

Architectural ornamentation using
terra cotta: Evolution, use, and restoration
with emphasis on Louis Sullivan and
the Merchants National Bank

by

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A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF ARCHITECTURE

Major: Architecture

Signatures have been redacted for privacy

Iowa State University
Ames, Iowa

1990

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INTRODUCTION

The purpose of this thesis is to investigate architectural ornamentation as it pertains to terra cotta.

The use of terra cotta is nothing new; in fact nearly all the ancient civilizations used it to some degree. Terra cotta, at the same time, is not a material that has been used to a great degree since the 1930s. So why should I be interested in a building material that ended in the 1930s?

I believe that the time is right for another cycle of ornament in architecture. People want a building that is different from the next, a building that they can call their own. One reason the restoration industry is so successful, for example, is that the public is mandating the repair of old buildings. Terra cotta is the perfect material with which to add individuality to a building. Terra cotta can be made cheaper and faster than stone, and, with our technology today, can be made to last longer.

To understand terra cotta it is important to learn the material's history, its manufacturing process, and uses.

A historic overview of terra cotta will be broken down into two sections. The first will cover the use of terra cotta from the Greeks and Romans through the Middle Ages to the 1870s. The time period will be studied to look for

major uses of the material and any advances that occurred from civilization to civilization.

The second history section will cover the time period of 1870 to the early 1900s. During this time period great advances were made in terra cotta technology. What were the reasons for this great explosion? Terra cotta has been called the "right material at the right time". Why was it the right material, and how was it used? These questions will be the basis for studying the rise in popularity of terra cotta.

In the next section I will look at an architect, Louis Sullivan, whose name is synonymous with terra cotta design. He was a pioneer in the use of terra cotta as both a fireproofing material and as an ornamental element. Looking at Sullivan and two banks he designed, I hope to better understand how he used terra cotta not as just a stock element, but as an integral part of the whole building.

Many steps must be considered when manufacturing terra cotta. Within this process, there are major obstacles that need to be addressed to insure successful results. In the section on the manufacturing of terra cotta the process will be broken down into its various steps which will then be explained in depth. By analyzing the manufacturing steps, I hope better to understand not only how a piece of

terra cotta is produced, but what takes place during these steps. I also hope to gain a better understanding of problems that arise and how manufacturers in the past have combatted these problems.

The problems of deterioration and maintenance are very important because many of the existing terra cotta buildings are nearly a century old. This section of the thesis attempts to answer the following questions. What are the major causes of deterioration? Were the problems in the original manufacturing, design and installation, from water penetration, or improper attempts to clean, