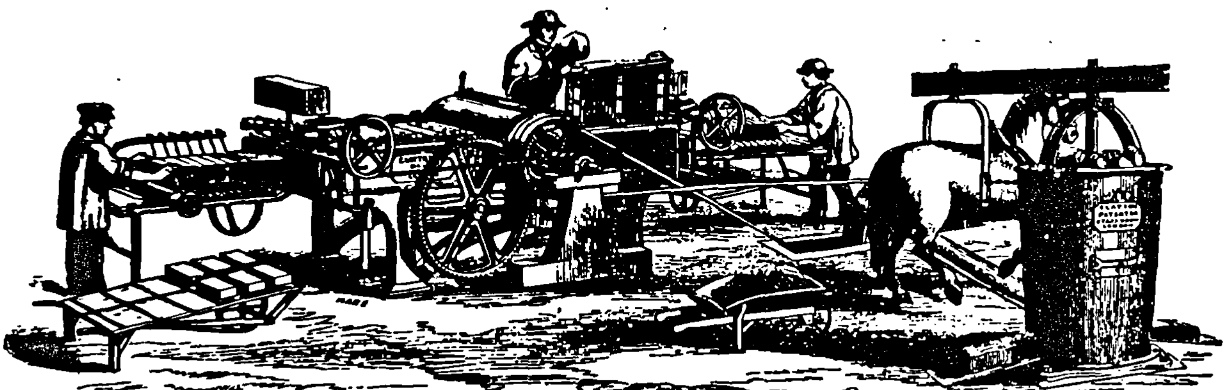


Figure 7.8. Henry Clayton's General Purpose "No. D" Brick and Tile Machine.
[From Henry Clayton, Son & Howlett, Atlas Works (1871) p. 32]

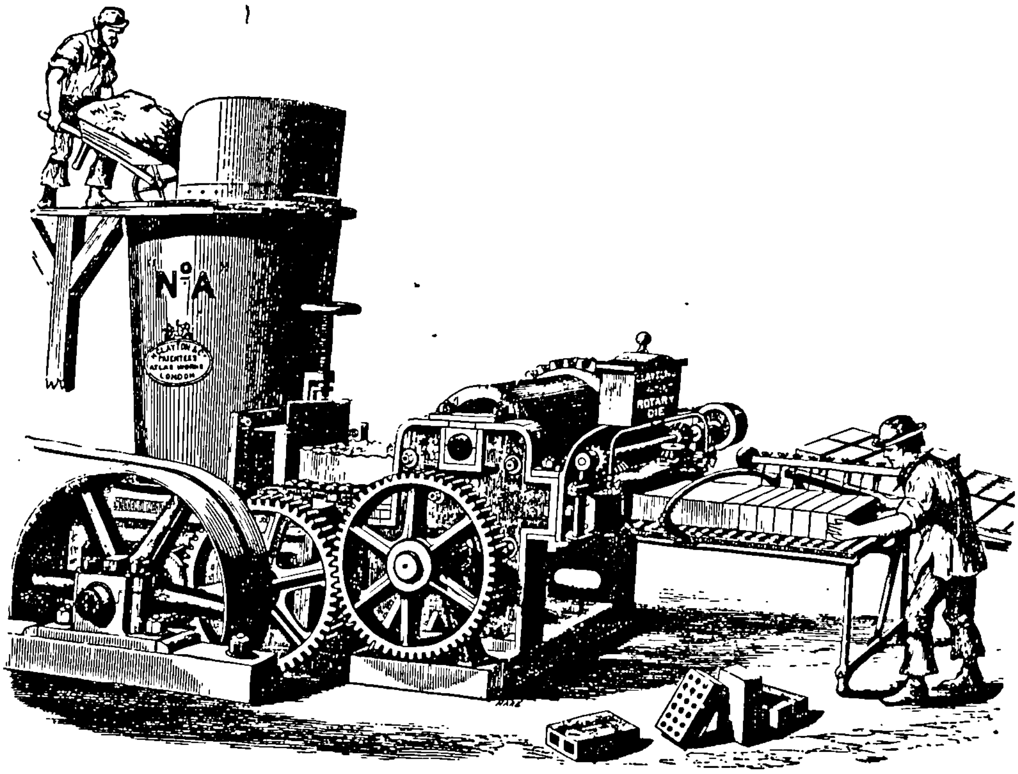
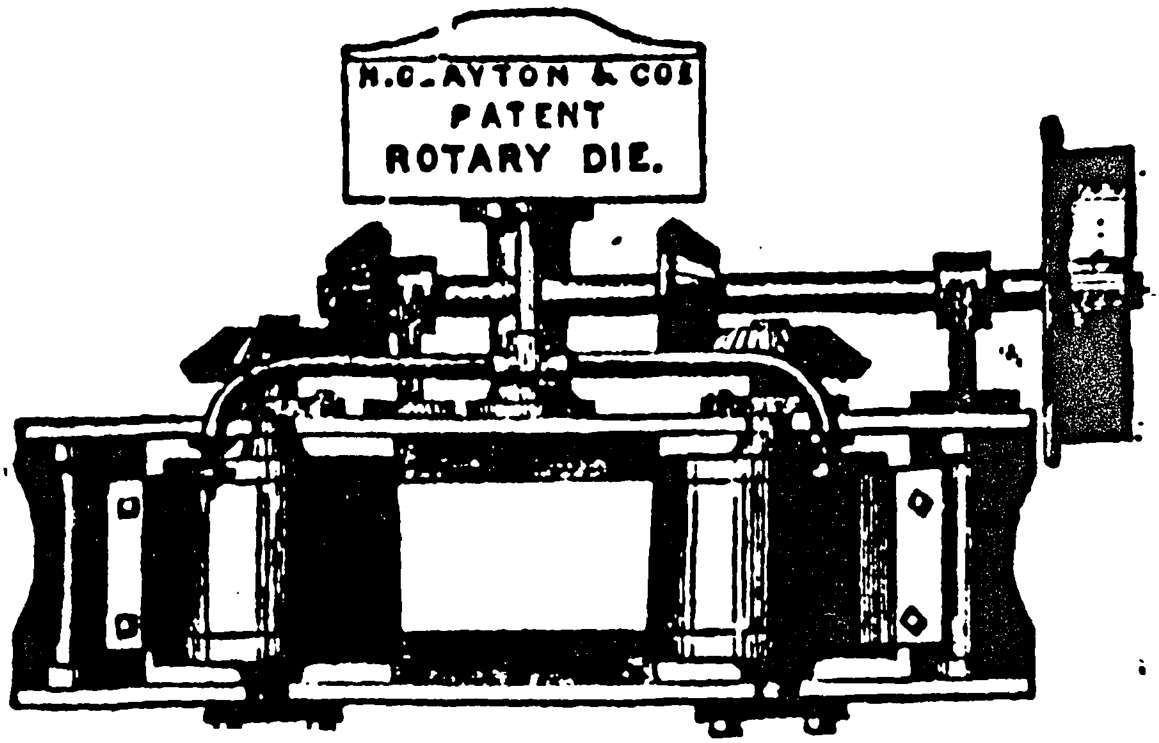


Figure 7.9. Henry Clayton's Combined Two-Process Brick Machine.
[From Henry Clayton, Son & Howlett, Atlas Works (1871) p.24]

Figure 7.10. "Patent Rotary Orifice Brick Die" manufactured by Henry Clayton & Company, c. 1868.
[From The Builders' Trade Circular July 15, 1869, p. 13]



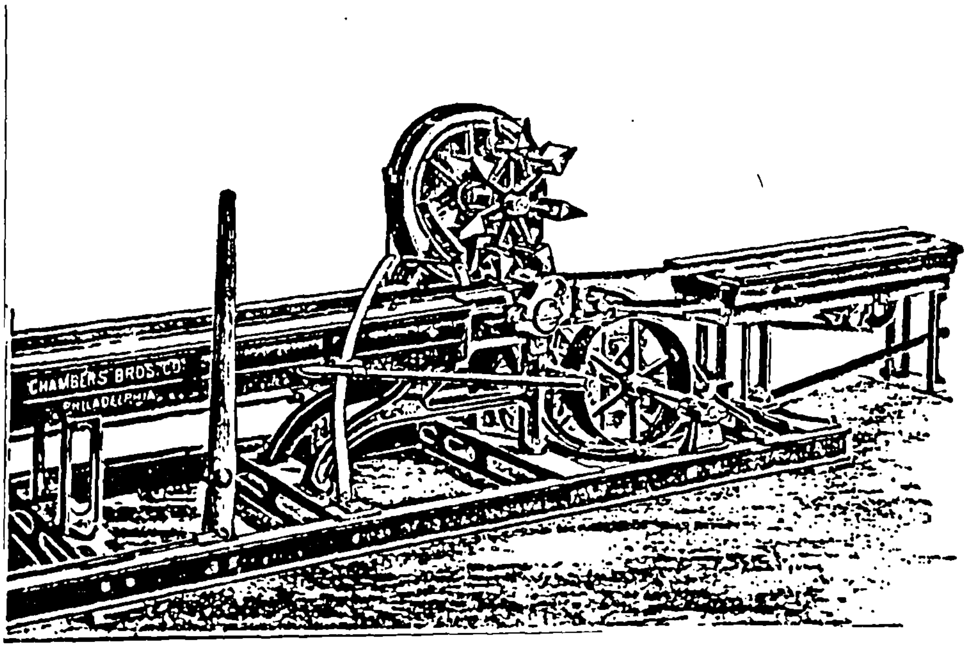
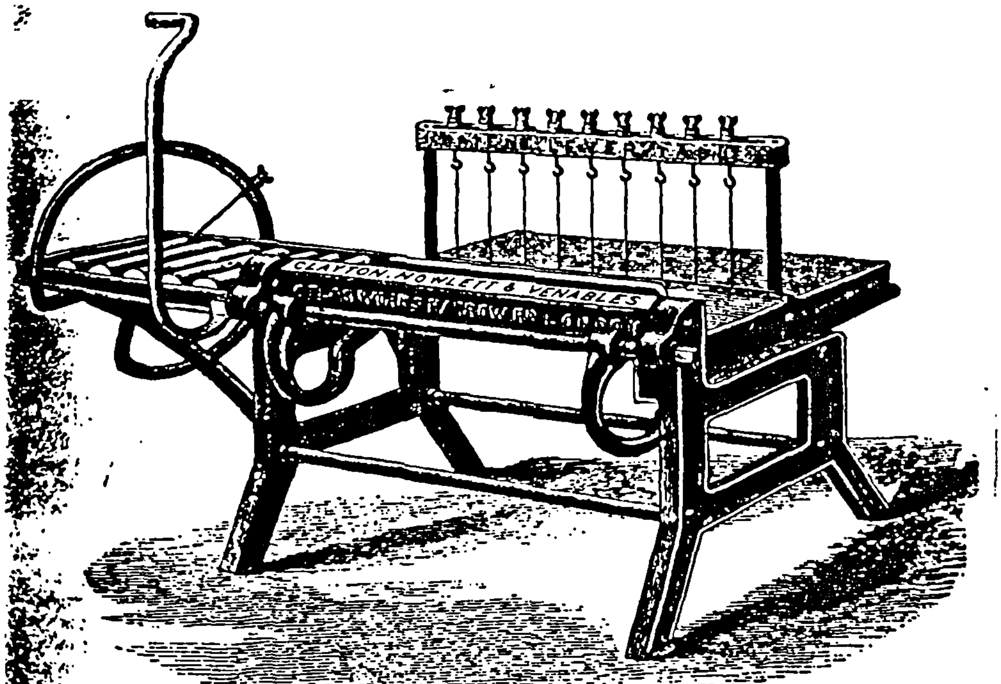


Figure 7.11. Cutting apparatus manufactured and sold by Cyrus Chambers of Chambers Brothers and Company of Philadelphia, Pennsylvania, c. 1864.
[From Emile Bourry, A Treatise on Ceramic Industries (1901) p. 287]

Figure 7.12. End-delivery brick-cutting table manufactured by Clayton, Howlett and Venables, London, c. 1890.
[From M. Powis Bale, The Building News (1890) p. 301]



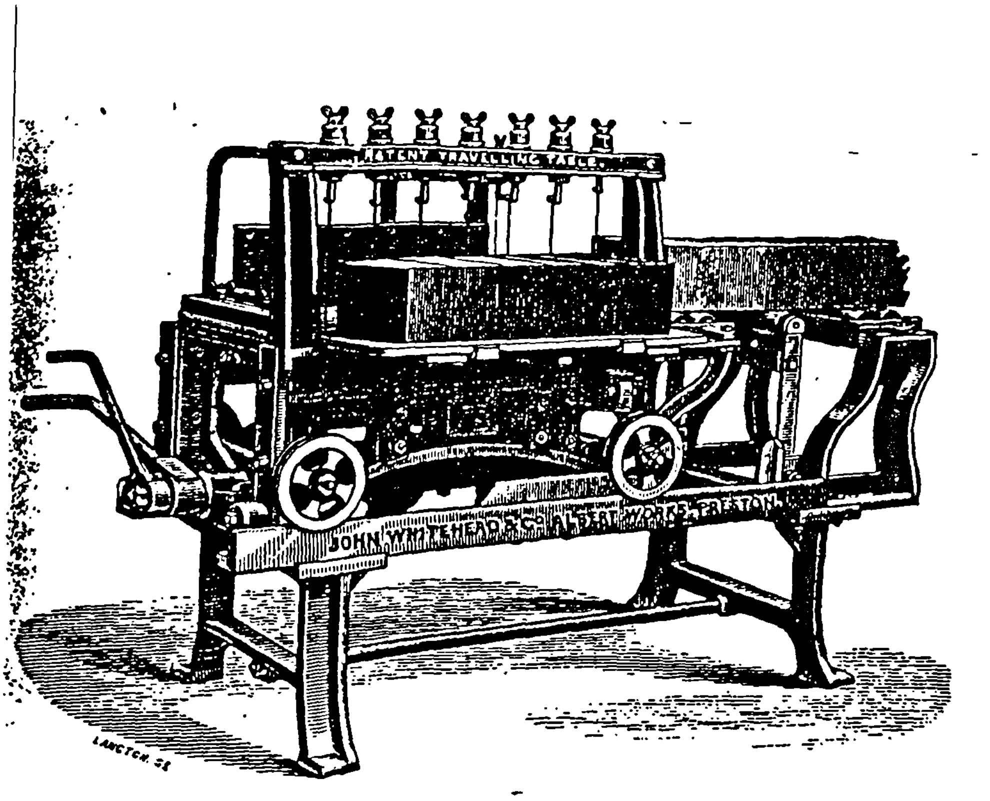


Figure 7.13. Travelling cutting table patented by J.D. Pinfold and manufactured by John Whitehead, c.1890.
[From M. Powis Bale, The Building News (1890) p.301]

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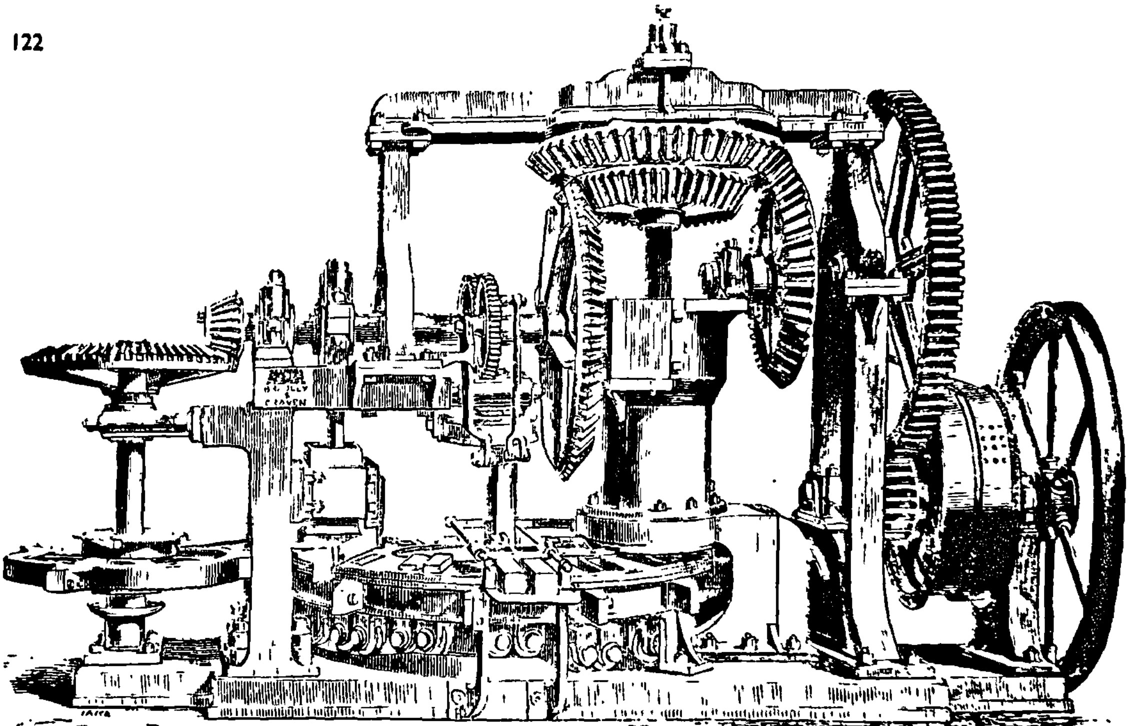


Figure 7.14. Bradley and Craven's semi-dry brick moulding and pressing machine, c. 1862.
[From Bradley and Craven, Limited, The First Hundred Years (1963) p. 80 and John Woodforde, Bricks to Build a House (1976)]

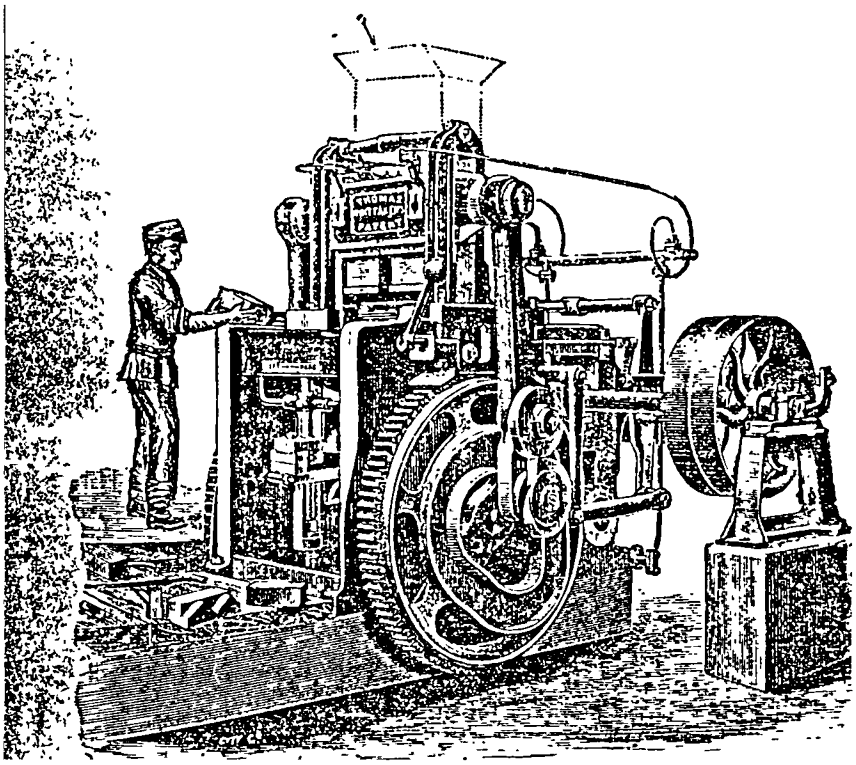


Figure 7.15. Semi-dry brickmaking machine manufactured by Christopher Whittaker and Company, Accrington, c.1890.
[From M. Powis Bale, The Building News (1890) p.443]

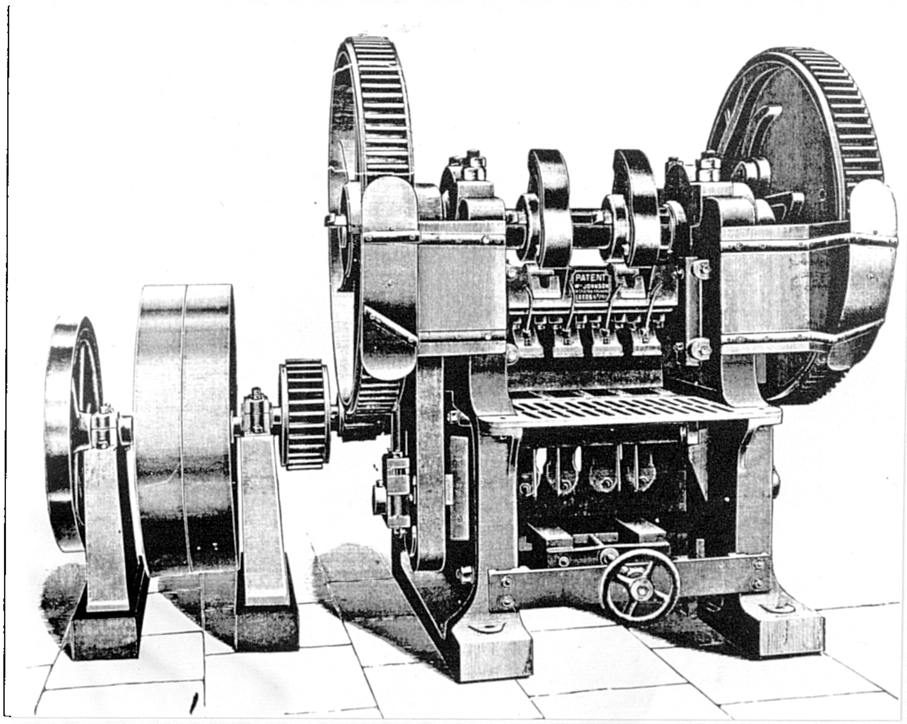


Figure 7.16. Johnson's Patent "Universal" Moulding and Pressing Machine.
[From William Johnson, Armley, Leeds trade catalogue, 1894]

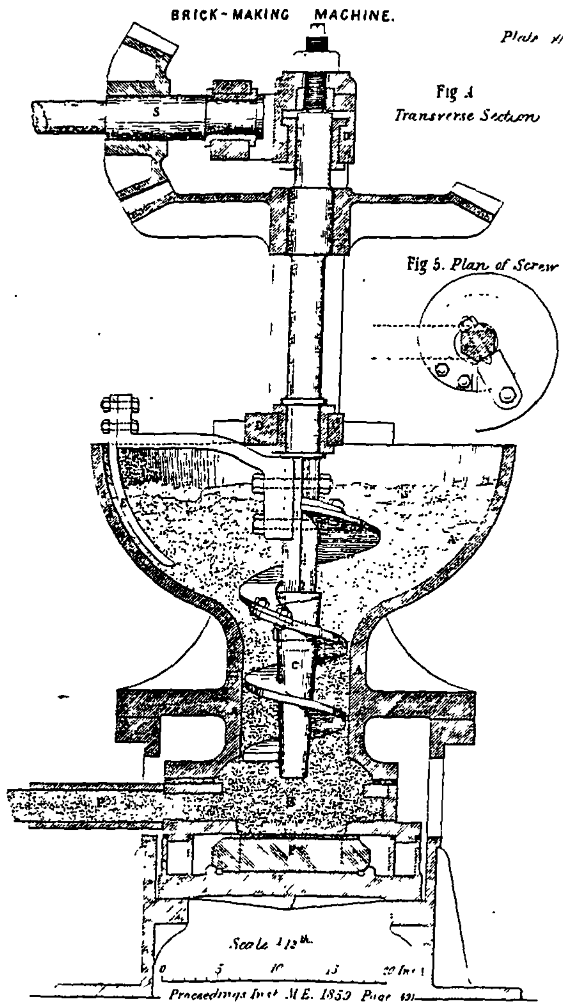
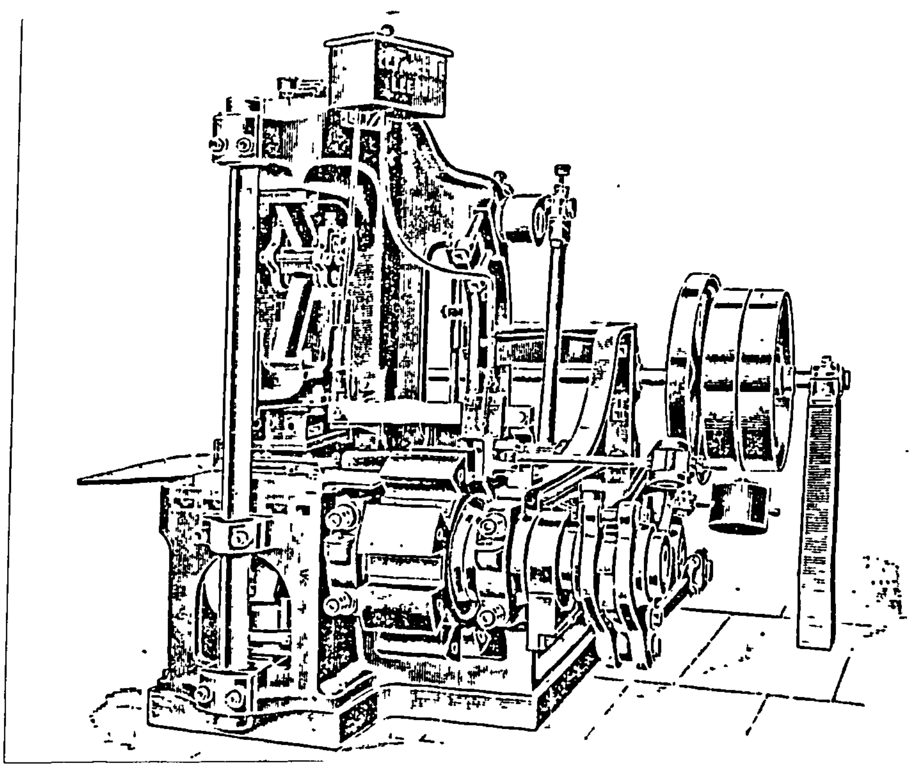


Figure 7.17. Brickmaking machine patented by Joseph Pimlot Oates, British Patent No. 730, 1857.
[From John Clift, Proceedings of the Institution of Mechanical Engineers (1859) plate 50]

Figure 7.18. Fawcett's stiff-plastic brickmaking machine, c. 1900. [From Emile Bourry, A Treatise on Ceramic Industries (1901) p. 290]



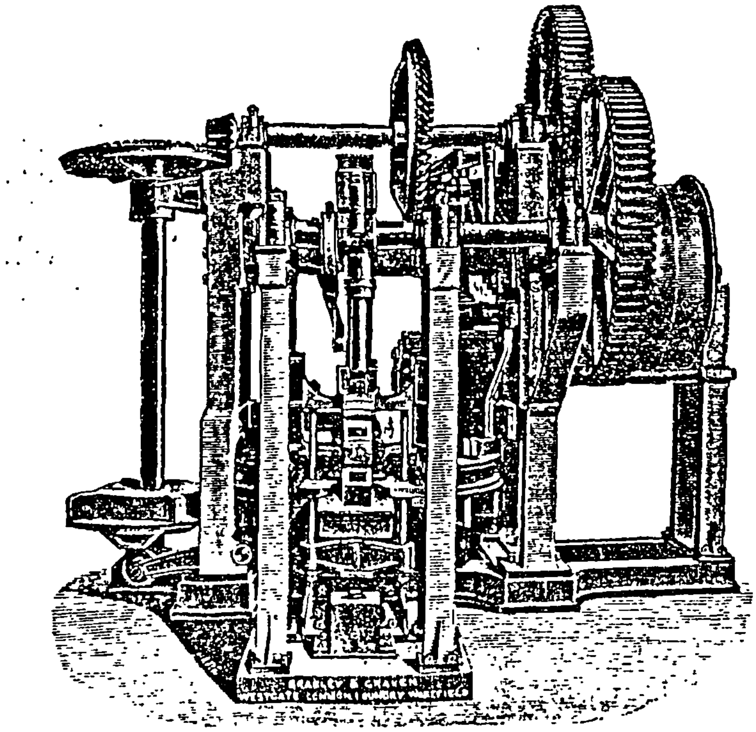


Figure 7.19. Stiff-plastic brickmaking machine by Bradley and Craven of Wakefield, c. 1890.
[From M. Powis Bale, The Building News (1890) p. 443]

CHAPTER EIGHT

ARCHITECTS AND MACHINE-MADE PRODUCTS

8.1.

The Price of Machine-Made Bricks

After the excise duties on bricks were repealed in 1850, many architects anticipated the widespread adoption of machinery and dramatic improvements in brick products. But by the end of the decade it was obvious to some that this would not happen immediately. One author commented in 1862 that "the greater portion of bricks are the same" (The Builder 1862, p. 283). Complaints about the varied qualities of bricks available on the market continued in the architectural press: "What very different things a brick stands for", stated one disgruntled observer (The Builder 1858, p. 33). A primary aim of those interested in the development of brickmaking machinery was to lower the price of bricks in the face of increasing demand. Architects were particularly disappointed that after repeal of the duties, the price of bricks remained unchanged except for normal periodic fluctuations.[1] One participant in a discussion at the RIBA in 1861 commented: "The high price of bricks at the present moment was an extraordinary fact...the duty had been taken off and now good stocks were much more expensive than when the duty was on" (The Builder 1861, p. 52). The professional press frequently printed complaints by architects about the high price of bricks (The Builder 1860, p. 335). Many still believed that the widespread acceptance of mechanized processes would contribute to a general lowering of brick prices.

Unfortunately, the much greater costs involved in establishing machine brickworks usually meant that machine-made bricks were more expensive. Examples of machine-made bricks from Thomas Cubitt's Burham brickworks cost between 45s. and 52s. per thousand in 1855 (Hobhouse 1971, p. 315). These prices were in contrast to hand-made London stocks which fluctuated between 28s. per thousand in 1854, from 23s. to 24s. per thousand in 1859, and just over 35s. per thousand in 1860. In 1856, Robert Rawlinson complained that "he had specified several times within the last five years for machine-made bricks, but had to resort to hand-made ones either because there was none on offer or a most extravagant one for machine-made bricks" (Chamberlain 1956 p. 497). By the time of the Royal Commission on Trades Unions in 1867, however, Alfred Mault, Secretary of the General Builders Association in Birmingham, claimed that some machine-made bricks were being sold for considerably less than hand-made products. He produced samples of Platt's pressed facing and common bricks which he said were priced at 26s. and 17s. respectively as opposed to 38s. and 20s. for the equivalent hand-made bricks (BPP <u>Trades Unions Commission</u> 1867, Ques. 4728).[2]

Another participant claimed that houses built with machine-made products cost less, not only because of the reduced prices of the bricks themselves, but also because machine-made goods were slightly larger and, hence, fewer were used. Mr. John Bristow produced calculations based on actual measurements to show that the cost of using hand-made bricks to build a house with an annual value of £75. was £172.5s., whereas the same sized house built with machine-made products required only £129.10s.6d. worth of bricks. This provided a total savings of £42.14s.6d.[3] Bristow also remarked that with machine-made products there was three to four per cent less waste due to damage, less mortar was used, and the cost of laying was reduced, "for a man has to stoop as many times for an inferior brick as he has for a superior one" (BPP <u>Trades Unions Commission</u> 1867, p. 259). The bricks chosen for this testimony were made by Platt's dry clay process at the company's large works in Oldham. The size of this establishment and the speed of the machinery allowed this significant reduction in price. For other mechanized processes such as extrusion machinery, however, the difference was not so great. As late as 1885 it was reported that machine-made bricks cost 17s.4d. while those made by hand were

19s.3d. per thousand at the yard. Not only was the difference between the two not great, but also the overall prices were not significantly less than when the duties were in effect. One observer complained: "Considering the perfection which machinery had attained, he thought the price ought to be cheaper" (Ward 1885 p.34).

8.2.
Testing the Quality of Bricks

Architects also hoped the adoption of machinery would improve the overall quality of bricks on the market. Few in the profession, however, had a clear idea of exactly what constituted good quality bricks. After years of condemning inferior clay products, most had a better idea of what they didn't want a brick to be. Many architects found it difficult to describe the characteristics of "a good brick" except to use such vague terms as "hardness", "great strength", or "truthful" shape. In reviewing bricks at the Architectural Exhibition in 1858, The Builder praised the products of one manufacturer: "Every line is true; and truth, whether in bricks or men, is a fine thing." The author went on to suggest that a "good brick" should be "a compact regular form that would hold its own under a weight of 60 or 70 tons and would last forever" (The Builder 1858, p.33). Besides regularity of form, non-absorbency was another characteristic many architects frequently attributed to good quality bricks (The Builder 1861, p.52). But even as late as 1880 when The Building News asked its readers to consider, "What is a Brick?", it observed: "The question seems easily answered, but we doubt whether one in a hundred would give a satisfactory reply, and describe with any degree of accuracy the salient points of a good brick" (The Building News 1880, p.201).

Because there were no established professional standards, many architects were interested in tests on bricks which they hoped would enable them to evaluate differences between machine-made and hand-made bricks and to identify characteristics of superior products.[4] The results of independent experiments were reported frequently in the professional press, and later in the century systematic investigations of the properties of bricks and the strength of brickwork were undertaken by The Builder and the RIBA. Although the extent of testing in this country was considerably less than on the Continent, these activities ultimately helped the profession to clarify its standards with regards to clay products (Butterworth 1953 p.825). But this was a gradual process and precise definitions of "a good brick" only slowly emerged after several decades of haphazard experimentation.

The earliest tests on individual bricks were undertaken to determine strength by measuring resistance to crushing. The purpose of many of these experiments was to compare machine-made and hand-made products. The results often were used by supporters of machine brickmaking to "prove" the superiority of bricks made by certain machines. In 1847, Thomas Cubitt used a hydraulic press to test the crushing strength of various bricks manufactured at his Thames Bank works. A kiln-burnt, machine-pressed brick bore a weight of 60 tons, the limit of the ram, without breaking while the best hand-made washed stock brick cracked under a pressure of 36 tons and was crushed by 44½ tons. A hand-made place brick, faced with plaster to make an even bed, broke under a weight of 11 tons and was crushed by 16½ tons (The Builder 1847, p.537). A similar experiment was undertaken in 1853 by the engineering firm, Ransomes of Ipswich, to compare the strength of Robert Beart's perforated bricks, made by his improved extrusion process, and solid Suffolk bricks (presumabely hand-made). The Builder reported that the perforated bricks "bore a pressure of 31 cwt. per square inch or 68 tons 18 cwt. on the whole surface of the bricks", but the solid ones "crushed to pieces with 8¾ cwt. per square inch -- equal to 16 tons 12 cwt. on the whole surface of the brick." The author went on to state that "our readers will of course not suppose that this difference is all due to the perforations", although he did not suggest a more likely explanation (The Builder 1853, p.77). Bricks made by Oates' "Patent Solid Brick Machines" were tested for crushing strength at the Oldbury Brick Works in 1859 along with local hand-made blue bricks. It was reported that the strength of bricks made by the machine was double that of the blue bricks, "being an average of 150 tons as compared with 76 tons, or 8024 lbs. per square inch compared with 4203 lbs. (Clift 1859, p. 254).

The Metropolitan Board of Works carried out 293 experiments on the strength of various bricks between 1859 and 1863. Many of the bricks they tested were machine-made products. In one group of tests in 1862, wire-cut bricks made by Clayton and Company machinery were compared with hand-made London stocks and pavoirs. The machine-made samples tested considerably stronger, requiring 41 tons to crush in contrast to 14 and 23 tons for the hand-made bricks. In other experiments from this series, machine-made bricks similarly withstood greater pressures than most hand-made products. For example, in 1859 and 1860 a variety of bricks from Webster's brickworks in Burham were tested, including shipper stocks, thought by some to be the hardest category of those made in the vicinity of London, hand-made gault bricks, machine-pressed gault bricks and ordinary wire-cut bricks. Another group of machine-pressed gaults from Aylesford also were included in the samples tested. The maximum weight supported by the hand-made gault bricks before crushing was between 20 and 33 tons, while the shipper stocks sustained from 37 tons up to 55 tons. In contrast, the sample of machine-pressed gault bricks required from 42 to 55 tons to crush and the ordinary wire-cut bricks sustained a pressure of 73 tons. Machine-pressed and wire-cut bricks from the same yards in Burham and Aylesford were tested yet again in 1863 along with a wider sample of well known hand-made bricks from various parts of the country. Again, the maximum pressure they were able to sustain was greater than several types of white bricks from Suffolk and the famous Fareham red facing bricks. They were only surpassed by the best blue bricks from Tipton and firebricks from Tonbridge (Proceedings of the Institution of Civil Engineers 1865-66, p. 99).

The apparent "success" of the machine-made products in sustaining greater weights before crushing seemed to substantiate many of the claims made by proponents of machine brickmaking.

Nevertheless, there was scepticism among some members of the architectural profession about the value of testing for the crushing strength of individual bricks. W. Hawkes, a contributing visitor to a meeting of the RIBA in 1861, commented: Such tests "tell you that which you hardly ever want to know." He believed that "a comparison of the transverse strength of bricks may be made with much more certainty than their power to resist a crushing force." He proposed to test bricks to their breaking point in the same way that iron girders and beams were tested. Hawkes experimented with bricks from all over the world, including "nine pieces of Roman tile from Wroxeter" and hollow bricks from France. Among the British samples were several machine-made bricks -- some from Leed's made by Bradley and Craven's machines, four of Platt's dry clay bricks, and extruded perforated bricks from Rugby. He recorded the weight and size of each brick, the weight each sustained before breaking, and how long the weight was carried before the brick broke. Only Bradley and Craven's machine-made bricks were able to maintain pressures exceptionally greater than the hand-made samples, while the perforated bricks and Platt's dry clay bricks had rather poorer results in comparison (Papers of the RIBA 1860-61, p. 121-29).

Hawkes' paper generated a heated discussion. Some participants defended the poor showing of the hollow and perforated bricks by relating their own favourable experiences with these products or citing the results of previous experiments. One stated that he personally had tested perforated bricks which had sustained a pressure of eighty-three tons without crushing. Others, like Charles Barry, Junior, felt the results of Mr. Hawkes' experiments, like other tests to determine resistance to crushing, "failed to be of great practical utility" because, as he pointed out, "it should be remembered that walls were not made of bricks alone" (The Builder 1961, p.52). This led the discussion into speculation about the relative strengths of mortar and bricks in a masonry wall, but it was felt generally that this was impossible to test.

Doubts about the value of strength testing were expressed on other occasions. In an address to the Glasgow Architectural

Society in 1870 on the nature and properties of bricks, John MacDonald described a series of recent experiments on the strength of bricks made with different amounts of additives in the clay mixtures such as ashes and sand. After giving the test results, MacDonald concluded: "These tests, though very satisfactory in demonstrating the pressure good bricks will sustain in an isolated position, fall far short of showing how much weight they will sustain in a wall well bedded and compactly built together with good lime" (The Builder 1870, p. 143). The Architectural Publication Society also considered the hydraulic press "a very doubtful instrument" for testing the strength of materials. They cautioned the readers of their Dictionary about the significance of such tests: "So many unforeseen contingencies occur in the execution of large works, but which it is easy to guard against in hand experiment, and there is so wide a range in the power of different materials to resist permanent or temporary loads, that it behoves the architect not to receive the laws so deduced with implicit confidence" (Architectural Publication Society Vol. 1, p. 145). Finally, when the Manchester Society of Architects appointed a committee in 1868 to examine and systematically test various bricks made in the area, they decided not to test for crushing strength, "such experiments on individual bricks giving no reliable data for calulating the weight that would crush a mass of brickwork" (Manchester Society of Architects 1868, p. 3).

Apparently, no one at the time believed experiments could be devised to test the strength of brick walling. Charles Barry, Junior stated at the RIBA in 1861 that "the resisting power of a brick to the machine might easily be ascertained, but a similar test could not be applied to the wall..." (The Builder 1861, p. 52). Most architects accepted the opinion expressed by Mr. H. More, an engineer, who along with others believed that bricks "would sustain one hundred per cent more pressure when thus built than when isolated in the press" (The Builder 1870, p. 143). In 1879 Rivington's Notes on Building Construction supported this view when it advised students that "the compressive stress brought upon evenly bedded bricks is generally far less than they are able to bear" (Rivington 1879, p. 115).

The profession was interested also in the quality of non-absorbency in brick products. One source commented, "the amount of water absorbed by bricks is to a certain extent an indication of their quality" (Rivington 1879, p. 113). Architects were concerned about absorbency for two reasons. One was the tendency of many brick walls to admit and retain large amounts of moisture, thus creating damp and unhealthy dwellings. The second was the injurious effect of frost on saturated bricks. The testing committee of the Manchester Society of Architects summed up the preferred attributes: "For the purposes of securing dryness of dwellings, etc., the brick which imbibes the least moisture, and that the most slowly, and which parts with it most rapidly, is the most desirable..." (Manchester Society of Architects 1868, p. 7) But it was also a problem if the bricks were too non-absorbent because then ordinary mortar often would not adhere, requiring expensive cements to set them properly (The Builder 1895, p. 397). A contributor to The Builder commented in 1861 that "it was discreditable to the science of the day that some means were not taken to make bricks non-absorbent and yet adhesive" (The Builder 1861, p. 52).

Debate about the absorbency of bricks was particularly important with regards to the development of dry or semi-dry process machinery during the late 1850's and 1860's. Promoters of these machines made the usual claims of excellence for their products, emphasizing their "fine, flat surfaces and sharp outlines" (Engineering 1867, p. 197). Bricklayers also appreciated the perfect shape of dry clay bricks because they could be laid quickly and accurately (BPP Trades Unions Commission 1867, p. 43 and 61). Although not available universally, by the late 1860's dry pressed bricks had been used in several prominant locations around the country, including the Strangeway's Gaol at Manchester, the railway stations of the Great Northern and the Lancashire and Yorkshire Railways in Wakefield, and in portions of St. Pancras Station in London (Engineering 1867, p. 197; Simmons 1969, p. 53). In earlier discussions about the process, however, participants not only expressed doubts about the strength and durability of dry clay bricks, but also reported experiences which suggested they absorbed large quantities of water and frequently scaled off in freezing weather (Proceedings of the Institution of Mechanical Engineers 1859, p. 46). As we have seen, others complained about weaknesses in the arrises of dry clay pressed bricks. Consequently, experiments devised to measure the power of absorption and retention of water in bricks were intended especially to test dry clay products in comparison with ordinary bricks made by a plastic process. Architects did not have extensive experience with these new products and many hoped that testing would either "prove" or "disprove" their reliability.

The 1868 Committee of the Manchester Society of Architects prepared two different absorption experiments, one in which the bricks were totally immersed and another in which they were laid on edge in three-quarters inch of water. The bricks chosen for testing included ten hand-made samples from yards around Manchester, dry clay bricks from Platt Brothers at Oldham, Hutchinson's machine-made bricks, and a sample of machine-made products submitted by the Builders' Association (process and origin unknown). The Committee measured the total quantity of water absorbed (calculated at the percentage by volume), the rates of absorption (both the percentage by volume and the actual quantity per cubic foot measured at different time intervals), and the rates of drying. In terms of the total quantity of water imbibed, Platt's dry clay bricks tested favourably, absorbing 18.6 per cent of their bulk of water, an amount lower than all of the hand-made bricks and the Builders' Association machine-made samples (Manchester Society of Architects 1868, p. 8).

The tests for rates of absorption and drying, however, were considerably more contradictory and inconclusive. Bricks that took up a significant proportion of water in the first quarter hour did not continue at that rate throughout the test, but eventually were surpassed by initially less absorbent bricks. Conversely, it was found that "the bricks which parted most eagerly with their moisture at first were the longest in drying and vice versa."

These confusing results led the Committee to doubt their value and it was suggested that the figures for the total amount of water absorbed per cubic foot were the most reliable and useful because, they concluded, "the penetrating effect of damp must be gauged by...the actual quantity taken up" by each brick (Manchester Society of Architects 1868, p.9). Another observation made during the testing was that when the bricks were fully immersed, the release of air bubbles indicated that they took in water more rapidly at their ends and sides than at their top and bottom beds. The Committee stated: "This would seem to point to the desirableness of applying pressure in moulding in a different direction to that in which it is generally done" (Manchester Society of Architects 1868, p.7). There is no indication that machine makers heeded this advice.

Finally, the Committee measured all the bricks and weighed them with the intention of establishing their density. Although they felt it was important to comment on the hardness of each sample, they had not invented a method for testing this characteristic and, therefore, could only observe that "hardness is not necessarily commensurate with density." The Committee went on to say that although one of the machine-made bricks and one hand-made brick were equal in density, the former appeared to be considerably harder. On the other hand, another "highly dense" machine-made sample was "rather wanting in toughness." But they were unable to define "hardness" and "toughness", and could only speculate vaguely that tough, homogenous bricks seemed to be those that had "adequate kneading and tempering of the clay", a characteristic that could have applied to products made by any process (Manchester Society of Architects 1868, p.7).

In spite of these somewhat inconclusive results and ambiguous observations, the *ad hoc* experiments conducted by the Society were important for being one of the first efforts by architects systematically to test the various properties of bricks with the intention of comparing hand-made and machine-made products. In completing their report, members of the Committee tried to define comprehensively the characteristics of good quality bricks. They specified that good bricks should be of a uniform size, rectangular with "true faces" and only the sides and ends smooth. They should not absorb more than twenty per cent of their bulk when saturated, be uniformly burned with a metallic clang when struck, and be "tough and pasty" rather than granular in texture. The report concluded: "Hand-made bricks cannot, as at present made, be relied on for complying with the above requirements. They are generally very deficient" (Manchester Society of Architects 1868, p.11).

On the other hand, one of the most decisive opinions expressed by the group was that Platt's dry clay process was too expensive and complicated to be introduced in the area for common brickmaking. They especially objected to the large space and capital expense needed to set up the necessary clay preparation machinery for manufacturing dry clay bricks. They also felt the system of burning used at the Platt's Brothers' works, the Hoffman kiln, was "beyond the means of most brickmakers and would only be remunerative where a very considerable quanitity of clay is at hand" (Manchester Society of Architects 1868, p.11). The Builders' Association machine-made bricks were considered superior to hand-made products, but were thought to be too large with a granular texture, friable arrises and much too absorbent. Hutchinson's machine-made bricks were declared the best bricks tested. The Committee said they were "sound, homogenous, not granular and possess a surface well adapted for making a good mortar joint." They also commented on their low absorptive capacity and reasonable price (Manchester Society of Architects 1868, p.12). Presumably, these were bricks made by William Hutchinson, an engineer from Salford, with an "extrusion press" machine which was an early development of the stiff-plastic process. It combined an ordinary extrusion machine with a separate hydraulic finishing press. The machine was patented in 1869, after the Committee's favourable endorsement (British Patent No. 2063, 1869).

The Manchester architects were decidedly in favour of machine brickmaking.[5] They wrote: "If machinery could produce an article superior in the most important requirements, and but little inferior to others, at a much lower price, its introduction would no doubt be welcomed by all engaged in building operations" (Manchester Society of Architects 1868, p. 11). Although these comments were encouraging for the cause of machine brickmaking, the conclusions of the testing committee did not support proponents of dry or semi-dry clay brickmaking. Nor did they succeed in "proving" the superiority of bricks made by this process. The results of the tests and subsequent experience with dry clay bricks caused many professionals to distrust these products. Instead the findings of the Society helped direct the attention of architects towards the advantages of clay building products made by the alternative stiff-plastic process.

The ambiguous results of the Manchester experiments were disappointing in that they did not provide architects with the conclusive evidence they required to establish professional standards. Moreover, it also seemed that commonly available bricks were deteriorating progressively as time went by rather than improving as architects had anticipated. During the 1870's and 80's expressions of dissatisfaction about the quality of bricks appeared frequently in the architectural press. "Our ordinary stock bricks are, in this present year of grace 1870, probably the worst in the world", wrote the editor of The Builder, "they are such as no engineer or architect, worthy of the title, would have allowed to be delivered on any works under his direction five-and-twenty years ago" (The Builder 1870, p. 99). Again in 1872 the same journal exclaimed that "it is a matter of very serious regret that nothing seems to arrest the increasing deterioration of ordinary building bricks" (The Builder 1872, p. 837). Some still considered the best solution to this problem was the universal adoption of machinery: "There can be no doubt in the mind of any competent judge, that good bricks could be more rapidly and more cheaply made by machinery than bad bricks are now made by hand...Yet in the grand industry of brickmaking proper, reform is still successfully impeded" (The Builder 1870, p. 99).

But many architects increasingly realized that the application of machinery would not provide a *simple* solution to the problem of poor quality bricks. Experience with machine-made bricks and exposure to many different clay products at the numerous building trades and architectural exhibitions during these decades made architects more aware of the great variety of brick earths, types of machines, and preparatory treatments available. Many began to accept what brickmakers had long been saying, that no single machine or process could operate successfully under all circumstances of manufacture. Thus, a leading article in The Building News in 1880 admitted: "It is desirable, in manufacturing bricks of first-class character, to adopt *suitable* machines..." After reviewing the various clays and brickmaking systems, both manual and mechanical, on offer in the country, the author concluded that "under the circumstances we have described, it is quite impossible that any uniformity of weight, size, colour or strength can prevail, and the confusion consequent thereon is in some degree heightened by the knowledge that no ready means of test can be commanded." The article went on to suggest that the most reliable method for architects to judge the quality of bricks was the "cart test": "No brick for any purpose whatever should be considered good unless it can stand the brunt of being tipped out of the cart or waggon in which it is carried from the point of manufacture to its destined resting place" (The Building News 1880, p.201 and 202).

Organized experiments with bricks in the third quarter of the nineteenth century continued to be sporadic, the methods used were questionable, and the results were, for the most part, inconclusive or unreliable (Ward 1885, p.24-26).[6] Although architects recognized the need for accurate information about the properties of bricks to guide them in choosing appropriate building materials, this data was not forthcoming. In 1880 one professional journal commented that "it is only prudent for us to suggest that a good sound, and in every sense competent, brick should be thoroughly homogenous in texture, and even in whatever may be the required colour, having a capacity of withstanding a certain defined tensile, transverse or compressive strain" (The Building News 1880, p.202). But the results of testing up to that point were not sufficient to establish such guidelines definitively. Instead, architects were forced to rely on their own knowledge and visual judgement rather than on scanty "scientific" findings to help them determine which were the best bricks.

By the 1880's and 90's, experience had convinced many architects of the inferiority of bricks made by the semi-dry process. Speaking to the Inventors' Institute in 1888, William Johnson said, "the experience of a few years has proved bricks of this kind to be deceptive, from their porosity and light crushing strain and tendency to disintegrate by exposure to damp...This class of brick is almost universally condemned both by architects and engineers, and has almost entirely gone out of use in many parts where it had previously been in favour" (The Builder 1888, p.86). A correspondent to The Builder, signing himself "FRIBA", also remarked that "some clays will not stand the semi-dry process, and suffer severely when exposed to the weather. In some of the midland counties, where bricks by the dry process were made in large quantities, the manufacture is almost entirely stopped on this account" (The Builder Vol.LXVI 1894, p.274). Another contributor to a discussion at the Architectural Association confirmed that "he could point out several London buildings where Midland pressed and machine-made bricks were now in a state of disintegration" (The Builder Vol.LXVIII 1895, p.64). One of these was St. Pancras Station whose dry clay pressed brick facings on portions of the coal wharves spalled prematurely and had to be replaced (The Builder Vol.LXXIII 1897, p.414).

Besides learning from experiences like these, architects also depended upon easily recognizable physical characteristics, such as the cart test, to help them evaluate the quality of bricks. For example, in reviewing the displays of bricks at the Building Exhibition at Agricultural Hall in 1882, one writer commented favourably about a group of products because of their "hard metallic ring" and "surface like iron" (The Builder 1882, p.336). John Slater similarly described "a good brick" to the Architectural Asociation in 1895 in terms of visual and tactile features -- regularity of shape, toughness ("it ought not to snap when broken, but should require two or three hard blows"), homogeneity, and clearness of ring. He also added non-porosity and strength as desirable characteristics. By these he meant the rate at which a brick absorbed water and the strength of bricks built into walls rather than individual bricks: "The rate at which a brick --or, for that matter, stone either -- absorbs water is a more important element in its goodness than its total absorptive power, because when built in a wall the bricks are exposed only to intermittent wettings" (The Builder 1895, p. 64).

It had been twenty-seven years since the Manchester Society of Architects concluded their experiments. Interest in brick testing was renewed in the early 1890's when Fletton bricks, made by the much distrusted semi-dry process, appeared on the market. A series of communications to The Builder in 1894 again debated the question "Which is the Best Brick?". The discussion was initiated by "A Lover of a Good Brick" (revealed later as a manufacturer of London stock bricks) who pointed out the shortcomings of machine-made bricks and asserted the pre-eminence of the hand-made brick. He maintained that while Flettons were attractive to look at, they would not stand the weather and they absorbed large amounts of water. The author also stated that machine-made gault and Leicestershire bricks suffered from "the defect of staining or vegetation", were brittle, and would not stand fire (The Builder Vol. LXVI 1894, p. 255). The response to these opinions was a deluge of letters in defence of machine-made bricks from brickmakers, architects, and civil engineers who attested especially to the quality of Fletton bricks which, according to one contributor, were "the best possible common bricks procurable... superior to stocks in every respect." Although the editor of The Builder declared, "in respect of durability there is little to choose, as far as time has at present shown, between stocks, Fletton and gault bricks", in 1895 the journal began a comprehensive examination of bricks in "The Student's Column" which included a review of all tests previously conducted as well as new experiments on absorption (The Builder Vol. LXVI 1894, p. 274 and 284).

The column reiterated the importance of the property of absorption in bricks and stated again the dilemma: "If it absorbs much moisture there is the liability of its becoming shattered by the action of frost, of producing damp walls, of vegetating, and of being destroyed by chemical action introduced into the material by atmospheric agency or through the medium of the decaying vegetable matter on its surface. On the other hand, if the brick is practically non-absorbent there is difficulty in getting mortar to adhere to it, and indeed of using it for building purposes at all unless set in cement, or other expensive material" (The Builder Vol. LXVIII 1895, p. 397). Fifteen different bricks, "well-known in the market", and one sample of terra cotta were selected for testing. The bricks were placed in a large container on edge, some supported on flat blocks so that the upper face of each brick stood one quarter inch out of the water. It was believed that by totally immersing the bricks, the air would not have an opportunity to escape and thus impair the rates of absorption. Unlike the Manchester tests, the quantity of water absorbed was calculated by weight rather than by volume.

The results of rates of absorption and drying were similar to earlier tests in that they showed "striking anomalies." Observers noted that "the brick which is longest in arriving at full saturation, is also longest in becoming thoroughly dry." But in contrast to the Manchester findings, the tests revealed that bubbles escaped uniformly over the entire surface of the bricks rather than only at the sides and ends, causing the investigators to speculate that improved methods of manufacture had removed that previous "objectionable" tendency. The bricks were submitted to a second test in which they were broken in half before being immersed in the water. The results showed that the amount of water absorbed was greater for each brick. The amount of difference was greatest for machine-pressed bricks, which confirmed that in products made by this process, "the outermost portions act as a thick skin of a less impervious character than the bulk of the interior." The Builder speculated that even bricks judged to be of good quality with low absorptive capacity would become very *porous* in "exposed situations by a driving rain", and advised architects to undertake absorption experiments themselves before selecting materials (The Builder Vol.LXVIII 1895, p.437-38).

The tests also attempted to investigate the property of hardness in the bricks as opposed to their resistance to crushing. For this purpose "hardness" was identified as "the net result of the metallurgical processes called into operation on the application of intense heat whereby the various constituents become partially fused or agglutinated." "Toughness" was defined as "the strength, or the behaviour on the application of force, of the aggregate fused." The method chosen for testing was adapted from the scale of hardness used to distinguish minerals, that is a scratch test resulting in a degree of hardness from one to ten, one indicating that the substance could be scratched by the finger nail and ten indicating a substance harder than steel. There was considerable difficulty in applying the test to bricks which were made up of different minerals because one mineral might test harder than others. But those conducting the experiments proposed to ignore the properties of individual minerals and consider only the material as a whole to determine "the relative state of coherence of the particles composing a brick, and in a measure also its soundness." Two machine-made bricks from near Chester, one wire-cut and the other pressed, tested hardest at 9.0, but other machine-made bricks tested much lower at 3.0 on the scale (The Builder Vol.LXVIII 1895, p.438).

The results of this experiment became significant when they were compared with the absorbency tests. The relative order of the bricks after the two tests was virtually the same. The investigators pronounced, "we may lay down the general rule that the absolute hardness of a brick, as tested by the scale adopted for minerals by mineralogists, is in a measure an indication of its relative power of absorption -- the harder the brick the less moisture it absorbs" (The Builder Vol.LXVIII 1895, p.438). In concluding the series, The Builder stated their intention had been to show how the method of brick manufacture influenced the weather-resisting properties and general quality of commonly used bricks, and to show "the various chemical, physical, mineralogical and metallurgical properties of the particular class of earths used in different parts of the country." But the results were not at all conclusive with regards to machine-made bricks. Two very similar bricks made by the same machine process showed very different test results indicating that the properties of the clay and the compatability of the material to the process used were ultimately the most decisive factors in determining the quality of bricks (The Builder Vol. LXVIII 1895, p. 490).

Architects participated directly in another series of unique and valuable tests on bricks in the late nineteenth century. These were the brickwork experiments conducted by the RIBA to determine "the amount of resistance possessed by brickwork under great crushing loads." A sub-committee of the Science Standing Committee, after a great deal of difficulty gathering subscriptions to defray costs[7], commenced building experimental brick piers on 24th July 1895 on a vacant piece of land at the West India Docks. Four piers each were constructed of four different types of bricks -- hand-made London stocks and three machine-made samples, gault, Leicester red, and Staffordshire blue bricks. The piers were six feet high and eighteen inches square. Two each were laid in lime mortar and the other two in cement. Prior to the experiment, samples of the individual bricks and the mortar were tested separately for crushing strength by Professor Unwin at the Central Technical College. The sub-committee crushed one each of the piers at the end of four months and the others at the end of ten months when the mortar was more mature: "The reason for deciding upon having tests at two different periods was to ascertain what additional strength the brickwork gained in six months, as this is of importance, considering the great rapidity with which brick buildings are now run up, and sometimes loaded with great weight while the brickwork is quite green and very little of the mortar set" (Street and Clarke 1896, p. 333-345).

The machine used in the experiments was a specially-designed hydraulic press loaned for the duration by Sir William Arrol. Professor Unwin, one of the investigators, acknowledged the difficulties in using a machine of this type: "An hydraulic press used as a testing machine has got a very bad name, and not undeservedly, because what the pressure-gauge on the hydraulic press directly gives you is only the pressure in the ram cylinder, and it does not give the load that the press exerts. There is a difference between the two, due to the very large friction of the ram." This difference due to friction could be as much as twenty-five per cent. "To avoid criticism of the results", the sub-committee found a way to determine the real loads exerted on the piers to an accuracy they claimed was under one per cent. They did this by crushing some copper cylinders in "a very accurate testing-machine", comparing them to cylinders crushed in their own machine, and calculating the margin of error (Journal of the Royal Institute of British Architects 1896, p. 353). The machine was designed to exert a pressure of 500 tons on each specimen, corresponding to water pressure of nearly 1,000 lbs. per square inch (Tuit 1896, p. 353).

Various problems complicated the testing. For example, it was discovered that while building some of the piers, the bricklayers found the Leicester red and Staffordshire blue bricks too hard to cut, so they used London stocks to fill in large portions of two piers. This obviously destroyed their experimental value and delayed testing while new piers were constructed. Then, when crushing commenced after four months the sub-committee discovered that "the underside of the upper part of the testing frame was concave to the extent of about half an inch, and did not permit the equal distribution of the pressure upon the heads of the piers." Consequently, a lead casting had to be made to fit the concavity and equalize the pressure. Also, when the first piers were crushed, the pressure was applied too suddenly, "and the divisions on the gauge indicating the pressure were so small as not to admit of any reliable registration of the results." A new valve exerting pressure more slowly was obtained and the testing was resumed (Street and Clarke 1896, p. 340-41).

Sub-committee members carefully recorded the compression in inches of each pier at different pressures, noting the time and special characteristics of its crushing. In addition, photographs were taken, one set showing the piers under stress and another after crushing, and drawings were made to illustrate the exact nature and location of their failure (Figures 8.1. and 8.2.). In a report to the Institute after the first series of tests, Matthew Garbutt presented tables of data and described the group's findings, stating that "the observed effects of pressure were similar in most cases, but varied in degree with the different materials." First, audible crackling noises were heard from inside the brickwork followed by the mortar squeezing out of the joints and falling off. Then cracks appeared in single bricks and small corners or pieces of the facing spalled off. As the joints became seriously compressed, large cracks along the final lines of rupture appeared just before the piers bulged outwards and collapsed. According to Garbutt, the final failure was much more sudden in piers constructed with harder bricks laid in cement. He also noted that "the vertical line of joints formed by the closers was a plane of weakness" in all the piers (Garbutt 1896, p.345).

At the end of ten months, the remaining piers were crushed and additional data was compiled which showed the expected results of considerably increased strength over the first series of tests. This was attributed partly to the quality of the mortar used as well as to the age of the pier. Garbutt commented on "the great difference between the strength of bricks and of brickwork, the enormous disproportion being due to the quality of the material interwoven with the bricks as a means of uniting and holding the mass together." He warned that if mortar was not properly prepared or the brickwork not carefully bedded, "it introduces unequal pressures in different parts of the body, and the work fails in detail until so much of the whole is destroyed that the remainder suddenly collapses." Garbutt also reported that the sub-committee would make one final experiment "upon short lengths of walls built without closers, and of a more perfect bond than can be obtained with piers 18 inches square" (Garbutt 1897, p.84). In October and November 1896 the walls were constructed, each about 6 feet high by 27 inches long and 18 inches thick. In addition to the four bricks previously tested, a wall also was built using Fletton bricks for comparison.

In January 1898 a final report outlining the results from all the experiments was presented to the Institute by members of the sub-committee. They announced their intention not to establish any fixed rules about the strength of brickwork, but suggested that "any member of the Institute may, by a study of the tables of results, form his own conclusions as to the safe limits." Nevertheless, they offered several observations based on the evidence. One was that cement mortar increased the resistance to crushing of brickwork by as much as one-half and materially aided the weaker bricks in their combined strength much more than lime mortar. Also, accepting that a safe load was equal to one-fifth of the crushing load, the committee calculated that with lime mortar Stock bricks would support 3½ tons, Gault bricks 6 tons, Flettons 6 tons, Lesicester Reds 9 tons, and Staffordshire Blues 23 tons per square foot. Similarly, with Portland cement mortar mixed one part to four, "stocks would be equal to about 8 tons, Gaults 10 tons, Flettons 11 tons, Leicester Reds 17 tons, and Staffordshire Blues 24 tons per square foot." This, according to one member, "proved" that stock bricks were unreliable "for large or lofty buildings subject to heavy loads" and were fit only for small works. One final assertion was that "under the ordinary or average conditions of practice, the form of brickwork does not appear very greatly to affect the strength", although it was admitted the workmanship in the sample piers and walls was "very much better than one would get in ordinary practice" (Street and Clarke 1898 p. 77-80).

This and other irregularities caused several members of the profession to question or criticize the validity of the experiments. William Woodward pointed out discrepancies throughout the series in the quantity and quality of sand used in the mortar, in the thickness of the joints and the character of the grouting, and inconsistencies in the quality of bricks used. Another thought the tables were misleading because they were based on indiscriminate averaging of the results. Some were calculated on averages of the first and second experiments and some on averages of the second and third. In other cases the sub-committee had decided to retest some piers "to see if better results could be got", and for these the tabulations were based on averages of two sets of results from one experiment only. Finally, the President of the Institute, George Aitchison, commented that "it seemed extraordinary that when experiments were made on brickwork in mortar, the mortar used was such that no architect would ever employ, although it was employed in the last century. No one would now think of using mortar for any work where strength was wanted that had only 2 of sand to 1 of lime." He also noted that because bricks "are never perfectly homogenous nor alike", a larger number of the same sort of bricks should have been included in the tests (Journal of the Royal Institute of British Architects 1898, p. 133-135).

The aims of the sub-committee in undertaking the brickwork experiments were never fully realised because of these anomalies and because of their unwillingness to analyse the data and present definitive conclusions. Despite this failure, the group defended the importance of the tests by pointing out that no other comparable series of experiments on brick structures had been conducted except by the American Institution of Civil Engineers. Although the results of the two sets of tests were carefully studied and compared by the group, differences between them were striking and no reliable corollaries could be drawn.

Experimentation with bricks and brickwork during the 1890's provided abundant new data to assist architectural professionals in the selection of appropriate clay building products. However, as architects became more confidant about their knowledge of the properties and expected performance of various bricks on the market, they increasingly turned their attentions towards the appearance of machine-made bricks. For a very long time the profession had demanded the qualities of strength, density and uniformity in machine-made bricks. But once these characteristics seemed to be commonly available, architects soon realised the aesthetic consequences of this preference.

Although tests had shown repeatedly that hand-made bricks were usually weaker and less reliable than machine-made products, by the 1880's and 90's there was renewed admiration for hand-made goods because of their texture and varied colours. Commenting on the debate in the pages of The Builder over which was the best brick, the journal's editor acknowledged: "The appearance of bricks is so much a matter of taste that no universal consensus of opinion is at all probable." But he went on to report: "There are architects of our acquaintance who, so far from being displeased with the roughness and irregularity of the ordinary stock, appreciate the texture resulting therefrom so highly as to prefer 'shippers' to the usual facing qualities" (The Builder 1894, p. 284). Similarly, a contributor to a meeting of the Architectural Association in 1895 stated, "to his mind the machine certainly produced an undesirably smooth face, and an absence of that 'texture' only found at present in hand-made bricks, and which was so very important" (The Builder 1895, p. 64).

Likewise, consistency in the colour of machine-made bricks was abhorred by some architects. The editor of The Building News complained about the "monotonous and depressing" treatment of brickwork in the South of England where "large blank surfaces of red brick are displayed in all their bright intensity of glaring colour" (The Building News 1889, p. 858). Speaking to the Manchester Society in 1896, J. Miller Carr declared that "uniformity of colour is bad in any material which by its nature admits of variety." Carr went on to ask, "is it not a fact that building materials have an increasing value from a decorative point of view exactly in proportion to the richness and variety of their colour?" He lamented that every step in the production of the modern machine-pressed brick ensured that it was the most uniform of manufactured building materials.

As we have seen, the texture and colour of London stock bricks was the result, first, of sanding the moulds before filling them with clay and, second, differences in the position of bricks in the kiln while burning. Persistent demand by building professionals for clay products with softer colours and more open texture undoubtedly contributed to the survival of hand-brickmaking firms in many parts of the country throughout the nineteenth and into the twentieth century. It also resulted in some machine manufacturers experimenting with new machinery to improve the quality and intensify the production of sand-faced bricks in the London brickfields. This had been the intention of the many moulding machines patented early in the century. But M. Powis Bale wrote in 1890 that "the combination of the two operations of moulding and pressing in the same machine has proved itself not by any means an easy problem to solve; consequently, many failures have occurred -- variations in size, sand flaws, and other imperfections resulting" (Bale 1890, p. 645). Thus, after the introduction of extrusion and dry clay brickmaking processes, there was little interest during the second half of the century in further developing machinery that imitated hand-moulding.

Nevertheless, numerous patents were registered as inventors from time to time attempted to overcome the difficulties of moulding soft clay by machinery. Some of these, like the machine patented in 1865 by Peter Bawden, included a procedure for "pressing sand into brick surfaces after moulding" (British Patent No. 3125, 1865). P. E. Bland's rotating mould-drum machine, patented in 1867, also specified an apparatus for sanding the outer faces of the bricks before they were pressed (British Patent No. 3220, 1867). William Johnson of the Castleton Foundry, Leeds was especially determined to perfect the mechanized sand-faced process and in 1888 he described his new machine at a meeting of the Inventors' Institute. This consisted of an ordinary pug mill and wire cutting apparatus to shape the bricks. After being cut they were rolled in sand and transferred to the press which had a circulating table containing five mould boxes with loose sides hung by hinges. After the bricks were placed into the open boxes, the loose sides slowly began to close tightly pressing the clay while a descending ram pressed the upper surfaces (The Builder 1888, p. 86; Bale 1890, p. 645). Similar methods were employed in the Norris, Berry, and Monarch machines introduced into this country from America after the turn of the century as the aesthetic interest in and demand for sand-faced products continued to grow (Noble 1953, p. 757).

As consumers of clay building products, architectural professionals were a significant group component in the network responsible for the development of brickmaking machinery during the nineteenth century in Britain. Prior to the repeal of the excise duties on bricks in 1850, the profession generally encouraged mechanization of the brickmaking industry and anticipated widespread changes in the price, quality, and appearance of bricks. They were disappointed when, after the tax was abolished, noticeable improvements were not forthcoming. This dissatisfaction prompted architects to examine more closely differences between the various hand and machine brickmaking methods and to attempt to establish professional standards for clay goods. Although experiments with bricks were haphazard throughout most of the century, the profession gradually acquired the knowledge and confidence they needed to define their needs and preferences for brick products, although over time their predilections were modified somewhat. These preferences, when translated into economic choices in the marketplace, both fostered and impeded the development of particular machine processes. For example, the architects' distrust and avoidance of dry clay process bricks stimulated serious experimentation with the alternative semi-plastic or stiff-plastic brickmaking process. Similarly, their later aversion to the harsh, uniform colours and smooth textures of machine-pressed bricks may have been an important factor in the renewal of interest in machinery suitable for manufacturing sand-faced bricks. Thus, the attitudes and desires of this very important group of consumers profoundly influenced the path of technical change within the brickmaking industry.

NOTES

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1. See, for example, the fluctuations in prices reported by the Glasgow Master Brickmakers Association between 1863 and 1900 (BPP Report on Wholesale and Retail Prices 1903, p. 290).

2. The company itself stated the bricks fetched a price of 30s. to 34s. per thousand (Engineering 1867, p. 197).

3. In a smaller house valued at only £18. per year, the total savings was £11.0s.3d. (BPP *Trades Unions Commission 1867*, p. 271).

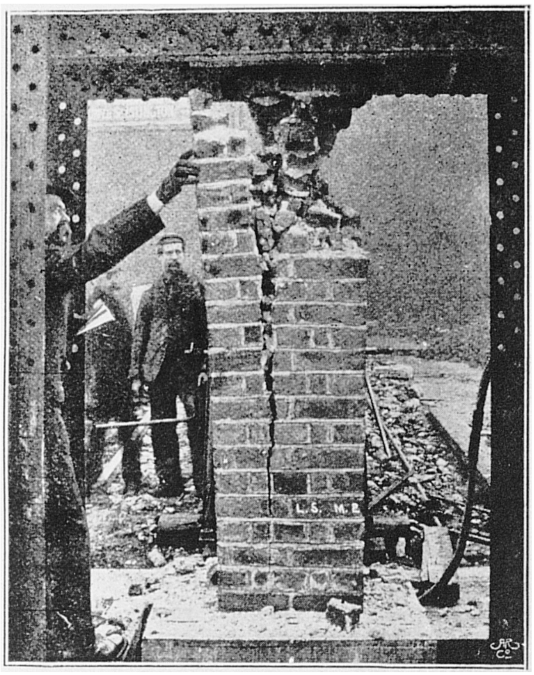
4. For the history of the testing of other building materials see Pugsley (1944, p. 492-505). This contains a good bibliography of works prior to that date. See also Smith (1981, p. 49-65).

5. It must be remembered that these experiments were conducted at the end of the lengthy Royal Commission on Trades Unions in 1867 during which were exposed the atrocities committed by the unions against machine brickmakers in the vicinity of Manchester. This and the subsequent Manchester Outrages Inquiry focused attention on the debate about the relative merits of hand- and machine-made bricks. Although the unions succeeded in forcing out of business most machine brickmakers, many architects and builders working in the area, including Alfred Waterhouse, remained favourably disposed towards machine-made bricks.

6. This was in contrast to France where a permanent laboratory to test the properties of building materials was established by the Ecole Nationale des Ponts et Chaussees in 1831. Similar laboratories were set up at the Munich Polytechnic in 1868 and in Berlin in 1875 (Butterworth 1953, p. 825).

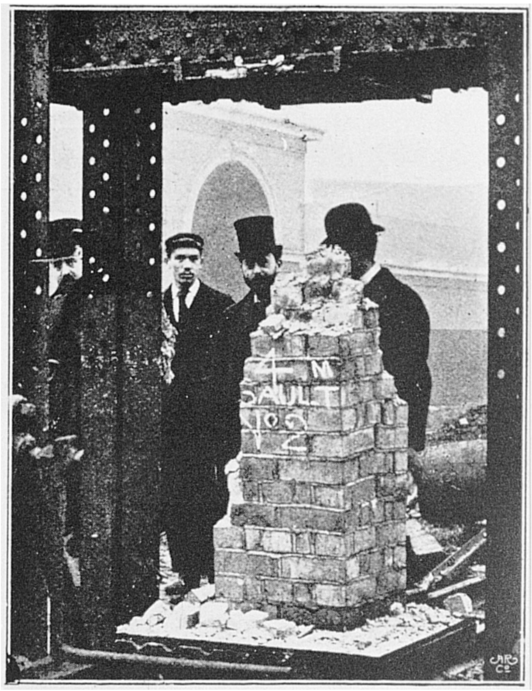
7. The Committee apparently also had difficulty gaining the approval of other architects in the RIBA. William C. Street, Hon. Secretary, reported they had "received very little sympathy from the elder members of the Institute, who appear generally to be of the opinion that the present sum of human knowledge on these and

kindred subjects is quite enough for the present and succeeding generations" (Journal of the Royal Institute of British Architects 1897, p. 17).



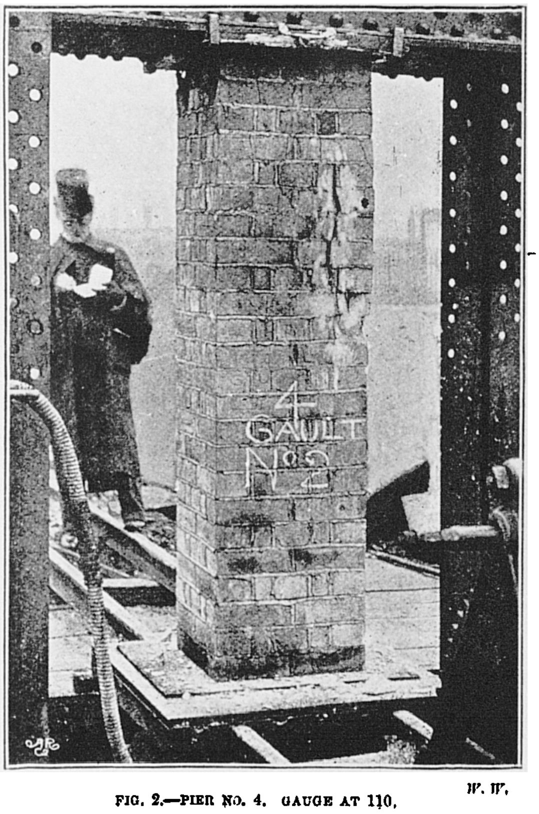
T. H. H.

FIG. 1.—PIER NO. 2, AFTER COMPRESSION.



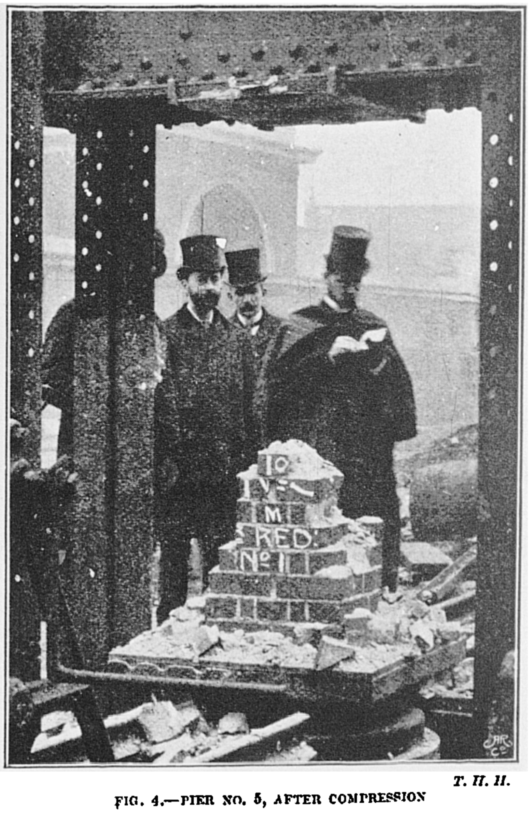
T. H. H.

FIG. 3.—PIER NO. 4, AFTER COMPRESSION.



W. W.

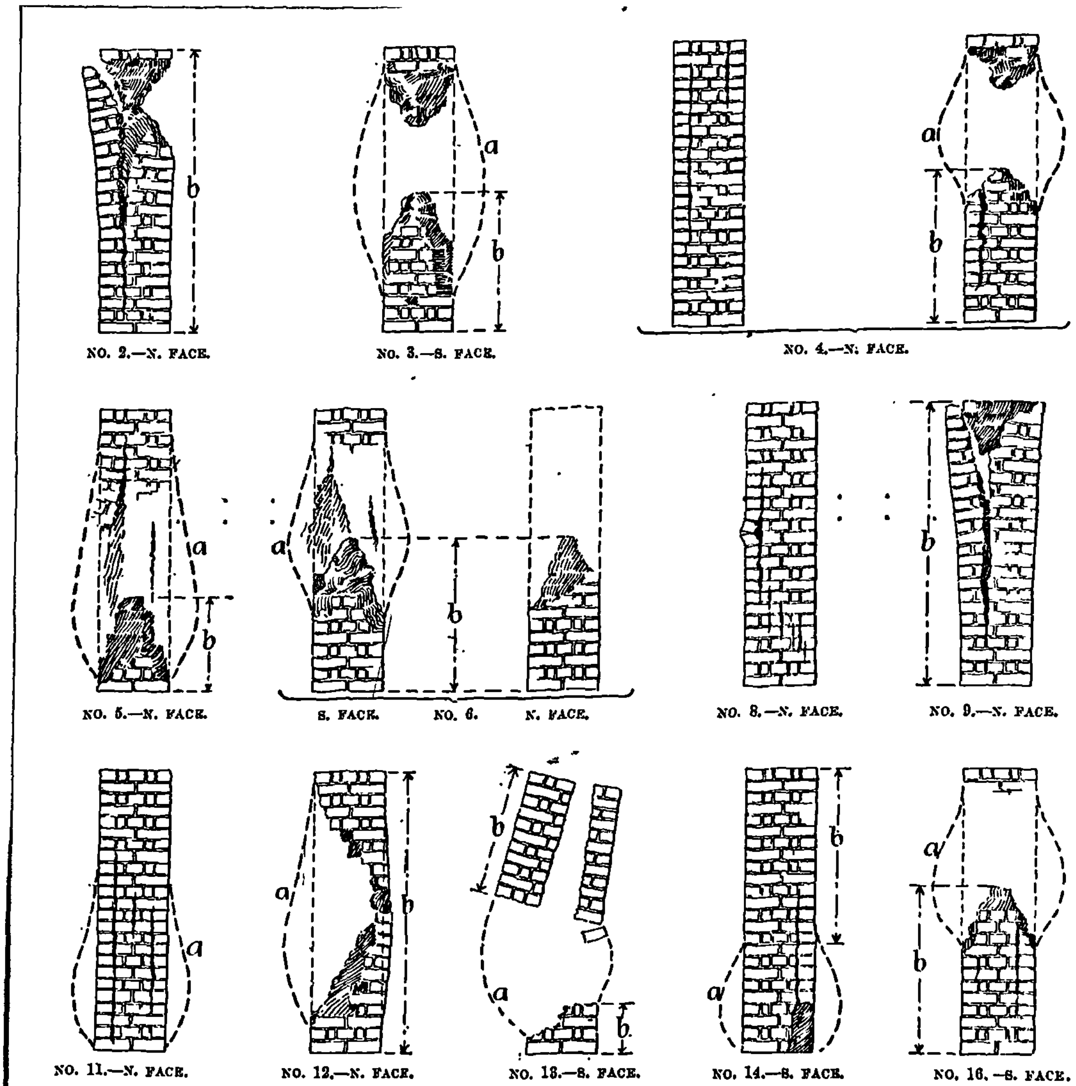
FIG. 2.—PIER NO. 4. GAUGE AT 110.



T. H. H.

FIG. 4.—PIER NO. 5, AFTER COMPRESSION

Figure 8.1. Photographs of brickwork tests conducted by the RIBA in 1896.
[From Journal of the RIBA 3rd. Ser. Vol. III, 1896, p. 335]



a . . . a, Approximate outline during final collapse. *b . . . b*, Portions which remained in shape after collapse of pier.
Approximate scale of four feet to one inch.

FIG. 13.—DIAGRAMS SHOWING WAYS IN WHICH PIERS FAILED.

Reproduced from drawings by Mr. Matt. Garbutt [*A.*].

Figure 8.2. Drawings showing the locations of brick pier failures during tests conducted by the RIBA in 1896.
[From Journal of the RIBA 3rd Ser. Vol.III, 1896, p.346]

CHAPTER NINE

HOLLOW BRICKS IN BRITISH ARCHITECTURE PRIOR TO 1850

Previous chapters have attempted to explain the complex process of technological change within the British brickmaking industry during the nineteenth century, beginning with the emergence of brickmaking machinery in the late eighteenth and early nineteenth centuries and culminating in the gradual restructuring of the industry itself and the eventual transformation of clay building products. In particular, these chapters have considered the role of architects in stimulating and influencing the development of mechanized brickmaking, although these machines were process innovations not directly consumed by the architectural profession. Machinery for making bricks and tiles generated a profusion of new products made with plastic materials. Many of these were designed specifically for the architectural market, such as cement-based artificial stones and a variety of clay decorative and constructive units. One relatively new product made more economically feasible by mechanization was the hollow brick, an innovation which persisted throughout the century in different guises intended for various applications. Because architects were primary rather than secondary consumers of these new building products they were in a position to more directly influence their development. This and the following chapters intend to show how the architectural profession profoundly affected the ultimate form and character of hollow clay building materials during the nineteenth century.[1]

9.1.

The Early History of Hollow Bricks

Nineteenth century architects were well aware of the long history of the use of hollow clay wares in building beginning with the Romans who used them for lining rubble stone walls, for constructing flues in hypocaust floors, and as voussoirs in arches (Hamilton 1958a, p.41-61). Hollow cylindrical bricks were found among the ruins of the tomb of Scipio in the Via Appia in Rome (Cummings 1860, p.360), and it was known that the ceiling of St. Stephen's, Rome was built of small clay tubes, six or seven inches long and three inches in diameter (The Builder 1849, p.183). Eck illustrated the famous dome of St. Vitale in Ravenna, from the sixth century, which was built of small terracotta tubes arranged in spiralling lines, while larger vases, 22 inches high, were inserted in the walls below (Eck 1841, plate IV).

According to Cummings, other buildings in Ravenna, including the baptistry of the cathedral and the church of St. Maria in Porto, also contained clay tubes or vases (Cummings 1960, p.360). Additional examples were excavated during the nineteenth century at Roman building sites in Britain, including the flue tiles found at Lymne in Kent (reported in The Illustrated London News in October 1850), specimens retrieved at Bath (The Builder 1852, p.71) and hollow arch tiles discovered in London near the city wall at Moorfields in 1817 (Cummings 1860, p.362; Figure 9.1.).

Almost as well publicized were the non-constructive "acoustic jars or vases" found in medieval churches throughout the country during the nineteenth century (Hills 1882, p.65-96).[2] These were hollow earthenware vases, no more than twelve inches high with openings of five or six inches, that were built into churches dating predominantly from the fifteenth century. They were placed either in the floor below the choir stalls or solidly built into walls with their openings pointing towards the nave or choir. The earliest examples found in this country were at

Fairwell Church, Staffordshire, an event that was reported in The Gentleman's Magazine in 1771 (p. 59). Subsequent discoveries were made at St. Nicholas Church, Ipswich in 1848, St. Peter-Mancroft in Norwich in 1852 and at various other locations such as Fountains Abbey, St. Olave's, Chichester and Leed's Church, Kent. There was some speculation at the time that the jars may have been used for keeping relics or as burial urns (Hills 1882, p. 81). But the theory now generally accepted is that they were for acoustic purposes, "to add resonance and amplification to speech and music", an adaptation of the bronze or clay vessels built into Greek or Roman theatres described by Vitruvius (Hills 1882, p. 88-89; Harrison 1967-68, p. 54).

Other descriptions of hollow clay constructive units appeared in nineteenth century travellers accounts. Burkhardt's Travels in Nubia, published in 1822, contained an account of earthenware jars used to construct the walls and parapets of peasants' houses in Upper Egypt (Cummings 1860, p. 359). In 1857, The Builder reviewed W. K. Loftus' Travels and Researches in Chaldea and Susiana, in which the author pointed out the decorative patterns created by embedding terracotta cones in walls of mud and chopped straw (The Builder 1857, p. 470; Hills 1882, p. 67). C. W Pasley, in his Outline of a Course of Practical Architecture, published in 1826 for the Royal Corps of Engineers, reported that hollow earthenware pots were "introduced in Calcutta within the last 20 years" to arch over "apartments of considerable width". He stated that the origin for these seems to have been Syria where they were commonly used and were called "Syrian floors or roofs" (Pasley 1826, p. 178). Another author described a similar encounter with clay wares in India. He stated: "In Bengal, the floors of bungalows are usually constructed with earthenware pots, commonly called 'kedgeree pots', turned over, with their orifices on the ground. Charcoal is filled between the interstices, and a coat of brick concrete is laid on top, thus forming a perfectly dry floor" (The Builder 1852, p. 71).

A French architect, M. de St. Fart, is usually credited with reviving the use of hollow clay pots in Europe when he constructed several experimental vaulted floors in 1785. The hexagonal pots he used, manufactured at Goblet's tile yard in the Rue Copean in Paris, measured seven inches long by four inches across. They were closed at both ends and bedded in plaster of paris within a timber framework. A committee from the Académie d'Architecture examined these floors and prepared an official report praising the experiments (Bannister 1950, p. 233; Hamilton 1958a, p. 40; and Hamilton 1958b, p. 7).[3] St. Fart's intention was to create a lighter-weight version of the incombustible brick vaulted floors that were developed earlier in 1754 by Comte Felix Francis d'Espie of Toulouse and popularized by architects in both France and England during later decades (D'Espie 1754).[4]

The theatre at the Palais-Royal, built by Victor Louis in 1790 for Louis-Philippe-Joseph, Duc de Chartres, is thought to be the first modern example of hollow pot construction after recognition of St. Fart's experiments by the Académie (Bannister 1950, p. 284; Hamilton 1958b, p. 7). It is known that a number of English architects travelled to Paris where they viewed this remarkable fireproof building.[5] By 1792, Sir John Soane used similar pots at the Bank of England to construct the shallow dome in the Bank Stock Office, the semi-circular apse in the Lothbury Court, the vault of the Old Colonial Office, and part of the great Rotunda (Steele and Yerbury 1930, p. 12; Summerson 1984, p. 138 and Pl. 56; Figure 9.2. and 9.3.). The cotton manufacturer, William Strutt, also received first-hand information about the floors at the Palais-Royal from the architect, John Walker, and Matthew Boulton. He immediately incorporated pots into a mill at Derby and a warehouse at Milford, both constructed in 1792-3 (Fitton and Wadsworth 1958, p. 201-205; Johnson and Skempton 1959-60, p. 180-189).

Other evidence suggests a somewhat earlier re-use of hollow clay building units in this country by the architect, Henry Holland (<u>The Builder</u> 1849, p. 212). Among the building accounts for Holland's Carlton House, built in 1783-5 for the Prince of Wales, are included bills for the construction of "cone" vaulting in the basement of the riding house situated just outside the garden walls.[5] Although estimates for the building were prepared in 1784, Dorothy Stroud's biography of Holland indicates that the architect was in Paris in October 1785, causing some delay in the completion of the project. This was shortly after the favourable publicity given St. Fart's experiments with hollow pots by the Académie and Holland may have seen or heard about the innovation at that time (Stroud 1966, p. 73).[7]

An alarming increase in the number of disastrous fires in large factories, warehouses, theatres and other substantial buildings encouraged leading architects to investigate new construction methods for preventing the spread of fire. In 1792, the Association of Architects, an informal organization of London practitioners, appointed a committee to consider the causes of frequent fires in the metropolis and to test or report on the various methods available for preventing them. The results were published in a pamphlet written by Henry Holland entitled Resolutions of the Associated Architects, with the Report of a Committee by them Appointed to Consider the Causes of the Frequent Fires and the Best Means of Preventing the Like in Future (1793). The three principle means of prevention recommended by the committee were David Hartley's patented iron plates, Lord Stanhope's plaster applied to ceilings and floors, and a chemical solution used to coat wooden surfaces, called "Wood's liquid". Although the committee did not conduct trials with hollow pots, they concluded "that arches of cones, or bricks, or tiles, used instead of Plates (iron) or Plaister, will answer the purpose, but they are more weighty and expensive" (Association of Architects 1793, p. 11). Nevertheless, by 1826 Pasley wrote that hollow pots or cones had "come into common use in England, but not in private buildings, as appears to be the case in France" (Pasley 1826, p. 178).

While Soane employed hollow pots at the Bank of England to lighten the weight of the Bank Stock Office dome, most other examples of their use in the early nineteenth century were for the purposes of constructing fireproof floors and ceilings. For example, at his mill in Derby, Strutt built the ceiling of the top story with hollow pot arches suspended from tie beams in the roof. All other stories contained brick arches supported on iron columns. In the warehouse at Milford, only part of the outer arches on each floor were of hollow pots to reduce the thrust on the outer walls (Skempton and Johnson 1959-60, p. 182, 189) Soane covered the basement story of the Treasury Building with shallow cone arches rising only six inches and resting on iron girders placed approximately six feet apart. Sir Robert Smirke included similar arches in some of the ceilings of the General Post Office (1823-29), although their rise was much greater, being nearly one third the span.

Another extensive application of hollow pot arches was in the rebuilding of Buckingham House by John Nash (1825-30). In addition to building many of the ceilings in the usual way, those forming parts of the building's flat roof were constructed in a double tier of arches varying from four to six foot span and springing from Bath stone skewbacks resting on the flanges of deep girders. The top row of arches was then covered with a layer of common bricks and coated with Lord Stanhope's "fireproof" composition (Pasley 1826, p. 180-81). The United Service Club also was said to have contained hollow pot flooring, although it isn't certain whether this referred to the first club house built by Smirke on Lower Regent Street in 1816-17 or to Nash's new building on the corner of Pall Mall, constructed in 1827 (Webster 1890-91, p. 265). Other well-known examples of their use included the ground floor passages in the National Gallery, built 1828-32 by William Wilkins (Liscombe 1980, Plates 103 and 104), the ceiling of the Banqueting Hall for the Fishmongers Company in 1832-34 by Henry Roberts (Curl 1983, p. 69), and the vault of the room added to the University Library at Cambridge in 1837-39 by C. R. Cockerell (Architectural Publication Society Vol. 1, p. 164).

Pasley reported that pots of two different sizes were available in England. One was approximately 8 inches high and 4½ inches wide at each end, weighing about 4¼ pounds. The smaller type was the same width but only 5¾ inches high and weighed 2⅛ pounds. Both sizes had the same shape, that is, square at one end and circular at the opposite end with a small hole like a common flower pot in the circular end (Figure 9.4.). This hole and the scoring along all of the surfaces acted as a key for the large amounts of mortar required to hold the mass together and fill the interstices (Pasley 1826, p.179). Pasley's description conforms approximately with actual samples collected from archaeological sites by the Greater London Council, although some pots found in situ at Trinity House, Tower Hill, dating from 1793-7, were only 7⅛ inches high and tapered from 4½ inches across the square end to only 3⅞ inches diameter at the circular end (MSS in the collection of the former Greater London Council). These dimensions would have made them more of a "cone" shape, one of the names by which pots were commonly known. Pasley explained that "no doubt it must have been intended that the square at the top should have been somewhat greater than the diameter at bottom, but it may not perhaps be easy to make such pots very accurately..." (Paley 1826, p.179).

The pots used by William Strutt at Derby, Milford and later at the "new mill" at Belper, were shaped much more like ordinary flower pots, suggesting that they were custom-made for this project rather than a being a standard, commonly available item. Each pot was a five inch high straight-sided cylinder, 4 to 4½ inches in diameter, with a hole in one end and a separate circular cover for the opposite end that provided a flat surface for the layer of sand upon which the brick paving was laid (Skempton and Johnson 1959-60, p.189). According to a contemporary source, the pots used in Strutt's mill were made at the Smalley Common Pottery (Figure 9.5.)[8]

These and other pots used during the period were hand-made by the same methods used to make drainage pipes or other hollow goods such as chimney pots and garden pots. Although they would not have been taxed like bricks, they were, nevertheless, very expensive. Building accounts for Strutt's mill at Belper indicate that pots for the top story arches were bought for 52s6d per thousand, compared with 19s to 21s per thousand for bricks to build ordinary arched flooring (Fitton and Wadsworth 1958, p.208).[9] This exceptional expense undoubtedly explains why in this country pots were used only in major building projects and not in smaller domestic situations.

In the early nineteenth century there were various other experiments with hollow clay building units. Several inventors patented improved clay pots and flues to enhance the efficiency of chimneys (British Patent Nos. 777, 1838; 9711, 1843; 10,915, 1845; and 11,440, 1846).[10] More importantly, during the 1830's and 40's three additional influences stimulated public interest in hollow clay products for building. These were the sanitary reform movement, the development of tile-making machinery, and changes in the excise duties on bricks. In particular, Edwin Chadwick and his circle of sanitary reformers were instrumental in publicizing and promoting the use of hollow clay products for building and in sponsoring or encouraging experiments with new building materials.

9.2.
The Sanitary Reform Movement and Machine-Made Hollow Bricks

During the nineteenth century, problems associated with overcrowding and disease in industrial towns were aggravated by outbreaks of cholera and typhus beginning in 1832 and striking at intervals over the next several decades. Edwin Chadwick's exhaustive Report on the Sanitary Conditions of the Labouring Population, published in 1842 for the Poor Law Board, revealed officially for the first time the full extent of the nation's health problems derived in part from inadequate water supplies, poor drainage, badly ventilated houses and overcrowding. This report inspired and brought together a small group of like-minded men, guided by Jeremy Bentham's political philosophy and driven by Christian conscience and evangelicalism, whose common purpose was to further investigate the prevailing conditions and to convince political leaders to adopt appropriate legal and administrative reforms. In addition to Chadwick, this group of reformers included the Drs. Southwood Smith, Arnott and Kay (Boase 1965 Vol.2, p.163; Vol.3, p.647) and politicians Lord Normanby, Viscount Morpeth, Lord Ashley (later the Earl of Shaftesbury), Earl Grey and the Duke of Norfolk. These men participated in subsequent inquiries, such as the Royal Commission on the Health of Towns in 1843, and directed governmental agencies, like the General Board of Health, established in 1848. Many also belonged to the Health of Towns Association, founded in 1844 "to diffuse among the people the valuable information elicited by recent inquiries, and the advancement of science, as to the physical and moral evils that result from the present defective sewerage, drainage, supply of water, air and light, and construction of dwelling houses" (Wohl 1984, p. 144).

Most sanitary reforms from this period were aimed at improving the external environment of towns. Recommendations included the provision of sufficient supplies of water for both domestic use and water-bourne public sewage systems, and the widening of streets and opening of courts to encourage better ventilation. These measures were based upon the prevalent "pythogenic" or effluvia theory of disease which maintained that poisonous gases, or miasma, emanating from putrifying matter contaminated the air and resulted in illness and epidemics (Southwood Smith 1830, p. 348). Belief in the effluvia theory concentrated public health reform on removing accumulated excrement and impure air from the general environment. Specific suggestions aimed at promoting healthy construction were missing altogether from early reform legislation. Deficiencies in construction which caused a dwelling to be "unfit for human habitation" were not defined or regulated until the last quarter of the nineteenth century.[11] Earlier legislation had effectively promoted unhealthy construction. For instance, the duty on windows had discouraged adequate ventilation, while the brick duties may have encouraged the use of porous, damp-retentive materials that "held water like a sponge" (The Times 26 May 1851). Building regulations, like the Metropolitan Building Act, were concerned chiefly with fire prevention or the removal of hazardous buildings instead of sanitation control.

Most early experiments in constructing sanitary dwellings were undertaken in haphazard fashion by private organizations, such as model dwelling societies, or individual reformers who built rural labourers' cottages on private estates.[12] Building experiments concentrated initially on three areas of improvement -- securing greater dryness and warmth, providing easily cleaned surfaces that would not absorb noxious gases, and removing vitiated air from crowded houses. Of these three expedients, improved ventilation was considerd most important by many reformers.

Ventilation and its relation to human health was a popular subject for scientific investigation during the second quarter of the nineteenth century and the topic of numerous publications. [13] Robert S. Burn defined ventilation, as it applied to buildings, simply as "a means for the supply of fresh air and the withdrawing of foul air" (Burns 1853, p. 1). Early experiments had shown that "the specific gravity of air vitiated by respiration or combustion (the two great processes that deteriorate air in ordinary buildings) is under ordinary circumstances less than that of common air; it gives way accordingly, and is pressed up by the pure and denser air" (Burns 1853, p. 7).

Many of the arrangements devised for ventilating public buildings before mid-century relied on complex systems of apertures and passages or flues in walls connected with an artificial heating apparatus or mechanical fans, bellows or pumps to effect a movement of air. In some cases, as in Dr. Reid's plan for the Houses of Parliament, a large furnace created a current of rising hot air that withdrew the stale air from the ceiling of the chambers and, at the same time, caused fresh air to be drawn into an underground passage from which it rose through vents in the floors of the rooms (Tomlinson 1850, p. 217-17). Other methods used fans to force in fresh air, either at the level of the floor or above head height, while vitiated air escaped through openings in a domed or coved ceiling. This was the arrangement adopted by Charles Barry at the Reform Club in 1839 (Architect's Journal 21 Feb. 1985, p. 51-52).

For smaller buildings and dwellings, it was more economical to use natural air currents. Apertures or ducts inserted in chimneys, roofs or behind cornices enabled foul air to be removed, while valves or passages placed near the floor allowed fresh air to enter the rooms (Burns 1853, p.10). Many of the building experiments by sanitary reformers were undertaken to demonstrate the value of these cheap and simple but effective methods of ventilation, and to encourage their adoption by ordinary architects and builders. According to one expert giving evidence before a Parliamentary Committee: "Heating and ventilation, especially the latter, seldom enter into the mind of the builder when he projects his building; he begins as if he did not know that ventilation could be necessary; he trusts to the doors and windows, to neither of which belongs the business of ventilation" (Tomlinson 1850, p.218).

Many ventilating systems, even those intended for modest dwellings, utilized hollow clay tubes as flues in walls or under floors. Tomlinson reported on an early invention by Benford Deacon for ventilating and heating rooms with hot water (British Patent No. 3664, 1813). It was described as follows: "The air was drawn from an underground tunnel or cellar by means of a fan, which forced it into the rooms through small iron or earthenware tubes placed in boiling water. The vitiated air was conducted into a tube or channel at the ceiling and conveyed above the roof..." (Tomlinson 1850, p.237). Deacon's patent covered a method for making the tubical bricks by hand as well as their arrangement in the building (Figure 9.6). Apparently, the system was not widely applied in this country.[14] In another example, John Burridge of Blackfriars Road, London obtained a patent in 1825 for "improvements in bricks, stones, or other materials, for the better ventilation of houses and other buildings" (British Patent No. 5184, 1825). Bricks of the usual shape and size were provided with a lengthwise hollow core by fixing a piece of wood or metal in the brick moulds at the time of manufacture. Their purpose was to conduct air around the ends of timber beams to prevent dry rot or decay.

The sanitary reformers also were concerned about the harmful effects of damp in dwellings constructed with poor quality, absorbent building materials. Soft, porous bricks not only admitted and retained moisture, but also, according to the effluvia theory, absorbed noxious gases produced by the contaminated environment. Dampness as such was not considerd a "nuisance" under the public health legislation. Nevertheless, Chadwick and his circle were keenly aware of the need to discover new materials or techniques that would be impervious to damp and easily cleaned. At various times he and other sanitary reformers intiated or supported experiments with glazed bricks, concrete panels, and cavity wall construction for this purpose (Gauldie 1974, p. 134). But Chadwick particularly championed the cause of hollow pots and tubes which increasingly were appreciated for their insulating value in building as well as their utility in ventilating systems and fireproof floors.

Chadwick's personal interest and knowledge of hollow clay wares originated in his advocacy of earthenware pipes for town sewers. During his association with the Metropolitan Commission of Sewers, he was well informed of the latest methods for manufacturing drainage tiles and pipes (Lewis 1952, p. 294-296). Hand made earthenware "pitcher pipes" or "pot-pipes" were used in several locations around the country for the conveyance of water as early as the 1820's. By 1842 John Roe, engineer for the Holborn and Finsbury district of London, demonstrated that efficient sewers and drains could be constructed with stoneware socket pipes which he had made at the Lambeth potteries (The Builder 1860, p. 428-9). The expense of hand-made clay pipes, however, was prohibitive for large scale sewer applications, and often they were made of poor quality materials with irregular joints. Rapid advances in the development of tile and pipemaking machines during the 1840's, aimed initially at the agricultural market, greatly improved the accuracy and strength of hollow clay wares. Prices also dropped considerably because of mechanization, and on the basis of reduced cost and presumed increased efficiency, Chadwick placed his authority and that of the Board of Health behind pipe sewers. He supported mechanization of the potteries and encouraged them to raise the quality of products used in town drainage schemes. By mid-century Chadwick estimated that approximately fifty miles of glazed earthenware pipes were being manufactured in the country each week (Lewis 1952, p. 296).

Considering the high cost of hand-made hollow pots for fireproof flooring in public buildings, it is reasonable to expect that some inventors began to apply mechanized methods to the production of these specialized clay products in an attempt to lower prices. Extensive publicity in the 1830's was given to James Frost's invention for a method of constructing flat roofs and fireproof floors of a maximum width of ten feet with two courses of square earthenware tubes laid at right angles to each other and covered with a coat of cement stucco (British Patent No. 4710, 1822). Pasley reported that the tubes were "2½ inches square externally, and made by a machine in lengths of 10 feet, but cut previously to being baked into pieces only 1 foot long" (Pasley 1838, p. 164). Loudon also mentioned that they were "pressed through moulds by machinery", but he described them as only "an inch and a half on the side externally, with a tubular space of an inch and a quarter on the side internally" and about two feet long (Loudon 1839, p. 865). Frost's patent specified his method of construction, but did not give details about the tubes themselves or their manufacture.[15] Apparently, the system was used to construct floors in Frost's own house at No. 6 Bankside, London where they could be seen by interested parties. According to Pasley, floors and roofs constructed in this way were considered stronger than ordinary flat tile roofs because of the tubular shape of the bricks (Pasley 1838, p. 164).

Even more sophisticated machine-made hollow clay products were registered on the Continent, but most were not immediately available in this country. In 1841 Thunderer and Stellewerk of Vienna patented large hollow bricks with two or four longitudinal perforations and alternating projections and indentations along their sides which allowed the bricks to fit securely together in vaultings. They were "manufactured in a machine which would submit the clay to strong pressure, giving it greater density and tenacity" (The Building News 1858, p. 317; Figure 9.7). The following year a French patent was granted to a M. Collas "for the manufacture of cylinders, solid or hollow, mouldings, etc., with all sorts of plastic materials, ceramic and others, by the mechanical means of a press" (The Building News 1858, p. 318). Collas registered two types of special bricks with his patent, one for filling in between the girders of floorings, and another for constructing partition walls (Figure 9.8.).[16]

In this country Robert Beart of Godmanchester invented a unique mechanical process for manufacturing bricks with multiple vertical perforations. In his patent of 1845 he described a method for "making a hollow brick by forcing earth through a moulding orifice having a series of cores to form holes in the brick, the object being to obtain a lighter brick and one that will burn better" (British Patent No. 10636, 1845). Ten years before, Beart had patented a small extrusion machine for tilemaking which he adapted and used to manufacture his new bricks. Whereas in other early patents, hollow bricks were moulded into complicated shapes and special sizes to correspond with each new construction system, Beart's perforated bricks were identical to common bricks except for the holes. At his works near Arlesey along the Great Northern Line, Beart commenced production of his bricks which he claimed were easily integrated into ordinary building schemes. One contemporary source commended Beart's new brick: "It affords the maximum of resistance to vertical pressure or crushing force, and at the same time gives a vertical bond which makes the construction more solid and saves the necessity of making two classes of goods--headers and stretchers" (The Building News 1858, p. 317). The inventor also patented specially-shaped bricks with horizontal perforations which were used for window and door mouldings or for walls needing longitudinal air-ducts.

The primary aim of Beart's patent was to reduce the weight of his bricks, which were made with the somewhat heavy gault clay in Bedfordshire, and incidentally to reduce costs by shortening the drying and firing time. In addition, like other patented clay products with cavities, the perforations in Beart's bricks also provided a degree of insulation when they were used for external walling. Chadwick and others undoubtedly were aware of these developments which occurred at the same time as improvements in pipe and tile manufacture. However, because the inventions were covered by patent protection, giving patent owners exclusive rights to manufacture and sell their products, they were not entirely suitable for the requirements of building reformers who needed very inexpensive and easily obtainable materials to construct low-cost sanitary dwellings throughout the country.

The solution to this problem ultimately came from within the reform group itself. John Elliott, an architect from Southampton and Chichester, claimed to have had the idea of using ordinary machine-made clay drainage pipes for constructing the walls of farm cottages as early as 1842 when tilemaking machines were first introduced on a wide scale. The idea apparently was neglected until 1846 or 1847 when he borrowed a hand-operated machine from a local manufacturer, Bullock Webster of Houndsdown. Webster had gained experience with machinery of this type by assisting another inventor, Frederick Etheridge of Southampton, with the development of his patented pug mill extrusion machine in 1842. While serving as architect for the Duke of Richmond, a strong supporter of sanitary reform, Elliot used the machine to manufacture ordinary clay tubes, seven inches square by twenty inches long, and erected the walls and roofs of labourers' cottages on the Duke's estate. Although these first experimental cottages were not successful, the architect was convinced of the importance of his idea and presented revised plans and specimens of the tubes to Lord Robert Clinton, who passed them on to the Royal Agricultural Society of Ireland. He also sent samples to the office of Edwin Chadwick (The Builder 1949, p. 199-200; Colvin 1954, p. 191).

On one occasion, Chadwick himself claimed to have invented the idea, declaring in 1867: "The first machine-made hollow bricks ever made as far as I am aware were made at my instance by my friend, Lord Fortescue, with his tile machine and used in 1847 for the construction of some of his new cottages" (Chadwick 1867/68, p. 266).[17] He stated also that Lord Ashley had used hollow bricks at about the same time for similar constructions on his estate. The original source for this very practical idea may never be ascertained, but it is certain that details of experiments such as these would have circulated quickly amongst the members of organizations like the Metropolitan Health of Towns Association. Also, many of the aristocratic landowners concerned with reform issues probably purchased pipe machinery sometime during the 1840's for large-scale land drainage schemes. By 1847, trade literature for The Ainslie Brick and Tile Machine Company boasted that the firm manufactured "the only machines by which the hollow brick, so highly approved for building and horticultural purposes, can be made" (Royal Agricultural Society of England 1847).

Another member of the Health of Towns Association to experiment with hollow bricks was Earl Grey. An ordinary pipe-tile machine manufactured the simple rectangular hollow tubes, 12 inches long, approximately 6½ inches by 5 inches in section, and slightly wedged shape, used to construct the arched roofs over cattle sheds on the Earl's estate at Howick in Northumberland sometime prior to 1850 (The Builder 1850, p. 53; Journal of the Royal Agricultural Society 1854, pp. 181-184). This method of construction was chosen mainly for its light weight , but it also demonstrated the savings made possible by using hollow materials which reduced the thickness of the walls needed to support them. The arches had a rise of 8 feet 6 inches and their outward thrust was contained by tie-rods secured to both stone and cast iron springers placed from 6 to 10 feet apart. The bricks were set in lime mortar and required a coating of cement or paint to make them water tight. The cost, as published in a contemporary journal, was significantly less than traditional construction. The total cost of the hollow brick roofs was £56. 17s. compared with £78. 14s. for a roof of timber and slates (The Builder 1854, p. 158; Figure 9. 9.).

Joseph Gwilt reported that hollow pipe tiles also were employed (presumably for fireproof floors) as early as 1846-7 in the experimental model lodging houses in George Street, St. Giles, built for the Society for Improving the Condition of the Labouring Classes by Henry Roberts, an architect member of the SICLC

Dwellings Committee and later the group's Honarary Architect. Gwilt's account stated that the materials used in the dwellings were the "patent bonded hollow bricks or rebated tiles" manufactured by Hertslet and Co. (Gwilt 1867, p. 554). Lewis Hertslet was Chief Clerk of the Metropolitan Sewers Commission but, according to R. A. Lewis, he became impatient with delays and disagreements within the Commission and resigned in 1949. Chadwick later alleged that Hertslet then went into business manufacturing hollow bricks to supply some of the projects initiated by the Commission, such as the Phillips Tunnel (Lewis 1952, p. 230). If Gwilt's assertion is correct, Hertslet may have been involved in this business several years earlier.

Edwin Chadwick indirectly influenced another important experiment with hollow brick construction prior to mid-century, that of the great arched ceiling over St. George's Hall, Liverpool, completed in 1849 by Robert Rawlinson. Harvey Lonsdale Elmes designed the building after winning a competition in 1839. Work began in 1842, but the architect's health began to decline, and he eventually went abroad where he died in 1847 (Colvin 1954, p. 191). Rawlinson was left to complete the main structure of the hall and its vaulted ceiling, 169 feet long with a span of 65 feet. A bill of quantities made out by Elmes early in the project had specified solid brickwork for the arch, but subsequent plans to ventilate the room by Dr. Reid necessitated an additional 400 square feet of open space in the design. After Elmes' departure, Rawlinson worked out a solution to the problem, but on a visit to the steward's office at Castle Howard he saw some newly-made drainage pipes which reminded him of a previous encounter with hollow goods in Chadwick's London headquarters.[18] Rawlinson returned to Liverpool and found a local machine maker, Thomas Scragg of Tarporley, who was willing to make some experimental clay tiles, four by four inches square and twelve inches long with a two inch circular longitudinal cavity. After conducting simple load tests on the bricks, he obtained permission from the building committee and Dr. Reid to commence building. According to a report sent to the committee, only 100,682 hollow tiles were required to complete the arch compared with 163,973 ordinary bricks as previously specified. A comparison of the total weight of each of the materials indicated a savings of over 166 tons in favour of the tiles (The Builder 1849, p. 184).

The Builder published detailed descriptions of the construction of the arch with accompanying illustrations extending over three successive issues. The significance of Rawlinson's achievement was acknowledged and the potential utility of hollow bricks recognized by the editor when he wrote: "Many doubts have been thrown upon the practicability of turning this ceiling, by architects and builders; but its completion will be a full answer to all objections. Ceilings and arches have been turned with pottery-ware and tiles by the Romans, Italians and French, but not of this magnitude and character. The successful completion of this arch will give an impetus to hollow brick and tile constructions, as the tile-making machines offer great facilities for their manufacture; and for all purposes where combined strength and lightness are required -- as in ceilings, vaults, fireproof flues-- the advantages are great. They will also be used for purposes of ventilation, for partition walls, and for lining external walls to prevent the admission of damp" (The Builder 1849, p. 153).

Experimentation with hollow brick construction was further stimulated by another significant development prior to mid-century. In 1839 modifications to the excise duties on bricks lifted the strict regulations governing form and size. Whereas previously a brick was restricted to precisely 10 inches by 5 inches by 3 inches, changes in the law set the maximum size for a single taxable brick at 150 cubic inches regardless of shape (Dobson Part 2 1850, p. 83). This meant that over-sized hollow bricks no longer were taxed with double duty so long as they displaced only up to 150 cubic inches of water. Finally, in 1850 the excise duties on bricks were repealed altogether, thereby removing a major obstacle to the manufacture and use of hollow clay constructive units.

The relaxation and eventual removal of the tax inspired many inventors to devise a proliferation of unusually shaped new bricks suitable for sanitary construction. One of the most widely publicized new products dating from just prior to the repeal of the duties was the ventilating brick invented by Messrs. Beedle and Rogers of Wokingham, Berkshire. Each "H"-shaped brick was nine inches square by three inches thick with a semi-circular indentation at both ends and a small depression in each arm of the "H", possibly to provide a key for the mortar. When connected in a wall, the circular spaces left by the junction of two bricks created flues for the passage of fresh air or heat upwards through the building (The Practical Mechanic's Journal 1849, p. 142; The Builder 1849, p. 359; Figure 9.10). However, the primary advantage of the bricks may have been their economy. According to Dobson: "From their peculair form, these bricks only contain the same quantity of clay, viz., 150 cubic inches, and are thus only liable to single duty whilst they occupy double the space of common bricks (Dobson Part 1 1850, p. 34).[13]

An anonymous contributor to The Builder in March 1850 wrote: "Seeing we shall have the brick duty speedily taken off, and that we shall have no hindrance to the form, size or pattern of bricks or tiles for building purposes, I send a sketch of a tile I have used for some time for partitions (and as a substitute for battening walls) with great success. They are light, cheaper than lath and plaster, besides preventing sound, and when built with good sand mortar or cement are as solid as brick" (The Builder 1850, p. 152). The illustration showed bricks in the shape of an inverted "U" , 3 inches square by 12 inches long and ⅝ inch thick with a slight hump in the centre of the closed end. They were stacked one upon the other with the open end downwards. Apparently the bricks were never patented. Another new alternative was the "peculiar form of brick, to be used for the prevention of damp walls and for heating and ventilating purposes", patented by William Percy (British Patent No. 11,236, 1846). These were the size and shape of ordinary bricks, but each stretcher was moulded with a single groove along its length and a semi-circular indentation at each end while headers had two grooves running crosswise with indentations on both sides. When laid in courses, the grooves connected and formed channels circulating air both horizontally and vertically within the walls.

During the second quarter of the nineteenth century a heightened awareness of the need for sanitary reform in building and concurrent advances in mechanized clayworking methods converged in the 1840's to produce a period of intense investigation and experimentation with newly-developed hollow clay building products. These products appeared to offer solutions to some of the most severe constructional deficiencies. The relaxation and eventual repeal of the excise duties on bricks provided additional impetus to this endeavor. By 1850 some members of the architectural profession confidently endorsed hollow building products and recommended them for a wide range of constructive purposes. In 1849, Robert Rawlinson wrote enthusiastically that "hollow bricks can be made subservient to improved construction; they may be worked and combined with stone, brick, iron , and timber; they may be made to serve in numerous instances all the purposes of solid material, with advantages peculiarly their own." But the architect went on to say: "I do not contemplate a superceding with hollow bricks all practised forms and modes of construction, but an adaptation where reason can clearly demonstrate an advantage" (The Builder 1849, p. 185). Only the widespread use of these new products in subsequent decades would confirm these advantages.

NOTES

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1. Butterworth and Foster pointed out that in Britain the word "brick" is currently used specifically to describe a building unit sized 9 inches by 4½ inches by 3 inches. Units of larger sizes and different shapes are referred to as "blocks" (Butterworth and Foster 1956, p.460). Many of the hollow clay constructive units used in the nineteenth century were larger than ordinary bricks and many were of unusual shapes. For the purposes of this and the following chapters, the word "brick" will be applied to all these units.

2. For a summary of literature relating to acoustic jars see Harrison (1967-68 p.49-58).

3. This was included subsequently in Eck's Traité de Construction en Poterie et Fer (1841, p.3-6).

4. For a history of the "folk" construction that inspired this work and for d'Espie's contribution to its development, see Bannister (1968, p.163-175). Following the translation of d'Espie's book into English by Louis Dutens in 1756, the first William Beckford used brick vaults in rebuilding his country house, Fonthill, in Wiltshire. For a review of the English translation of d'Espie's book, see The Gentleman's Magazine (1756, p.139-40).

5. One of these was George Saunders, a London architect, who was particularly concerned about fireproof construction because of his interest in theatre architecture. He published A Treatise on Theatres in 1790 (Colvin 1978, p.719).

6. According to Dorothy Stroud, these were built by Henry Wood of Sloane Square, and the bills were still unpaid in 1794 when there was an inquiry into the Prince's debts (Stroud 1966, p.71).

7. Stroud also points out that Holland's chief assistant and his Clerk of Works during the project were French. Other unsubstantiated accounts of the early use of hollow pots for vaulting appear in an unpublished report in the files of the former Greater London Council. These include specimens discovered by

demolition contractors and builders at a house in Beckenham Place, said to date from 1773, and in the vaults at Trinity House, Tower Hill, built by Samuel Wyatt between 1793 and 1797. This reference courtesy of John Fidler.

8. The pamphlet published by the Association of Architects in 1793 stated that a local source in London was a Mr. Morris at Child's Hill, presumably a tilery.

9. A total of 35,609 were used costing £93.9s.5 1/2d.

10. See Fletcher (1968) for a discussion of improvements in chimney pots and stacks during the period.

11. See Gauldie (1974, p.138 and 254) for definitions of the phrase in later reports and commissions.

12. For a comprehensive history of sanitary housing experiments during the nineteenth century and the role of philanthropic organizations see J.N. Tarn (1971 and 1973). See also Gaskell (1986) for a discussion of model housing.

13. See, for example, Reid (1844); Tomlinson (1850); and Tredgold (1836)

14. The Dictionary of the Architectural Publication Society, (Vol.2, p.67) reported that Denton's(sp.) invention "was lost until it appeared in France as a novelty". In a treatise published by Packh at Pesth in 1831, New Mode of Constructions with Hollow Bricks, Etc., it was stated that the bricks were made in France for a number of years, and employed in the construction of the harbour at Toulon," where they were seen by Prince Metternick in 1825, who sent specimens to the Vienna Institute."

15. Machinery capable of extruding hollow tubes was patented as early as 1810 by Johann Deyerlein (British Patent No.3319), further developed by Joseph Hamilton in 1813 (British Patent No.3685), and again by William Bush and Robert Harvey in 1817 (British Patent No.4183; See Chapter Five).

16. The Building News (1858, p.317) described similarly shaped hand-made bricks patented earlier in Austria by a Lieut.-Colonel Fischer of Schaffhausen, Switzerland. They were manufactured by pushing a metal mandrel through the clay in the

moulds, but it was thought the resulting bricks lacked strength because their cavities were so large.

17. Fortescue served as Parliamentary Secretary of the Poor Law Board from 1847-51.

18. Rawlinson shared Chadwick's interest in sanitation and worked as an inspector under the Public Health Act in 1848, was head of a sanitary commission sent to the Crimea in 1855, and chairman of a Royal Commission on the pollution of rivers in 1865 (Boase 1965 , p. 451).

19. Bricks of this design were discovered in 1981 by Mr. A. Wright in an extension to a cottage (now demolished) at Cricket Hill, Yateley, near Wokingham. Upon inspection, Mr. Wright noted: "The systematic demolition had revealed a structure with many elements of economic construction and evidence of second hand materials..." A single wall in the two-story extension to the cottage was constructed with the unique bricks. My thanks to Mr. Wright for this information.

Figure 9.1. Roman hollow tiles excavated at Bath during the nineteenth century.
[Photograph by author]

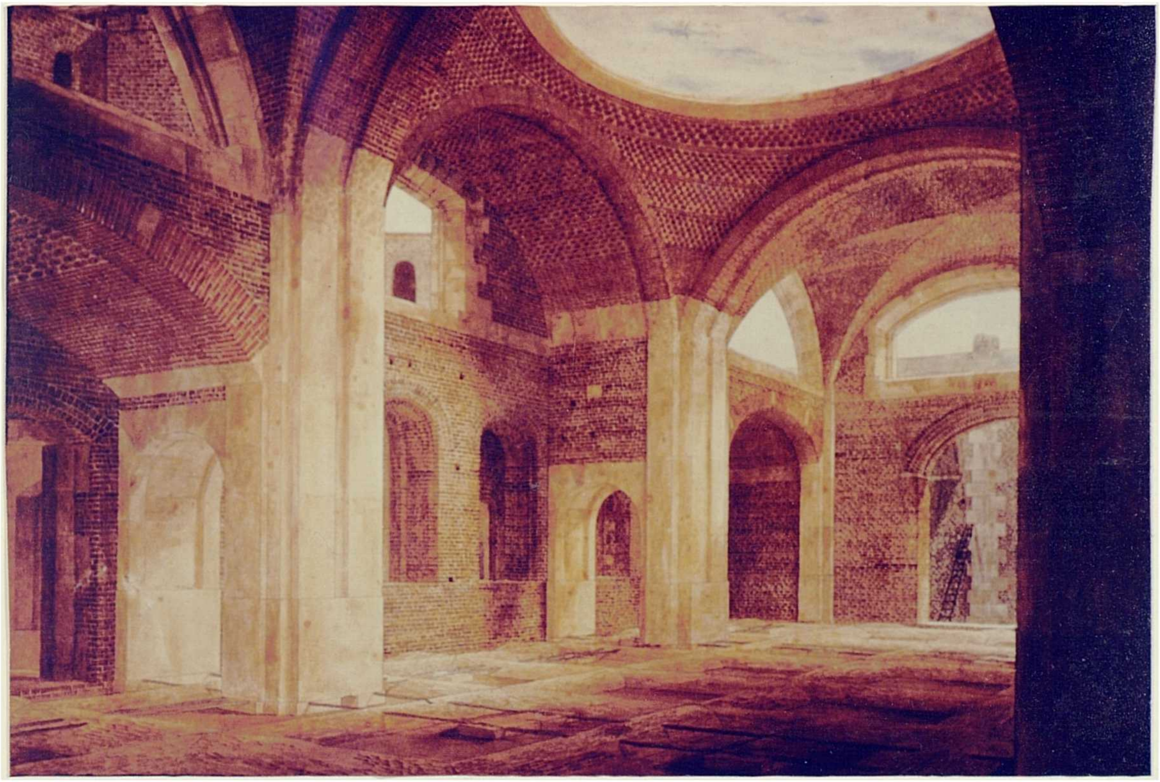


Figure 9.2. The Bank of England by John Soane; the Consol's Office before plastering, progress drawing by J. Gandy, 1799.
[From John Summerson, John Soane (1983) p.72]

Figure 9.3. The Bank of England by John Soane; vault of the Old Colonial or Five Per Cent Office, 1818, showing construction with earthenware cones, progress drawing by J. Gandy.
[From John Summerson, John Soane (1983) p.69]

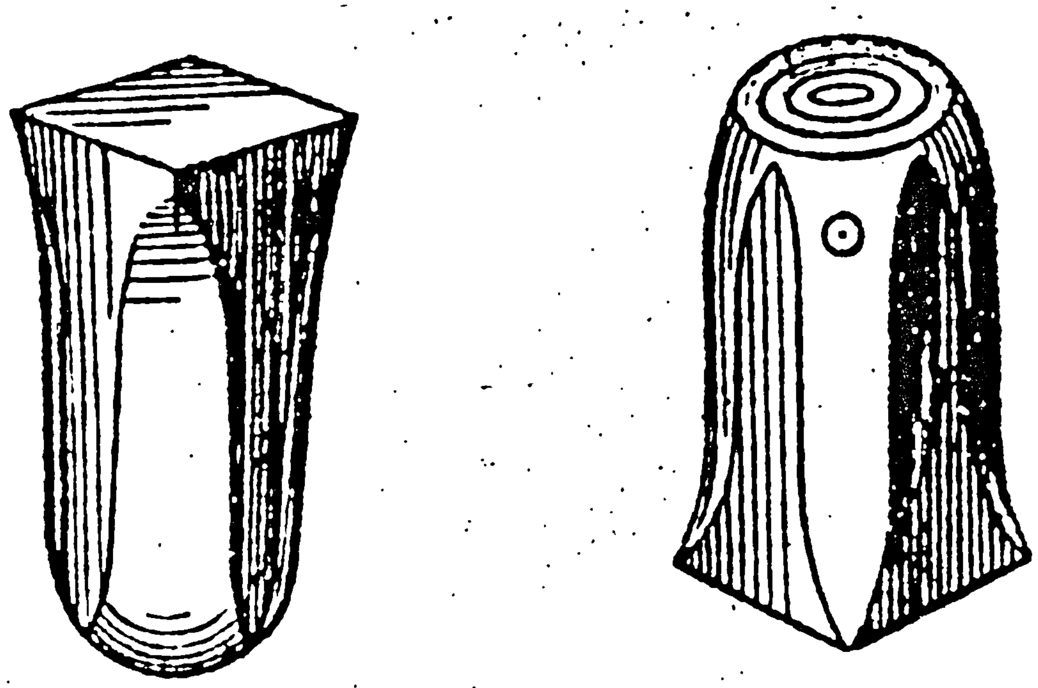
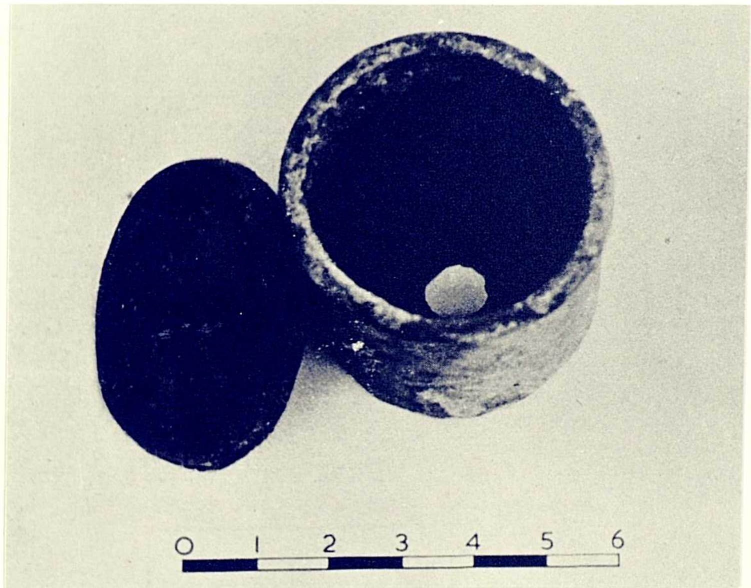


Figure 9.4. Hollow clay pots used in England for vaulting at the end of the eighteenth century.
[From S.B. Hamilton, Transactions of the British Ceramic Society (1958) p.42, after C.W. Pasley, Outline of a Course of Practical Architecture (1826) p.178]

Figure 9.5. Hollow pots used by William Strutt in a roof at Belper.
[From S.B. Hamilton, A Short History of the Structural Fire Protection of Buildings Particularly in England (1958) plate 1]



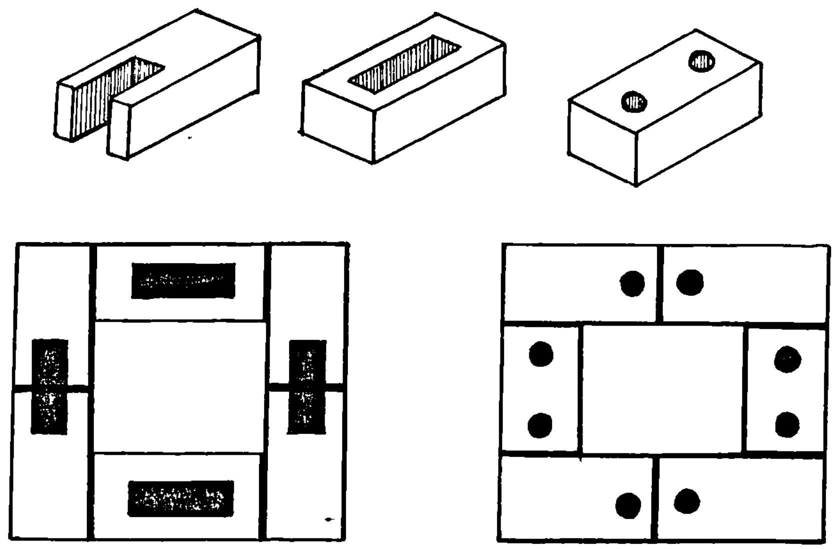
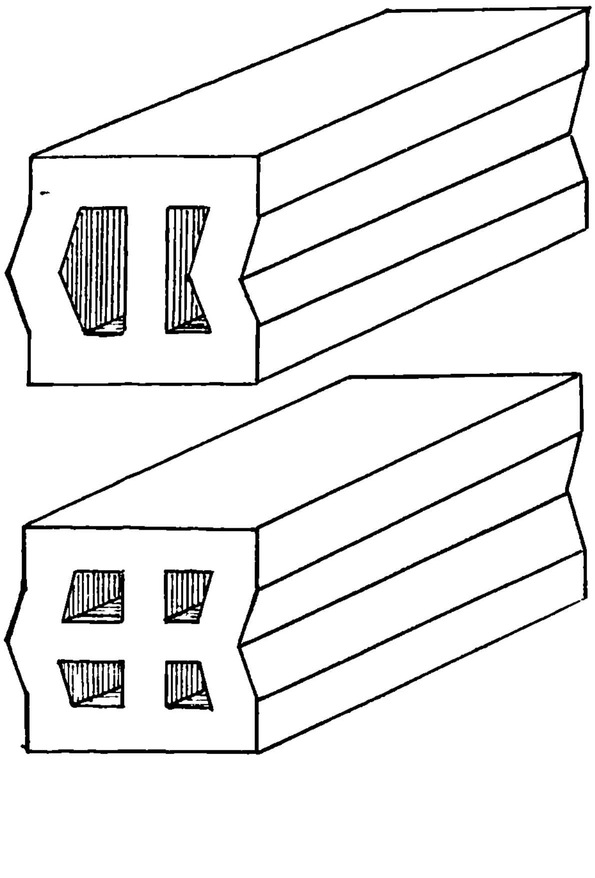


Figure 9.6. Benford Deacon's ventilating hollow bricks, British Patent No. 3664, 1813.
[Adapted from The Building News (1858) p. 317]

Figure 9.7. Hollow bricks for vaultings by Thunderer and Stellewerk of Vienna, c. 1841.
[Adapted from The Building News (1858) p. 317]



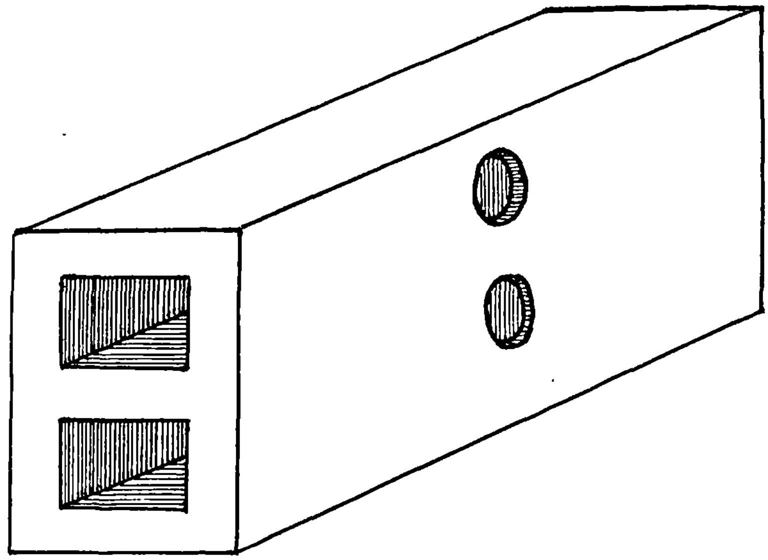


Figure 9.8. Hollow partition bricks patented in France by M. Collas, c. 1842.
[From The Building News (1858) p. 318]

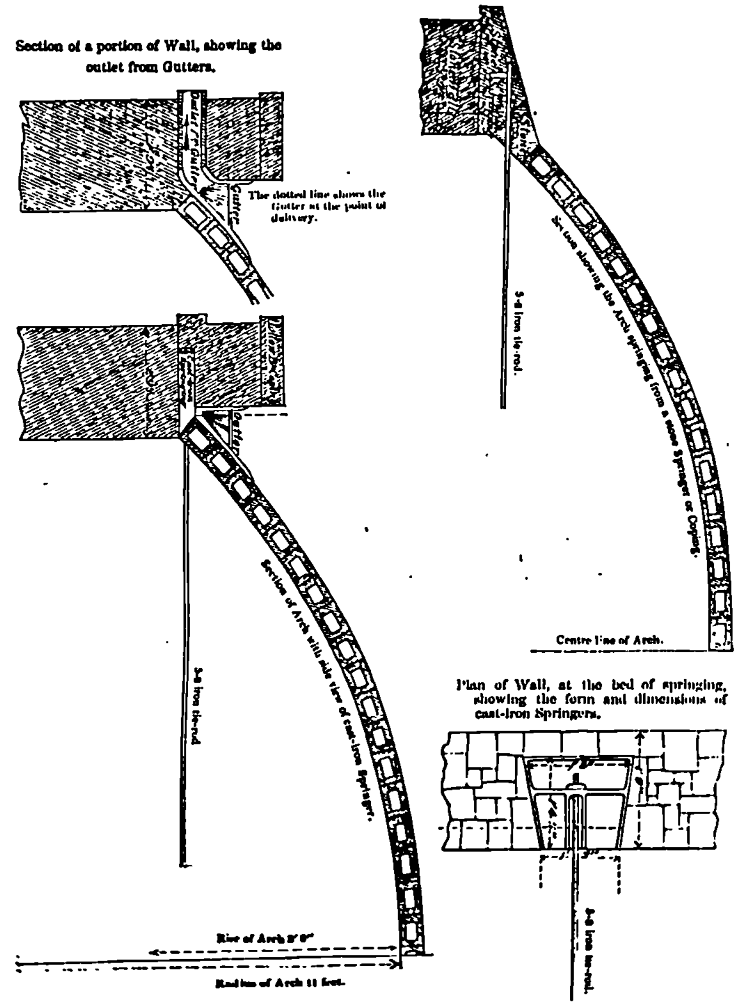


Figure 9.9. Hollow brick roof constructed on the estate of Earl Grey at Howich, c. 1850.
[From Journal of the Royal Agricultural Society of England (1854) p. 182]

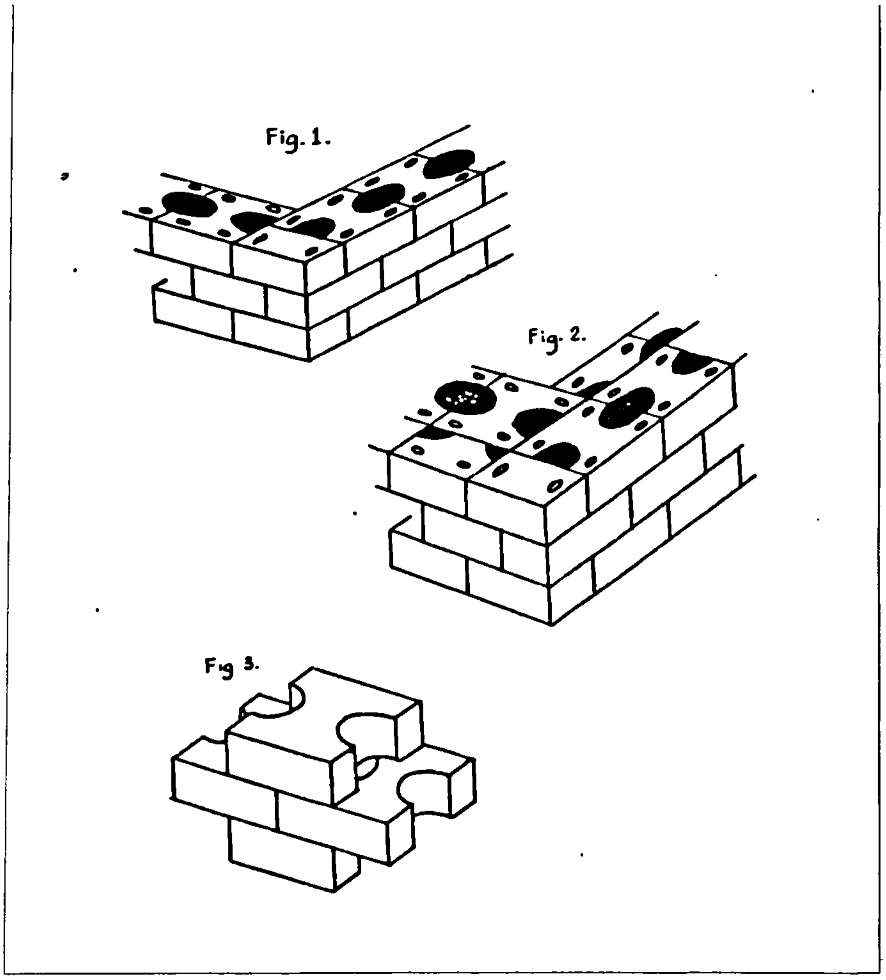


Figure 9.10. Beedle and Rogers ventilating bricks.
[From Edward Dobson, A Rudimentary Treatise on the Manufacture of Bricks and Tiles (1850) p.35]

CHAPTER TEN

THE DIFFUSION OF HOLLOW BRICKS AFTER 1850

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10. 1.
Performance Problems with Early Hollow Bricks

In an article taken from the Spectator in 1850 it was declared that "the old-fashioned rectangular brick had a number of disadvantages: its form offered but a poor hold for mortar and secured but an imperfect bond, while its porous texture rendered it liable to become waterlogged and permanently wet and heavy." According to this author hollow bricks provided a substitute with numerous advantages "hitherto unattainable" (The Builder 1851, p.518). One of the foremost supporters in this country of the use of hollow bricks for sanitary construction summarized what he believed were their foremost qualities: "They may be made cheaper than common bricks; they require much less clay. The material is finer, more compressed, and much better burned... Hollow bricks require less drying, and less fuel to burn. They are also lighter for carriage. Floors and partitions may be constructed fire-proof at the least cost of material... External works may be lined with the hollow bricks instead of being battened, so that rot will be prevented...Heat may be passed through every portion of both floors and walls (The Builder 1850, p.53). Another respected source, the Encyclopedia of Architecture, edited in 1852 by Edward Lomax and Thomas Gunyon, confidently added: "When used for houses, there is much less fear of damp than in new work as at present constructed; and an equability of temperature is ensured in the interior. Sound also is much less easily communicated by them than by common bricks" (Lomax and Gunyon 1852, p.500). This was remarkable commendation for a relatively new building product introduced less than ten years before and applied in only limited experimental situations.

Except for a handful of architects closely associated with the sanitary reform movement few professionals had acquired experience building with hollow bricks. The architectural press was sufficiently developed after mid-century to become an important source for the dissemination of information about new building materials. More importantly, during the 1850's and 60's the RIBA frequently scheduled papers and discussions on the topic of sanitary construction and provided an opportunity for members to compare experiences and observations about the new products. Like other brickmaking innovations, however, the maturation and eventual widespread acceptance of hollow bricks for ordinary construction depended to a great extent upon a crucial period of trial and user feed-back to overcome initial design and production difficulties. One major obstacle to the manufacture and use of hollow bricks, the excise duties, had been lifted. But early performance difficulties, problems with availability, high prices, and incompatibility with accepted building practices created a great deal of uncertainty about the use of hollow bricks amongst many architectural professionals. This uncertainty was perhaps the greatest obstacle of all to the diffusion of hollow clay products.

One of the first difficulties architects and builders had to contend with when attempting to use early hollow bricks was the lack of uniform quality in products found on the market. Two principle advantages claimed for hollow bricks were their strength and their ability to repel moisture. The material used to manufacture these products was presumably more finely textured than for ordinary bricks. Also, in the process of being extruded through machinery, they were supposedly subjected to greater pressure than hand-moulded bricks. Because they were perforated, it also was claimed that hollow bricks were more thoroughly dried and burnt than solid bricks having formed a "fire-skin" inside and out that added to their impermeability" (The Builder 1850, p.53).

Unfortunately, not all manufacturers bothered with special clay mixtures, nor were all extrusion machines equally reliable in producing consistently high quality products. Hollow bricks "of an inferior and exceedingly spongy character which did not keep out the wet" frequently appeared on the market in the vicinity of London after mid-century and, according to Edwin Chadwick, "impaired or frustrated" attempts to use them (Roberts 1861-62, p. 106). To avoid building failures, Chadwick advised architects to buy only goods which had been burned at a high temperature or to use glazed hollow bricks instead. But The Builder observed in 1851 that "at present, at least, such bricks must be made not by the common brickmaker, but by the potter", thus adding considerably to the cost of construction (The Builder 1851, p. 206).

Chadwick realized that consistently poor quality hollow clay goods would jeopardize the widespread adoption of these potentially useful products, whether they were intended for sewers or for buildings. His concern over this problem led him to conduct tests personally on a machine invented by Bennett A. Burton of Southwark in 1849 (British Patent No. 12,645, 1845; The Builder 1849, p. 183; Chadwick 1867/68, p. 276). Burton's invention claimed to increase the density of pipes and hollow bricks by subjecting them to additional pressure "whilst the clay was only so partially dried as not to have entirely lost its plasticity". According to Chadwick "this second pressure corrected the twist given to the pipes in drying, and produced very complete accuracy of form, and increased very considerably the strength and impermeability of the stoneware" (Chadwick 1867/68, p. 267). The extra process purportedly made the pipes or bricks "75% stronger than pipes manufactured in the ordinary way" (The Builder 1850, p. 9). Although it was said that Burton had an establishment in London to manufacture the machines, and they received extensive publicity (presumably because of Chadwick's support), there is no evidence that they were widely distributed.

Robert Rawlinson suggested another solution to the problem. He proposed strengthening hollow tubes or bricks with short ribs projecting from the inside corners which held small dowels running parallel to and supporting the fragile sides of the bricks (Figure 10.1.; The Builder 1850, p. 53). Rawlinson did not patent his invention and the idea was taken up later by others such as W. Pidding who patented cellular bricks with "internal stays or ribs

(British Patent No. 2950, 1866).

In a discussion at the RIBA after a reading of Henry Robert's paper, "On the Essentials of a Healthy Dwelling, Etc", Chadwick acknowledged a related problem associated with hollow brick construction, that is, glazed or overly hard-burnt bricks would not adhere to mortar. This was a deficiency frequently attributed to machine- pressed bricks during the 1840's. It was a complaint reiterated by various authors well into the 1860's, such as Joseph Gwilt who wrote in his Encyclopedia: "A defect in the solidity of work arises from the use of many of the hollow, perforated and machine made bricks in that their surfaces are so hard as to prevent the mortar sticking, unless they be first coated with sand. Many walls on being pulled down have shown that the mortar had had no hold upon the bricks, a key had been formed between two bricks by the holes at their end, but no proper adhesion had taken place" (Gwilt 1867, p. 553). Chadwick's public response to this dilemma was to advise practitioners to use cement rather than ordinary mortar, an expedient which most architects acknowledged added to the cost of a building project (Roberts 1861/62, p. 105).

An equally serious and apparently frequently encountered problem with early patented hollow brick systems was the lack of adequate bonding of the courses. Many claims for the economy of these systems were based upon the fact that they eliminated headers which allowed thinner walls to be built. Two consequences resulted from this attempted savings. One was that the structure was weakened because of the lack of cross-bonding, while rain also was allowed to penetrate to the interior of the building through uninterrupted joints in the narrow walls. These problems often were exacerbated when mortar failed to adhere properly to the bricks. The large number of registered patents after mid-century that attempted to remedy this deficiency suggests that many previous systems did not live up to their claims of impermeability and strength.

The highly-publicized hollow bricks patented by Henry Roberts, honorary architect to the Society for Improving the

Condition of the Labouring Classes, attempted to correct these difficulties by providing a longitudinal bond through the centre of the wall by overlapping parallel courses of bricks with either chamfered or square rebated joints (Figure 10.2. and 10.3.; British Patent No. 12,896, 1849). The square joints were proposed for thicker walls carrying heavier weights or as a lining for walls of flint, stone or common bricks (Roberts 1853, p.33). Robert's patented bricks received wide notoriety when they were used to construct the model cottages erected by the SICLC near the grounds of the Great Exhibition in 1851, often referred to as "Prince Albert's Model Houses" because of the Prince Consort's patronage (Official Descriptive Illustrated Catalogue of the Great Exhibition 1851 Vol.2, p.774-5; The Times 26 May 1851; The Builder 1851, p.311, 343; Artizan 1852, p.161; Roberts 1853; Curl 1983, p.98, 218, and 226; Foyle 1953, p.122-126).

The dwellings consisted of four three-bedroomed flats, two on each floor, with access provided by a central open staircase (Figure 10.4.). The splayed bricks used in the external walls were twelve inches long and rose three courses to the foot. They and the six-inch bricks used for partitions were laid in mortar, but four-inch partition bricks were set in cement with two tiers of hoop iron bond to ensure adequate strength. The floors and roofs were constructed of hollow brick arches carried on cast iron springers with wrought iron tie rods (Figure 10.5.). All arches were turned in cement and levelled over with approximately four inches of concrete. Quoins, door and window jambs, lintels and chimneys also were made of specially shaped hollow bricks patented by Roberts. The cost of the four dwellings totalling £458. 14s.7d., paid for by Prince Albert, obviously did nothing to demonstrate the economy of hollow brick construction (Curl 1983, p.98). The contemporary press commented that the experiment did "not claim perfection", but was "undertaken by his Royal Highness principally to stimulate the efforts of those whose position and circumstances enable them to carry out similar undertakings" (The Times 26 May 1851). According to The Builder, "disappointments were experienced in reference to a considerable number, on which account the structure should be regarded rather as the pledge of future excellence in hollow brick construction than as its full accomplishment" (The Builder 1851, p. 311).

In addition to Henry Roberts' patent, various other inventors over the next several decades attempted to improve the bonding in hollow brick construction. One of the most frequently devised solutions was bricks or blocks of irregular shapes with projections on one or more sides to secure stronger joints. Bricks patented by William Austin (British Patent No. 2975, 1856; Proceedings of the Institution of Civil Engineers 1853-54, p. 205) and by J. J. Bodmer (Bitish Patent No. 1598, 1865) had interlocking or dovetailed joints, while G. H. Johnson designed rhomboidal hollow bricks with projecting ribs, lugs or flanges intended to fit into recesses in adjacent bricks (British Patent No. 3622, 1869). H. P. Holt's building blocks had mortise and tenon joints (British Patent No. 951, 1875) and F. Prestage proposed "rectangular, circular or hexagonally shaped tubes with flanges at one or both ends" (British Patent No. 2160, 1875).

Other ordinary cubical-shaped bricks were given either shallow grooves or ribs (British Patent No. 1328, 1856, J. Briggs) or small holes in their external surfaces to form a key to strengthen the mortar joints in hollow brick walls (British Patents No. 1445, 1856, T. Schwartz; No. 3377, 1867 and No. 1591, 1868, J. H. Johnson for Francis Louis Sabrout). Another frequently patented solution was the provision of perforations through which pins or dowels could be passed to secure the construction. Sometimes these were combined with interlocking parts and grooved surfaces to ensure greater stability, as in the patent by J. Briggs in 1856 (British Patent No. 1324). The horizontal hollow bricks suggested by M. Crawford from Poole (British Patent No. 791, 1860) had vertical perforations in the centre of the bricks for the insertion of smaller tubular dowels to lock the courses together. This also was the basis for B. H. Smithett's patented bricks (British Patent No. 1078, 1864), although he recommended that the hollow metal dowels be filled with cement or clay. The polygonal-shaped hollow building blocks patented by S. Hart in 1873 (British Patent No. 142) had indentations at each end to receive iron bars which clamped them together.

Such complicated building systems may have improved the strength of walls constructed with hollow clay wares, but most still retained uninterrupted joints through which moisture could move easily. As one author commented, they "became at every course a level waterway or channel to the interior of the wall" (Building News 1857, p. 171). The design of Henry Roberts' bricks, overlapping in the center of the wall, was the first and apparently the most successful attempt to solve this weakness for many years (Foyle 1953, p. 123). Most other solutions that proposed to joggle the bricks at their outer edges to increase rigidity in the bonding were unable to obstruct rain penetration (Butterworth and Foster 1956, p. 468-9; Searle 1931, p. 486). The inability of most longitudinally perforated hollow clay constructive units to prevent the ingress of moisture more successfully than standard brick walls undoubtedly discouraged their widespread acceptance by architects despite the claims for increased dryness and warmth circulated by promoters. Unfortunately, few inventors other than Roberts appreciated the importance of this feature or attempted to correct the shortcoming.

10.2.
Availability, Cost and Compatibility of Hollow Brick Systems

Another likely impediment to the popular use of hollow bricks after mid-century may have been the diffuculty of finding brickmakers with appropriate machinery to provide sufficient quantities of the material to complete large building projects. For example, when constructing the hollow brick arched flooring in the Streatham Street Model Houses for Families undertaken by the SICLC in 1850, Henry Roberts complained that he was unable to procure enough hollow tiles from W. Cubbitt & Co. and had to turn some of the narrower arches "with the tiles flatways; being four inches deep" rather than six inches deep as they were normally laid. For other arches he resorted to common half-bricks (Curl 1983, p. 88; Roberts 1853, p. 12). The availability of hollow bricks for general use was very much dependent upon the widespread adoption of extrusion brickmaking machinery. Until the 1870's only a small number of large-scale brick producers were totally mechanized. The majority of brickyards throughout the country persisted in using hand brickmaking methods, many until the end of the century. Tile machines for agricultural purposes would have been available for making hollow bricks in rural locations, but architects and builders working in urban areas may have found it difficult to obtain quantities of hollow building products except around the potteries where socket pipes for sewers were manufactured. In 1852 the Artizan described the hollow bricks in Prince Albert's Model Cottages at the Great Exhibition, but expressed doubts that they would be extensively employed because of "the necessity of making them by machine" (Artizan 1852, p. 160-61).

If local brickyards were unable or unwilling to provide hollow bricks for building, then it was often necessary to acquire them from other sources, sometimes at a considerable distance from the building site. This obviously greatly increased the price of the material and the overall cost of a project. For example, the especially high cost of the model dwellings at the Great Exhibition was due in part to the need to transport the polychromatic shaped and glazed bricks from manufacturers in various outlying districts: "The straw-coloured from Aylesford, near Maidstone; the red from the Buxley Works, near Esher; and the glazed, of a grey tint, in the central compartment, were made by Mr. Seagar, Vauxhall, of a clay from the North of Devon; the light-coloured glazed at the Staffordshire Potteries" (The Builder 1851, p. 343). In addition, the bricks for partitions were supplied by Thomas Cubitt from his Thames Bank works (Hobhouse 1971, p. 308).[1]

In another example, the hollow bricks required for arched fireproof floors in the houses erected in 1855 for the Worcester Association for Building Dwellings for the Labouring Classes also were transported a long distance. Although the bricks specified were of ordinary size and simple rectangular section, they were supplied by the Aylesford Pottery Company, Belvedere Road, Lambeth, at the enormous cost of 70s. per thousand delivered to the railway station in London. The cost of transport from there to Worcester was at the contractor's expense (Worcester Association MSS 705: 192BA5589/134iii).[2] Admittedly, this was a trial project, but it provided little encouragement for local architects to repeat the experiment until manufacturers in the vicinity could begin to supply hollow clay products at a much reduced price.

The high price of hollow bricks was offset somewhat by their increased size, which meant that fewer were required in building. But evidence of excessive costs such as in Worcester is in striking contrast to contemporary arguments in support of hollow brick construction which stressed their overall economy. One advocate summarized the advantages as follows: "Their manufacture requires a less quantity of raw materials, a smaller expenditure in the preparation, less time in drying, less fuel in burning, and less weight in transportation, so that larger loads may be moved for a given sum. In building, these bricks occupy twice the space taken up by ordinary ones in the walls and less than half the usual quantity of mortar will suffice in laying them" (Building News 1862, p. 33). Chadwick and his supporters always included cost comparisons in their efforts to promote hollow bricks. In 1849 The Builder reported the comparative cost of ordinary solid bricks and hollow tiles from specifications for the ceiling over St. George's Hall. These showed that the cost of 146,322 hollow tiles was £239. 17s. 2½d. less than if solid bricks had been used (The Builder 1849, p. 199). Robert Rawlinson also prepared estimates for Chadwick on the cost of constructing an ordinary nine inch wall with hollow bricks, which he claimed was 3s. per yard as opposed to a common place brick wall at 4s. 6d. per yard (RIBA Papers, Etc. 1861-62, p. 96). In recommending his patented bricks in 1853, Henry Roberts maintained that "when made under favourable circumstances, the fair selling price of the patent bonded hollow bricks is about one-fourth more than that of ordinary bricks, at which rate, owing to the increase of size, a savings of nearly 30 per cent will be effected...with a reduction of 25 per cent in the quantity of mortar, and a similar saving in the labour, when done by accustomed workmen" (Roberts 1853, p. 32).

The experiences of those using hollow bricks, however, did not always substantiate these claims. As one contemporary source pointed out in 1868, "one advantage is invariably gained at the sacrifice of some other" (Building News 1868, p. 579). For instance, enlarging the cubical content of the bricks to minimize their weight and reduce the quantity of clay used often made them more suceptible to breakage while being transported long distances. Many mechanically extruded hollow or perforated bricks were particularly prone to cracking or tearing along their thin sides or inner webs. In manufacturing hollow bricks with extrusion machinery, a die plate carrying one or more cores suspended from thin rods were attached across the orifice of the clay receptacle. As the column of clay passed the cores, the perforations were made in the plastic material. However, the rods also made narrow slits through the side walls of the column or through the internal partitions. As the clay advanced beyond the die, these breaks were joined again, but experience demonstrated that this union often was imperfect and the larger bricks were considerably weakened at these points (The Patent Journal 1856, p. 108).

Many patented hollow brick systems required a large number of specially shaped bricks and each brick was designed for a particular purpose in the building. Once even partially broken or weakened, a hollow brick was found to be virtually useless and unable to fulfill its function in the structure. This was in contrast to broken stock or place bricks which remained usable for other parts of the building. As a consequence, it was necessary to order a larger quantity of hollow bricks to compensate for breakage (Taylor 1862-63 Part 1, p. 84; Building News 1868, p. 579).[3] One speaker at a meeting of the RIBA summarized the feelings of some architects when he said: "I have always found that the larger the brick the more expensive the wall notwithstanding the opinion often expressed that walls can be built more cheaply of large bricks than of small. I was once of this opinion, but my intimate knowledge of the different processes employed in the brick yards and potteries in this kingdom, has convinced me that the reverse is the case, and only when I find them offered at such price as will effect this, will I believe that the difficulties and expenses attending their manufacture have been overcome. Till then I will consider it only as an opinion in which I put no faith, and which is opposed to the very nature of the manufacture of brick earth" (Taylor 1862-63 Part 1, p. 84).

The need to pay royalties to patentees of hollow brick systems was thought by many (particularly the sanitary reformers) to retard their general acceptance (Artizan 1852, p. 161). A brickmaker wishing to commence production of the new bricks bore a double burden, first, the initial expense of acquiring special equipment and, second, a yearly manufacturing fee. A licence for the right to make Henry Roberts' "patent bond" hollow bricks cost three guineas for manufacturing up to 50,000 three- or four-inch course bricks or 25,000 six-inch course bricks in a twelve month period. For making 100,000 of the smaller bricks or 50,000 of the larger bricks for the same period the fee was five guineas (Henry Clayton and Company 1860). This was in addition to the cost of purchasing dies for the machinery. The dies cost 30s. each, but as the construction of Roberts' patented system required up to eight differently shaped bricks, the complete set, including mandrils and horses for the machines, amounted to £10. These expenses undoubtedly were passed on to the consumer in the form of high prices, causing one contemporary source to state, "an objection to the use of perforated bricks is that, from the difficulty of their manufacture, they are so much dearer than good sound stocks" (Architectural Publication Society Vol. 2, p. 67).

In a discussion at the Society of Arts in 1862, Robert Rawlinson expressed his regret that so many hollow brick products had been patented and stated that "he could conscientiously say he had carefully eschewed patents, for he knew by experience that it was very seldom indeed that patents paid" (The Builder 1862, p. 926). Social reformers sought simple, inexpensive solutions to the problems of sanitary construction. Most sincerely anticipated that hollow bricks would be made easily and economically with ordinary tilemaking machines and become as readily available as common bricks. Patent protection and the payment of royalties added to the cost of successful hollow brick systems and may have deterred many architects and builders from using them in projects where they were needed most.

Between 1855 and 1858, at a crucial period in the development of hollow brick construction, a tangle of patent disputes further impeded adoption of these new products and discouraged additional experiments. Unfortunately, documentary evidence relating to these controversies is scanty, probably because they dealt with simple factual discrepencies or duplications between the patents rather than with more important questions of law.[4] But there is no doubt that the litigation interrupted proposed building projects utilizing hollow bricks and added to the growing uncertainty amongst architects. In October 1855 The Builder reported that Mr. Wigginton, the architect for a group of model dwellings in Dudley, "intended using hollow bricks, but was prevented by the dispute between patentees and the disinclination of the local brickyards to undertake the contract" (The Builder 1855, p. 498). Two years later "M. M. G.", in a letter about hollow bricks to the Building News, admitted that he "found the difficulty of surmounting these patents infinitely greater than the obstacles thrown in our way by Act of Parliament [i.e. the brick duties]; the latter I could have possibly settled by the payment of extra duty -- the former could not be accomplished either for love or money" (Building News 1857, p. 135).

The dispute appears to have started when Jules Henry Borie, a French engineer, was granted a French patent in 1848 (No. 7632) and with his brother began manufacturing hollow bricks in Paris by a process and with machinery similar to that patented several years earlier by the Englishman Robert Beart.[5] In 1850 Borie was granted a British patent for "improvements in the construction and arrangement of the moulds through which the clay is forced...", the object of which was to render the bricks lighter and to allow an increased number of perforations (British Patent No. 13,369). By "moulds" Borie meant the die plate used in the manufacture of hollow or perforated products which in previous machines like Beart's often left the bricks weakened where the clay was separated by the bars or rods holding the perforating cores. Borie simply rearranged the bars or rods so that instead of severing the thin walls of the bricks as the clay was forced through the orifice, they cut it laterally along the length of the internal partitions (Figure 10.6.). When manufacturing bricks with many vertical perforations the cross-bar was arranged horizontally along an internal division of the brick with the cores supported by rods branching across the numerous angles of the partitions (The Patent Journal 1856, p.108).

After winning medals for their invention in the International Exhibitions of 1851 and 1855, the Borie brothers proceeded in the French courts against several competing manufacturers for infringement of their patent. Because they used machinery virtually identical to Beart's prior invention they dropped their claim to originality of the process and based their lawsuits solely on the novelty of their products. First they obtained an arbitration award against M. Chaudet, Jun. who produced vertically perforated bricks with joggled ends designed to lock together and improve bonding (The Builder 1858, p.317). Another case decided in favour of the Bories was against their rivals, Chevalier, Bouju et Cie. of the Rue de Rennes in Paris. This firm made large hollow bricks with three longitudinal perforations which were used primarily for building fireproof flooring. According to one contemporary source, they were stronger and lighter than the Bories' bricks, "very much cheaper" because they required less plaster, and were "the most generally used" bricks for their purpose in France (The Building News 1857, p.251). A third action was taken against Mortier, Courtois et Cie.. This company had purchased Henry Clayton's brickmaking machinery at the Paris Exhibition of 1855 and manufactured the "Tuile Courtois", a hollow tile for roofing, some of which were used by Captain Francis Fowke to cover the roof of the Sheepshanks Gallery in South Kensington (The Building News 1858, p.201 and 317; The Builder 1858, p.137).

Details of these cases were circulated in England by

French patent law journals and by a pamphlet published in Paris entitled "Fabrication des Briques Creuses. Mémoires pour M.M. Chevalier, Bouju & Cie, Defendeurs, contre M.M. Borie & Cie., Plaignants" (The Building News 1858, p.317). News of the decisions provoked indignant responses in the architectural press in this country. As a result of the judgements, according to one British patent agent, "the Messrs. Borie are confirmed in the monopoly of all kinds, shapes and forms of hollow bricks that have been or may hereafter be invented" and "if one of Beart's machines were sent to France, although patented three years before Borie's, it could not be used" (The Building News 1858, p.382-3). One editor reported disdainfully that "the case has again been decided in favor of Messrs. Borie, on the grounds that they ought to be indemnified for their outlay in introducing Beart's invention, and apparently on the principle of the most contemptible Chauvinism -- that it is necessary to the glory of France that the invention of hollow bricks should be made apparently due to French inventive genius" (The Building News 1858, p.317).

It is difficult to trace Borie's efforts to assert the predominance of his patent in England or to identify precisely the consequences of his actions on British hollow brick manufacture and construction. As early as 1853 it is known that an official referee under the Metropolitan Building Acts approved "Norton and Borie's" patent hollow bricks as sound bricks within the meaning of the act for a Congregational church and school designed by a Mr. Hodge at Battlebridge in the district of Clerkenwell. Although Borie's bricks were mentioned by name, this judgement was not intended to sanction their particular products, but rather it was a welcome endorsement for hollow clay building products in general (The Builder 1853, p.491). Another source referred to evidence in Brogniart's Traité des Arts Ceramique, which it said " was invoked by M. Borie to upset Mr. Beart's patent in England". There is no indication, however, that such a case was brought against Beart who continued successfully for many years to produce and sell his perforated bricks (The Building News 1858, p.318). If the Borie brothers initiated an action, they may have been discouraged by the strength of Beart's patent protection in this country.

A third author alluded to further activities when he wrote in 1857: "No sooner do we find the duty repealed, and a perfect freedom given to make any kind or description of brick, than a second party steps in [Borie?], disputes the legitimacy of Mr. Roberts's patent, and succeeds in obtaining an injunction, and the result has been that from this day to the present the progress of hollow brick manufacture has been nil" (<u>The Building News</u> 1857, p.135). Again, there is no other evidence of a successful petition by Borie against Henry Roberts. The scarcity of information relating to these disagreements leaves many questions unanswered. No further references to the disputes appeared after 1858 and we must assume the matters were resolved. But it is apparent that for several years controversies surrounding hollow brick patents may have prevented willing practitioners from using the new products and at least temporarily interrupted their development.

An equally serious obstacle to the general adoption of hollow bricks, and a factor that increasingly entered into the conversations of architects, was the "unwillingness" or "inability" of builders or building labourers to use the new products. This was attributed to two causes -- first, the actual difficulty of manipulating the bricks and, second, the building operative's general indifference to change. Some architects acknowledged that bricks of unusual size or shape were more awkward to handle. For example, there would have been considerable difficulty in lifting and laying Henry Roberts' patented hollow bricks because his special system of bonding required that half the bricks were bedded with their wider face upwards.[15] Similarly, the hollow bricks patented in 1858 by J. Bunnett for fireproof floors measured 10⅜ inches long, 9⅜ inches wide, 6 inches deep and weighed 21 pounds each. These certainly would have required two hands if not two workmen to place (<u>The Builder</u> 1859, p.55).

Many architects expressed doubts about the ability of ordinary bricklayers to handle hollow bricks. In a discussion at the RIBA on "Sundry Sanitary Building Appliances", the architect Frederick Marrable thought that workmen using the new products "would probably break them frequently", but he believed that with experience they soon would handle the bricks with confidence. He likened the difficulties in manipulating hollow bricks to the problems encountered by plasterers when Portland cement was first introduced until they became used to handling the new product (Taylor 1862/63 Part 1, p. 96). Sir William Tite, on the other hand, felt it would be necessary to employ skilled labourers to ensure that hollow brick construction was properly executed, a fact that undoubtedly would increase the cost of construction. He added that building workmen would have to take greater care with the new products and "not build at the railway speed they were doing now" (Taylor 1962/63 Part 1, p. 95). In a similar discussion at the Society of Arts, still others expressed the opinion that "country bricklayers" in particular would be either unwilling or unable to use the new materials "so readily as to build with them substantially as they were accustomed to do under the old brick-and-mortar system" (The Builder 1862, p. 925).

After nearly twenty years of promoting hollow brick construction, Edwin Chadwick regretted in 1868 that these products had not been more extensively taken up, a fact he ascribed in part to a lack of interest on the part of common builders. He wrote: "The common builder rarely feels any interest in changes and is usually prejudiced against them, as requiring a change of habits in construction" (Chadwick 1867/68, p. 277). The reluctance of some general contractors to accept hollow bricks may have been motivated not so much by a total aversion to new methods, but rather by the fear of disruption or financial loss that often occurred to those who first took up an innovation or deviated from accepted practices. Chadwick recognized the problem: "Any improvements requiring new forms which need care or study in alterations and adaptations for which there is no general demand can only be executed at increased expense to the first individual who adopts them" (Chadwick 1867/68, p. 277).

He seems to have learned this lesson in rational economic behaviour from Thomas Cubitt and often told the story about how he approached the builder and asked him to adopt hollow bricks for some labourers' tenements and cottages Cubitt was then erecting. Although he acknowledged the soundness of the principle, the sanitary benefits, and possible cost reductions which hollow bricks might allow, Cubitt declined to use them saying: "If I adopt that new and large form of brick, which requires the use of both hands to set it, my men will strike and I shall have all the labour of overcoming resistance; and when I have done it, and shown how much more cheaply the construction may be made, others will follow me and I shall have no profit and nothing but trouble and vexation for my labour. I will not, therefore, undertake it" (Chadwick 1867/68, p.278; Roberts 1861-62, p.97; Hobhouse 1971, p.308).[7] This story usually was related to illustrate the opposition of trades unions to innovations in building. Chadwick himself held the rather harsh view that "the ignorant selfishness of the wage classes stood in the way of the needed improvements of the dwellings of the wage classes" (<u>RIBA Papers, Etc.</u> 1861-62, p.97).[8]

10.3. Hollow Bricks in Building After Mid-Century

As we have seen, many difficulties and obstacles attended the manufacture and employment of hollow brick building systems during the early years of their development. For a short time in the mid-1850's patent disputes may have completely inhibited further experimentation with these new products. Yet despite these problems, interest in hollow clay constructive units persisted in the decades following the Great Exhibition. New patents for hollow goods continued to appear, many of which were for specialized clay products like hollow mantles, chimney flues, and cornices. Looker's ventilating brickwork featured a hollow mantle with a series of connected hollow tubes which conducted warm air from the fireplace to other rooms in the dwelling and allowed vitiated air to be removed through the chimney. The system was demonstrated in the Architectural Exhibition at Suffolk Street in 1856 and at Mr. Looker's brickworks at Kingston-Upon-Thames (<u>Mechanics' Magazine</u>

1856, p. 61; The Builder 1856, p. 166). Another manufacturer, M. B. Newton, introduced hollow earthenware stairs as an improvement over "the present inflammable, dirt-harbouring and creaking mode of construction." He proposed forming each riser and tread of one piece of clay with six or seven horizontal perforations (The Builder 1858, p. 157 and 197).

In the late 1850's an architect, John Taylor, Junior, applied machinery to the manufacture of perforated ventilating floor tiles and damp proof courses made of highly vitrified brown stoneware (British Patent No. 1631, 1859 and No. 1662, 1859). The damp proof slabs were 3 inches thick and in lengths of 4½ inches, 9 inches, 14 inches and 18 inches to correspond with brick walls of any width (Figure 10.7.). Taylor went further than most manufacturers in publicizing his inventions by presenting two papers, one to the Society of Arts in December 1862 and another to the Royal Institute of British Architects the following month. He announced that he was "most happy to receive the directions of Architects, and co-operate with them, as to the intended application of the foregoing materials, etc. into any proposed building of importance..."(Taylor 1862-63, pp. 77-98; The Builder 1861, p. 39; 1862, p. 904). At about the same time Taylor's competitor, the manufacturer J. G. Jennings, patented hollow coping bricks "to facilitate drying and burning", machine-made perforated stoneware air bricks pierced with different patterns, and hollow sleeper blocks for supporting floors in damp situations (British Patent No. 2458, 1856 and No. 1502, 1858; Rivington 1879, p. 134, 136 and 119). Some of these unique products were recognized as definite improvements over alternatives such as slate or tar damp proof courses and iron air gratings, and they were marketed successfully well into the twentieth century (Adams 1910, p. 71).

The most widespread application of hollow clay products for building in the decades after mid-century was for fireproofing large public buildings.[9] The early use of hollow pots for this purpose by leading architects had established this construction method as safe and reliable. Mechanization allowed increased quanitities of hollow goods to be produced and thus lowered their prices. The new tubular-shaped bricks made by machinery were considered more efficient for constructing arches in fireproof floors and ceilings. They were larger and fit tightly together and so required less mortar to stabilize the construction (The Builder 1849, p. 184; The Building News 1857, p. 251). Also, because they were usually fully encased with a layer of cement or concrete, problems with bonding and moisture retention were not as great as when constructing walls with hollow bricks. Hollow arch bricks were more easily manufactured with ordinary tile-making machines because they were simply shaped, thus obviating the need to use a patented system. Nevertheless, some patents were registered such as that by Joseph Bunnett of Deptford in 1858 for large joggled hollow bricks with three or six longitudinal perforations (Figure 10.8.; British Patent No. 1292). Bunnett's bricks were tied together with iron rods passing through the cavities which were then attached to angle-iron wall plates. They enabled an arch of up to 21 feet in width to be constructed with a rise of only 2¾ inches (The Builder 1859, p. 55, 139; Webster 1890/91, p. 266 and 269).[10]

One well-known example of machine-made hollow goods used for fireproofing was the alpaca mill built by Titus Salt at Saltaire in 1851-53. This large building had floors constructed of hollow bricks manufactured on location by "Clayton's patent process". They were rectangular in section with two longitudinal perforations and a slight projection on one side which connected with an indentation in the adjoining brick to effect a tighter bond (Figure 10.9.). Because each brick was moulded with the appropriate curve, the soffits of the arches in the mill remained smooth and required no plastering (Fairbairn 1864, p. 180). In another example, an ordinary tilemaking machine at St. Nicholas' Brick and Tile Works near York made the hollow flat arch bricks for fireproof floors in a new building erected in 1853 at the Retreat, a lunatic asylum owned by the Society of Friends. The twelve inch long bricks had two perforations and apparently were made to specifications by J.P. Pritchett, the York architect in charge of the project (Building Accounts 1853 H/1/2, The Borthwick Institute, York; The Builder 1854, p. 150).

Among the many other examples of fireproof construction described in the professional press after mid-century was the new Law Fire Insurance offices in Chancery Lane, designed by the architects Pownall and Bellamy in 1858. Fireproof floors in this building were constructed with cast iron girders spanned by arches with three layers of hollow tiles set in cement and levelled with concrete. No particular manufacturer was mentioned in connection with the tiles, so presumably they were ordinary unpatented hollow tubes. "Plain hollow tiles" also were used in some of the partition walls to further add to the building's fireproof qualities and "to prevent the transmission of sound" (The Building News 1858, p. 572). The Courts of Appeal extension at Pill-lane and Morgan-place in Dublin was completed in 1857 with floors of hollow brick arches supported on metal girders (The Builder 1857, p. 710). In addition, H.E. Kendall, Jrn., the architect of the Essex County Lunatic Asylum, also built in 1857, used special hexagonally-shaped hollow bricks for arched fireproof ceilings (The Builder 1857, p. 273).

It is difficult to estimate the full extent of the use of hollow bricks for fireproofing large public buildings during these decades. Details of the construction of many new buildings appeared regularly in several architectural journals, but they revealed a great variety of "fireproofing" methods in use. Some architects still preferred iron girders and solid brick arches, although the large number of closely spaced girders needed to support the exceptional weight of the bricks greatly increased the cost of construction. They were recommended particularly for warehouses and factories containing heavy equipment, but sometimes they were applied in other situations such as the London offices of the National Discount Company at Cornhill and Birchin Lane designed by F.J. and Horace Francis in 1858 (Fairbairn 1864, p. 140; Rivington 1879, p. 367; The Builder 1858, p. 10).

Another popular solution for fireproofing, used mainly for ceilings and roofs, consisted of flat arches formed with two or more courses of flat clay tiles resting on iron girders. According to Rivington, the first course of tiles was laid dry upon the centring and covered with cement. Then up to four other courses of tiles, each breaking joint, were laid over until the desired thickness was attained (Rivington 1879, p. 369). As early as 1849 one author commented on the "great strength" of this method stating that it was "very much used in and about London" (Dobson 1849, p. 48). Tile arches were used frequently in large houses such as the mansions erected for H. T. Hope, M. P. in 1850 (Godwin 1850, p. 60) and for Baron Rothschild in 1862, both in Piccadilly, London (The Builder 1862, p. 786). Henry Currey, a Fellow of the RIBA, also selected tile arches and wrought iron springers for the corridors and ceilings of the basement and kitchen in the London Bridge Railway Terminus Hotel described at the Institute in 1861. The arches were of three thicknesses of tiles set in Roman cement (Currey 1861-62, p. 116).

Concrete fireproofing systems introduced in the 1850's also competed with hollow bricks for popularity. One early paper read at the RIBA described French ceilings of gypsum plaster poured over a web of light iron bars supported by rolled iron joists (The Builder 1854, p. 28 and 149-50). Similarly, fireproof floors invented by Dennett & Ingle of Nottingham consisted of gypsum-based concrete arches poured onto specially constructed centres. They were supported at the walls by projecting masonry courses and by iron girders placed at intervals of 10 to 12 feet across the room. The spandrels were either left open and covered with joists and board flooring or filled in with concrete and paved (Rivington 1979, p. 372; Webster 1890-91 p. 268-9).[11]

Even more well-known was Fox and Barrett's system of fireproof construction which was widely adopted for hospitals and offices as well as warehouses. In this system small wrought iron joists were spaced twenty inches apart supported by the main girders. At right angles to the joists and resting upon their bottom flanges were rough strips of wood laid between one-half and one and a half inches apart. A layer of concrete was poured between the joists over the fillets fully encasing the iron and protecting it from eventual fires (The Architect and Building Operative 1849, p. 221; Proceedings of the Institution of Civil Engineers 1853, p.244-272; The Builder 1854, p.53-54).

It is clear from an examination of the journals dating from this period that no particular method of fireproof construction took precedence over others. Hollow brick systems were just one of many options available to architects and builders. Evidence suggests that many architectural professionals had used or were willing to adopt hollow bricks for fireproof flooring and were convinced of their superiority for that purpose. On the other hand, it seems few were willing to accept hollow bricks for other types of construction despite the enthusiasm shown by the sanitary reformers.

The Prince's model cottages provided wide public exposure to new possibilities for building with hollow bricks and there was a marked expansion of interest in the new products outside the sanitary reform group after the Great Exhibiton. Even in relatively isolated locations new experiments were undertaken. For example, in 1852 Mr. George Gilbert, a brickmaker from the village of Banham in Norfolk, offered for sale "hollow bricks, glazed and unglazed, white and red...made in all respects similar to those of Prince Albert's Cottages at the Exhibition" (Emigrants letters, from settlers in Canada and South Australia, collected in the parish of Banham, Norfolk 1852). The bricks were manufactured under Roberts' patent with Whitehead's tilemaking machine purchased at the Exhibition by the local rector. By 1854 a school near the village church in Banham was erected with large stone-coloured hollow bricks (White's History, Gazetteer and Directory of Norfolk 1854, p.756). Some of these bricks still may be seen in a porch and portions of a wall in the building, now used as a dwelling (Figure 10.10. and 10.11.).

Cottages continued to be built throughout the country under the auspices of the SICLC according to recommended plans by Henry Roberts which were published by the organization as early as 1844. Many of these were constructed with Roberts' patented hollow bricks. Between 1850 and 1852 a branch of the Society in Tunbridge Wells built a group of model cottages along Newcomen Road using the bricks. At about the same time the Duke of Manchester, a vice-president of the SICLC, also adopted Roberts' plans and the patent bricks to erect two lodges on the edge of his estate at Kimbolton. Similarly, two rows of houses patterned after the Model Cottages at the 1851 Exhibition were constructed by the Windsor Royal Society under the patronage of the Queen and the Prince Consort (Curl 1983, p. 108, 116, and 123).

Descriptions of other projects utilizing hollow building products appeared with increasing frequency in the press during the 1850's and 60's. In one example, at a meeting of the Architectural Institute of Scotland Mr. James Gowan, a railway contractor, explained his use of hollow partition bricks for heating and ventilating working class houses at Rosebank between Glasgow and Edinburgh in 1858. Fresh air was warmed in a chamber behind the kitchen grate and carried throughout passages in the hollow brick walls by mechanical ventilators to extraction flues in the ceilings (The Builder 1858, p. 237). Similarly, the architect Peter Thompson described a "ragged church" he erected in 1854 at Redhill near Reigate, Surrey for a congregation which did not "feel themselves at ease in the new medieval churches". Large hollow bricks 18 inches long by 9 inches wide and 4 inches thick were used for walls and piers, and the entire building was warmed with hot water. Thompson also supervised the construction of a hollow brick villa for Dr. Southwood Smith near Weybridge (The Builder 1854, p. 624). These were not meant to be model or demonstration structures, but they were, nevertheless, exceptional or singular situations worthy of special notice by the architectural press.

The performance of early hollow brick systems did little to hasten their acceptance by hesitant professionals. Not only were the bricks themselves often of poor quality, but many systems were not designed to provide adequate bonding to ensure the strength of the construction or to prevent the ingress of moisture through joints. Moreover, throughout this important period in the development of hollow brick technology, supplies were scarce and prices were high because few manufacturers were equipped to produce sufficient quantities of the new machine-made products. A series of patent disputes in the mid-1850's further discouraged much needed experimentation with hollow bricks for several years. Although promoters did their best to create interest in hollow clay products, few architects were completely convinced of their superiority over other methods of damp prevention and ventilation. For the most part, during the decades after mid-century the use of hollow bricks for any construction other than fireproof flooring was inextricably associated with sanitary reform or philanthropic building, and projects utilizing these products remained essentially experimental in nature.

NOTES

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1. Many years later during evidence given to the Royal Commission on the Housing of the Working Classes in 1884, Edwin Chadwick stated that the cost of these dwellings was artificially increased because of the involvement of Prince Albert: "Afterwards I learned to my surprise that that building had been made dearer, for the workpeople did not do above one third of a day's work, because they were doing it for a Prince; and the man told me that these bricks that I spoke of, pot bricks with glazed surfaces, could be put in at 24s. per thousand had charged the Prince 10 guineas per 1,000, because he said: 'Do you think I am going to supply this to the Prince at the same price as I would supply it to the common people?' My example of economical construction was done away with" (BPP Housing of the Working Classes 1884-85, Ques. 13,947).

2. This company may have been associated with the Aylesford Pottery Company brickfield in Kent, which at the time of the Children's Employment Commission investigation in 1866 was completely mechanized (BPP Childrens Employment Commission 1866, p.142).

3. Butterworth and Foster speculated that it was in part the number of "specials" needed for building with Henry Roberts' hollow bricks that caused them to fall into disuse (1956, p.472).

4. Per conversation with staff at Leeds Patent Library, September 1987.

5. See Hamilton (1958, p.47-48) for a discussion of Borie's patent and manufacturing process taken from E. Lejeune, Manuel du Briquetier et de Tuilier, 5th Ed., undated.

6. Butterworth and Foster have suggested that this was another reason for the ultimate disuse of Roberts' bricks (1956, p.472).

7. It is interesting to note that although Cubitt refused to use hollow bricks in his own building projects (except perhaps

for occasional experiments), he was willing to employ the machinery at his Thames Bank brickfields to manufacture them for others. Cubitt supplied the hollow partition bricks for the Model Cottages at the Great Exhibition (Hobhouse 1971, p. 305).

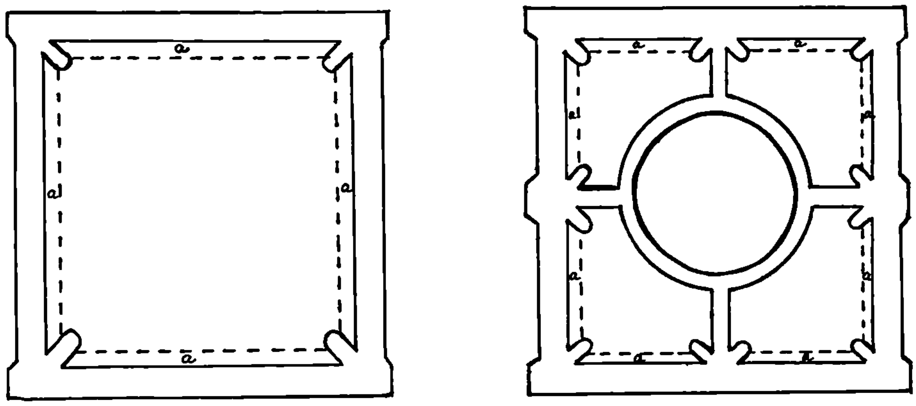
8. The opposition of building tradesmen to new materials or methods of working was acknowledged by architects throughout the century. One professional journal noted that "the building trades are not quite so responsive to commercial changes as they are to those of the weather". This article went on to state: "The rank and file...can do ordinary work tolerably well, but are completely at a loss when something is submitted to them a little out of the common groove. They have learned the trade under a master who had a special class of work, and were confined to one or two branches. Anything a little more difficult or elaborate at once baffles the workman" (The Building News 1891, p. 87).

9. For a general history of structural methods of fire protection see Hamilton (1958).

10. According to Webster, Bunnett's system was used to build the floors of the Grosvenor Hotel and parts of Victoria Station in Pimlico. See also British Patents No. 791, 1860, M. Crauford and No. 1398, 1863, S. St. B. Guillaume for other examples of patented hollow brick fireproofing systems.

11. According to an advertisement in the Building Trades Directory of 1886, Dennett's fireproof floors were included in, among others, the new Foreign Office(1862-73), Bradford Town Hall(1869-73), The Holborn Restaurant, London(1873), St. Thomas' Hospital(1868-71), Manchester Town Hall(1868-77), The Grand Hotel(1879), and the Criterion Restaurant(1870-74), both in London.

Figure 10.1. Sections of hollow bricks invented by Robert Rawlinson, c.1849. Angle ribs enable dowels, *a a a a*, to be inserted on all sides to strengthen and close the joints.
[From <u>The Builder</u> (1850) p.53]



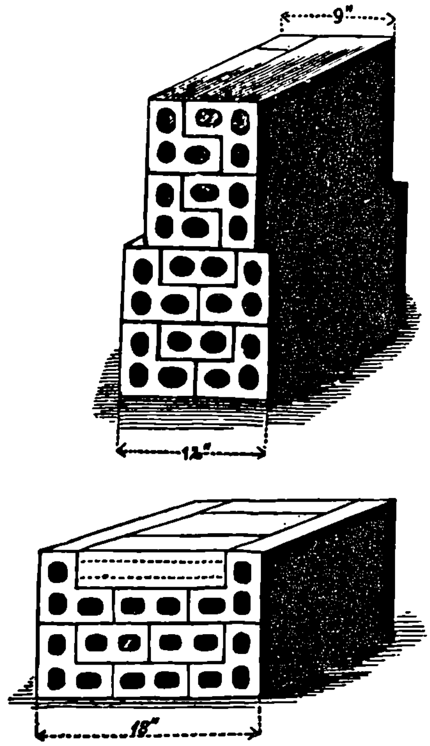
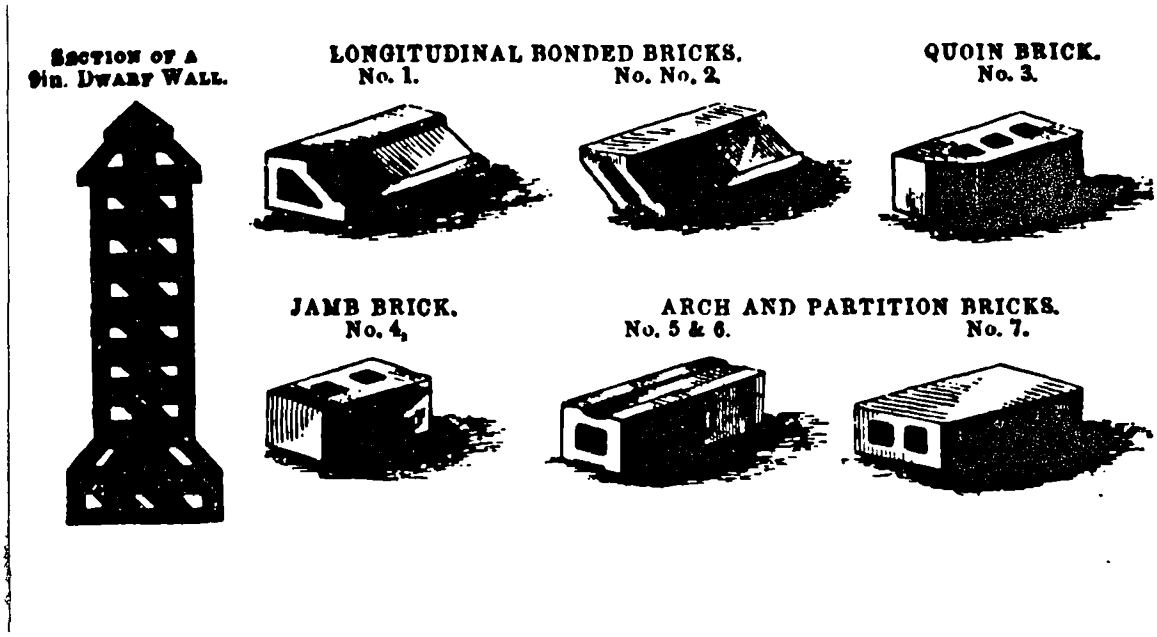


Figure 10.2. Sections of wall built with Henry Roberts' Patent Bonded Hollow Bricks.
[From Henry Roberts, The Dwellings of the Labouring Classes (1853) p.33]

Figure 10.3. Henry Roberts' Patent Bonded Hollow Bricks, British Patent No. 12,896, 1849.
[From Henry Roberts, <u>The Dwellings of the Labouring Classes</u> (1853) p. 33]



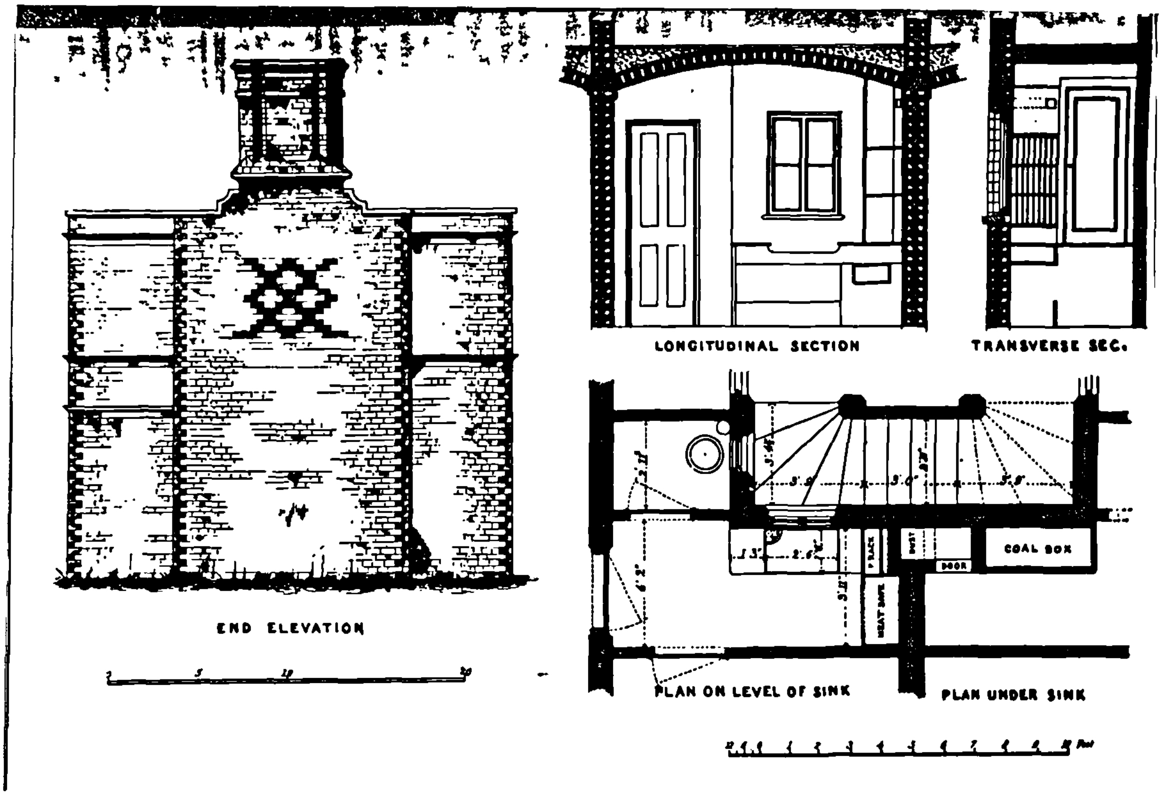
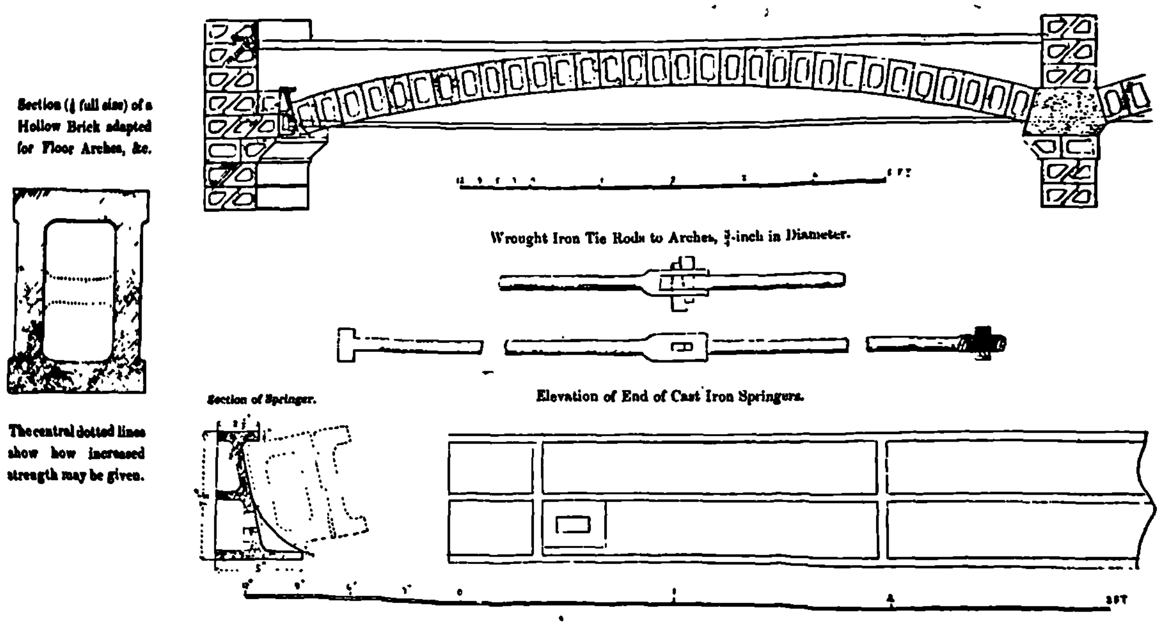


Figure 10.4. Prince Albert's Model Houses for Families at the Great Exhibition, 1851; end elevation, longitudinal and transverse sections, and detailed plan around common stair.
[From James Steven Curl, The Life and Work of Henry Roberts, 1803-1876 (1983) p.95]

Figure 10.5. Prince Albert's Model Houses for Families at the Great Exhibition, 1851; section showing the floor and roof arches. [From Henry Roberts, The Dwellings of the Labouring Classes (1853) p. 34]

SECTION, SHOWING THE FLOOR AND ROOF ARCHES TO H.R.H. PRINCE ALBERT'S EXHIBITION MODEL HOUSES, AND THOSE TO THE MODEL HOUSES IN STREATHAM STREET AND PORTPOOL LANE.



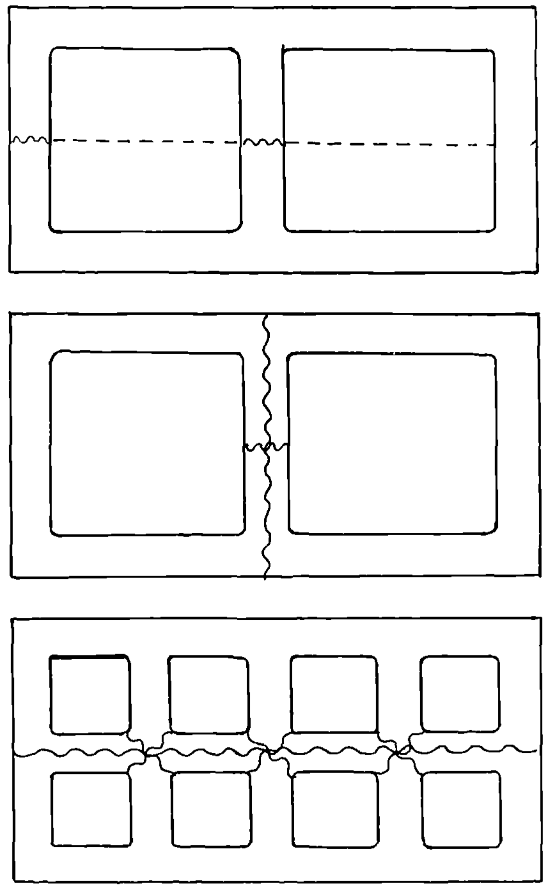
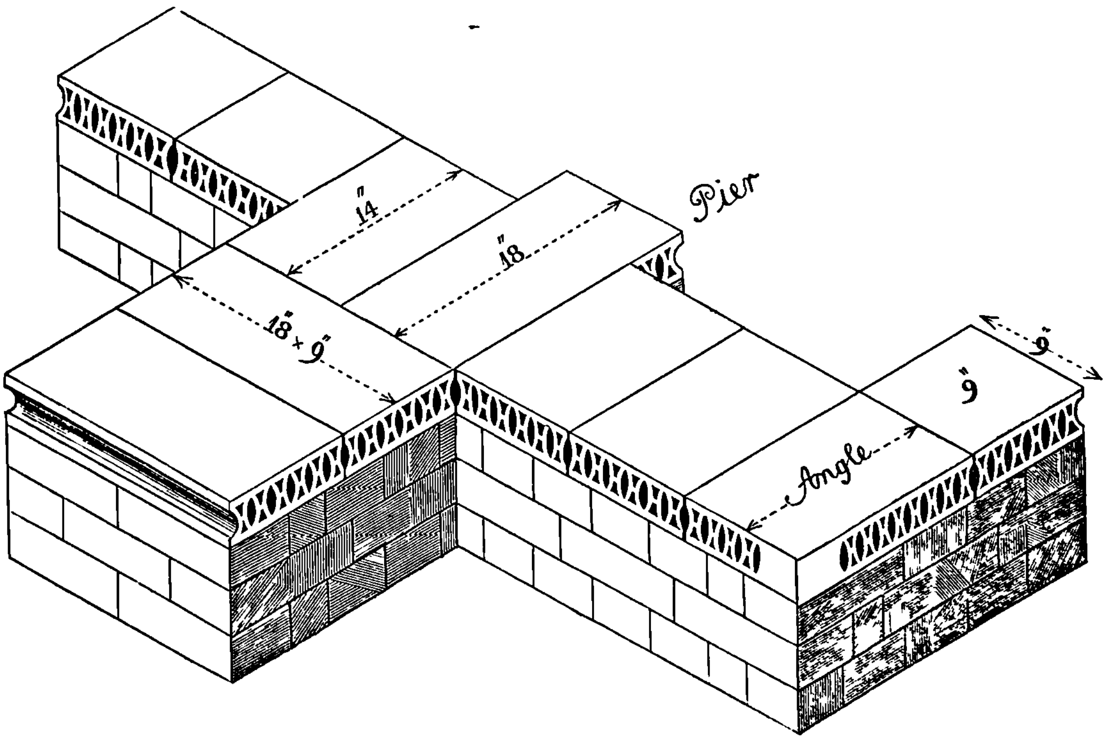


Figure 10.6. Improvements in hollow bricks patented by Jules Henry Borie, British Patent No. 13,369, 1850. In previous methods of manufacture (top), the rods holding the perforating cores cut laterally through the outer surfaces of the bricks, thus weakening them. Borie re-arranged the rods so they only cut through the internal divisions of the bricks (centre and bottom).
[From The Patent Journal (1856) p. 108]

Figure 10.7. Hollow stoneware damp proof slabs invented and manufactured by John Taylor, Junior, British Patent No. 1662, 1859. [From John Taylor, RIBA Papers, Etc. (1863) p. 79]



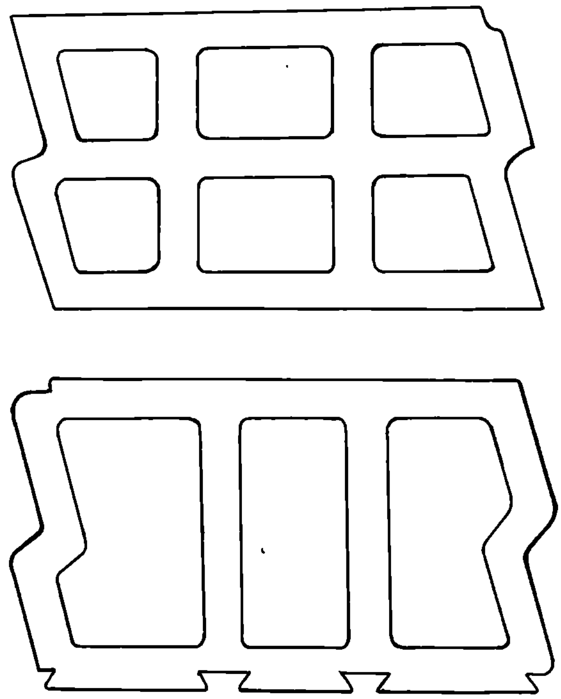


Figure 10.8. Interlocking hollow bricks for fire-proof floors and ceilings patented by J. Bunnett, British Patent No. 1292, 1859. [Adapted from drawing enrolled with patent]

Figure 10.9. Section of machine-made hollow bricks used for arched fireproof flooring at Saltaire, c.1851.
[Adapted from William Fairbairn, The Application of Cast and Wrought Iron to Building Purposes (1864) Plate III]

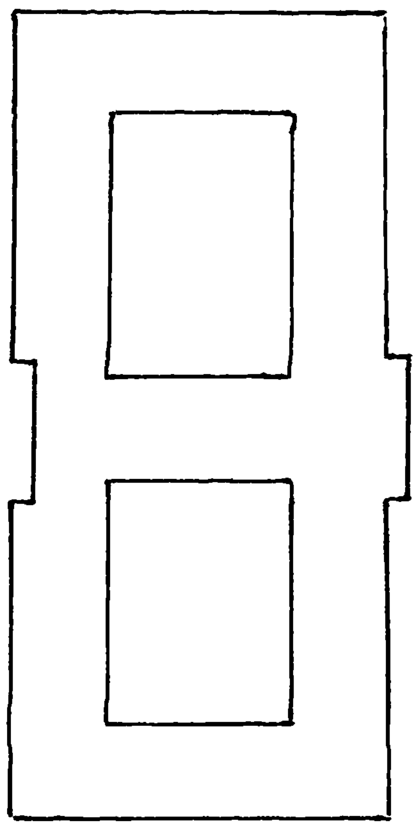


Figure 10.10. (top) and 10.11. (bottom) Porch constructed of hollow bricks in building at Banham, Norfolk (top). Close-up (bottom). [Photographs by author]

CHAPTER ELEVEN

HOLLOW BRICKS AND PROFESSIONAL CONTROVERSIES

11. 1.
Professionalism and Risk-Taking

Except for the small number of architects working closely with sanitary reformers and philanthropic organizations, most in the profession remained cautious and uncertain about the use of hollow bricks for ordinary construction in the period after mid-century. In part, this was because most patented hollow clay products did not fulfil the many promises made by their promoters. It also was a reflection of many architects' general distrust of new and untried building materials and processes. This was closely linked to the process of "professionalization" which began in the late eighteenth century and had as its aim the establishment of social respectability and prestige for the new professional architects who gradually replaced the "gentlemen-architects" and master craftsmen of the previous century (Saint 1983, Chapter 3).

In the early nineteenth century economic growth and the demand for professional services from an increasingly socially diverse clientele brought many new practitioners into the field of architecture. No longer entitled to social superiority on the basis of aristocratic connections, some members of this new group of architects soon began to formulate their own unique "professional" ideology which would set them apart as a distinct social entity. Architects were just one of many new occupational groups aspiring to acquire the privileges of professional status during the period, "to defend the social position which they had inherited from their pre-industrial predecessors" (Duman 1979, p. 117).

After the Institute of British Architects was founded in 1834, its members were concerned primarily with demonstrating that the skills, training and, above all, the ethical conduct of professional architects were clearly distinguished from common building tradesmen. The moral justification for greater social status for the profession centred on the ideal of service. For the professional architect, obligations to the client were supposed to take precedence over the selfish desire for profit which presumably motivated the common building practitioner. The reputable architect's aversion to new or untried materials and techniques often was equated with these obligations. As one member of the Liverpool Architectural Society stated: "The responsibility of the architect was quite sufficient to make him careful to guard against any recklessness, because his professional character would be at stake" (The Builder 1860, p.92).

The circumspection of the profession towards new building products and methods was intended partly to protect the interests of the client, but also to avoid censure by the general public should new experiments not succeed. The editor of The Builder apparently supported this prudence as he explained to a correspondent in 1871: "Fear of increasing expense beyond the desire of the employer [client], and of running risk with new inventions, often leads architects to avoid desirable precautions, trusting that what has answered the purpose in other places may do so again" (The Builder 1871, p.109). At "a practical night" held by the RIBA in 1861 a special committee, "On Construction and Materials", was created to consider "any new materials or appliances that might be brought under their notice." But it was acknowledged that the committee "required great care in their working, so as not to commit the Institute to new and untried processes." They explained their caution in these matters: "The Times and other authorities were sometimes apt to blame architects for not adopting novelties, which however, if they were to use them without due caution and full consideration, they would be the very first to assail, and would allege that architects were too fond of introducing crude or imperfect innovations" (The Builder 1861, p.51).

On another evening devoted to "Sundry Sanitary Building

Appliances", the speaker, John Taylor, further justified this view: "I think our profession is not to be blamed for the extreme caution with which its elder members, at least, adopt anything that is new; nor must we censure them for waiting till success has been proved, by others, to be beyond all doubt. The reason is obvious, when we reflect that the credit due to the success of the novelty goes to the inventor, while the blame for its failure is attributed to the architect" (Taylor 1862-63, p.77). At a meeting of the Inventors' Institute in 1872, Banister F. Fletcher similarly told the group: "The architect who is building a house probably goes to see an invention, likes it, thinks he will try it,-- hesitates -- finally probably decides against its employment, from fear that it may not be successful. Yet, I think, little blame can attach to him: if the invention succeeds, the merit is the inventor's; if it fails, all the blame falls on him, for selecting such a 'fandangle, stupid thing': such will be the language his client may use to him" (The Builder 1872 p.24).

It is not entirely clear who these architects believed would empirically "prove" the success of new products or techniques if they themselves did not participate in building experiments. But this professional caution created a difficult dilemma for inventors. Until innovations were employed sufficiently widely to enable weaknesses or inherent design faults to be detected, little opportunity existed for refining or further developing the products. And yet, professional architects were hesitant to adopt new products that weren't already perfected or proven by long use. According to one author writing in support of the professional position: "It is one thing to assert that a certain material will resist all the influences of climate and moisture, last longer than any other, and another thing to actually put it to the test for a given time and observe the actual effect produced upon it." The author went on to cite the stonework of the Houses of Parliament as "a standing example of the difference between the assumed properties of a building material and its actual behaviour under trial. That magnificent structure is literally 'perishing by inches', and it appears as if nothing can be done to arrest its decay" (The Building News 1868, p. 579).[1]

Typically, many professional architects believed the solution to this difficult problem was "further actual trial and experiment" or testing of new products to "prove" their reliability. This was especially true with regards to hollow bricks. According to one architect, "very few of them had been sufficiently tested to enable them [the architects] to say much about them" (Taylor 1862-63, p. 96). Edwin Chadwick recognized that trials were necessary to convince architects and builders of the superiority and utility of hollow goods. But he also believed that individuals should not be expected to undertake such testing on their own and he pointed out that "some public means were necessary for these purposes" (Roberts 1861-62, p. 96).

Up to then only intermittent and haphazard attempts to test hollow bricks or hollow construction had been made and reported in the architectural press. In 1849 Robert Rawlinson tried to demonstrate the strength of hollow bricks prior to recommending them for use in the ceiling of St. George's Hall, Liverpool. According to a subsequent account, he "loaded upwards of thirteen tons onto a row of four bricks without any of them fracturing or crushing." Chadwick similarly reported the results of experiments to ascertain the loading capacity of hollow brick arches, but the testing methods were not explained and the findings were somewhat vague: "A portion of a circular arch, constructed with earthenware pots 12½ inches deep and 5½ inches in diameter, supported besides its own weight a load of upwards of five tons, or the weight of more than 67 adult persons of 165 pounds each" (The Builder 1849, p. 184). Henry Roberts rather more convincingly tested the strength of the hollow tile fireproof arches he proposed to build in the floors and ceilings of the Streatham Street Model Family Houses, constructed in 1849-50. He built an experimental arch with a span of 9 feet 6 inches and a 7 inch rise securing it with ⅞ inch tie rods. He then loaded the arch with pig iron until it broke under a weight of 9 tons 14 cwt, recording the deflection with each addition of weight. He concluded that the floor would safely bear four times the weight if covered with the maximum number of people "at the rate of 120 pounds per foot superficial" (Roberts 1853, p. 12).

Hollow bricks were used conspicuously by J. B. White and Sons, cement manufacturers of Millbank, to build a large beam at the Great Exhibition to test the strength of Portland cement. The trial was set up originally to duplicate an experiment using stock bricks and Roman cement conducted in 1837 at the Nine Elms cement works of Francis and White. The Builder reported, however, that "a short time previously to the opening of the Exhibition it was suggested to them that if they made use of hollow bricks instead of the ordinary solid bricks, it would add much to the interest of the experiment (as experiments upon hollow bricks were much wanted)" (The Builder 1851, p. 603). Consequently, 1200 hollow bricks were used to build the beam, each sized 5⅝ inches by 4⅛ inches by ⅞ inch thick. They were laid with fifteen pieces of hoop iron dispersed among the courses. Although the results showed Portland cement to be superior in strength to Roman cement, it was widely believed that the exercise was useless. George Godwin concluded that it was a mistake using the hollow bricks rather than replicating the experiment as closely as possible with stock bricks. The difference in sectional area of the beam caused by the unusual size of the tubular bricks, the use of iron hoop bonding, and especially the unknown strength of individual hollow bricks as compared with ordinary stock bricks considerably complicated and left open to question the results of the test. (Godwin could only reiterate promoters' claims by saying that hollow bricks were "usually better moulded and more thoroughly burnt than ordinary stocks".) The experiment certainly did nothing to enlighten interested professionals about the qualities of hollow bricks (The Builder 1851, p. 603-4).

Another isolated test was conducted in 1859 by Joseph Bunnett, the patentee of joggled, interlocking hollow bricks for fireproof floors. Various experimental arches were erected at Bunnett's business premises at Deptford. One of these, of 15 feet span and 2 feet 3 inches width constructed with Portland cement, was loaded to 267 pounds to the square foot without failure.

Another, of 16 feet span was loaded with pig iron to over 300 pounds to the square foot (The Builder 1859, p.55 and 139). No other systematic investigations of hollow clay building products were made after 1860, either by individuals or public bodies. This was in contrast to the much larger scale of research undertaken by laboratories in France and Germany during these years (Butterworth and Foster 1953, p.825-827). The architectural press in this country only occasionally published data derived from Continental tests, as when the Building News reported "Experiments upon the strength of different systems of brick and cement floors" extracted from the Revue Industrielle in 1870 (p.319).

Throughout the period architects continued to complain about the lack of adequate testing of new products, placing the blame directly on the inventors of new building materials: "The inventors who have taken up this subject appear in many instances to be merely groping their way, and it is but seldom that their patents are the result of, or are supported by, well-documented and systematic experiments; and to this deficiency of scientific application the slowness of the progress hitherto made may be mainly attributed" (RIBA Papers, Etc. 1877-78, p.299). The lack of well-documented research to substantiate the many claims made about the performance of hollow bricks undoubtedly discouraged some architects who may have been willing to adopt the products had published evidence been available to support their choice. Although he was an enthusiastic supporter of hollow brick construction, Edwin Chadwick observed realistically that "young members of the profession had no means for making trial works, and could only look for practise with settled materials and forms", while "old members were too busy, as well as too habituated in old forms to occupy themselves with working out deviations which, for the lower class of construction, had the least promise of profit" (Roberts 1861-62, p.97). The result of this unfortunate situation was that experimental data was not forthcoming.

11.2.

Cavity Wall Construction: A Controversial Alternative

Among the many reasons why professional architects were reluctant to adopt hollow bricks for ordinary construction in the second half of the nineteenth century may have been the availability of alternative building methods for preventing damp and ventilating structures. One of these was cavity wall construction.[2] Many of the discussions about hollow bricks at professional meetings after mid-century included debates about the comparative merits of these two procedures. The technique of building masonry walls in two thicknesses with a hollow space between was mentioned in treatises by both Vitruvius (Book II, Chapter VIII) and Alberti (Book III, Chapter VI). It was used in this country during the eighteenth century to insulate icehouses[3], and in 1805 the method was described by William Atkinson in Views of Picturesque Cottages. Atkinson claimed the technique would save materials, prevent the conduction of heat and cold and, incidentally, provide more picturesque effects of light and shade by the deeper recesses of the building's openings (Atkinson 1805, p. 15). In 1818 Papworth illustrated a plan for a dairy constructed with double walls to allow the free circulation of air to preserve the temperatures inside (Papworth 1818, p. 90).

Other treatises or building manuals written during the first half of the nineteenth century gave detailed instructions for erecting walls with cavities. In 1821 Thomas Dearne's Hints on an Improved Method of Building described procedures for constructing nine and fourteen inch hollow walls (Figure 11.1.). In one method courses of stretchers were laid on edge alternating with courses of flat headers spanning the three inch wide vacuity. In another version half-stretcher bricks which had been divided longitudinally were used to achieve the cavity. The author also advised that the bottom three courses of the wall should be built solid and a drain brick should be placed at the bottom of the hollow at the level of the dwelling's floor to carry off water. Dearne claimed that his method was "strong enough for the external walls of second rate, or third rate country houses, two stories high."[4] J.C. Loudon's Encyclopedia, published in 1839, illustrated yet another variation of hollow construction called "Silverlock's" hollow walls (Figure 11.2.). These were built with bricks laid entirely on edge in Flemish bond, forming a four inch wide hollow space in the wall. It was suggested that piers could be built at intervals along the wall to strengthen the construction and add visual interest. Not only did this method permit a savings in the number of bricks used, but also according to Loudon, the walls could be heated by means of hot water or steam conveyed by tubes throughout the cavities (Loudon 1839, p. 186).[5]

At least one patent was granted in 1839 for "Improvements in Building the Walls of Houses and other Edifices" by Stephen Rogers. This was a method for constructing hollow walls with the bricks laid on edge, every third brick in each course being a tie-brick. The inventor claimed a savings of one-third in bricks, one-third in mortar and "a total saving of at least twenty-five per cent in building a house" (British Patent No. 8218, 1839). Still other techniques for building hollow brick walls were described by the Architectural Publication Society (Figure 11.3.). In one of these, the bricks were laid flat with stretchers only on one side of the wall and alternating headers and stretchers on the other. In the next course this arrangement was reversed and so on up the wall creating a 4½ inch cavity in the centre. Another method, having a 2¼ inch cavity, consisted of two strechers alternating with one header in each course, the header backed in with a "dubbing-out bat" on the inside skin of the wall. In each successive course of bricks the header was laid midway between those of the courses above and below (Architectural Publication Society Vol. II, p. 69).

Loudon advocated hollow wall construction especially for rural cottages, boundary walls, agricultural buildings or for barracks, workhouses and factories which required special systems of heating (Loudon 1839, p. 175). He provided several plans for cottages specifying hollow walls built of brick or stone or a combination of the two. Loudon also recommended the use of a hollow wooden box which could be drawn up inside the cavity during construction to ensure a uniform width between the two thicknesses (Loudon 1839, p.640). Only isolated applications of hollow wall construction have been identified dating from prior to mid-century. A Mr. Nicholson of Rochester adopted the technique for building a house in St. Margaret's (Achitectural Publications Society Vol.II, p.70), while Dearne's method was used for cottages in Milkhouse Street at Cranbrook, Kent and in Ordnance Barracks at Shorn Cliffe near Dover and at Portsmouth (Pasley 1826, p.252-53). Loudon also reported that several cottages were built with Silverlock's hollow walls on the estate of Robert Donald in Woking (Loudon 1839, p.189).[5]

In 1840 S.H. Brooks suggested hollow walls for a somewhat better class of dwelling, an Italian-style cottage illustrated in his <u>Designs for Cottage and Villa Architecture</u> (Figure 11.4.). Brooks recommended the two thicknesses of wall should be constructed entirely of stretchers bonded together every third or fifth course by a special brick, 14 inches by 9 inches, and stabilized by stone quoins at the corners. The five inch hollow space in the centre of the wall was used "with suitable ventilators" to circulate and heat the air in rooms (Brooks 1840, p.59-60). Again, only a few examples are known of similar techniques being adopted for larger buildings, one in a villa at East Cowes (<u>Illustrated Builders' Journal</u> 1865, p.117), and the other in the alpaca mill at Saltaire, completed in 1854 by architects Lockwood and Mawson for Titus Salt. The side walls of this structure were built hollow to ventilate the building (<u>The Builder</u> 1854, p.437). Similarly, Thomas Deane designed Queen's College, Cork in 1849 "with apertures in the walls on every side" for vitiated air to escape (Godwin 1850, p.54).

During the third quarter of the nineteenth century cavity wall construction became the chief rival of hollow bricks for buildings requiring special attention to ventilation and damp prevention. Although Chadwick and other sanitary reformers preferred hollow bricks, they frequently recommended hollow wall construction as an alternative for working class housing or rural cottages (Roberts 1853, p. 25). Many of the problems attending the manufacture and use of hollow bricks were spared with cavity wall construction. The expense and difficulty entailed in making specially shaped hollow bricks were avoided as cavity walls were built with ordinary stock bricks. Fewer disagreements with the work force were experienced because the techniques used to build them were more compatible with traditional skills and methods of bricklaying. And, finally, there was not the potential for dispute resulting from patent protection and the payment of royalties.

Many other applications of this building technique have been identified after mid-century. As an example, W. Milford Teulon designed Overstone Hall at Kettering near Northampton in 1862 with double walls, "quite independent of each other; the internal one being of brick, tied to the outer by means of galvanized iron clamps" (The Builder 1862, p. 149-151). Also in 1862 the Inspector-General of Fortifications at the War Office prepared and distributed to the Royal Corps of Engineers both at home and abroad proposed plans for regimental hospitals "requesting that the principles of construction therein shown should be adopted in all future designs for military hospitals." The plans specified that "walls of the wards should be built hollow for warmth, and when constructed of brickwork, the vacuity should not be less than 9 inches from the external face, and need not exceed 2¼ inches". Two hospitals had been erected already according to the plans, one at York Barracks and the other at Hounslow (The Builder 1862, p. 872).

Another hospital built with hollow walls was the Carmarthen Lunatic Asylum by the architect David Brandon. The Builder described the plans in 1863: "In the construction of the walls, local stone will be used, cased with brickwork on the inside, with a vacancy between the brick and stonework to ensure dryness." Brandon designed the building in accordance with instructions issued by the Commissioners in Lunacy (The Builder 1863, p. 605). Schools also were built with cavity walls, such as Rotherham National Schools by a London architect W. White and the "cheap-school and chapel" erected near Romsey in 1860 by the architect E. W. Lower of Guildford (The Builder 1860, p. 580). Later, at

University College, Aberystwyth, John Seddon built walls in the south wing with a cavity "to ensure dryness" (J. Seddon 1871, p. 148-155).

The technique was thought to be most appropriate, however, for modest rural dwellings in exposed locations as an alternative to massively thick walls for preventing the penetration of damp and preserving warmth. After mid-century treatises on the housing of agricultural workers and sponsored competitions for model cottages produced many new designs utilizing hollow wall construction (Associated Architectural Societies Reports and Papers 1861, p. 67-70). [7] The architectural press also occasionally published plans for cottages and descriptions of new techniques for building hollow walls contributed by architects (The Builder 1863, p. 131). In 1860 the Duke of Bedford was singled out for commendation after erecting on his estate "scores upon scores" of labourers' cottages with partially hollow nine-inch walls (The Quarterly Review 1860, p. 279-82 and 289; Gaskell 1986, p. 24-29). According to a correspondent writing in The Builder in 1862, eighty per cent of the working class dwellings erected during the previous ten years at Southampton were built with hollow walls (The Builder 1862, p. 283). This suggests that the technique had become sufficiently widespread that it no longer was considered a novelty requiring special notice in the architectural press. In 1862 a reader of The Builder, responding to a contributor's description of a method for building hollow walls, commented that "walls so formed are not uncommon, but have a very ugly aspect" (The Builder 1862, p. 268).

One important advantage of cavity wall construction over hollow bricks was its simplicity and ease of building. It also provided an easy and inexpensive solution for ventilating small rural dwellings. But, as with hollow bricks, various problems with constructive details began to emerge as the method became more widely adopted. One objection sometimes voiced was the lack of strength in hollow walls. For example, Frederick Pollock, in his Essay and Design for a Pair of Labourer's Cottages written in 1851, refused to recommend the technique because he thought most cavity walls were not securely bonded. He also believed that those built with stretchers laid on edge were unsightly and "not such as gentlemen would be inclined to allow in their estates" (Pollock 1851, p. 6). Another author complained that hollow walls with only narrow cavities "would inevitably get choked with mortar so thoroughly that the wall would be to all intents and purposes a solid wall, admitting the damp as if no hollow existed" (The Builder 1862, p. 250).

As with hollow brick construction, the major problem facing builders of cavity walls was preventing the penetration of moisture while ensuring the stability of the construction. The earliest treatises recommended inserting through headers as often as possible to strengthen the walls, but these allowed water to penetrate through the joints as easily as solid brickwork. One solution to this problem was to dip the concealed sides of the bricks in boiling tar to provide a non-absorbent barrier to the moisture (Rivington 1879, p. 218). Other builders resorted to slate or light iron cramps instead of bricks to tie the two leaves together. One early type was H-shaped with two parallel bars about three inches long by one inch wide, connected at the middle by a bar of the same width as the wall's cavity. The parallel bars rested in the frogs of the brickwork in each thickness of wall, while the connecting bar had a special moulding cast on to prevent moisture moving along the cramp (The Builder 1862, p. 283). Another version was a single iron bar with two V-shaped ends which were built into the inner and outer walls. The bar was bent downwards at the middle so that water travelling along its length would drop to the bottom of the cavity (The Builder 1854, p. 190; Architectural Publication Society 1865, Plate 1; Building Trades Directory 1870, p. 113).

Other products devised to restrict the ingress of moisture in hollow walls included variously-shaped hollow bonding bricks of vitrified or glazed pottery. J. G. Jennings patented a perforated bonding brick with special vertical recesses along its sides to obstruct the passage of water across the cavity (British Patent No. 1502, 1858). Another inventor, John Taylor, designed an improved brick shaped like a modified S-curve so that the end built into the outer wall was in a lower course than that in the inner wall, thus preventing the passage of moisture horizontally along the surface of the brick (Figure 11.5.; Rivington 1879, p. 216). Taylor also suggested placing overlapping roofing slates vertically inside the cavity and securing them by the same iron bars that also tied the two portions of the wall together (The Building News 1874, p. 598; 1876, p. 331).

According to some builders, the penetration of damp from one wall to the other was best prevented simply by circulating the air in the cavity. It was believed that small air-grates or openings inserted in the bottom and top of the outer wall would admit a current of air and keep the inner wall dry (The Builder 1860, p. 64 and 142). In a discussion at the Society of Arts, Robert Rawlinson declared, "of all curses in a house an air-tight roof was perhaps the greatest. The same might be said of air-tight walls and fittings..." (The Builder 1862, p. 926). Others supported the opposite theory that "dampness does not come from without, through the wall, but is deposited from the air within when it comes in contact with the walls, which have been made cold..." (The Builder 1860, p. 64). Proponents of this view believed that confined air in the cavity was non-conducting and would not only keep the walls dry, but also preserve a uniform temperature within the dwelling (The Builder 1869, p. 52). This dispute continued for many years in professional publications, apparently without achieving a consensus of opinion (Beckett 1876, p. 156).

Another disagreement concerned the appropriate thickness of each section of wall to ensure optimum strength and resist damp. In some parts of the country cavity walls were constructed with one portion of ordinary nine inch brickwork for stability and the other a thinner four and a half inch leaf laid in stretcher bond. These were especially common in cities subject to building regulations which required masonry walls to be laid "in such manner as to produce solid work" (Metropolitan Building Act 1844 Schedule D Part II; The Builder 1866, p. 201).[8] On one side of this argument were those who believed it was preferable to build the thicker wall on the outside to provide an ample barrier to the weather, to prevent warmth escaping from the dwelling, and to present a more aesthetically pleasing bond on the building's exterior. Another advantage of this arrangement, according to one source, was that the ends of joists supported by the narrow inner wall remained dry because of the free circulation of air in the cavity. (Architectural Publication Society Vol II, p. 69; <u>The Building News</u> 1876, p. 331).

Others believed thicker walls in exposed situations would admit more moisture and bring it closer to the inside of the dwelling, whereas damp absorbed by a thinner wall was "at once intercepted by the air space, kept out of the greater portion of the wall, and at a considerable distance from the interior of the building." This method also was considered safer as the weight of floor joists or beams was carried on the stonger nine-inch interior wall (Beckett 1876, p. 156; Rivington 1879, p. 215; Stevenson 1880, p. 173). By the end of the century the author of one building manual reported that public opinion seemed to be on the side of constructing the thicker leaf on the inside of the wall (Sutcliffe 1899, p. 107).

It is obvious that no clear consensus of opinion emerged within the profession about how best either to use hollow bricks or to construct cavity walls. But these differences of opinion and discussions about the various problems encountered when building with hollow bricks were necesssary and important for the future development of both innovations. Neither hollow bricks nor cavity walls were initially perfect solutions to the architects' problems of ventilation and damp prevention. Both required a lengthy period of trial and user feedback to direct attention to specific faults or weaknesses and to allow for modifications and alterations which would improve their performance and bring them more into line with the expectations and needs of consumers. These disputes and the consequent avoidance of the adoption of both innovations continued for several decades, influenced also by a more wide-ranging debate about the comparative merits of hollow versus solid construction. Some architects began to examine more closely and challenge the notion of hollowness as opposed to solidity in building. The outcome of these explorations profoundly affected the rate of adoption of both hollow bricks and cavity walls during the last half of the nineteenth century.

11.3. Hollow Versus Solid Construction: The Architectural Debate

Comparisons of hollow and solid construction were concerned with three basic qualities -- sound transmission, fire safety and, above all, strength. Authors such as Edward Lomax and Thomas Gunyon alleged that when hollow bricks were used for internal partitions, sound was "much less easily communicated by them than by common bricks" (Lomax and Gunyon 1852, p. 500). Others agreed, including Joseph Gwilt who claimed they "deadened sound more effectually" than solid work (Gwilt 1867, p. 554; The Builder 1850, p. 152; The Times May 26, 1851). Similarly, cavity walls were considered by some to be "a better sound-killer than any other contrivance", especially in party walls" (The Building News 1882, p. 833). But not all authors agreed with this view. Rivington's Notes on Building Construction, published in 1879, observed that one objection brought against perforated bricks was that "they transmit sound readily" (Rivington 1879, p. 117). Also, in discussing the advantages and disadvantages of hollow walls in his book on House Architecture, J. J. Stevenson reported that "an air space, though good for keeping out cold, rather helps to transmit sound, and carries it sometimes in a curious erratic manner along the walls to distant parts of the house." Stevenson's solution to this problem was to fill the cavity with sand and fine gravel, thus creating a solid wall (Stevenson 1880, p. 192).

A corresponding difference of opinion emerged regarding the potential fireproof qualities of walls built with hollow spaces as opposed to solid construction. From the late eighteenth century architects accepted unquestionably the technique of constructing arched masonry floors with hollow clay pots or tubes as a means of protecting buildings from fire. The small size, light weight and "earthy composition" of these hollow objects made them ideally suited for fireproof floors, especially when they were encased in cement. Publicity given the Prince's Model Cottages at the Great Exhibition asserted that buildings constructed entirely of hollow building materials would be completely fireproof (The Times May 26, 1851). But when The Builder reviewed various methods for preventing fires in dwellings, one expert advised: "In rendering houses fireproof, the next important object to using fireproof materials is that of having all the walls and partitions...filled in with such materials as will render them in effect solid." The author recommended a mixture of clay or loam and Roman cement injected with steam to solidify the mass in the cavities (The Builder 1845, p. 17).

Several papers on the subject of fire-resisting or fireproof construction were published and presented at professional meetings in the decades after mid-century, and a regular correspondence in architectural journals suggested a variety of methods for protecting buildings from destruction by fire.[9] But the "experts" frequently disagreed about the most suitable materials to use. Some like William Fairbairn maintained the safety of hollow iron columns and girders connected by iron tie rods for constructing fireproof warehouses and factories (Fairbairn 1864, pp. 137-1860). One entrepreneur from Liverpool, Samuel Holme, "who had great experience in building warehouses", advised that hollow columns should be connected so they could be cooled in case of fire by a current of air circulating between them (Lewis 1865-66, p. 111). Others, such as Thomas Morris, an Associate of the RIBA, believed that "iron was not a trustworthy material", but supported the theory that "confined air was a non-conductor of heat" and noted that air-tight compartments in floors and walls often obstructed the progress of severe fires (Lewis 1865, p. 126). A patent based on this principle was granted in 1867 to J. H. Johnson for "hermetically closed hollow or cellular blocks intended to be let in between the beams, joists, girders or supports of buildings and secured therein by plaster or cement" (British Patent

No. 3377, 1867). Another RIBA Fellow, J.H. Parker, declared that "hollow walls and floors are what you want for warming rooms and resisting fire." He recommended a construction system like that used by the Romans with hollow concrete walls and floors built with hollow tiles which would "resist any amount of heat" (Fowler 1870-71, p. 80).

Captain Shaw of the London Fire Brigade warned, however, that the use of hollow and perforated bricks incurred considerable risk because, he explained, "in the case of fire there is great danger of those walls falling in consequence of the confined air within them expanding and splitting the bricks" (Lewis 1865, p. 125). This authoritative opinion provided additional support for advocates of solid construction techniques. One correspondent to The Builder in 1861 suggested a building technique using "wrought iron hollow cellular beams, joists and wall-plates" with hollow clay blocks for arched floors which were filled during construction with a mixture of sawdust and alum. According to the author, this was similar to the way fireproof safes were sometimes constructed. When exposed to high temperatures the alum would dissolve and produce with the sawdust a "wet fire-resisting and non-conducting medium" which would lower the heat and thus reduce damage to the building (The Builder 1861, p. 829).

Various newly patented techniques for building "solid" fireproof floors and ceilings with iron or wooden members filled or encased in cement or concrete were introduced during this period. One early paper read at the RIBA described French ceilings of gypsum plaster poured over a web of light iron bars supported by rolled iron joists (The Builder 1854, p. 28 and 149-50). Fox and Barrett's system of fireproof construction, patented as early as 1844, also consisted of layers of cement and concrete spread over wooden laths laid between wrought or cast iron girders and joists (Proceedings of the Institution of Civil Engineers 1853, pp. 244-72; The Builder 1854, p. 53-54). Fox and Barrett's floors proved to be extremely popular in subsequent decades despite being covered by patent protection. Other variations on concrete fireproofing systems were introduced by Matthew Allen, Archibald Dawney, and the

Measures Brothers in 1862, Julius Homan (British Patent No. 1593, 1865), Thaddeus Hyatt, W.H. Lindsay & Co., Dennett and Ingle of Nottingham, and Richard Moreland in 1866.[10]

Concern over the effects of air, either confined or circulating, on the spread of fires in large buildings diminished sufficiently by the 1870's for a number of new patented flooring systems to appear which combined concrete with hollow clay blocks or tubes (Figure 11.6.). Following two new patents in 1871 for hollow flooring tiles (British Patent No. 2912, M. Bates and No. 3291, R. and J. Stanley), Lewis Hornblower of Liverpool patented his "Cellular Terra Cotta Fireproof Girder Floor" in which iron girders or joists were entirely encased with hollow earthenware blocks and filled with concrete or cement. Flat arches of hollow bricks embedded in concrete were laid between the girders resting on the clay skewbacks (British Patent No. 3714, 1873; Cates 1877-78, p. 298). Doulton and Co. of Lambeth introduced another floor of specially-shaped hollow fire-clay skewbacks and voussoirs which encased and protected the girders and formed flat arches of approximately eight feet span (Webster 1890-91, p. 270). Lindsay's system consisted of two foot long rectangular hollow bricks laid so that the air spaces were at right angles to the supporting joists. The entire construction was covered with a layer of concrete (Webster 1890-91, p. 217). Later patents by Julius Homan (British Patent No. 3932, 1885 and No. 11,937, 1889) also were based on tubular bricks laid longitudinally between steel girders and covered with a layer of concrete (Hamilton 1958b, p. 19; Adams 1909, p. 230).

Various other hollow tile flooring systems were introduced in this country from America in the 1880's and 90's, including those from the Pioneer Fire-proof Construction Company of Chicago and The Raritan Hollow and Porous Brick Company of New York (Webster 1890-91, p. 272-73). Reduction of weight was one recognized advantage gained by using hollow tiles in fireproof floors. But by the end of the century there also seemed to be a revival of interest in using these hollow spaces for ventilation. According to Webster, an important feature of Fawcett's

"Ventilated" Fireproof Floor (British Patent No. 2815, 1888) was the hollow tubes placed at right angles to the joists but dropped slightly below so they encased the lower end of the ironwork and left an open space "to form a free passage of air" (Webster 1890-91, p. 272; Hamilton 1958a, p. 50). This renewed confidance in the movement of air through walls and floors is illustrated by a new patented hollow fireproof flooring system introduced by the Banks Fireproof Construction Syndicate and demonstrated at their "Exhibition of Fireproof Construction and Fire Tests" at the St. Pancras Ironworks in 1894. The floor consisted of a four-inch thick concrete arch poured directly over a bed of sheet iron which was supported above a suspended ceiling of steel lathing encased in plaster. Between the two layers was an air space "through which, by the use of air bricks in the exterior walls, a current of air [was] allowed to pass", the design being based on the principle of "a moving body of air acting as a non-conductor" (The Builder Vol. 67 1894, p. 307).

Comparisons of hollow and solid walls also considered the important question of strength. Until the mid-1860's professional publications promoted the idea that walls built with hollow spaces were equally strong as solid walls. This was believed especially of cavity walls which The Builder claimed, "for the same amount of materials may be made stronger if hollow than if solid" (The Builder 1860, p. 64). An article reprinted from the American publication, Architect's and Mechanic's Journal, stated that "for all purposes of stability, where a mere power or force of compression is to be overcome, as in the case of ordinary public and private structures, the hollow wall has many advantages, and experiments have shown that an equal mass of materials so built or disposed as to leave a vacuum or spaces between their outer or enclosing bodies, but occasionally banded across, both vertically and horizontally at moderate intervals, and with sufficient substance to unite the exterior bodies firmly together, will not only be far more rigid and firm than the like quantity of materials so built or disposed in a solid mass, but will likewise bear a much greater superincumbent pressure" (The Building News 1860,

p. 753; <u>Illustrated Builders' Journal</u> 1865, p. 151).

In subsequent decades, however, the strength of hollow construction was increasingly doubted. William Simmons, a correspondent to <u>The Building News</u> in 1882, declared: "My advise to persons about to build hollow walls is that of <u>Punch</u> to those about to marry -- Don't." Simmons objected to the lack of strength of hollow walls and to their expense. He also thought that "they are liable to become the breeding-place and recreation ground of all kinds of vermin." Simmons recommended building walls with an inner and outer shell of half bricks leaving a space at least half a brick wide and then packing the centre with cement or selenitic lime concrete (<u>The Building News</u> 1882, p. 833). After reviewing a new method for constructing interior walls with hollow tubes embedded in a patent fire-proof cement, the editor of <u>The Builder</u> expressed a similar view when he wrote: "We confess we are in favour of a partition which is solid throughout rather than one with hollow spaces in it" (<u>The Builder</u> 1893, p. 457). Finally, at the discussion of a paper presented by H. H. Statham to the Seventh International Congress of Hygiene and Demography in 1891, J. P. Seddon, a Fellow of the RIBA, said he agreed with Mr. Statham in his "jeremiad against hollows". He explained: "Hollow walls were a prejudice. They were intolerable for harbouring vermin. A very perfect and cheap wall could be made with two 4½ inch brick walls, with an inch air space. The inside joints might be left a little open, and the cavity filled in with Portland cement grouting, and the courses might be bonded by a few tie-courses being placed under or over the window. The walls thus become very solid. Hollow walls, like everything that was hollow, were injurious" (<u>The Builder</u> 1891, p. 147).

For most of the century building practitioners in many towns were constrained and possibly philosophically influenced by conservative building regulations insisting that all walls should be built solid. The revised Metropolitan Building Act of 1855 controlled the thickness of external walls in new buildings based on their height in relation to their number of stories. The Form of Bye-laws written in 1858 and the Model Bye-laws of 1877 enabled other local authorities to regulate wall thicknesses according to local custom (Gaskell 1983, p. 24; Harper 1985, p. xx and xxii). In some cases, for instance in the legislation enacted in Newcastle in 1866, this meant that buildings of one or two stories were required to have solid walls at least fourteen inches thick (Gaskell 1983, p. 60).

These acts usually were patterned after London's Metropolitan Building Act of 1844 in stipulating that all walls should be built of "sound bricks or stone, or of such bricks and stone together, laid in and with mortar or cement in such manner as to produce solid work" (Tredgold 1848, p. 14). Under the London acts provision was made for an official referee to adjudicate in cases where unusual materials or construction methods were proposed. As we have seen, in one such case the referee allowed perforated bricks but specified that they should be of the same size as ordinary stock bricks, that the headers should have only six transverse perforations and the stretchers three longitudinal perforations separated by a thickness of not less than one-half inch (The Builder 1853, p. 491). Provisions for cavity wall construction only appeared in London legislation in 1894 and then with the restriction that one side of the cavity should be the same thickness as a solid wall (Harper 1985, p. xxvi).

For many years building legislation clearly conflicted with some of the more progressive professional opinions regarding the strength of hollow construction. In this country experiments were undertaken occasionally to determine the strength of individual hollow bricks or hollow brick arches in fireproof floors, but only foreign laboratories attempted to test the strength of hollow brick walls. The results were seldom published in Britain (Butterworth and Foster 1956, p. 464). So although some architects expressed confidence in the strength of walls containing hollow spaces, in practice they adopted hollow bricks only for the smallest dwellings, undoubtedly because of the potential weakness of the bond in most hollow brick systems. Architects trusted the strength of cavity walls for slightly larger buildings, but the technique was rarely applied to structures of more than three stories.

Uncertainty amongst architects about the value or desirability of leaving hollow spaces in walls and floors led to many variations in building practice. For example, in 1875 new "sanitary" working class housing sponsored by the Improved Industrial Dwellings Company in Goswell Road, London and designed by the architect Henry Macaulay, was built with hollow brick walls filled "for the sake of economy" with concrete made from old materials found on the site. Ventilation was provided by simple vertical shafts in the brickwork (The Builder 1875, p. 347). A number of new patents also appeared for hollow brick products which could be either left empty or packed with rubble or concrete to form solid work, thus appealing to architects on both sides of the dispute. An early patent in 1863 by S. St. B. Guillaume specified square hollow bricks for arches or walls with the hollow "sometimes filled with tiles, etc." (British Patent No. 1398, 1863). Johnson's improved hollow bricks, with projecting flanges to "embrace closely the bottom of a similar block when placed thereon", were made of clay by machinery and could be "made solid or hollow, but by preference they are hollow so as to form hollow ventilating walls for grain bins and similar structures" (Figure 11.7.; British Patent No. 3622, 1869). Another example was the invention by P. A. Gaillon for cellular clay blocks with mortise and tenon joints and the hollows "filled partially or entirely with concrete or sand" (British Patent No. 2414, 1873).

Despite prevalent suspicions about the performance of iron in fires, some of these patents specified hollow metal "bricks" like A. Tronchon's "cast iron boxes united by interlocking tongue and groove joints" and filled with sand to deaden sound (British Patent No. 2238, 1860). E. Strangman invented "hollow boxes or cells of cast iron bolted together" and further specified that "these cast iron boxes or cells may either be left open or cased in on the inside and may be filled with rough stone, brick, or timberwork according to the nature of the building or part of the building for which they are employed" (British Patent No. 1053, 1861). Weekes' patent in 1868 also related to iron bricks with internal strengthening ribs which were clipped together for additional stability (British Patent No. 2284, 1868).

One highly publicized invention was the cellular construction patented by the architects, Samuel Parr and Alfred Strong (Figure 11.8.). These were short hexagonally shaped clay tubes laid side by side in the wall, "filled wholly or partially with concrete", and capped at both ends with plain hexagonal tiles made with a rim that fitted inside the tubes (British Patent No. 1416, 1868). Another alternative was to cap only the ends of the tubes forming the interior surface of the wall while filling the exterior ends with a partial plug of Portland cement and ballast and then facing the entire wall with a layer of cement or pieces of stone. Although the patentees pointed out "the value of the cavity or air-cell in the tubes as making the wall weather-proof", for larger buildings requiring greater strength it was recommended to fill the tubes entirely with concrete and further strengthen them with iron dowels or bolts (The Builder 1868, p. 353). The system was used experimentally in a hall constructed by the Strand Hotel Company. In a series of patents granted in 1873, Thaddeus Hyatt perfected similarly shaped "hexagonal cells filled with concrete and used in constructing roofs, partitions, floors and walking and other surfaces." The bricks were made of thin metal or various other moulded materials, and like Parr and Strong's patent they were capped at both ends with glazed tiles (British Patent No. 3381, 1873; No. 3658, 1873). Both of these new products suffered from the same defect as other hollow brick systems in that they required numerous "specials" to complete corners or quoins, door and window openings.

Another related product that emerged from the debate over solid versus hollow construction was the perforated clay facing block used to construct hollow walls filled with other cheaper materials such as inferior bricks, concrete or rubble. One of the earliest of these new facing blocks was patented by W. Walton in 1861 (Figure 11.9.; British Patent No. 1093; The Builder 1861, p. 830). Each of Walton's L-shaped bricks had a bevelled upper and lower edge on its narrow exterior face and large horizontal perforations in the portion bonded into the wall. G. Follett proposed facing blocks made of hard stoneware "or like waterproof material" in a modified P-shape. The open portions of the blocks were built into the brickwork while the thin slabs were rabbeted and fit together to form a facing on the outer surface of the wall (British Patent No. 2206, 1869).

The architect John Taylor introduced large L-shaped perforated blocks 12 inches by 4½ inches on the face which were bonded into ordinary brickwork leaving hollow channels in the wall (Figure 11.10.). He also invented a smaller brick made of "best red earth" with a single circular perforation for facing concrete walls. Each brick was 9 inches long by 2¾ inches on the face, but they were moulded by machine together in a larger block containing six loosely attached bricks to avoid the risk of warping during manufacture and to save space during transport (Figure 11.11.). On the building site the bricks were easily split apart with a chisel, laid in courses on each side of the intended wall, and concrete was poured in course by course to create a solid mass (Figure 11.11.; Taylor 1862-63, p.85-87).[11] A similar system was illustrated in The Builder in 1868. Stables and a coach house at Hersham Lodge, Walton, Surrey, designed by the architects Walford, Donkin and Evill, were built of concrete with special facing bricks made by the Broomhall Tile Company (Figure 11.13.). The twelve inch long L-shaped bricks were moulded in pairs as a single tube-shaped block, but were separated on the site and used to build hollow walls which were then filled with cement concrete (The Builder 1868, p.658). A company respresentative told a meeting of the RIBA in 1876 that the blocks had been used in railway works outside of Dublin and "with good success" in house building at Mortlake and Richmond (Payne 1875-75, p.191-92).

Filling hollow bricks and lining concrete or brick walls with perforated facing blocks offered one solution to the problem of solidity and, hence, the strength of construction. But many architects objected to these products on the basis of appearance and cost. For example, walls built with Parr and Strong's hexagonal bricks had a curious honeycomb surface pattern which one author believed "would not suit all architectural purposes" (T.R. Smith

1874-75, p.209). According to another critic, Taylor's large facing bricks "did not produce a satisfactory effect for the fronts of buildings, owing to their not being perfectly flat." Sir William Tite, president of the RIBA in 1863, objected to the standardization of these products and felt their rigid dimensions "would require the rooms to be multiples of the same dimensions, and all the walls, etc. at right angles" (Taylor 1862-63, p.95).

With regards to costs, J. Douglas Matthews told a meeting of the Architectural Association that walls filled with concrete and lined with facing bricks were obviously more expensive than ordinary brickwork and could only be justified "where great thickness was required for strength and appearance" (The Builder Vol.34 1876, p.516). The editor of The Building News expressed the same opinion when he wrote: "It is difficult to arrive at the exact comprehension of the object aimed at, and supposed to be gained by the use of hollow tiles, which are intended to be filled with concrete. One would be inclined to imagine that if the hollow box requires to be filled with concrete to give it strength enough to act as a building material, it would be simpler to omit the enclosing envelope, and use the concrete in the shape of a solid block... There appears to be very little use in enclosing so cheap a material as concrete in so expensive an envelope as that of pottery ware" (The Building News 1868, p.579). This argument was concerned not only with the cost of filled hollow brick products. It also reflected the popular moral objection to "shams" and "dishonest" construction which was at the heart of Gothic Revival architectural theory. And it alluded to concurrent debates raging within the profession during the third quarter of the nineteenth century about two other "new" building materials -- concrete and terra cotta.

Roman cement concrete was used in Britain during the first half of the nineteenth century to construct foundations, fireproof flooring, and when formed into large blocks frequently called "artificial stone", to build sea and river walls. The development of Portland cement, with its vastly improved cohesive strength, encouraged further experimentation with this new material and culminated in Francois Coignet's patent in 1855 for monolithic concrete construction (British Patent No. 2659; Halstead 1961-62, p. 37-54; Skempton 1962-63, p. 117-152; Hamilton 1956). Various experiments during the 1860's revealed the many difficulties involved in building with concrete in monolithic form. These problems were examined and discussed by architects throughout the 1870's at meetings of the RIBA and the Architectural Asssociation (Blomfield 1870-71; Wonnacut 1871, and Payne 1875-76). They also were reviewed in a book by Thomas Potter in 1877 entitled, Concrete: Its Use in Building.

Many of the uncertainties and anxieties about concrete were similar to those raised about other new building materials. Doubts were expressed about the strength and durability of concrete construction, which was liable to fail when poor quality materials were used. There were disagreements over the need or desirability of employing skilled labour. Architects also were apprehensive about the tendency of concrete to absorb damp, and about its high cost compared with more traditional materials. But an even greater cause for concern amongst many professionals was the offensive appearance of concrete. At the Royal Institute of British Architects in 1871 Professor Robert Kerr carefully distinguished between the structural and aesthetic possibilities of concrete: "That [concrete] is a material which has a future is beyond doubt; whether it is capable of being brought into use for architectural purposes (artistically speaking), is a question which may admit of debate..." (Blomfield 1870-71, p. 183). Many architects thought concrete had a "coarse, rough, uneven, and uninviting" appearance while others were repelled by its drab colour (Blomfield 1870-71, p. 184; Payne 1975-76, p. 180).

Generally speaking, nineteenth century architects had no clear idea of how to design in concrete. Charles Drake, inventor of a patented concrete moulding apparatus, remarked in 1876 that "the real stumbling block to the progress of concrete building is the want of architectural treatment." He believed the profession was slow to adopt concrete construction because "as soon as it was seen not to conform to the rules laid down by the men of 'past' ages for the architectural treatment of brick or stone it was neglected" (Payne 1875-76, p. 229). Most architects agreed with Thomas Potter who thought concrete should be used "without pretence of being something totally different from what it is" (Potter 1877, p. 5). Charles Barry, Junior also stated that "it is undesirable in using concrete of ordinary character to try to imitate features appropriate to other building materials..." (Payne 1875-76, p. 254). But the more "honest" logical alternative, which Peter Collins later described as a "reduction of all surfaces to pristine nudity", also was not aesthetically acceptable (Collins 1959, p. 98).

Various suggestions were proposed for the appropriate decoration of concrete, paticularly the application of colour and surface decoration. Alexander Payne advised architects to aim for broad wall surfaces, shallow projections and ornamentation consisting of inlaid tiles, sgraffito, or stencilled patterns (Payne 1875-76, p. 183). But many architects considered monolithic concrete "unadaptable to artistic treatment." As one Associate of the RIBA pointed out, it had "nothing of the agreeable appearance which belongs to work built up piece by piece" (Blomfield 1870-71, p. 184-185). This attitude led some back to the idea that concrete was best treated as a purely structural material in the form of utilitarian blocks or as a core or filling for walls faced with finer materials like clay bricks. Others insisted that these were not "legitimate" treatments of the new material and not novel enough (Payne 1875-76, p. 180 and 245). The editor of The Builder replied to a correspondent: "A very good house may doubtless be built of concrete blocks, but it would not be a 'concrete house' for all that" (The Builder 1867, p. 495).

The dispute over the appropriate treatment of monolithic concrete continued on into the 1880's when, according to Collins, it reached an impasse. But the development of other alternatives, particularly concrete blocks, continued separately. The Building News was a steadfast advocate of concrete blocks "for temporary structures, as camp buildings, temporary assembly halls, club-rooms, railway stations, churches and school buildings." It regularly illustrated new patented systems which usually took the form of large hollow blocks with grooved or rusticated faces resembling ashlar (Figure 11.14.; The Building News 1857, p.1008; 1861, p.387; 1868, p.447; 1875, p.192; 1876, p.490; and 1879, p.411). After 1900 simple, hand-operated concrete moulding machines were introduced for use on large building sites (Figure 11.15.; The "Caledonia" Concrete Block Machine Company n.d., p.4-13; Newbold 1925, p.164-183). These provided an economical and convenient means for mass producing concrete blocks for working class "cottage" estates where, previously, other sanitary building techniques like hollow bricks or cavity wall construction might have been proposed. The architectural profession disregarded concrete blocks until the end of the century when the fashion for stucco, rough-cast and pebble-dash was revived by architects like C.F.A. Voysey and Ernest Newton and offered an acceptable "artistic" solution to the problem of unadorned concrete surfaces. In 1905 the periodical, Garden City, commented that "concrete hollow blocks form perhaps the most interesting feature of the recent cottage building experiment... For appearance, strength, and durability, the concrete block will be generally preferred to bricks..." (cited in Gaskell 1986, p.72).

Controversies surrounding the filling of hollow or perforated bricks and blocks for the purpose of securing greater strength in construction also were closely related to similar disputes surrounding the revival of architectural terra cotta during the mid-nineteenth century.[12] The earliest building schemes employed terra cotta in the form of small solid blocks. Edmund Sharpe, the architect who built the experimental "pot churches" at Lever Bridge and Platt near Manchester in 1842 and 1844, stated later he was "anxious that, wherever it was possible, the terra cotta should be solid throughout." He found, however, that large solid pieces used for door and window jambs, arches and sills as well as for portions of the buttresses and pinnacles warped while drying and were difficult to burn thoroughly. Consequently, the backs of these specially-shaped pieces were hollowed out and later filled in with concrete "in such a manner as to render the whole perfectly solid" (The Builder 1876, p.554).

Charles Barry, Junior, in his important paper on terra cotta delivered at a session of the RIBA in 1868, believed that "for architectural work, the smaller the pieces, or nearer the pieces approach to the size of a large brick, the more economical will be the work." But he also admitted that there was "no practical difficulty or objection to using terra cotta in large pieces...made hollow for the purpose of insuring equal hardness and contraction throughout" and filling them with fragments of terra cotta in Roman cement. Barry and J.M. Blashfield, a terra cotta manufacturer from Stamford, tested variously shaped solid and hollow blocks of the material to ascertain their resistance to crushing. They found hollow pieces of terra cotta were considerably less strong than solid ones. Filling the cavities with Roman cement, however, nearly doubled the strength of the hollow blocks. Barry used filled-in blocks for constructing New Alleyn's College, Dulwich and stated: "I think this is the only legitimate way in which to employ the material, and give it its true value as a building material" (Barry 1867-68, p. 264, 269, and 270). But other architects, like Edmund Sharpe, thought that filling hollow terra cotta blocks was an "evil" solution because it was "pre-eminently unsatisfactory to reduce the ornamental part, or showside, so to speak, of the block to the condition of a shell, whilst honest stone or concrete does duty at the back as the real masonry of the building" (The Builder 1876, p.554)

This conflict was partially resolved during the 1870's when terra cotta buildings commonly were constructed with a combination of solid blocks or tiles and larger hollow pieces filled with Roman cement concrete (Stratton 1983, p.10). For example, in the Natural History Museum in London, built between 1873 and 1881 by Alfred Waterhouse, each course had hollow facing blocks bonded into the solid block walling alternating with thin terra cotta slabs (Figure 11.16.; Olley and Wilson 1985, p.35). According to one journalist, it was possible for hollow blocks to remain empty depending upon where they were used in the building and how much weight they had to carry (The Builder 1880, p.196). By the 1880's most structural terra cotta was moulded into hollow blocks from one to two inches thick with internal webs or stays for added support. Building manuals recommended filling the blocks only when they were "required to bear considerable weight" (Rivington 1879, p. 126; Gwilt 1888, p. 531). This advice resembled suggestions put forward twenty years earlier to solve similar problems with hollow brick construction.

It is evident that the third quarter of the nineteenth century was a period of intense debate, competition and experimentation with a variety of new building materials and construction techniques. Although none of these new products was an "ideal" solution to the problems which preoccupied the building industry, each offered a range of developmental possibilities and had at least the potential to "succeed". In conclusion, we must ask why hollow terra cotta blocks were more acceptable to the architectural profession than hollow bricks which were virtually ignored after 1860 except for certain very specialized purposes? The obvious difference between the two materials was that hollow bricks were standardized, machine-made components while the manufacture of terra cotta allowed architects direct control over the design and manipulation of the blocks used in building. This was a difference of paramount importance to nineteenth century architectural professionals who increasingly maintained that their "artistic" sensibilities set them apart from other ordinary building practitioners (Jackson 1893, p. 409).[13] Hollow bricks, in addition to other shortcomings, also lacked the creative possibilities of competing products.

When using terra cotta, Barry, Waterhouse and other architects personally prepared quarter scale and full-sized "shrinkage" drawings of all decorative details and often supervised delicate modelling and finishing of individual pieces before they were burned. This was what distinguished terra cotta from other materials as Charles Barry, Junior pointed out: "Terra cotta bears the impress at once of the mind of the designer and the skill of the modelling artist" so that "a far better reflex of the personality of the architect will thus be found in a building than can ordinarily be the case" (Barry 1867-68, p.265). According to many architects, terra cotta was "the more valuable material" because "more artistic skill was capable of being displayed" (Darbishire 1864-65, p.78). Although terra cotta suffered from a variety of weaknesses and complications, nineteenth century architects consistently favoured it over machine-made hollow goods. Speaking about clay building products at a meeting of the RIBA, Professor Kerr commented: "I am inclined to object to the principle of the infinite reproduction of identical detail in such a material" (T.R. Smith 1874-75, p.215).

Ironically, it was the custom-made nature of terra cotta production that ultimately undermined its economic viability. Although it remained a popular material into the twentieth century, demand for terra cotta was unpredictable and manufacturing costs were obviously high with so little repetition in design. Complications frequently arose in the production of blocks for large building projects. This led to the collapse of some firms and caused others eventually to cease manufacturing the material in periods of general economic decline (Stratton 1983, p.357-358).

Ultimately the demand for inexpensive, standardized building products increased in the early twentieth century and there was a renewal of interest in machine-made hollow bricks and blocks in a variety of materials. By 1925 large hollow brick-blocks, sometimes called "cavity bricks", were used for "rapidly-erected walls of exceptional lightness" or the inner membrane of walls sheathed with facing bricks. The Mansfield or Clare "Interloc" blocks and Frewen double cavity bricks were large cellular blocks made of carefully prepared brick earth with strengthening internal webs and external tongues or ridges and grooves which locked together to stabilize the construction. Besides their light weight and ease of construction, it was claimed the blocks would act as an insulating medium and provide flues or conduits for pipes. Newbold stated: "The design of such materials is sound, for a cube with thin walls, reinforced with a diaphram or web which is integral with the structure has, like a circular tube, wonderful powers of resistance both to vertical and lateral stresses, as we see in a hollow bamboo or a drawn steel tube" (Newbold 1925, p. 80).

The changing attitudes and social environment that initiated this shift in emphasis and the acceptance of hollow clay constructive units by the building industry and architectural profession during the twentieth century constitutes an account of technological change outside the scope of this thesis, but one that remains to be written.

NOTES

1. For the failure of stonework in the Houses of Parliament see BPP Report of the Committee on the Decay of Stonework in the New Palace of Westminster (1861, Questions 1900-3 and 1949) cited in Port (1976, p. 98).

2. A brief summary of the history of cavity wall construction may be found in Brunskill and Clifton-Taylor (1977, p. 143-148) and Ritchie (1973, p. 40-49).

3. Per conversation with Susan Roaf.

4. According to the Architectural Publication Society's Dictionary, Dearne sent a communication to the Repertory of Arts in 1814 illustrating his walls (Vol. II, p. 69). Details also appeared shortly afterwards in Pasley (1826, p. 252-53) and Loudon(1839, p. 168-175). Brunskill and Clifton-Taylor termed walls so constructed, "Dearne's Bond" (1977, p. 68).

5. This construction method is sometimes called "rat-trap bond" and is usually described as a vernacular building technique. See Brian (1972, p. 11-15), Brunskill and Clifton-Taylor (1977, p. 143), Perrins (1980-82, p. 218-220), and Smith, T. P. (1975, p. 344-47). Most examples of rat-trap bond date from after 1840 and although there has been debate about its origin, it seems to have been derived from Silverlock after Loudon's publication.

6. For another example before mid-century see Smith, J. and T. (1835-36, p. 52-60).

7. See also the list of publications compiled and discussed by The Quarterly Review in 1860 (p. 267).

8. Cavity wall construction was not officially recognized in London until provisions were included in the new London Building Act of 1894 (57 and 58 Vic.[cap. lxxviii]). Amendments during the 1880's to the Public Health Act of 1875 (38 and 39 Vic. cap. 55 sec. 157), which excluded London, also contained specifications for the construction of hollow walls (Harper 1985, p. xxv).

9. For a summary of these papers see Hamilton (1958b) and

various issues of The Builder between 1856 and 1861.

10. Illustrations of some of these systems are in Webster (1890-91, p. 265-69) and Hamilton (1958b, p. 17-19); see Cates (1877-78, p. 299-304) for an explanation of Hyatt's patent; for a description of Dennet and Ingle's floors and a list of major buildings employing the system see Laxton's Price Book (1886, p. 229) and the Building Trades Directory (1886, p. 740).

11. These perforated facing blocks were intended to overcome some of the problems of manufacturing and using the solid L-shaped facing blocks previously patented by Taylor in 1856. These blocks, which according to the inventor were given a "lengthened and extensive use", were employed at St. Mark's, Silvertown, the docklands church by S. S. Teulon completed in 1862 (Architects' Journal 17 February 1988, p. 65; 9 March 1988, p. 68-69).

12. See Stratton (1983) for a comprehensive account of the terra cotta revival during this period.

13. According to T. G. Jackson, "In architecture, as in the other arts, it is the faculty of design that makes the artist. It is this that differentiates him from other men..." For a discussion about the concept of the "art-architect" and the rift between "art" and "professionalism" in the late nineteenth century see Saint (1983, p. 62-66).

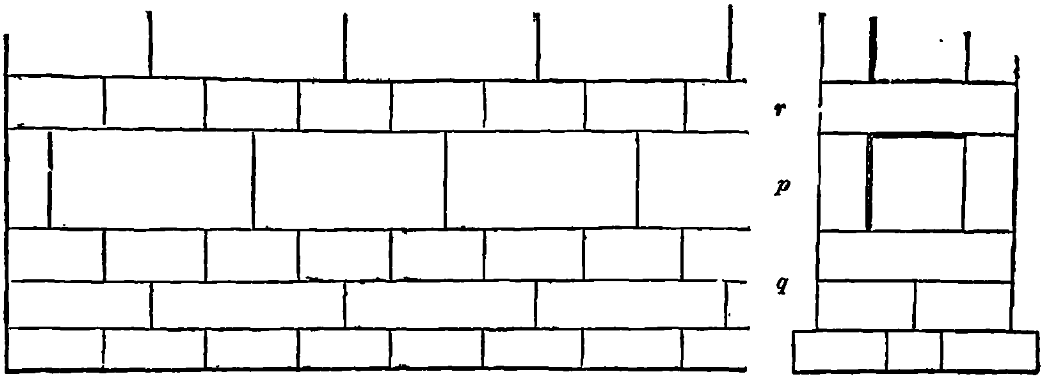


Figure 11.1. Dearn's method of building hollow walls; elevation and section of part of a wall.
[From J.C. Loudon, Encyclopedia of Cottage, Farm, and Villa Architecture (1839) p.168]

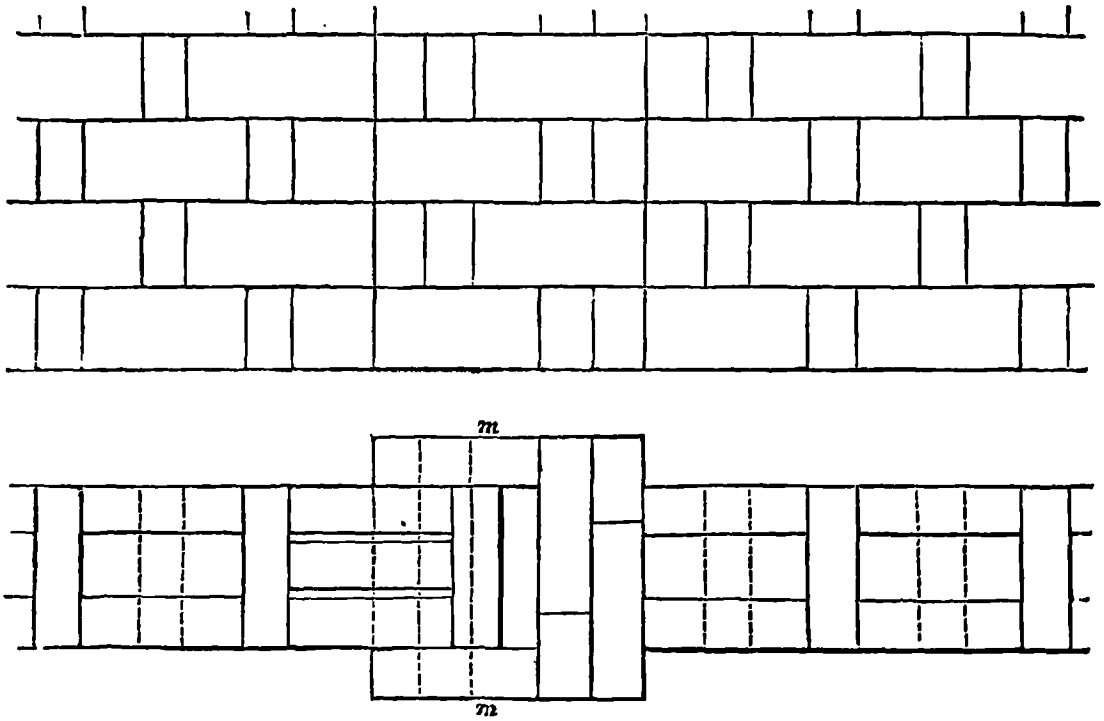


Figure 11.2. Plan and elevation of Silverlock's hollow walls.
[From J.C. Loudon, Encyclopedia of Cottage, Farm, and Villa Architecture (1839) p.186]

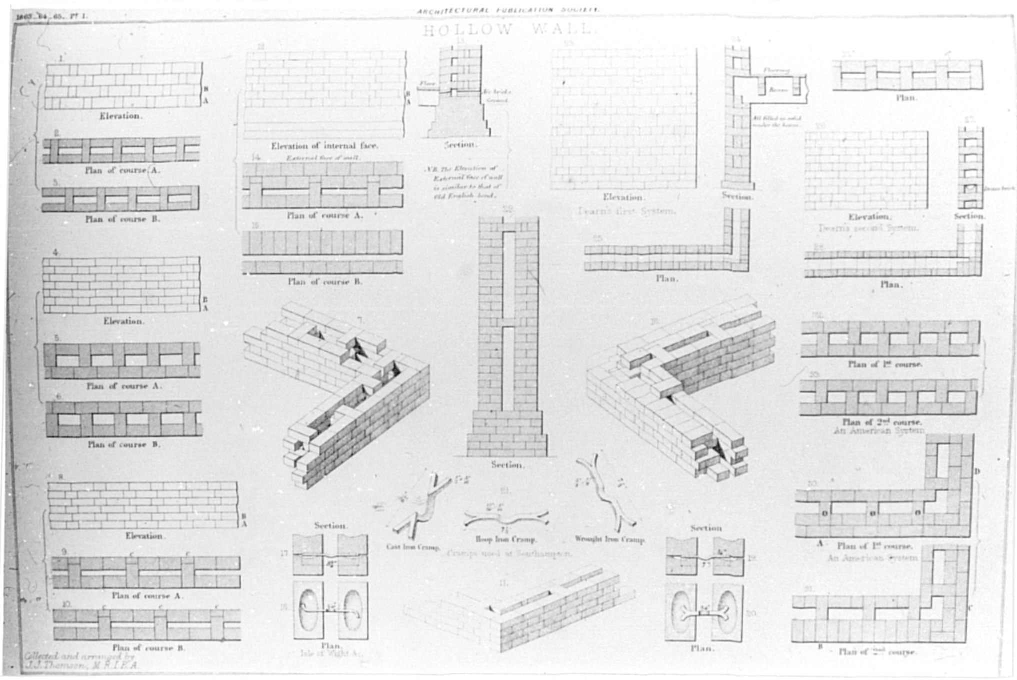
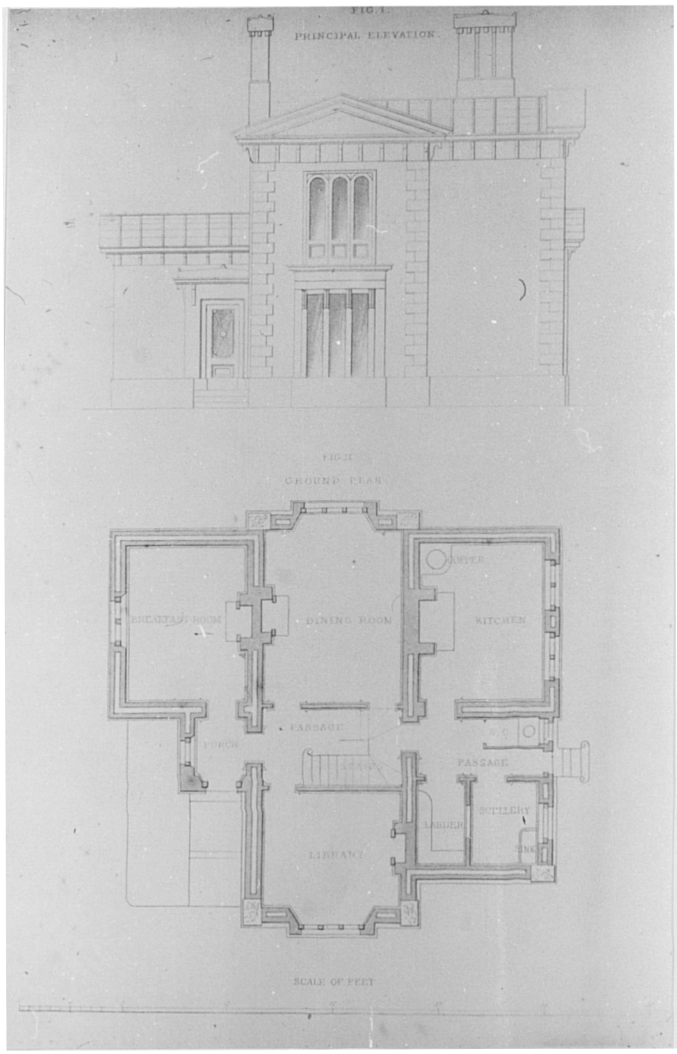


Figure 11.3. Various techniques for constructing hollow walls during the nineteenth century.
[From Architectural Publication Society, Illustrations Vol.I (1865)]

Figure 11.4. Principal elevation and ground plan of an Italian cottage by S.H. Brooks constructed with hollow walls, 1840.
[From S.H. Brooks, <u>Designs for Cottage and Villa Architecture</u> (1840) Plate XLIV]



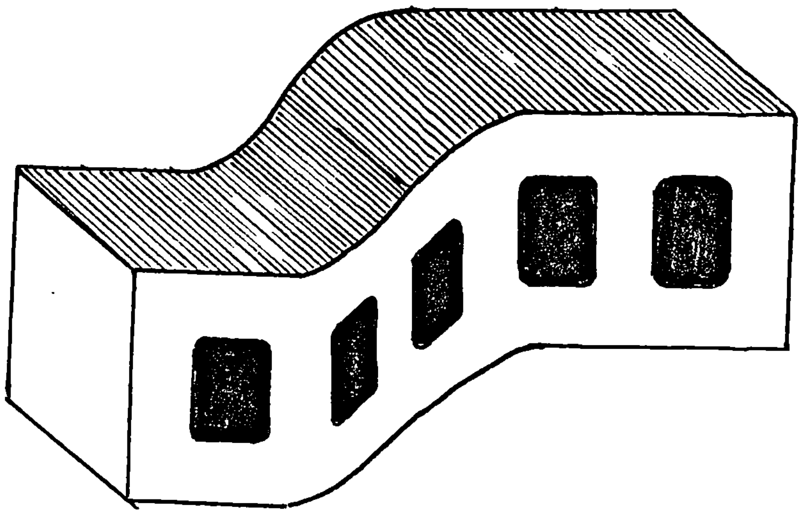


Figure 11.5. Hollow bonding bricks with modified S-curve designed by John Taylor.
[From Rivington's Notes on Building Construction Part III (1879) p. 135]

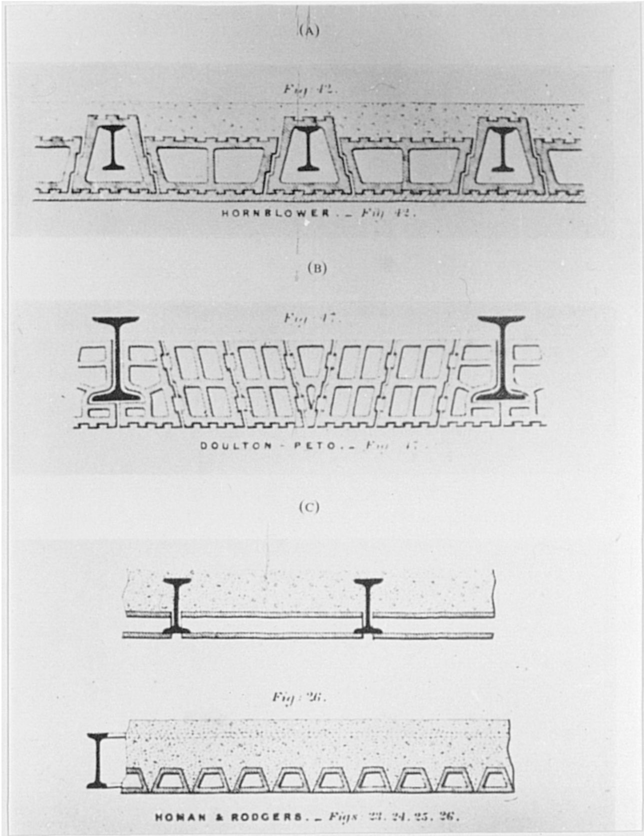


Figure 11.6. Patented fireproof flooring systems. Top, by Lewis Hornblower; middle, by Doulton and Peto; bottom, by Homan and Rogers.
[From S.B. Hamilton, <u>A Short History of the Structural Fire Protection of Buildings, Particularly in England</u> (1958)]

Figure 11.7. Johnson's hollow building bricks, British Patent No. 3622, 1869.
[Drawing enrolled with patent]

FIG. 2.

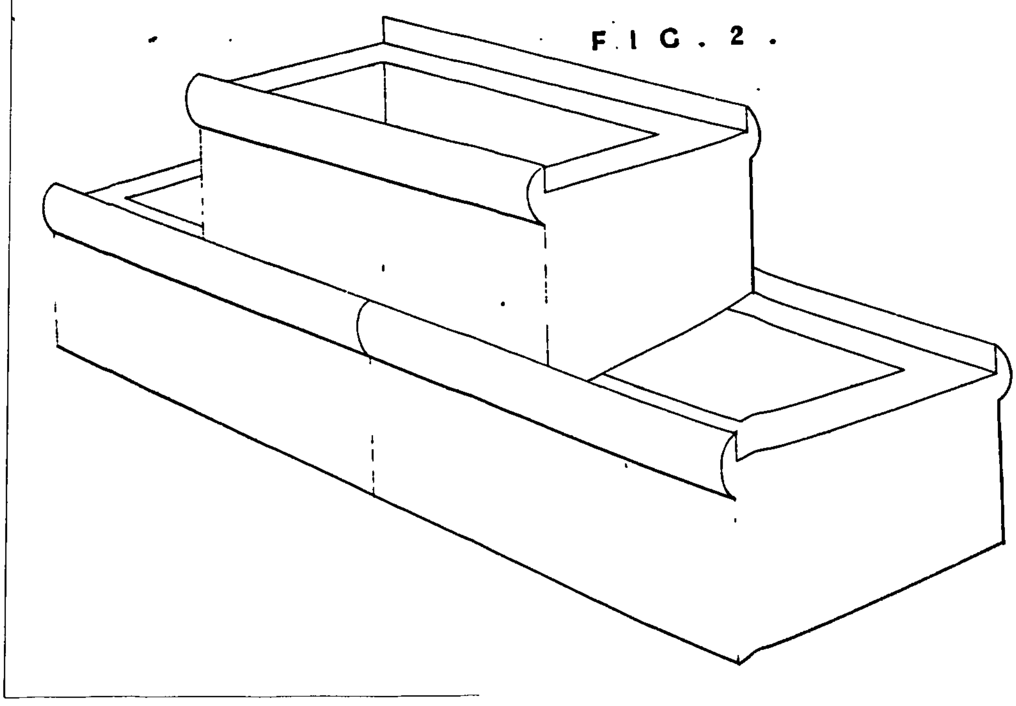
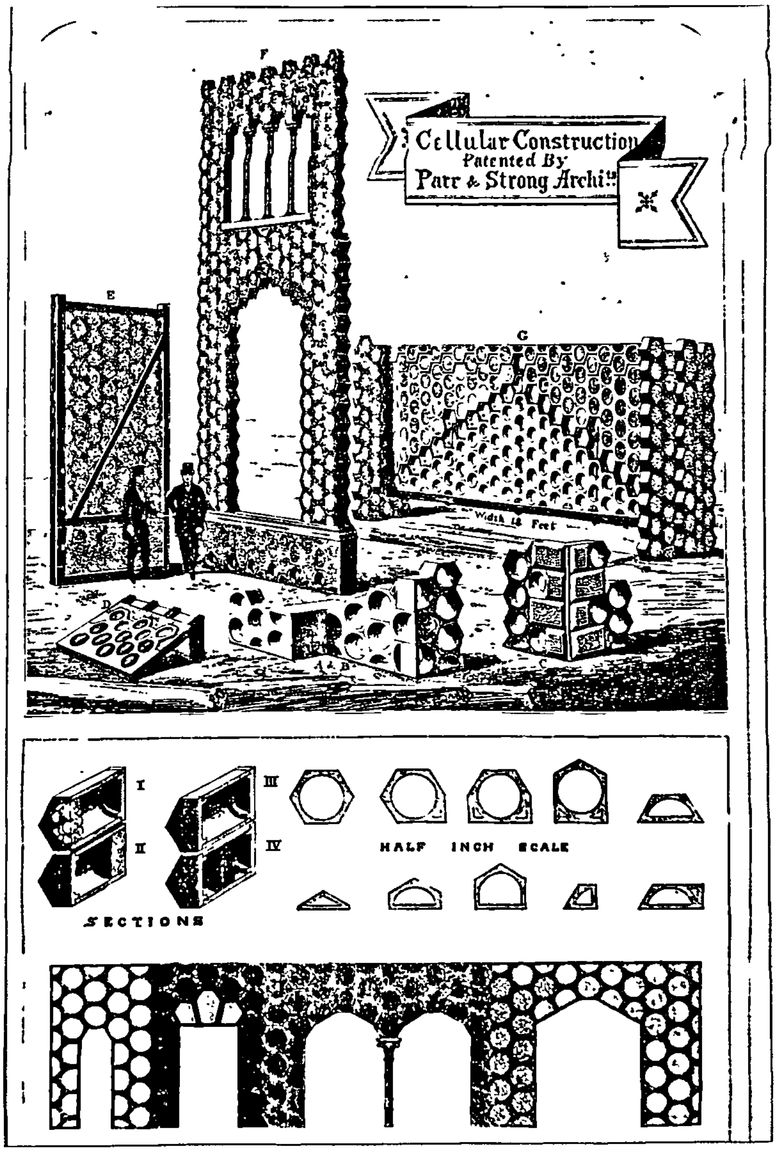


Figure 11.8. Cellular construction by architects Samuel Parr and Alfred Strong, British Patent No. 1416, 1868.
[From The Builder (1868) p. 354]



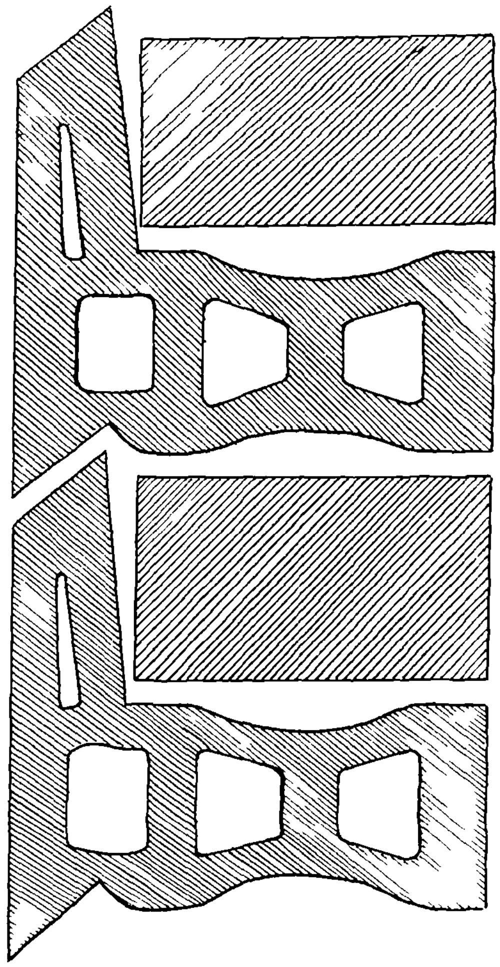


Figure 11.9. Interlocking facing bricks patented by W. Walton, British Patent No. 1093, 1861.
[Adapted from drawing enrolled with patent]

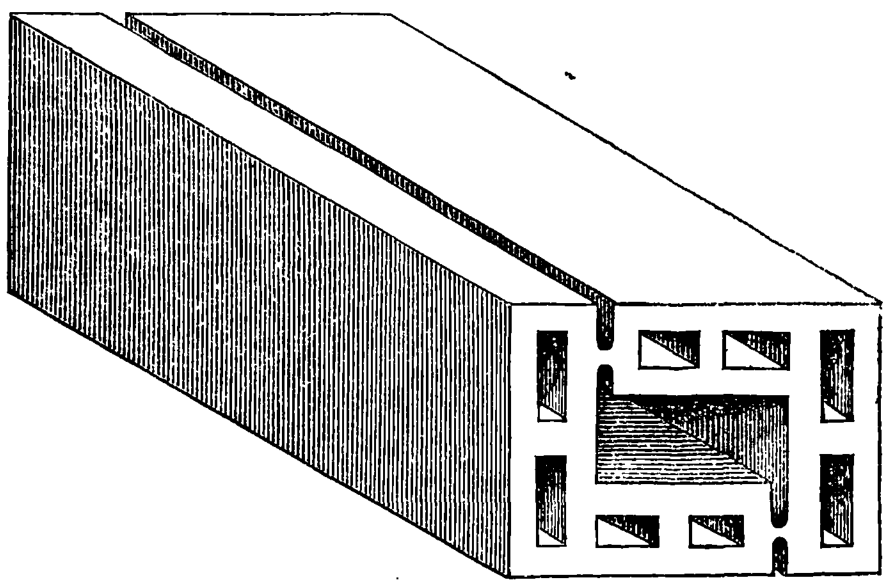


Figure 11.10. Perforated facing blocks introduced by John Taylor, c. 1863.
[From John Taylor, Junior, RIBA Papers, Etc. (1863) p.84]

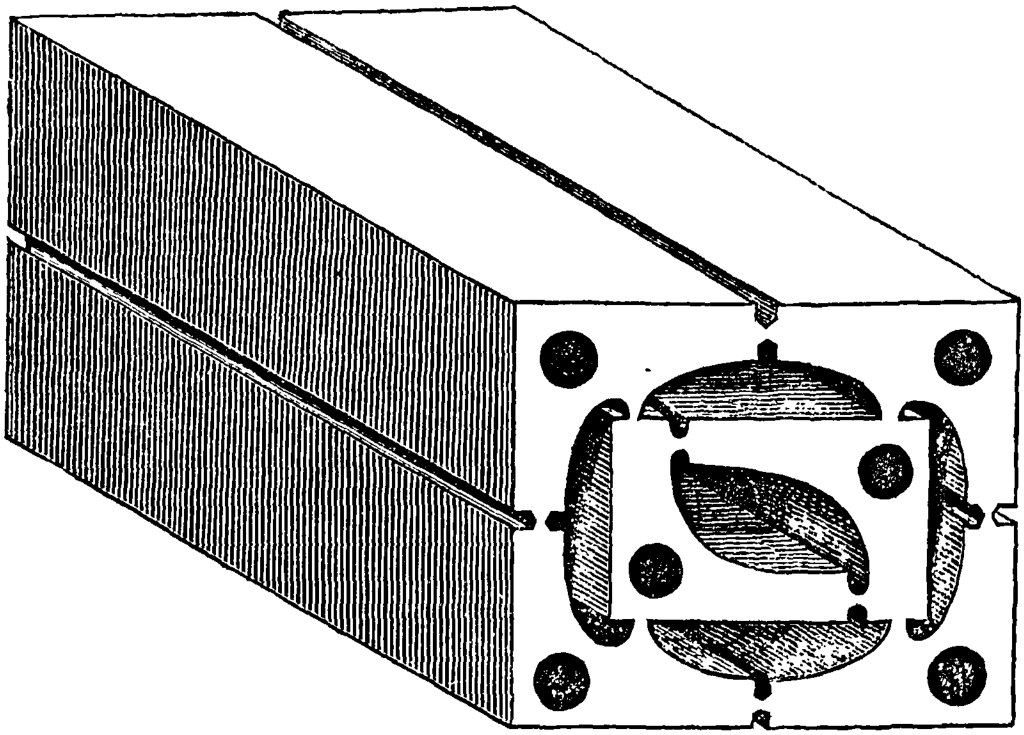


Figure 11.11. John Taylor's perforated facing bricks for bonding in with concrete; machine-extruded in one piece to prevent breakage, 1863.
[From John Taylor, Junior, RIBA Papers, Etc. (1863) p.86]

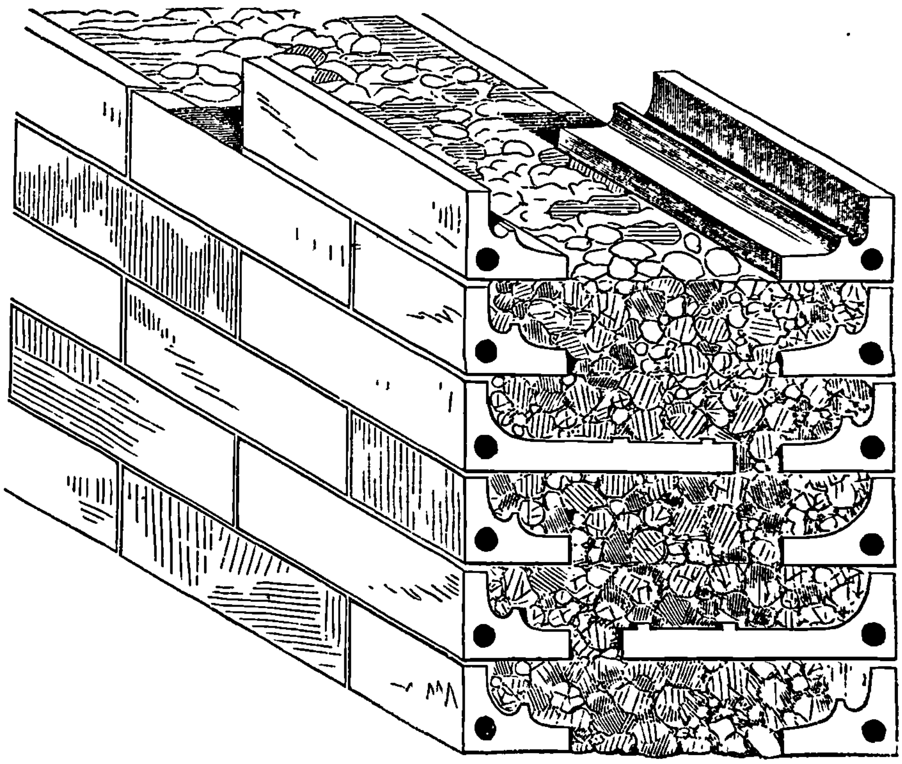


Figure 11.12. John Taylor's perforated facing bricks built into a concrete wall.
[From John Taylor, Junior, RIBA Papers, Etc. (1863) p.86]

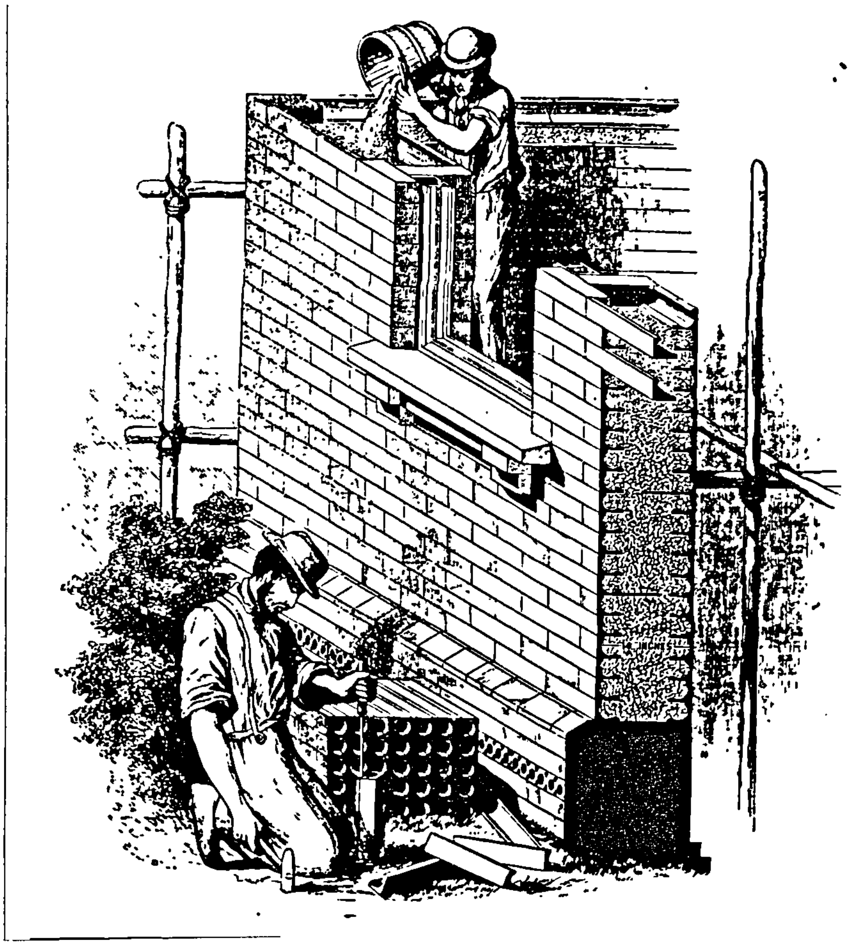
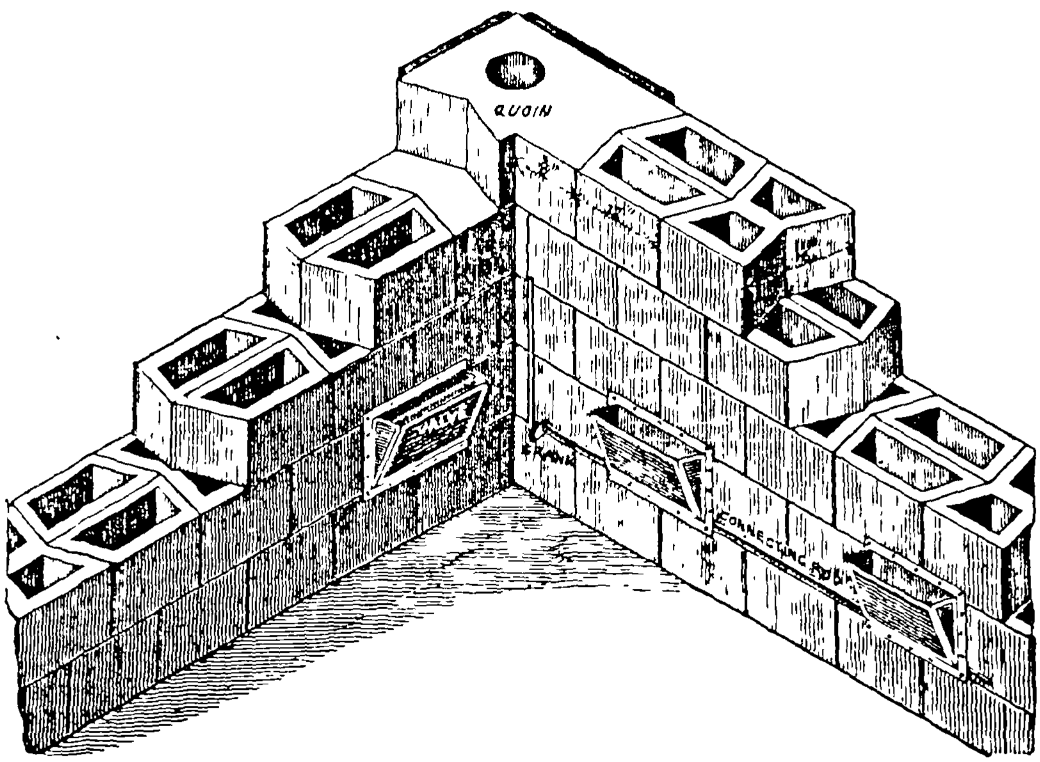


Figure 11.13. Construction of a concrete wall in stables and coach house at Hersham Lodge, Walton, Surrey using facing bricks manufactured by the Broomhall Tile Company.
[From The Builder (1868) p.658]

Figure 11.14. Ransome's hollow building blocks made of concrete artificial stone.
[From The Building News (1868) p.447]

RANSOME'S HOLLOW BUILDING BLOCKS.



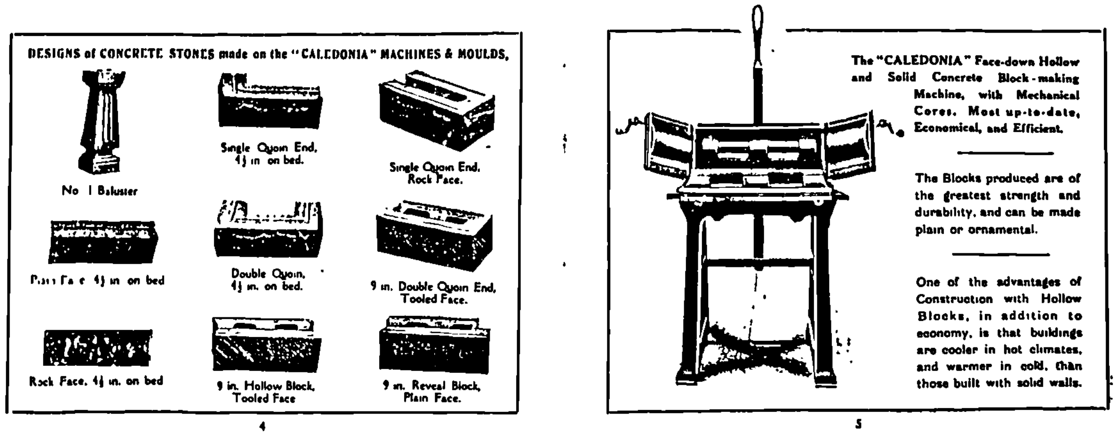


Figure 11.15. The "Caledonia" concrete block machine and moulds. [From The "Caledonia" Concrete Block Machine Company (n.d.) p.4-5]

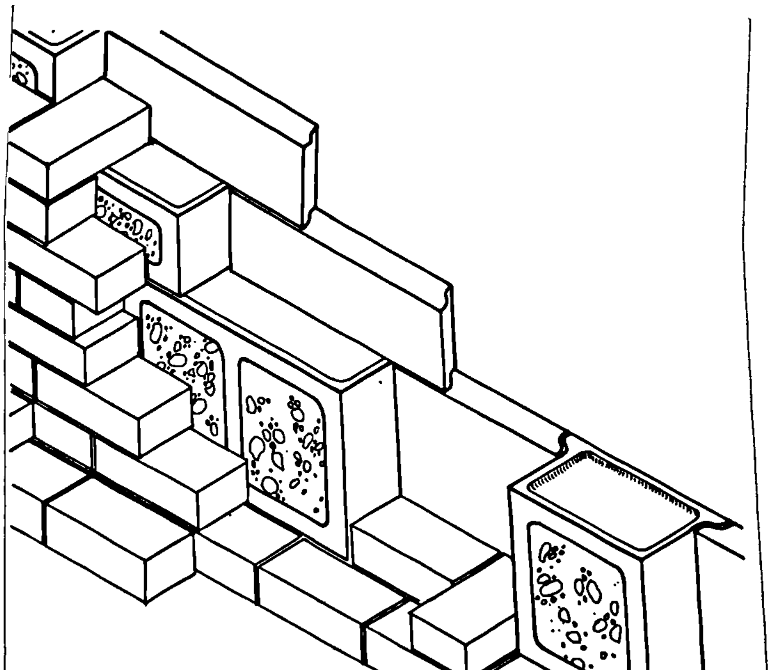


Figure 11.16. Filled terra cotta blocks bonded into the structural brickwork at the Natural History Museum, London, completed 1881. [From John Olley and Caroline Wilson, Architects Journal (1985) p.41]

SUMMARY AND COMMENTS

The intention of this thesis has been to analyse the process of technological change by examining the development of two separate but interrelated innovations in brickmaking during the nineteenth century in Britain. Clayworking machinery provided a mechanized substitute for the predominant hand methods of brick manufacture. Hollow bricks were a machine-made product innovation generated by and dependent upon the widespread adoption of brickmaking machinery. The aim of the study has been to show that technical innovations are shaped by a set of complex, interacting social relations which together comprise a technological system or network. It also has tried to show that rather than being passive recipients of new technology, the building industry and especially the architectural profession were active participants in the creation of new technological systems and contributed to the shaping of new brickmaking processes and products.

The social shaping of technology occurs in various ways. It happens directly when the desire to create or maintain a particular pattern of social relations influences the choice of technologies. For instance, the continued reliance of the brickmaking industry on cheap and abundant juvenile workers for most of the nineteenth century encouraged the adoption of simple, labour intensive machinery rather than expensive, fully automatic devices. Technology also is shaped indirectly when prevailing social relations affect the framework of costs within which economic choices are made (MacKenzie and Wajcman 1985, p. 23). The brickmaking industry was made up of numerous small-scale, localised firms with little capital or incentive to invest in expensive heavy equipment. Thus, for many decades the industry avoided complicated dry clay brickmaking systems and chose instead the smaller and cheaper extrusion machines.

Groups within the social environment can alter the course of technological development in several ways. They can foster or inhibit particular technologies. They can influence the choice between two competing paths of technical progress. And they can determine specific design charactistics of artefacts or techniques. The preceding chapters have described examples of each of these activities. But conveying the "seamless web" character of technological change has not been an easy task. The components or "actors" in a technological system are rarely sharply defined or delineated. Sometimes members of one social group overlap with another. Or the influence of a particular group can increase or recede over time. Events or actions often occur simultaneously rather than in a consecutive, linear pattern. Similarly, the system is usually dynamic rather than static, that is, in a state of multi-directional flux. A shift or change occurring in one set of relations often initiates concurrent changes in others until the entire system becomes stabilized. The theoretical approach outlined in Chapter One offers a practicable methodology for writing about technological change in the British brickmaking industry. It also provides a useful structure for the following summary and comments.

The origins of nineteenth century brickmaking innovations in Britain can be traced back to the values, institutions and economic incentives that made up the wider social system. Cultural values such as a belief in man's mastery over nature, progress, competition, and growth were encouraged and rewarded. Social institutions were developed to support these values including a legal framework for the protection of property and commerce, re-organization of industrial structures, opportunities for the acquisition of skills and the diffusion of knowledge, and the creation of new professional groups. Within this cultural environment other factors such as population growth, the accumulation of capital, investment in industry, expanding transport facilities, and urbanization created strong economic incentives for the generation of new technology.

The flexible structure of the traditional brickmaking industry had enabled it for centuries to respond to a wide range of physical and climatic conditions as well as periodic changes in the consumption of bricks. But in the late eighteenth and early nineteenth centuries an unprecedented increase in building and demand for clay building products placed enormous pressure on the industry to raise its productivity. This pressure revealed shortcomings within the traditional system that imposed restraints on the ability of brickmakers in many locations to expand and regulate output. For example, the seasonal nature of the work often led to shortages and fluctuations in the price of bricks. In addition, as good quality surface clays gradually were depleted in areas of high demand, brickmakers were forced to establish works at greater distances from urban locations and to rely on expensive modes of transport to convey their products. Further restrictions were imposed when the excise duties on bricks were increased, and new regulations intended to facilitate the collection of the tax actually hindered production in most brickyards. These conditions provided major inducements for the introduction of mechanical devices such as pug mills, wash mills, and crushing rolls to expand productivity and lower operating costs.

A more serious impediment to increased productivity, however, was the prevalent subcontract system of work organization within the brickmaking industry. At the centre of this system was the brick moulder in the socially important position of "gang" leader responsible for hiring other members of the work groups. Although the system was adopted because of its adaptability, it effectively allowed a highly independent and sometimes unpredictable workforce to regulate the rate and quantity of output in each field. Brickmasters who attempted to interfere with these traditional work practices frequently met with resistance. The processes controlled by the moulders were considered the most problematic in terms of expanding and regulating production, and inventive activity was concentrated on this aspect of brick manufacture. Consequently, the most frequently patented innovations in brickmaking during the first half of the century were machines for moulding or shaping bricks and tiles.

Brick consumers also were convinced that the irresponsible behaviour of the moulders and their gangs was a major cause of the general decline in the quality of clay building products. Some newly organized groups of architects, intent upon demonstrating their professional integrity and raising their status in the increasingly diversified building industry, condemned the deplorable condition of bricks on moral grounds. Others hoped to restore dignity and prominance to the profession by developing new architectural theories which stressed honesty and propriety in the use of building materials and encouraged the employment of vibrantly coloured and moulded bricks. Architects from both groups advocated innovations in brickmaking which would improve the quality, colour, and decorative potential of clay building products.

The earliest mechanized devices for brickmaking were not radically new inventions, but rather they were closely patterned after familiar techniques for moulding and finishing bricks by hand. Many simply expanded the operation of existing implements like the pug mill. Initially three types of machines were introduced -- moulding machines, re-presses, and dry clay presses. Many of these machines offered potential solutions to production problems in the brickmaking industry. But like most new technologies, they were crude and inefficient when first introduced. Wet clay moulding machines especially suffered from a variety of technical difficulties, the greatest of which was the tendency of wet clay to stick to moving parts of the machine. Re-presses, operating on partially dried bricks rather than soft, wet clay, were less affected by these problems. They complemented rather than superceded traditional work practices and so were easily integrated into most brickyards prior to mid-century.

Dry clay pressing machines offered numerous advantages over other processes. Bricks made from dry, powdered clay did not obstruct the operation of the machine, they were less prone to damage than newly moulded wet clay bricks, and they could be taken directly to the kiln, thus accelerating the production process. But there was little practical experience gained from the use of these machines in brickfields prior to mid-century.

Without the opportunity to test new machinery in actual brickmaking situations, inventors were unable to identify defects or imperfections and make the necessary modifications to ensure their successful operation. And until the superiority of these innovations over hand methods was proven, brickmakers remained unwilling to invest in new machinery. The greatest obstacle to experimentation with brickmaking machinery prior to 1850 was the tax on bricks. The minimum compensation allowed by the law for ruined bricks often was not sufficient to cover the actual damage caused by imperfect machines. Moreover, in eliminating the need for drying newly-moulded bricks, dry clay presses were unable to comply with the strict regulations governing the arrangement and counting of brick products imposed by the legislation. Thus, moulding and pressing machines remained in a preliminary stage of development throughout the first half of the century.

Further advancement of clayworking machinery was stimulated during the 1840's by the growing interest in agricultural drainage which created a lucrative new market for devices capable of manufacturing large quantities of clay tiles and pipes. Moulding and pressing machines failed to meet the needs of these new tilemaking consumers. Instead, the extrusion process for manufacturing hollow clay goods was adopted and rapidly surpassed other methods in performance and popularity. Extrusion machines also suffered initially from technical imperfections. But in ten short years defects were corrected and machine design became stabilized as a result of the exhibitions and competitions sponsored by the Royal Agricultural Society. These events were instrumental in clarifying for machine manufacturers the requirements of agricultural tilemakers and in encouraging and rewarding the development of machines most suited to those needs. Modifications and refinements made during the decade in response to use and feedback by consumers established the superiority of the extrusion process over other clayworking methods. By 1850 these machines were widely diffused throughout the country. Consequently, in the second half of the century the familiarity and success of the extrusion process meant that it was the mechanized method most frequently adopted by brickmakers in the manufacture of clay products.

The excise duties on bricks were repealed in 1850, thus removing a major obstacle to the use of machinery for ordinary brickmaking. This coincided with a substantial increase in the number of patents granted for machines and a period of prosperity and rapid economic growth in many industries. The market for clayworking machinery expanded as new trade and investment opportunities were created. While demand from the agricultural sector at home continued to grow, overseas markets were an additional source of profits for extrusion machine manufacturers. An important series of acts regulating the formation of companies and granting limited liability created new opportunities for brickmakers to invest in machinery and to establish large-scale operations. Although a significant number of new companies was registered, many failed and the demand for high-production machinery was concentrated in a very small number of large firms. For most of the century the British brickmaking industry was dominated by small-scale, local producers who relied on an abundance of low paid, juvenile workers to maintain profits in an increasingly competitive market. In response, machine makers developed and marketed a variety of inexpensive, versatile, and labour-intensive machines designed to complement the predominant structure and work practices of the industry.

Although the character of the market broadly influenced the types and sizes of brickmaking machinery produced, there remained a great deal of flexibility in the way particular implements developed. Distinctive features or capabilities of certain machines were determined by specific design decisions made by manufacturers in reponse to problems defined by various groups of consumers. But problems were defined somewhat differently both within and between groups of consumers. Prospective purchasers of machinery in the brickmaking industry were concerned primarily with gaining independence from skilled moulders and with raising levels of productivity, while consumers of clay products were more interested in improving the quality of bricks. These conflicting attitudes inevitably led to controversies and difficult choices for machine makers. Ultimately compromises had to be made in the way machines were designed. For example, innovations designed to increase the output and versatility of extrusion machines were continually undermined by slower, hand-operated cutting tables which were more compatible with the limited skills and established patterns of work within the brickmaking industry. Although fully-automatic continuous cutting devices were capable of considerably increasing the production of extruded bricks, small-scale producers preferred the manual tables even though they produced ragged, distorted bricks which were no better than many hand-made products.

The stabilization and widespread acceptance of extrusion machinery in the second half of the nineteenth century occurred not because a consensus was reached among the various groups of consumers about the superiority of the process, but rather because one dominant group, the small-scale producers in the brickmaking industry, imposed its favoured solution onto other groups. Extrusion machinery was unable to raise the overall quality of bricks on the market as many architects had anticipated. But the building industry accepted this solution for two reasons. One was that the industry had become accustomed to the practice of constructing walls with an outer layer of high-quality stone or brick and a backing or infill of second-rate products. This ensured that there was always a need for inferior bricks in building. The second reason was that at the same time other mechanized methods were being developed that promised to increase the availability and lower the price of the visually perfect bricks architects demanded for building facades.

After mid-century several machine manufacturers attempted to overcome the numerous problems associated with the production of dry or semi-dry pressed bricks. By the end of the century large brickmaking firms in the Oxford Clay Vale had perfected the process and exclusively utilized machinery of this type. However, the semi-dry process was limited to only certain types of clays and was not suitable for the material commonly found in many parts of the country. Thus, a new mechanized method was developed for a wider range of clay types combining elements from the plastic and semi-dry systems. This new method, called the semi-plastic process, ultimately succeeded in producing moderately-priced, homogenous, and uniform bricks acceptable to most building practitioners.

Architects were united in their dissatisfaction with common building bricks, but there was by no means a consensus of opinion within the profession about the preferred qualities of clay products. Personal experience and judgement guided most architects in the selection of these materials. Increasingly professional groups realized the need for systematic experimentation with bricks and brickwork to establish standards and evaluate differences between the various hand and machine brickmaking methods. Although the results of brick tests were often ambiguous and inconclusive, they ultimately succeeded in helping to clarify the needs and preferences of the profession. This, in turn, enabled architects to make economic choices that profoundly influenced the path of machine development within the brickmaking industry.

Architects played a more conspicuous role in shaping the form and use of newly invented clay building products generated by the diffusion of brickmaking machinery. Rapid advances in the development of extrusion machines during the 1840's improved the quality and reduced the cost of many hollow clay goods. A concurrent awareness of the need for sanitary reform in building suggested an expanded role in building for machine-made hollow constructive units such as tubes or bricks for vaultings or fireproof floors. Sanitary reformers also recommended hollow bricks for building the walls of dwellings which they claimed would prevent the penetration of damp and provide channels or flues for ventilating rooms. By 1850 when the tax on bricks was repealed, some building professionals confidently endorsed hollow bricks for a wide range of constructive purposes. But like other brickmaking innovations, the development and eventual acceptance of these products for ordinary construction depended upon a crucial period of trial and user feed-back to overcome initial design and production difficulties.

As primary consumers of hollow clay building units, architectural professionals were in a unique position to direct the development of these new products into quite specific forms. But initial building experiments using patented hollow brick systems revealed that most were unable to fulfil the numerous promises made by promoters. Many bricks on the market were of inferior quality, and because of design faults most were unable to prevent the ingress of moisture through joints or to ensure stability. Supplies of hollow bricks also were scarce and prices were high because few brick manufacturers were equipped to produce large quantities of these new products. Experimentation with hollow goods was further disrupted in the mid-1850's by a series of patent disputes. These difficulties and shortcomings did little to convince consumers of the superiority of hollow bricks over other building methods or to encourage their adoption. Consequently, in the decades after mid-century their use for any purpose other than fireproof flooring was limited to isolated sanitary reform experiments.

The hesitation of architects in adopting hollow bricks for ordinary construction was based in part on the profession's distrust of new and untried building materials and processes. This was not merely conservatism, but rather a concerted effort to establish and protect the ideal of professional responsibility as a way of distinguishing architects from other building practitioners. If we examine closely the decision-making process from the perspective of these architects, we can see that they were confronted by not only imperfect, high-priced hollow brick systems, but also a full range of competing products and techniques designed to prevent the harmful effects of damp and assist ventilation. For example, cavity wall construction was a less radical innovation that utilized ordinary stock bricks rather than specially-shaped units and was more compatible with customary skills and accepted methods of building. Similarly, modified hollow clay products like perforated facing bricks were designed to integrate with traditional brick and later monolithic concrete construction. In many cases these alternatives were cheaper, easier to use, and they presented a more familiar and pleasing appearance.

Most of these innovations clearly were not perfect solutions to the numerous constructional problems that challenged the building industry during the century. No particular product or technique was obviously superior to the others. Although building professionals regularly debated the comparative merits of each alternative, no clear consensus of opinion emerged. The decision-making process was made more difficult when some architects began to challenge the wisdom of erecting buildings with hollow cavities in walls and floors. Because few reliable tests were undertaken to evaluate the strength or fire-resistance of hollow building methods, many practitioners remained suspicous and increasingly inclined to fill hollow goods with cement or concrete to create solid work. Although others protested on moral grounds against this "dishonest" use of materials, most hollow clay products, including architectural terra cotta, were employed in this way during the late nineteenth century. Ultimately, terra cotta "succeeded" in becoming a widely accepted building material much favoured by architects, while hollow bricks stabilized into the more specialized, utilitarian form of fireproof flooring systems. Again, the profession's determination to separate itself from ordinary building practitioners influenced their preference for "artistic" terra cotta rather than machine-made hollow clay goods.

A number of recurring themes are revealed in this analysis of technological change. First, we have seen that the displacement of hand brickmaking practices by mechanized substitutes was dependent upon a complex interaction of numerous "actor" elements or groups within the social environment, each with its own interests and spheres of activity. Specific technological problems were defined by the meanings or expectations these groups attached to particular apects of brick manufacture or the resulting clay products. The interests and attitudes of these social groups also determined when a new mechanized method finally satisfied their needs and constituted an acceptable substitute for the existing processes or products. Only then was a brickmaking innovation understood to "succeed".

Second, brickmaking innovations were rarely complete or ready for application at the time they were invented. They were crude or imperfect and required a lengthy period of trial and feed-back by consumers to enable inventors to identify defects and work out solutions to production problems or design deficiencies. At any given moment, all of these innovations had at least the potential to "succeed". As critical inventive activity continued in response to user feed-back, new machinery or brick products were altered and refined to suit the needs and expectations of consumers. Thus, the final form each innovation acquired was determined by its use. If a new product or technique was not used extensively then it could not develop beyond the initial stage of invention. Moreover, inventions that were not used during this crucial period eventually "failed", not because they were necessarily "bad" inventions, but because they were not given the opportunity to "succeed".

Finally, we have seen that there was not only one perfect technical solution to the problems of the brickmaking industry. Because relevant groups in the social environment were responsible for defining the problems and identifying appropriate solutions, there was immense flexibility in the way brickmaking innovations were designed. Controversies inevitably arose both between and within social groups as disparate elements attempted to analyse the advantages and disadvantages of competing processes or products. The outcome of these disputes ultimately determined the design of innovations. Sometimes compromises were made. On other occasions the favoured solution of one dominant group prevailed over others. Ongoing or unsolved controversies also had the effect of blocking further development of some innovations. Evaluations of superiority by groups of consumers take place at many different times during the development of a new technology. Consequently, evaluations may change over time. We have seen that innovations considered unacceptable at an early stage of their development eventually acquired the characteristics necessary to meet consumers' demands and thus ultimately "succeeded".

New techniques for manufacturing bricks and new clay building products traditionally have not been thought of as significant innovations in terms of their influence on architectural development during the nineteenth century. Many histories of architectural technology have concentrated on the more "progressive" technical developments in building, innovations such as large-span metal roofs, steel-frames, and reinforced concrete construction. In documenting the development of these materials and methods of construction historians have called our attention to the obviously "successful" solutions to the most difficult challenges facing the building industry. But in doing so they have left us with an unbalanced view of technological change.

Ordinary architects and builders during the period were confronted by numerous less formidable but equally perplexing problems. They were constantly concerned with economy and experimented with measures to reduce building costs. They searched for ways to rectify a variety of health and safety problems such as heating, ventilation, and the prevention of fire and damp. At the same time many architects were determined to maintain acceptable standards of taste, propriety and ethics. As this study has shown, the resolution of these problems often called for minor inventions or refinements to existing technologies. These seemingly insignificant innovations offered potentially important improvements in the day-to-day design and construction of buildings during the nineteenth century. Although they did not noticeably "revolutionize" architecture, their cumulative effect was considerable and they must not be underestimated. Far from being passive or disinterested recipients of new technology, nineteenth century architects actively pursued and participated in the creation of technical solutions to the many constructional problems confronting them.

APPENDIX A

Patents for Brickmaking Machines, 1741 to 1850

DATE	NUMBER	NAME
1741	575	William Bailey
1798	2215	Francis Farquharson
1798	2216	James Douglas
1800	2368	Isaac Sanford
1801	2543	Samuel Miller
1808	3103	William Stewart
1810	3319	Johan Deyerlein
1811	3473	Thomas Gilbert
1813	3685	Joseph Hamilton
1817	4183	Robert Harvey
1820	4482	John Shaw
1820	4507	Lemuel W. Wright
1824	5036	William Leathy
1825	5086	Edward Lee George Harrison
1825	5166	Alexander Galloway
1825	5246	Thomas Staniford (Stainford), George Henry Lyne
1826	5353	William Choice Robert Gibson
1828	5681	William Mencke
1829	5866	John Cowderoy
1830	5890	Samuel Wright
1830	5917	Ralph Stephenson

DATE	NUMBER	NAME
1830	5937	Henry Robert Devenoge
1830	5985	Samuel Roscoe Bakewell
1832	6257	John James Clark John Longbottom John Nash
1833	6428	Robert Beart
1834	6738	Robert Beart
1835	6876	Edward Jones
1836	7253	George, Marquis of Tweeddale
1837	7353	Miles Berry
1837	7391	Richard Roe
1838	7551	Charles DeLaveleye Francis Parry
1838	7757	George, Marquis of Tweeddale
1839	8267	James White
1840	8548	Richard Prosser
1841	8772	George Child
1841	8897	Robert Cook Andrew Cunningham
1841	8956	Andrew McNab
1841	8965	John Ainslie
1841	9165	William Irving
1842	9243	James Hunt
1842	9244	Charles Wye Williams
1842	9521	Charles Smith
1842	9538	Frederick Etheridge
1843	9610	Joseph Kirby
1843	9659	William Betts William Taylor

DATE	NUMBER	NAME
1843	9751	Thomas Forsyth
1844	10020	William Basford
1844	10022	Samuel Wright
1844	10132	Henry Clayton
1844	10147	John Denton
1844	10152	William Hodson
1844	10188	Henry Holmes
1844	10200	Richard Wilson
1844	10237	William Worby
1844	10276	William Ford
1844	10299	James Smith William Jolly
1845	10481	John Ainslie
1845	10506	Thomas Middleton
1845	10577	Richard Weller
1845	10636	Robert Beart
1845	10845	Alfred Hall
1846	11041	William Benson
1846	11155	John Ainslie
1846	11236	William Percy
1846	11249	Spencer Garrett
1846	11276	James Hastings
1846	11282	Frederick Ransome John Crabb Blair Warren
1846	11365	Pierre Fontainemoreau
1846	11374	Henry Franklin
1846	11408	James Farnsworth

DATE	NUMBER	NAME
1847	11972	Thomas Martin, Jr.
1848	12115	Thomas Spencer
1848	12197	Joseph Skertchley
1848	12311	James Hart
1849	12454	Thomas Snowdon
1849	12495	Charles Jacob
1849	12601	Richard Lightoller Thomas Whaley
1849	12645	Bennett Burton
1849	12831	William Morris
1849	12884	Thomas Grimsby
1850	12914	Henry Dorning
1850	13064	William G. Elliott
1850	13275	Robert Beart

[Source: Bennett Woodcroft. Subject Matter Index of Patents of Invention 1617-1852. Part I. (1854)]

APPENDIX B

Prices of Selected Tilemaking Machines Before 1850

(Note: All machines hand-powered unless stated otherwise.)

MACHINE MAKER	TYPE OF MACHINE	AMOUNT/YEAR
Robert Beart	Pug mill moulding (horse-powered)	£60./1833
" "	Hand-fed moulding	£12./1837
Tweeddale Co.	Roller extrusion	£40./1843
John Read	Single-action piston extrusion	£6.-7./1843
F.W. Etheredge	Pug mill extrusion	£43./1843
Robert Beart	Single-action piston extrusion	£10./1847
Bullock Webster	Double-action piston extrusion	£25./1847
John Hatcher, Cottam & Hallen	Perpendicular piston extrusion	£25./1847
Richard Weller, Garrett & Son	Double-action piston extrusion	£25./1847
Barratt, Exall & Andrews	Perpendicular piston extrusion	£20./1847
John Ainslie	Roller/die extrusion	£35./1847
" "	Ditto (horse or steam-powered)	£50./1947
Henry Franklin	Pug mill extrusion	£35./1847
John Hatcher, Cottam & Hallen	Perpendicular piston extrusion	£20./1849
Richard Weller, Garrett & Son	Double-action piston extrusion	£25./1849
John Ainslie	Roller/die extrusion	£35./1849
Henry Franklin	Pug mill extrusion	£25./1849
Henry Clayton	Perpendicular piston extrusion	£26.-29./1849

MACHINE MAKER	TYPE OF MACHINE	AMOUNT/YEAR
John Eaton	Double-action piston extrusion	£20./1849
Thomas Scragg	Single-action piston extrusion	£22./1849
" "	Double-action piston extrusion	£24./1849
" "	Small single-action piston extrusion	£12.12s/1849
John Whitehead	Double-action piston extrusion	£23.-29./1849
" "	Large double-action piston extrusion	£30.-38./1849
John Holmes	Perpendicular piston extrusion	£25./1849

APPENDIX C

Locations of Purchasers of Selected Tilemaking Machines Before 1850

DATE	MACHINE	LOCATION
1847	Ainslie	Uxbridge, London
"	"	Evesham, Worcestershire
"	"	Nettlebed, Oxfordshire
"	"	Acton, Greater London
1850	"	Basford, Staffordshire
1836	Beart	Husbourne Crawley, Bedfordshire
1836	"	Weybridge, Middlesex
1847	"	Market Rasen, Lincolnshire
"	"	New Bolingbroke, Lincolnshire
"	"	Cullen, Grampian Region
"	"	Godmanchester, Lincolnshire
"	"	Huntley, Grampian Ragion
"	"	Wistow, Cambridgeshire
"	"	Bythorn, Cambridgeshire
"	"	Bury, Cambridgeshire
"	"	Hamerton, Cambridgeshire
1845	Clayton	Yarmouth, Isle of Wight
1843	Etheredge	Eling, Hampshire
1845	Hatcher	Hempstead Park, Cranbrook, Kent
1849	Scragg	Tarporley, Cheshire
1847	Swain	Penybont, Powys
"	"	Leominster, Herefordshire

DATE	MACHINE	LOCATION
1838	Tweeddale	Ballencrieff, Lothian Region
"	"	East Fenton, Borders Region
1839	"	Glencarse, Perth
1841	"	Brixton Hill, Surrey
"	"	Broomhall, Alnwick, Northumberland
"	"	Burringham, Crowle, Lincolnshire
"	"	Burton-Upon-Trent, Staffordshire
"	"	Chippenham, Wiltshire
"	"	Herne, Kent
"	"	Hoo St. Werburgh, Kent
"	"	Howden, Yorkshire
"	"	Hull, Humberside
"	"	Madeley, Shropshire
"	"	Oakley, Bedfordshire
"	"	Pluckley, Kent
"	"	Reading, Berkshire
"	"	Strathfield Saye, Hampshire
"	"	Sandon, Staffordshire
"	"	Seacombe, Cheshire
"	"	Wardle, Nantwich, Cheshire
"	"	Thatcham, Berkshire
"	"	Windsor Great Park
1843	Etheredge	Woodlands, Hampshire
1843	Read	Penshurst, Kent
"	"	Cranbrook, Kent
"	"	Horsemondon, Kent

DATE	MACHINE	LOCATION
1843	Read	Hadlow, Kent
"	"	East Peckham, Kent
"	"	Yalding, Kent
"	"	Chiddingstone, Kent
"	"	Benenden, Kent
"	"	Tunbridge Wells, Kent
1843	Tweeddale	Woburn, Bedfordshire
1846	Weller	Lewes, Sussex
"	"	Rise, near Hull, Humberside
"	"	Icklesham, Sussex
"	"	Guildford, Surrey
"	"	Poling, near Arundel, Sussex
"	"	Newtown, Powys
"	"	Hundsdon, near Ware, Hertfordshire
"	"	Littleton, Surrey
"	"	Mereworth, Maidstone, Kent
"	"	Ripley Kilns, Guildford
"	"	Allistree, near Derby
"	"	Woodbridge, Suffolk
"	"	Kirby Cane, Bungay, Suffolk
1849	Whitehead	Wansford, Cambridgeshire
"	"	Clumber Park, Nottinghamshire
"	"	Holker Hall, Cumbria
"	"	Catterick, Yorkshire
"	"	Alnwick, Northumberland
"	"	Elmdan, near Birmingham

DATE	MACHINE	LOCATION
1849	Whitehead	Colewood, Bolney, Sussex
"	"	Alston Hall, Derby
"	"	Bolton Hall, Clitheroe, Lancashire
"	"	Netherton, near Morpeth
"	"	Strathallen Castle, Tayside
"	"	Quernmore Park, near Lancaster
"	"	Dringhouses, near York
"	"	Rufford Hall, near Olmskirk
"	"	Leyland, Near Chorley, Lancashire
"	"	Calke Abbey, near Derby
"	"	Swinton Park, Bedale, Yorkshire
"	"	Latham, Ormskirk, Lancashire
"	"	Thrunton, Northumberland
"	"	Springfield, Wigan
"	"	Pemberton, near Wigan
"	"	Fishwick, Preston, Lancashire
"	"	Norwich, Norfolk
"	"	Stanton, Bakewell, Derbyshire
"	"	Rushton, Shropshire
"	"	Merton Bank, St. Helens
"	"	Rothbury, Northumberland
1850	"	Bickerstaff, near Ormskirk
"	"	Aswarley Park, Lincolnshire
"	"	Escrick Rectory, Yorkshire
"	"	Patrington, near Hull
"	"	Gawthorpe Hall, Padiham, Lancashire

DATE	MACHINE	LOCATION
1850	Whitehead	Shenton Hall, Hinckley, Leices.
"	"	Wroxham, Norfolk
"	"	Hatton, Dunkeld, Tayside
"	"	King's Lynn, Norfolk
"	"	Burton-in-Lonsdale, Cumbria
"	"	Blackawton, Totness, Devon
"	"	Haltwhistle, Northumberland
"	"	Ellingham Hall, Bungay
"	"	Lulworth Castle, Dorset

SELECTED BIBLIOGRAPHY

PERIODICALS

The Architect and Building Operative
The Architect's Journal
The Architectural Magazine
Artizan
Associated Architectural Societies Reports and Papers
The Athenaeum
The British Brick Society, Information
The British Clayworker
The Builder
The Builders' Trade Circular
The Building News,
The Church Builder
The Civil Engineer and Architect's Journal
The Ecclesiologist
The Edinburgh Review
Engineering
The Gentleman's Magazine
The Illustrated Builders' Journal
The Illustrated London News
Journal of the Royal Agricultural Society of England
Journal of the Royal Institute of British Architects
The Law Times
Mechanics' Magazine
Newton's London Journal of Arts and Sciences
Norwich Mercury
The Patent Journal
The Practical Mechanic's Journal
Proceedings of the Institution of Civil Engineers
Proceedings of the Institution of Mechanical Engineers
Papers of the Royal Institute of British Architects
The Quarterly Review
The Times
Transactions of the Yorkshire Agricultural Society
Yorkshire Gazette

BRITISH PARLIAMENTARY PAPERS (COMMONS)

"Report on the Present State of Certain Parts of the Metropolis and on the Model Lodging Houses of London" by R.D. Grainger, Esq., 1851 [388] XXIII.

New York Industrial Exhibition. "Special Report of Mr. Joseph Whitworth". 1854 [1718] XXXVI.103.

Fifth Report of the Commissioners on the Employment of Children and Young Persons in Trades and Manufactures. "Report on Brickfields" by Mr. H.W. Lord. 1866 [3678] XXIV.

Trades Unions, First Report from the Royal Commission with Minutes of Evidence. 1867 [3873] XXXII.

Trades Unions, Third Report from the Royal Commission with Minutes of Evidence. 1867 [3910] XXXII.

Trades Unions, Tenth Report from the Royal Commission. 1867-68 [3980-VI] XXXIX.

Scientific Instruction, Reports from Committees. 1867-68 XV.

Paris Exhibition, Reports from Commissioners. "Apparatus and Processes used in Agricultural Works (Class 50)" by Prof. T.C. Archer. 1867-68 XXX Pt.3.

Manchester Outrages Inquiry, Report to the Royal Commissioners. 1867-68 [3980] XXXIX.

Factories Act (Brick and Tile Yards) Extension Act. 1871 34 & 35 Victoria [194] II.49.

Reports of Inspectors of Factories. Half year ending 31 October 1872. 1873 [c.745] XIX.

Reports on the Vienna Exhibition. "Technical Papers on Special Sections of the Exhibition Contributed by Mr. W.H. Maw and Mr. James Dudge." 1874 LXXIII Pt.3.

Minutes of Evidence to the Report from the Select Committee on the Factory and Worckshop Acts. 1876 [c.1443.1] II.

Reports of Inspectors of Factories. Half year ending 31 October 1875. 1976 [c.1434] XVI.

Housing of the Working Classes. Minutes of Evidence. 1884-85 [c.4402-1] XXX.

Report on Wholesale and Retail Prices. 1903 LXVIII.

PUBLIC RECORD OFFICE, KEW, LONDON

BT 31 Companies Registration Office
Files of Disolved Companies, 1855-1963.

BT 41 Companies Registration Office
Files of Joint Stock Companies Registered Under the 1844 and 1856 Acts.

BOOKS AND ARTICLES

Abridgements of the Specifications Relating to Bricks and Tiles (1862)
London: Patent Office.

ADAMS, HENRY (1910)
Building Construction. London: Cassell and Company Ltd.

ADDY, S.O. (1898)
The Evolution of the English House. 2nd Rev. Ed., 1933.

ALBERTI, LEON BATTISTA (1485)
Ten Books on Architecture. Edited by Joseph Rykwert. Translated by James Leoni. London: Alec Tiranti Ltd, Reprint 1955.

ALDCROFT, DEREK AND HARRY W. RICHARDSON (1969)
The British Economy, 1870 to 1939. London: Macmillan.

ARCHER, JOHN H.G. (1985)
Art and Architecture in Victorian Manchester. Manchester: Manchester University Press.

ARCHER, T.C. (1868)
"Apparatus and Processes used in Agricultural Works (Class 50)". BPP Paris Exhibition, Reports from Commissioners. 1867-68 XXX Pt.3.

The Architects', Engineers' and Building Trades' Directory 1868. London: Wyman and Sons.

"Architecture a Profession or an Art" (1893)
The Nineteenth Century, 33: 65-82; 405-415; 631-634.

ARCHITECTURAL PUBLICATION SOCIETY (1853-1892)
The Dictionary of Architecture. London: Thomas Richards.

ASHWORTH, WILLIAM (1960)
An Economic History of England 1870-1939. London: Methuen.

_________ (1954)
The Genesis of Modern British Town Planning. London: Routledge and Kegan Paul.

ASPINALL, P.J. AND J.W.R. WHITEHEAD (1980)
"Building Plans: A Major Source for Urban Studies". Area, 12:199-203.

ASSOCIATION OF ARCHITECTS (1793)
Resolutions of the Associated Architects: With the Report of a Committee by them Appointed to consider the Causes of the frequent Fires, and the best means of Preventing the like in Future. London.

ATKINSON, WILLIAM (1805)
Views of Picturesque Cottages with Plans. London: T. Gardiner. Republished 1971, Gregg International Publishers Limited.

BABBAGE, CHARLES (1835)
On the Economy of Machinery and Manufacture. 4th Ed. London: Chas. Knight.

________ (1851)
The Exposition of 1851. London: Frank Cass and Company Limited. Reprint from 2nd Edn.

BAKEWELL, SAMUEL ROSCOE (1834)
Observations on Building and Brickmaking. Manchester: Prentice and Cathrall.

BALE, M. POWIS (1890)
"Bricks and Brickmaking". The Buiding News, p. 7-10; 91-93; 162-163; 228-230; 300-301; 372-374; 442-443; 534-535; 640; 756-758.

BANNISTER, TURPIN (1950)
"The First Iron-Framed Buildings". Architectural Review, p. 231-246.

________ (1968)
"The Roussillon Vault, Apotheosis of a 'Folk' Construction". Journal of the Society of Architectural Historians, 27, 3: 163-175.

BARLEY, MAURICE WILLMORE (1961)
The English Farmhouse and Cottage. London: Routledge.

BARNARD, JULIAN (1972)
Victorian Ceramic Tiles. London: Studio Vista.

BARRETT, JAMES (1853)
"On The Construction of Fire-Proof Buildings". Proceedings of the Institution of Civil Engineers, 12: 244-272.

BARRY, REV. ALFRED (1867)
The Life and Works of Sir Charles Barry. London: John Murray.

BARRY, CHARLES (1867-68)
"Some Descriptive Memoranda on the Works Executed in Terra Cotta at New Alleyn's College, Dulwich, Etc.". RIBA Papers, Etc. 1867-68, p. 259-276.

BEART, ROBERT (1841)
"On the Economical Manufacture of Draining-Tiles and Soles". Journal of the Royal Agricultural Society of England, 2: 93-104.

BECKETT, SIR EDMUND (1876)
A Book on Building, Civil and Ecclesiastical. London: Crosby Lockwood and Company.

BELLAMY, JOYCE (1970)
Yorkshire Business Histories: A Bibliography. Bradford: Crosby Lockwood and Son Limited.

BEVAN, G. PHILLIPS (1876)
The Industrial Classes and Industrial Statistics, Vol.12. London: Edward Stanford.

BIJKER, WIEBE E., THOMAS P. HUGHES, AND TREVOR J. PINCH (1987)
The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. Cambridge, Mass: MIT Press.

BIRCH, JOHN (1892)
Examples of Labourer's Cottages, Etc. London: William Blackwood and Sons, 2nd Edn.

BLOMFIELD, A.W. (1870-71)
"Remarks on Concrete Building". RIBA Papers, Etc. 1870-71, p.181-187.

BOASE, FREDERIC (1965)
Modern English Biography. London: Frank Cass & Co. Ltd.

BOND, JAMES, SARAH GOSLING AND JOHN RHODES (1980)
Oxfordshire Brickmakers. Oxford: Oxfordshire Museums Service Pulications, Number 14.

BOOTH CHARLES (1893)
Life and Labour of the People in London. Vols. 1 and 5. London: Macmillan, 2nd Ser.

BOURRY, EMILE (1901)
A Treatise on Ceramic Industries. London: Scott, Greenwood and Son.

BOWLEY, MARIAN (1960)
Innovations in Building Materials. London: Duckworth.

________ (1966)
The British Building Industry: Four Studies in Response and Resistance to Change. Cambridge: Cambridge University Press.

BOWYER, JACK (1973)
History of Building. London: Crosby Lockwood Staples.

BRACEGIRDLE, BRIAN (1973)
The Archaeology of the Industrial Revolution. London: Heinemenn.

BRADLEY AND CRAVEN, LIMITED (1963)
The First Hundred Years. Wakefield.

BRIAN, ANTHEA (1972)
"A Regional Survey of Brick Bonding in England and Wales". Vernacular Architecture, 3: 11-15.

BRIGGS, MARTIN (1925)
A Short History of the Building Crafts. Oxford: Oxford University Press.

________ (1953)
The English Farmhouse. London: Batsford.

BROGNIART, A. (1844)
Traite des Arts Ceramique. Paris.

BROOKER, KEITH (1981)
"Some Approaches to the Study of Small Scale Industries Prior to 1914". Business Archives, 47, N.S. 4, 3: 7-17.

BROOKS, S.H. (1840)
Designs for Cottage and Villa Architecture. London: Thomas Kelly.

BRULAND, TINE (1982)
"Industrial Conflict as a Source of Technical Innovation: Three Cases". Economy and Society, 11, 2: 91-121.

BRUNSKILL, RONALD (1971)
Illustrated Handbook of Vernacular Architecture. New York: Universe Books.

________ (1974)
Vernacular Architecture of the Lake Counties: A Field Handbook. London: Faber and Faber.

________ AND A. CLIFTON-TAYLOR (1977)
English Brickwork. Ward Lock Limited.

BUCHANAN, ANGUS (1975)
"Technology and History". Social Studies of Science, 5: 489-99.

BUCHANAN, R.A. (1962)
"Gentlemen Engineers: The Making of a Profession". Victorian Studies, 26, 4: 198-230.

BUCKINGHAMSHIRE COUNTY MUSEUM (1980)
Gazetteer of Buckinghamshire Brickyards 1800-1980. Buckinghamshire County Museum.

BUGLIARELLO, GEORGE AND DEAN B. DONER (1979)
The History and Philosophy of Technology. Urbana: University of Illinois Press.

Building Trades Directory (1870)

Building Trades Directory (1886)

BURGESS, KEITH (1969)
"Technological Change and the Lock-Out in the British Engineering Industry". International Review of Social History, 14: 215-236.

BURN, D.L. (1931)
"The Genesis of American Engineering Competition 1850-1870". Economic History, 2, 6: 292-311.

BURN, ROBERT S. (1853)
"Ventilation". In Architectural Publication Society Detached Essays and Illustrations. London: Thomas Richards.

BURNELL, GEORGE (1849)
Rudimentary Treatise on Limes, Cements, Mortars, Concretes, Mastics, Plastering, Etc.. London: John Weale.

________ (1862)
The Annual Retrospect of Engineering and Architecture. London: Lockwood and Company.

BURNELL, H.H. (1853-54)
"Description of the French Method of Constructing Iron Floors". RIBA Papers, Etc. 1853-54.

BURNETT, JOHN (1978)
A Social History of Housing 1815-1970. Newton Abbott: David and Charles.

BUTTERWORTH, B. (1953)
"The Properties of Clay Building Materials". In A.T. Green and Gerald H. Stewart, Eds. Ceramics, A Symposium. Stoke-on-Trent.

BUTTERWORTH, B. AND D. FOSTER (1956)
"The Development of the Fired-Earth Brick", Part I. Transactions of the British Ceramic Society, 55, 7: 457-80.

The "Caledonia" Concrete Block Machine Company n.d.

CAIRNCROSS, A.K. (1935)
"The Glasgow Building Industry (1870-1914)". The Review of Economic Studies, 2: 1-17.

_________ AND B. WEBER (1956)
"Flucuations in Building in Great Britain, 1785-1849". The Economic History Review, 2nd Ser., 9, 2: 283-297.

CAMBRIDGE CAMDEN SOCIETY (1841)
A Few Words to Church Builders. Cambridge: T. Stevenson.

CARR, J. MILLER (1896)
"Practical Lessons Derived from the Modern Use of Terra-Cotta". Paper read at the Manchester Society. Journal of the RIBA, 3rd Ser., 3: 327-330.

CATALOGUE ILLUSTRÉ DES MACHINES ET INSTRUMENS FABRIQUES PAR RANSOMES ET SIMS (1859)

CATES, ARTHUR (1877-78)
"Concrete and Fire-resisting Constructions". RIBA Papers, Etc. 1877-78, p. 296-312.

The Century's Progress: Yorkshire Industry and Commerce, 1893. Settle: Brenton Publishing, Reprint, 1971.

CHADWICK, EDWIN (1867-68)
"Report on Dwellings Characterized by Cheapness Combined with the Conditions Necessary for Health and Comfort". British Sessional Papers. House of Commons. 1867-68 Vol. XXX Part 2.

CHALKLIN, C.W. (1974)
The Provincial Towns of Georgian England: A Study of the Building Process 1740-1820. London: Arnold.

CHAMBERLAIN, HUMPHREY (1856)
"The Manufacture of Bricks by Machinery". Journal of the Society of Arts, 4, 185: 491-500.

CHAMBERS, BROTHERS AND COMPANY (1867)
Bricks and Brick-Making Machinery. Philadelphia: Sherman and Company.

CHRISTMAS, T. (1976)
The Bulmer Brick and Tile Company Ltd. (Inf. 10). Colchester: Colchester and Essex Museum.

CHURCH, ROY (1966)
Economic and Social Change in a Midland Town: Victorian Nottingham 1815-1900. London: Frank Cass & Co. Ltd.

________ (1975)
The Great Victorian Boom 1850-1873. London: The Macmillan Press Limited.

CLAPHAM, J.H. (1930)
An Economic History of Modern Britain: The Early Railway Age 1830-1850. Cambridge: Cambridge University Press, 2nd Edn.

CLARK, D.K. (1864)
The Exhibited Machinery of 1862. London.

CLARK, KENNETH (1962)
The Gothic Revival. London: John Murray, 3rd Edn.

CLIFT, JOHN E. (1859)
"Description of Oates Brick-Making Machine". Proceedings of the Institution of Mechanical Engineers, p. 249-263.

CLIFTON-TAYLOR, ALEC (1972)
The Pattern of English Building. London: Faber and Faber Limited.

COLLIER, L.J. (1966)
"Development and Location of the Clay Brickmaking Industry in the South-East Midlands of England Since 1800". PhD. Thesis, University of London.

COLLINS, PETER (1959)
Concrete: The Vision of a New Architecture. London: Faber and Faber.

________ (1965)
Changing Ideals in Modern Architecture 1750-1950. London: Faber and Faber.

COLVIN, H.M. (1954)
A Biographical Dictionary of English Architects, 1660-1840. London: John Murray.

________ (1978)
A Biographical Dictionary of British Architects, 1600-1840. London: John Murray, 2nd Ed.

CONSTANT, EDWARD W. (1983)
"Scientific Theory and Technological Testability: Science Dynamometers and Water Turbines in the 19th Century". Technology and Culture, 24: 183-198.

COONEY, E.W. (1955)
"The Origins of the Victorian Master Builders". Economic History Review, 8: 167-176.

________ (1960)
"Long Waves in Building in the British Economy of the Nineteenth Century". The Economic History Review, 2nd Ser. 13, 2: 257-269.

________ (1970)
"The Organization of Building in England in the 19th Century". Architectural Research and Teaching, 1, 2: 46-52.

CORDINGLEY, R.A. (1961)
"British Historical Roof-Types and Their Members". Transactions of the Ancient Monuments Society, p. 9.

COTTAM AND HALLEN (1847)
Catalogue and Descriptions of Aricultural Implements, Machines, Etc.. London.

COTTRELL, P.L. (1980)
Industrial Finance, 1830-1914. London: Methuen.

COWAN, HENRY J. (1966)
An Historical Outline of Architectural Science. London: Elsevier Publishing Company.

________ (1977a)
The Master Builders. New York: John Wiley and Sons.

________ (1977b)
Science and Building. London: John Wiley and Sons.

COWAN, RUTH SCHWARTZ (1987)
"The Consumption Junction: A Proposal for Research Strategies in the Sociology of Technology". In Wiebe E. Bijker, Thomas P. Hughes, Trevor J. Pinch. The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. Cambridge, Mass: MIT Press.

COX, ALAN (1979)
Brickmaking, A History and Gazetteer. Survey of Bedfordshire. Bedfordshire County Council.

________ (1989)
"Bricks to Build a Capital". In Hermione Hobhouse and Ann Saunders, Eds. Good and Proper Materials. London: The Royal Commssion on Historical Monuments of England and The London Topographical Society.

CROOK, J. MORDAUNT (1966)
"Sir Robert Smirke: A Pioneer of Concrete Construction". Transactions of the Newcomen Society, 38: 5-22.

________ (1969)
"The Pre-Victorian Architect: Professionalism and Patronage". Architectural History, 12: 62-78.

________ (1989)
The Dilemma of Style. London: John Murray.

CRUICKSHANK, DAN AND PETER WYLD (1975)
London: The Art of Georgian Building. London: The Architectural Press Ltd.

CUMING, H. SYER (1860)
"On the Use of Vessels and Hollow Bricks in Buildings". Journal of the British Archaeological Association, 16: 359-63.

CURL, JAMES STEVENS (1973)
Victorian Architecture, Its Practical Aspects. Newton Abbott: David and Charles.

________ (1983)
The Life and Work of Henry Roberts, 1803-1876. Chichester: Phillimore & Co. Ltd.

CURREY, HENRY (1861-62)
"London Bridge Railway Terminus Hotel". Papers of the RIBA, Etc. 1861-62, p. 116-117.

DARBISHIRE, HENRY A. (1965)
"A Few Suggestions on the Introduction of Coloured Bricks, Etc., in Elevations". RIBA Papers, Etc. 1864-65, p. 66-74.

DAVEY, NORMAN (1961)
A History of Builidng Materials. London: Phoenix House.

________ (1964)
Building in Britain. London: Evans Brothers Limited.

DAVIDGE, W.R. (1914)
"The Development of London and the London Building Acts". Journal of the RIBA, 3rd Ser., 21, 3: 33-69.

DEARLE, NORMAN B. (1908)
Problems of Unemployment in the London Building Trades. London: J.M. Dent and Company.

DEARN, T.D.W. (1807)
Sketches in Architecture Consisting of Original Designs for Cottages and Rural Dwellings. London: J. Taylor. Republished Gregg International Press Limited, 1971.

D'ESPIE, M. DE COMTE (1756)
"Review of The Manner of Securing All Sorts of Buildings from Fire", Gentlemen's Magazine, March, p. 139-140.

DIRCKS, HENRY (1867)
Inventors and Inventions. London: E. and F.N. Spon.

DIXON, ROGER AND STEFAN MUTHESIUS (1978)
Victorian Architecture. London: Thames and Hudson.

DOBSON, EDWARD (1849)
Rudiments of the Art of Building. London: John Weale.

________ (1850)
A Rudimentary Treatise on the Manufacture of Bricks and Tiles. London: George Woodfall and Son.

DUMAN, DANIEL (1979)
"The Creation and Diffusion of a Professional Ideology in Nineteenth Century England". The Sociological Review, N.S. 27, 1: 113-138.

DUMBLETON, MICHAEL (1979)
Brickmaking - A Local Industry. Bracknell and District Historical Society.

DUNN, ROBERT (1854)
"Description of Hollow Roofs, as constructed on the Estate of Earl Grey, etc.". Journal of the Royal Agricultural Society of England, Part I, 15:181-184.

DUTTON, H.I. (1984)
The Patent System and Inventive Activity During the Industrial Revolution. Manchester: Manchester University Press.

DYOS, H.J. (1968)
"The Speculative Builders and Developers of Victorian London". Victorian Studies, Supplement, 11:641-690.

EASTLAKE, CHARLES (1970)
A History of the Gothic Revival. Edited with an Introduction by J. Mordaunt Crook. Leicester: Leicester University Press.

ECK, C.L.G. (1841)
Traité de Construction en Poteries et Fer. Paris. 2nd Edn.

ELBAUM, BERNARD AND WILLIAM LAZONICK (1986)
The Decline of the British Economy. Oxford: Clarendon Press.

Emigrants Letters, from Settlers in Canada and South Australia, Collected in the Parish of Banham, Norfolk. (1852)
Norwich: Jarrold & Sons.

ERNLE, LORD, ROWLAND E. PROTHERO (1912)
English Farming, Past and Present. London: Longmans, Green and Company.

ETHEREDGE, FREDERICK WILLIAM (1845)
"On the Cheapest and Best Method of Establishing a Tile-Yard". Journal of the Royal Agricultural Society of England, 6:463-477.

EXHIBITION OF THE WORKS OF INDUSTRY OF ALL NATIONS (1851)
Reports of the Juries. London: William Clowes and Sons.

FAIRBAIRN, WILLIAM (1856)
Useful Information for Engineers. London: Longman, Brown, Green and Longmans.

________ (1878)
The Life of Sir William Fairbairn. Edited and Compiled by William Pole. London: Longmans, Green and Company, Abridged Edn.

________ (1864)
The Application of Cast and Wrought Iron to Building Purposes. London: Weale, 3rd Ed.

FAWCETT, THOMAS C., LTD. (1898)
Catalogue of Brickmaking Machinery. Leeds.

FERGUSON, EUGENE (1974)
"Towards a Discipline of the History of Technology". Technology and Culture, 15: 13-30.

FERRIDAY, PETER (1964)
Victorian Architecture. New York: J.B. Lippincott Company.

FINER, S.E. (1952)
The Life and Times of Sir Edwin Chadwick. London: Methuen.

FITTON, R.S. AND A.P. WADSWORTH (1958)
The Strutts and the Arkwrights 1758-1830. Manchester: Manchester University Press.

FLETCHER, BANISTER F. AND HERBERT PHILLIPS FLETCHER (1910)
The English Home. London: Methuen and Co. Ltd.

FLETCHER, VALENTINE (1968)
Chimney Pots and Stacks. Fontwell, Sussex: Centaur Press.

FLOUD, RODERICK (1976)
The British Machine Tool Industry, 1850-1914. Cambridge: Cambridge University Press.

FORD, W. (1842)
"Acount of Mr. Irving's New Machine for Constructing Tiles". Journal of the Royal Agricultural Society of England, 3, Parts II and III: 398-400.

FORES, MICHAEL (1979)
"The History of Technology: An Alternative View". Technology and Culture, p. 853-860.

________ (1981)
"The Myth of a British Industrial Revolution". History, 66: 181-198.

________ (1981)
"*Technik*: Or Mumford Reconsidered". History of Technology, p. 121-137.

________ (1982)
"Technical Change and the 'Technology' Myth". The Scandinavian Economic History Review, 30, 3: 167-188.

FOTHERGILL, BENJAMIN (1859)
"Description of a Dry-Clay Brick-Making Machine". Proceedings of the Institution of Mechanical Engineers, p. 42-51.

FOWLER, CHARLES (1870-71)
"On Fire-Resisting Materials and Construction with Reference to the Proposed New Building Act Now Before the House of Commons". RIBA Papers, Etc. 1870-71, p. 76-80

FOYLE, ARTHUR (1951)
"The Prince Consort's Model Houses, An Experiment in Hollow Brickwork". The Brick Builder, p. 122-126.

FRENCH, HENRY (1859)
Farm Drainage. New York: Orange Judd and Company.

GARBUTT, MATTHEW (1896)
"Notes on the Behaviour While Under Compression of the First Series of Brickwork Piers". Journal of the Royal Institute of British Architects, 3rd Ser., 3: 345-348.

GASKELL, S. MARTIN (1983)
Building Control. British Association for Local History: Bedford Square Press.

_________ (1986)
Model Housing, From the Great Exhibition to the Festival of Britain. London: Mansell.

GAULDIE, ENID (1974)
Cruel Habitations: A History of Working-Class Housing 1780-1918. London: George Allen & Unwin Ltd.

GIEDION, SIGFRIED (1948)
Mechanization Takes Command. Oxford: Oxford University Press.

________ (1954)
Space, Time and Architecture: The Growth of a New Tradition. Oxford: Oxford University Press.

GODWIN, GEORGE (1838)
"Hints on Construction; Addresses to Architectural Students". In Architectural Magazine, 5: 411-415; 464-468; and 514-519.

________ (1850)
Buildings and Monuments. London.

GOLD, BELA (1983)
"On the Adoption of Technological Innovations In Industry: Superficial Models and Complex Decision Processes". In Stuart Macdonald, D. McL. Lamberton, Thomas Mandeville, Eds. The Trouble With Technology: Explorations in the Process of Technological Change. London: Frances Pinter.

GORMAN, M. J. (1980)
"Brickmaking in Nottingham: Growth, Rationalism and Effects on Land Use". East Midland Geographer, 7, 5: 180-194.

GRACE, D. R. AND D. C. PHILLIPS (1975)
Ransomes of Ipswich: A History of the Firm and Guide to its Records. Reading: Institute of Agricultural History.

GRADIDGE, RODERICK (1980)
Dream Houses: The Edwardian Ideal. New York: Braziller.

GREEN, A.M. (1977)
"Victorian Model Dwellings in Worcester 1854-1876". *Business Archives*, 43, N.S. 3,4:34-44.

GUNTON, HARRY E. (1969)
"Costessey Brickworks". *Transactions of the Newcomen Society*, 4:165-168.

GWILT, JOSEPH (1826)
Rudiments of Architecture. London: Priestley and Weale.

________(1867)
The Encyclopedia of Architecture. London: Longmans, Green. (Reprint New York: Crown Publishers, 1982).

GWILT, JOSEPH (1888)
An Encyclopedia of Architecture, Historical, Theoretical and Practical, New Edition by Wyatt Papworth. London: Longmans, Green & Co.

HABAKKUK, H.J. (1967)
American and British Technology in the Nineteenth Century. Cambridge: Cambridge University Press.

HALL, A. RUPERT (1974).
"What did the Industrial Revolution in Britain owe to Science?". In Neil McKendrick, Ed. *Historical Perspectives, Studies in English Thought and Society*. Cambridge: Cambridge University Press.

________ (1978)
"On Knowing, and Knowing how to...". *History of Technology*, 3:91-103.

________ (1979)
"The Historical Relations of Science and Technology". In Peter Mathias. *The Transformation of England*.

HALSTEAD, P.E. (1962)
"The Early History of Portland Cement". *Transactions of the Newcomen Society*, 34:37-54.

HAMILTON, STANLEY BAINES (1952)
"The Historical Development of Structural Theory". *Proceedings of the Institution of Civil Engineers*, 1, Part III:374-419.

________ (1956)
A Note on the History of Reinforced Concrete in Building. London: HMSO.

________ (1958a)
A Short History of the Structural Fire Protection of Buildings Particularly in England. National Building Studies Special Report No. 27. London: HMSO.

________ (1958b)
"The History of Hollow Bricks". Transactions of the British Ceramic Society, 58, 2: 41-61.

HAMMOND, ADAM (1903)
The Rudiments of Practical Bricklaying. London: C. Lockwood and Sons, 11th Edn.

HAMMOND, M. D. P. (1977)
"Brick Kilns: An Illustrated Survey". Industrial Archaeology Review, 1, 2: 171-192.

HAMMOND, MARTIN (1981)
Bricks and Brickmaking. Princes Risborough: Shire Publications.

HARLEY, C. K. (1974)
"Skilled Labour and the Choice of Technique in Edwardian Industry". Explorations in Economic History, 11: 391-414.

HARLEY, L. S. (1974)
"A Typology of Brick". Journal of the British Archaeological Association. 3rd Ser., 37: 63-87.

HARPER, ROGER H. (1985)
Victorian Building Regulations: Summary Tables of the Principal English Building Acts and Model By-Laws 1840-1914. London: Mansell Publishing Limited.

HARRISON, KENNETH (1968)
"Vitruvius and Acoustic Jars in England During the Middle Ages". Transactions of the Ancient Monuments Society, N. S., 15: 49-58.

HARTWELL, R. M. (1971)
The Industrial Revolution and Economic Growth. London: Methuen and Company Limited.

HASLUCK, PAUL N. (1905)
Practical Brickwork. London: Cassell and Company Ltd.

HAWKES, W. (1860-61)
"On the Transverse Strength of Bricks, and on Expansion of Brickwork in a Furnace Chimney". Papers of the RIBA, Etc., 1860-61, p. 121-129.

HAY, GEOFFREY AND GEOFFREY STELL (1986)
Monuments of Industry: An Illustrated Historical Record. Edinburgh: HMSO.

HEALEY, PAMELA AND E.M. RAWSTRON (1955)
"The Brickworks of the Oxford Clay Vale". The East Midland Geographer, 1, 4: 42-48.

HEERTJE, ARNOLD (1983)
"Can We Explain Technical Change". In Stuart Macdonald, D. McL. Lamberton, Thomas Mandeville, Eds. The Trouble With Technology. London: Frances Pinter.

HENRY CLAYTON AND COMPANY (1860)
Henry Clayton & Company's Patent Improved Brick-Making Machines, Etc.. Supplement to general catalogue. London.

HENRY CLAYTON, SON & HOWLETT, ENGINEERS (1871)
Atlas Works. London.

HERSEY, GEORGE L. (1972)
High Victorian Gothic: A Study in Associationism. Baltimore: The Johns Hopkins University Press.

HEWETT, CECIL ALEC (1980)
English Historic Carpentry. Chichester: Phillimore.

HILLIER, RICHARD (1981)
Clay That Burns: A History of the Fletton Brick Industry. London: London Brick Company Limited.

HILLS, GORDON M. (1881-82)
"Earthenware Pots (Built Into Churches), Which Have Been Called Acoustic Vases". Papers of the RIBA, Etc. 1881-82, p.65-96.

HITCHCOCK, HENRY-RUSSELL (1972)
Early Victorian Architecture in Britain. New York: Da Capo Press.

________ (1978)
Architecture: Nineteenth and Twentieth Centuries. Harmondsworth: Penguin Books Limited, 4th Edn.

HOBHOUSE, HERMIONE (1971)
Thomas Cubitt: Master Builder. London: Macmillan.

HOBHOUSE, HERMIONE AND ANN SAUNDERS (1989)
Good and Proper Materials. London: The Royal Commission on the Historical Monuments of England and The London Topographical Society.

HOSKING, WILLIAM (1835)
Treatise on Architecture and Building. Edinburgh: Adam and Charles Black.

HUDSON, KENNETH (1972)
Building Materials. London: Longman.

HUGHES, THOMAS P. (1987)
"The Evolution of Large Technological Systems". In Wiebe E. Bijker, Thomas P. Hughes, Trevor J. Pinch. The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. Cambridge, Mass: MIT Press.

HUNT, JAMES (1841)
"On the Marquis of Tweeddale's Tile-Making Machine". Journal of the Royal Agricultural Society of England, 2, PartI: 148-150.

HUNT, ROBERT (1857)
Descriptive Guide to the Museum of Practical Geology. London: George E. Eyre and William Spottiswoode.

INNOCENT, C.F. (1908)
The Development of English Building Construction. Cambridge: Cambridge University Press.

INTERNATIONAL EXHIBITION (1862)
Reports of the Juries. London: William Clowes and Sons.

JACKSON, T.G. (1893)
"Architecture - A Profession or an Art". The Nineteenth Century, 33: 405-413.

JAMES, REV.T. (1861)
"Notes on Cottage Building". Associated Architectural Societies, Reports and Papers, 6, 7: 67-70.

JEFFERYS, J.B. (1946)
"The Denomination and Character of Shares, 1855-1885". The Economic History Review, 16: 45-55.

JENKINS, FRANK (1961)
Architects and Patrons. Oxford: Oxford University Press.

JOHNSON, H.R. AND PROF. A.W. SKEMPTON (1959-60)
"William Strutt's Cotton Mills, 1793-1812". Transactions of the Newcomen Society, 32: 179-205.

JONES, EDGAR (1985)
Industrial Architecture in Britain, 1750-1939. London: B.T. Batsford Limited.

JOPE, E.M., ED. (1961)
Studies inBuilding History. London: Oldhams.

KAYE, BARRINGTON (1960)
The Development of the Architectural Profession in Britain: A Sociological Study. London: Geroge Allen and Unwin Limited

KEELING, P.S. (1953)
"Geology and Ceramics". In A.T. Green and Gerald H. Stewart, Eds. Ceramics, A Symposium. Stoke-on-Trent.

KELSALL, FRANK (1989)
Stucco. In Hermione Hobhouse and Ann Saunders, Eds. Good and Proper Material. London: The Royal Commission on the Historical Monuments of England and The London Topographical Society.

KENWOOD, A.G. (1963)
"Residential Building Activity in North Eastern England, 1853-1913". The Manchester School of Economic and Social Studies, 31: 115-128.

KINDLER, ROGER A. (1974)
"Periodic Criticism 1815-40: Originality in Architecture". Architectural History, 17: 22-37.

KING, ANTHONY D. (1976)
"Architectural Journalism and the Profession: The Early Years of George Godwim". Architectural History, 19: 32-53.

________ , Ed. (1980)
Buildings ans Society: Essays on the Social Development of the Built Environment. London: Routledge and Kegan Paul.

KRANZBERG, MELVIN (1979)
"Introduction: Trends in the History and Philosophy of Technology". In George Bugliarello and Dean B. Doner. The History and Philosophy of Technology. Urbana: The University of Illinois Press.

LANDES, DAVID (1969)
The Unbound Prometheus. Cambridge: Cambridge University Press.

LAURIE, A.P. (1972)
Building Materials. London: Longmans.

LAW, JOHN (1987)
"Technology and Heterogenous Engineering: The Case of Portuguese Expansion". In Wiebe E. Bijker, Thomas P. Hughes, Trevor J. Pinch. The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. Cambridge, Mass: MIT Press.

Laxton's Builders Price Book for 1863. London.

Laxton's Builders Price Book for 1869. London.

Laxton's Builders Price Book for 1886. London.

LAYTON, EDWIN T., JR. (1974)
"Technology As Knowledge". Technology and Culture, 15: 31-41.

________ (1976)
"American Ideologies of Science and Engineering". Technology and Culture, 17, 4: 688-700.

________(1977)
"Conditions of Technological Development". In Inä Spiegel-Rosing and Derek de Solla Price, Eds. Science, Technology and Society: A Cross Disciplinary Perspective. London: SAGE Publications.

LAZONICK, WILLIAM (1979)
"Industrial Relations and Technical Change: The Case of the Self-Acting Mule". Cambridge Journal of Economics, 3: 231-262.

LENMAN, B.P. AND E.E. GAULDIE (1969)
"Pitfour Brickworks, Glencarse, Perth". Industrial Archaeology, 6.4: 340-353.

LESLIE, KIM C. (1971)
"The Ashburnham Estate Brickworks, 1840-1968". Sussex Industrial History, Winter.

LEWIS, J. PARRY (1961)
"Indices of House-Building in the Manchester Conurbation, South Wales, and Great Britain, 1851-1913". Scottish Journal of Political Economy, 8: 148-156.

________(1965)
Building Cycles and Britain's Growth. London: Macmillan.

LEWIS, MILES (1985)
"The Origins of the Cavity Wall". CHG Newsletter No.7. Construction History Group.

LEWIS, R.A. (1952)
Edwin Chadwick and the Public Health Movement 1832-1854. London: Longmans, Green and Company.

LEWIS, T. HAYTER (1865-66)
"Fire-Proof Materials and Construction". RIBA Papers, Etc. 1865-66, p. 109-126.

LILLIE, WILLIAM (1968)
The History of Middlebrough. Middlesbrough Corporation.

LINSTRUM, DEREK (1978)
West Yorkshire: Architects and Architecture. London: Lund Humphries.

LISCOMBE, R.W. (1980)
William Wilkins 1778-1839. Cambridge: Cambridge University Press.

LITTLER, CRAIG (1982)
"Deskilling and Changing Structures of Control". In Stephan Wood, Ed. The Degradation of Work?. London: Hutchinson.

LLOYD, NATHANIEL (1925)
A History of English Brickwork. London: H. Greville Montgomery.

LOMAX, EDWARD AND THOMAS GUNYON, EDS. (1852)
Nicholson's Dictionary of the Science and Practice of Architecture, Etc. London: Peter Jackson.

LOUDON, J.C. (1839)
Encyclopedia of Cottage, Farm, and Villa Architecture, Etc. London: Longmans.

MACDONALD, STUART, D. MCL. LAMBERTON, THOMAS MANDEVILLE (1983)
The Trouble With Technology: Explorations in the Process of Technological Change. London: Frances Pinter.

MACDONNELL, EDWARD (1981)
"Building an Industry on Clay: Brickmaking in Bedfordshire". Country Life, 169, 4373: 1684-1688.

MACHLUP, FRITZ AND EDITH PENROSE (1950)
"The PatentControvery in the Nineteenth Century". The Journal of Economic History, 10, 1: 1-29.

MACKENZIE, DONALD AND JUDY WAJCMAN (1985)
The Social Shaping of Technology: How the Refrigerator Got Its Hum. Milton Keynes: Open University Press.

MACLEOD, ROBERT (1971)
Style and Society: Architectural Ideology in Britain 1835-1914. London: RIBA Publications Limited.

MAINSTONE, ROWLAND (1975)
Developments in Structural Form. Cambridge Mass: MIT Press.

MAIWALD, K. (1954)
"An Index of Building Costs in the United Kingdom, 1845-1938". The Economic History Review, 2nd Ser. 7, 2: 187-203.

MANCHESTER SOCIETY OF ARCHITECTS (1868)
Report of the Committee Appointed to Consider the Manufacture of Bricks and Improvements of Brickmaking Processes. Manchester.

MARTIENSSEN, HEATHER (1976)
The Shapes of Structures. London: Oxford University Press.

MASON, REGINALD THOMAS (1974)
Framed Buildings of England. Horsham: Coach Publishing House.

MATHIAS, PETER (1972)
Science and Society, 1600-1900. Cambridge: Cambridhe University Press.

________ (1979)
The Transformation of England. London: Methuen.

MAW, W.H. AND JAMES DUDGE (1874)
"Technical Papers on Special Sections of the Exhibition". BPP Reports on the Vienna Exhibition. 1874 LXXIII Pt.3, p.382.

MAYR, OTTO (1976)
"The Science-Technology Relationship as a Historiographic Problem". Technology and Culture, 17,4:663-673.

MORE, CHARLES (1980)
Skill and the English Working Class 1870-1914. London: Croom Helm.

MOSELY, ANDREW (1861-62)
"An Outline of the Plan and Construction of the Westminster Palace Hotel". Papers of the RIBA, Etc, 1861-62, p.111-115.

MUMFORD, LEWIS (1934)
Technics and Civilization. New York: Harcourt, Brace and Company.

MUSSON, A.E. (1976)
"Industrial Motive Power in the United Kingdom, 1800-70". The Economic History Review, 2nd Ser., 29,3:415-439.

MUTHESIUS, STEFAN (1972)
The High Victorian Movement in Architecture, 1850-1870. London: Routledge and Kegan Paul.

________ (1982)
The English Terraced House. New Haven: Yale University Press.

NATIONAL BRICK ADVISORY COUNCIL, PAPER NO.5 (1950)
Clay Building Bricks in the United Kingdom. London: HMSO.

NATIONAL BUILDING STUDIES, BULLETIN NO.1 (1948)
Clay Building Bricks. London: HMSO.

NEVETT, T.R. (1982)
Advertising in Britain: A History. London: Heineman.

NEWBOLD, HARRY BRYANT (1925)
House and Cottage Construction Vol.II. London: Caxton Publishing Co. Ltd.

NICHOLSON, PETER (1823)
The New Practical Builder and Workman's Companion. London: Thomas Kelly.

NOBLE, JAMES (1836)
Professional Practice of Architects, Etc.. London.

NOBLE, W. (1953)
"The Heavy Clay Industry, 1900 to 1950". In A.T. Green and Gerald H. Stewart, Eds. Ceramics, A Symposium. Stoke-on-Trent.

NORTH, DOUGLASS C. (1981)
Structure and Change in Economic History. New York: W.W. Norton and Company.

OLLEY, JOHN (1985)
"The Reform Club". Architect's Journal, 181, 27:34-60.

________ AND CAROLINE WILSON (1985)
"The Natural History Museum". Architect's Journal, 181, 13: 3-55.

PACEY, ARNOLD (1975)
The Maze of Ingenuity: Ideas and Idealism in the Development of Technology. New York: Holmes & Meier, Inc.

________ (1983)
The Culture of Technology. Oxford: Basil Blackwell.

PAPWORTH, JOHN B. (1818)
Rural Residences. London: R. Ackerman. Republished, Gregg International Publishing Limited, 1971.

PARKES, JOSIAH (1843)
"Report on Drain-Tiles and Drainage". Journal of the Royal Agricultural Society of England, 4:369-379.

PARTINGTON, C.F. (1825)
The Mechanics' Gallery of Science and Art. London: Sherwood, Gilbert and Piper.

PASLEY, C.W. (1826)
Outline of a Course of Practical Architecture. Chatham.

________ (1838)
Observations on Limes, Calcareous Cements, Mortars, Stuccos, and Concrete, Etc. London: John Weale.

PASS, ANTHONY J. (1985)
"Thomas Worthington". In John H.G. Archer. Art and Architecture in Victorian Manchester. Manchester: Manchester University Press.

PAYNE, ALEXANDER (1875-76)
"Concrete as a Building Material". RIBA Papers, Etc. 1875-76, p.179-192; 225-254

PAYNE, P.L. (1985)
British Entrepreneurship in the Nineteenth Century. London: Macmillan, Reprint.

PENOYRE, JOHN AND JANE PENOYRE (1978)
Houses in the Landscape: Regional Studies of Vernacular building styles in England and Wales. London: Faber and Faber.

PERKIN, PROFESSOR H.J. (1969)
"The Social Causes of the British Industrial Revolution". Transactions of the Royal Historical Society, 123-143.

PERRINS, L.E. (1982)
"Rat Trap Bonded Brickwork in Hertfordshire". Hertfordshire Archaeology, 8:218-220.

PETERSON, CHARLES E. (1952)
"Notes on Imported Brick". Antiques, 62,1:50-51.

PEVSNER, NIKOLAUS (1972)
Some Architectural Writers of the Nineteenth Century. Oxford: Clarendon Press.

PHYSICK, JOHN (1982)
The Victoria and Albert Museum. Pxford: Phaidon.

PINCH TREVOR J. AND WEIBE E. BIJKER (1987)
"The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other". In Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch. The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. Cambridge, Mass: MIT Press.

POLLARD, SIDNEY (1964)
"Fixed Capital in the Industrial Revolution". The Journal of Economic History, 24,3:299-314.

________ (1965)
The Genesis of Modern Management. London: Edward Arnold Ltd.

POLLOCK, FREDERICK (1851)
Essay and Design for a Pair of Labourers' Cottages. London: Henry Wright.

PORT, M.H., ED. (1976)
The Houses of Parliament. New Haven: Yale University Press.

PORTER, G.R. (1912)
The Progress of the Nation. London: Methuen and Company Limited.

Portland Cement Plant (1894). Leeds: William Johnson, Engineer.

The Post Office Directory of the Building Trades 1870. London: Kelly and Company.

POSTGATE, R.W. (1923)
The Builders' History. London: The National Federation of Building Trade Operatives.

POTTER, THOMAS (1877)
Concrete: Its Use in Building and the Construction of Concrete Walls, Floors, Etc. London: E. & F. N. Spon.

POWELL, C. G. (1980)
An Economic History of the British Building Industry. London: The Architectural Press.

PRICE, RICHARD N. (1975)
"The Other Face of Respectability: Violence in the Manchester Brickmaking Trade 1859-1870". Past and Present, 66: 110-132.

________ (1980)
Masters, Unions, and Men: Work Control in Building and the Rise of Labour, 1830-1914. Cambridge: Cambridge Universsity Press.

Prospectus and Descriptive Statement of the Architectural Tile Company (1847)

PUGIN, A. W. N. (1836)
Contrasts. New York: Humanities Press, Reprint of 1841 edn., 1969.

________ (1841)
True Principles of Pointed or Christian Architecture. London: John Weale.

PUGSLEY, A. G. (1944)
"The History of Structural Testing". The Structural Engineer, p. 492-505.

PURSELL, CARROLL (1968)
"Parallelograms of Perfect Form: Some Early American Brick-Making Machines". The Smithsonian Journal of History, 3, 1: 19-27.

RANSOME MSS
The Institute of Agricultural History, Reading

READ, JOHN (1843)
"On Pipe-Tiles". Journal of the Royal Agricultural Society of England. 4: 273-274.

READER, W. J. (1966)
Professional Men: The Rise of the Professional Classes in Nineteenth Century England. London: Weidenfield and Nicolson.

REID, DR. (1844)
Illustrations of Ventilation. London

THE RETREAT, BUILDING ACCOUNTS (1853)
The Borthwick Institute, York.

RICHARDS, J. HAMISH AND J. PARRY LEWIS (1956)
"House Building in the South Wales Coalfield, 1851-1913". The Manchester School of Economic and Social Studies, 34: 289-301.

RICHARDS, JAMES M. (1958)
The Functional Tradition in Early Industrial Buildings. London: The Architectural Press.

RICHARDS, P.S. (1977)
"Brick Manufacture in Flintshire". Industrial Archaeology, 12,3: 226-246.

RICHARDSON, C.J. (1870)
Picturesque Designs for Mansions, Villas, Lodges, Etc. London: Atchley and Company.

RITCHIE, T. (1973)
"Notes on the History of Hollow Masonry Walls". Association for Preservation Technology, 5,4:40-49.

Rivington's Notes on Building Construction, Part III, Materials. London

ROBERTS HENRY (1853)
The Dwellings of the Labouring Classes. London: The Society for Improving the Condition of the Labouring Classes, 3rd Ser.

________ (1861-62)
"On the Essentials of A Healthy Dwelling and The Extension of its Benefits to the Labouring Population". RIBA Papers, Etc. 1861-62, p.93-108.

ROLT, L.T.C. (1970)
Victorian Engineering. Harmondsworth.

ROSENBERG, NATHAN (1963)
"Capital Goods, Technology, and Economic Growth". Oxford Economic Papers N.S. 15,3:217-227.

________ (1969)
"The Direction of Technological Change: Inducement Mechanisms and Focusing Devices". Economic Development and Cultural Change 18,1 PartI:1-24.

________ (1970)
"Economic Development and the Transfer of Technology: Some Historical Perspectives". Technology and Culture 11,4:550-575.

________ (1972)
"Factors Affecting the Diffusion of Technology". Explorations in Economic History. 10,1:3-33.

________ (1974)
"Karl Marx on the Economic Role of Science". Journal of Political Economy, p.713-728.

________ (1974)
"Science, Invention and Economic Growth". Economic Journal 84:90-108.

________ (1976a)
"On Technological Expectations". The Economic Journal 86:523-535.

________ (1976b)
Perspectives on Technology. Cambridge: Cambridge University Press.

________ (1979)
"Technology , Economy and Values". In George Bugliarello and Dean B. Doner. The History and Philosophy of Technology. Urbana: The University of Illinois Press.

________ (1982)
"How Exogenous Is Science?". In Nathan Rosenberg. Inside The Black Box. Cambridge: Cambridge University Press.

________ (1982)
Inside the Black Box: Technology and Economics. Cambridge: Cambridge University Press.

________ (1982)
"Marx as a Student of Technology". In Nathan Rosenberg. Inside the Black Box. Cambridge: Cambridge University Press.

ROYAL AGRICULTURAL SOCIETY OF ENGLAND (1847)
Show Catalogues, Ransome Collection, The Institute of Agricultural History, Reading.

________(1849)
A Catalogue of Agricultural Implements Exhibited at the Society's Show at Norwich.

________ (1850)
A Catalogue of Agricultural Implements Exhibited at the Society's Show at Exeter.

________ (1852)
A Catalogue of Agricultural Implements Exhibited at the Society's Show at Lewes.

ROYAL COMMISSION ON THE HISTORICAL MONUMENTS OF ENGLAND (1985)
Rural Houses of the Lancashire Pennines 1560 to 1760. Supplementary Series 10.

________ (1986)
Rural Houses of West Yorkshire. Supplementary Series 8. West Yorkshire Metropolitan County Council.

RUSKIN, JOHN (1865)
The Seven Lamps of Architecture. New York: John Wiley and Son.

SAINT, ANDREW (1976)
Richard Norman Shaw. New Haven: Yale University Press.

________ (1983)
The Image of the Architect. New Haven and London: Yale University Press.

SALZMAN, LOUIS FRANCIS (1952)
Building in England Down to 1540: A Documentary History. Oxford: Clarendon Press.

SAMUEL, RAPHAEL (1977)
Miners, Quarrymen and Saltworkers. London: Routledge and Kegan Paul.

________ (1977)
"Workshop of the World: Steam Power and Hand Technology in Mid-Victorian Britain". History Workshop 3: 6-72.

SAVILLE, JOHN (1955)
"Sleeping Partnership and Limited Liability, 1850-1856". Economic History Review, 2nd Ser. 8: 418-433.

________, Ed. (1973)
Working Conditions in the Victorian Age. Farnborough: Gregg.

SAUL, S.B. (1962)
"House Building in England 1890-1914". Economic History Review, 2nd Ser., 15, 1: 119-137.

________, Ed. (1970)
Technological Change: The United States and Britain in the Nineteenth Century. London: Methuen and Company Limited.

SCOTT, GEORGE GILBERT (1858)
Remarks on Secular and Domestic Architecture, Present and Future. London: John Murray, 2nd Edn.

________ (1879)
Personal and Professional Recollections. Edited by G. Gilbert Scott, Jr. London: S. Low, Marston, Searle and Rivington.

SCRUTATOR (1834)
"On the Present State of the Profession of Architect and Surveyor, and of the Building Trade in England". Architectural Magazine, 1: 12-16.

SEARLE, ALFRED (1915)
Clays and Clay Products. London: Sir Isaac Pitman & Sons Ltd.

________ (1931)
Modern Brickmaking. London: Ernest Benn Limited, 3rd Edn.

SEDDON, CAPTAIN, R.E. (1871-72)
"Our Present Knowledge of Building Materials and How to Improve It". Papers of the RIBA, Etc., 1871-72, p.143-157.

SEDDON, JOHN P. (1870-71)
"On the University College of Wales and Other Buildings At and Near Aberystwith". RIBA Papers, Etc, 1870-71, p.148-155.

SHANNON, H.A. (1932)
"The First Five Thousand Limited Companies and Their Duration". Economic History, 2, 7: 396-423.

_________ (1933)
"The Limited Companies of 1866-1883". Economic History Review, 4: 290-316.

_________ (1934)
"Bricks -- A Trade Index, 1785-1849". Economica, N.S., 1:300-318.

SIMMS, Frederick Walter (1838)
"On the Construction of Flat Roofs with Earthenware pots". Proceedings of the Institution of Civil Engineers, 1:5.

_________ (1843)
"An Account of the Brick-making at Blechingley Tunnel During the Winter of 1840 and Summer of 1841". Proceedings of the Institution of Civil Engineers, 2: 145-155.

SIMMINS, JACK (1968)
St.Pancras Station. London: George Allen and Unwin Ltd.

SINGER, CHARLES, E.J. HOLMYARD, A.R. HALL AND TREVOR I. WILLIAMS, EDS. (1958)
A History of Technology. Oxford: Oxford University Press.

SKEMPTON, PROF. A.W. (1963)
"Portland Cements, 1843-1887". Transactions of the Newcomen Society, 35: 117-152.

SMILES, SAMUEL (1863)
Lives of the Engineers. London: John Murray.

_________ (1967)
Industrial Biography: Iron Workers and Tool Makers. Newton Abbot: David and Charles Reprint, 1863 Edn.

SMITH, DENIS (1981)
"David Kirkaldy (1820-1897) and Engineering Materials Testing". Transactions of the Newcomen Society. 52: 49-65.

SMITH, GEORGE (1871)
The Cry of the Children from the Brickyards of England.

SMITH, JAMES (1831)
Remarks on Thorough Draining and Deep Ploughing. London.

SMITH, JOHN AND THOMAS (1835-36)
"On Whinstone Constructions, Etc.". Transactions of the Institute of British Architects 1835-36, 1, 1: 52-60.

SMITH, P. (1975)
Houses of the Welsh Countryside. London: HMSO

SMITH, T.P. (1975)
"Rat-trap Bond in Bedfordshire". Bedfordshire Magazine, 14, 112: 344-347.

SMITH, T. ROGER (1867)
"On Buildings for European Occupation in Tropical Climates, Especially India". RIBA Papers, Etc., p. 197-208.

________ (1874-75)
"On New Materials and Recent Inventions Connected with Building". RIBA Papers, Etc., p. 199-216

SPRING, DAVID (1963)
The English Landed Estate in the 19th Century: Its Administration. Baltimore: Johns Hopkins.

STAMP, GAVIN AND COLIN AMERY (1980)
Victorian Buildings of London, 1837-1887. London: The Architectural Press.

STANTON, PHOEBE (1972)
Pugin. New York: The Viking Press.

STEELE, H. ROOKSBY AND F.R. YERBURY (1930)
The Old Bank of England, London. London: Ernest Benn, Limited.

STEPHENS, HENRY (1848)
A Manual of Practical Draining. Edinburgh.

STEVENSON, J.J. (1880)
House Architecture. London: Macmillan and Company.

STEWART, CECIL (1956)
The Stones of Manchester. London: Arnold.

STOREY, RICHARD (1965)
"Hitch's Patent Bricks". The Journal of Industrial Archaeology, 1, 4: 231-232.

________ (1970)
"Hitch's Patent Bricks: Some Further Details". Industrial Archaeology, 7, 3: 319-324.

STRATTON, MICHAEL JOHN (1983)
"The Manufacture and Utilisation of Architectural Terracotta and Faience". PhD Thesis, University of Aston.

STRAUB, HANS (1952)
A History of Civil Engineering: An Outline from Ancient to Modern Times. London: Hill.

STREET GEORGE EDMUND (1874)
Brick and Marble in the Middle Ages: Notes of Tours in the North of Italy. London: John Murray, 2nd Edn.

STREET, WILLIAM AND MAX CLARKE (1896)
"Brickwork Tests; Report on the First Series of Experiments". Journal of the Royal Institute of British Architects, 3rd Ser. 3: 333-345.

________ (1897)
"Brickwork Tests: Report on the Second Series of Experiments". Journal of the Royal Institute of British Architects, 3rd Ser. 4: 73-96.

________ (1898)
"Brickwork Tests: Report on the Third Series of Experiments". Journal of the Royal Institute of British Architects, 3rd Ser. 5: 77-99.

STROUD, DOROTHY (1966)
Henry Holland: His Life and Architecture. London: Country Life Limited.

SUMMERSON, JOHN (1953)
Architecture in Britain, 1530-1830. Harmonsworth: Penguin Books.

________, Ed. (1968)
Concerning Architecture. London: The Penguin Press.

________ (1973a)
"London, the Artifact". In H.J. Dyos and Michael Wolff, Eds. The Victorian City, Vol.I. London: Routledge and Kegan Paul.

________ (1973b)
The London Building World of the Eighteen-Sixties. London: Thames and Hudson.

________ (1978)
Georgian London. Harmondsworth: Penguin Books.

________ (1983)
John Soane. London: Architectural Monographs. Academy Editions.

________ (1984)
"The Evolution of Soane's Bank Stock Office at the Bank of England". Architectural History, 27: 135-138.

SUTCLIFFE, G. LISTER (1899)
The Principles and Practice of Modern House Construction, Vol. I. London: Blackie & Son Ltd.

TANN, JENNIFER (1970)
The Development of the Factory. Cornmarket.

TARN, JOHN NELSON (1971)
Working Class Housing in Nineteenth Century Britain. London: Lund Humphries.

________ (1973)
Five Per Cent Philanthropy: An Account of Housing in Urban Areas, 1840-1914. Cambridge: Cambridge University Press.

TAYLOR, JOHN (1862-63)
"Sundry Sanitary Building Appliances". RIBA Papers, Etc. 1862-63, Part I, p. 77-98.

THOMPSON, F. M. L. (1968)
The Chartered Surveyor. London: Routledge and Kegan Paul.

THOMPSON, H. S. (1848)
"Report on the Exhibition of Implements at the York Meeting, 1848". Transactions of the Yorkshire Agricultural Society, 11: 41-45.

THOMPSON, PAUL (1971)
William Butterfield. London: Routledge and Kegan Paul.

TODD, GEOFFREY (1932)
"Some Aspects of Joint Stock Companies 1844-1900". THe Economic History Review, 4, 1: 66-69.

TOMLINSON, CHARLES (1850)
A Rudimentary Treatise on Warming and Ventilation. London: Weale.

TREDGOLD, THOMAS, ED. (1849)
Practical Carpentry, Joinery, and Cabinet Making. London: Kelly.

________ (1836)
Principle of Warming and Ventilation. London.

TROLLOPE, EDWARD (1857)
"Use and Abuse of Red Bricks". Associated Architectural Societies Reports and Papers, 4: 216-229.

TROWELL, FRANK (1982)
"19th Century Speculative Housing in Leeds, With Special Reference to the Suburb of Headingly, 1838-1914". DPhil Thesis, University of York.

TUIT, J.E. (1896)
"Description of the Hydraulic Testing Machine". Journal of the RIBA, 3rd Ser. 3: 352-353.

TURNER, MARGARET (1978)
"Handmoulding Bricks for History: The Bulmer Brickfield, Suffolk". Country Life, 164, 4242: 1319-1322.

TWEEDDALE MSS
National Library of Scotland, MS 14463.

UNWIN, WILLIAM CAWTHORNE (1888)
The Testing of Materials of Construction. London: Longmans, Green and Company.

URE, ANDREW M.D. (1835)
The Philosophy of Manufactures, Etc.. London: Charles Knight. Frank Cass Reprint, London, 1967.

________ (1839)
A Dictionary of Arts, Manufactures and Mines. London: Longmans.

VON TUNZELMANN, G.N. (1981)
"Technical Progress During the Industrial Revolution". In Roderick Floud and Donald McCloskey. The Economic History of Britain Since 1700, Vol. I: 1700-1860. Cambridge: Cambridge University Press.

WARD, HENRY (1885-6)
"Brickmaking". Proceedings of the Institution of Civil Engineers, Part 4: 1-38.

WARE, ISAAC (1756)
A Complete Body of Architecture. London: T. Osborne and J. Shipton

WATERHOUSE, ALFRED (1865-66)
"A Short Description of the Manchester Assize Courts". RIBA Papers, Etc. 1865-66. , p. 1652-176.

WATKIN, DAVID (1974)
The Life and Work of C.R. Cockerell. London: A. Zwemmer Limited.

WEBB, SIDNEY AND ARNOLD FREEMAN, EDS. (1912)
Seasonal Trades. London: Constable and Company Limited.

WEBER, B. (1955)
"A New Index of Residential Construction and Long Cycles in House-Building in Great Britain 1838-1950". Scottish Journal of Political Economy, 2, 2: 104-132.

WEBSTER, JOHN J. (1890-91)
"Fire-Proof Construction". Proceedings of the Institution of Civil Engineers, 105: 249-288.

WEILER, JOHN MICHAEL (1987)
"Army Architects: The Royal Engineers and the Development of Building Technology in the Nineteenth Century". DPhil Thesis, The University of York.

WESCOMBE, W.F. (1893)
"Brickmking, 1850-1890". The British Clayworker, p.2-4.

WHITE, JAMES F. (1962)
The Cambridge Movement: The Ecclesiologists and the Gothic Revival. Cambridge: Cambridge University Press.

WHITE, W.C.F. (1971)
"A Gazetteer of Brick and Tile Works in Hampshire". Proceedings of the Hampshire Field Club, 28:81-97.

WHITEHEAD, ROBERT A. (1964)
Garretts of Leiston. Hertford: Model and Allied Publications Ltd.

White's History, Gazetteer and Directory of Norfolk (1854)

WHITWORTH, JOSEPH (1854)
"Special Report of Mr. Joseph Whitworth". BPP New York Industrial Exhibition. 1854 [1718] XXXVI.103. p.120.

WIENER, MARTIN J. (1981)
English Culture and the Decline of the Industrial Spirit, 1850-1980. Cambridge: Cambridge University Press.

WIGGINS, JOHN (1840)
"On the Mode of Making and Using Tiles for Under-Draining, Practised on the Stow Hall Estate in Norfolk, Etc.". Journal of the Royal Agricultural Society of England, p.350-356.

WIGHT, JANE A. (1972)
Brick Building in England From the Middle Ages to 1550. London: John Baker Ltd.

WIGHTWICK, GEORGE (1835)
"A Few Observations on the Reviving Taste for Pointed Architecture, Etc." Architectural Magazine, 2:342-48.

________ (1853)
"The Principles and Practice of Architectural Design". Detached Essays and Illustrations. Architectural Publications Society. London: Thomas Richards.

WILLIAMS, J.A. (1968)
Buildings and Builders. London: Longmans, Green and Company Limited.

WILSON, CHARLES (1957)
"The Entrepreneur in the Industrial Revolution in Britain". History, 42:87-103.

WINGAY, G.E. (1977)
The Agricultural Revolution: Changes in Agriculture 1650-1880. London: Adam and Charles Black.

WODEHOUSE/KIMBERLEY MSS
Norfolk Record Office, Norwich

WOHL, ANTHONY (1984)
Endangered Lives: Public Health in Victorian Britain. London: Methuen and Company Ltd.

WOLFF, JANET (1981)
The Social Production of Art. London: Macmillan.

WONNACOTT, THOMAS H. (1871-72)
"On The Use of Portland Cement Concrete as a Building Material". RIBA Papers, Etc. 1871-72, p. 175-180.

WOOD, MARGARET (1965)
The English Medieval House. London: Phoenix.

WOOD-JONES, RAYMOND (1963)
Traditional Domestic Architecture of the Banbury Region. Manchester: Manchester University Press.

WOODCROFT, BENNET (1969)
Alphabetical Index of Patents of Invention. London: Evelyn, Adams and Mackay. First Published 1854.

_________ (1855)
Subject Matter Index of Patents of Invention. London: Eyre and Spottiswoode.

WOODFORDE, JOHN (1976)
Bricks to Build a House. London: Routledge and Kegan Paul.

WORCESTER ASSOCIATION FOR BUILDING DWELLINGS FOR THE LABOURING CLASSES MSS
Hereford and Worrcester Record Office.

WRIGLEY, Julia (1986)
"Technical Education and Industry in the Nineteenth Century". In Bernard Elbaum and William Lazonick. The Decline of the British Economy. Oxford: Clarendon Press.

YOUNG, D. (1970a)
"Brickmaking at Sandleheath, Hampshire". Industrial Archaeology, 9: 439-442.

________ (1970b)
"Brickmaking at Weymouth, Dorset". Industrial Archaeology, 9, 2: 188-196.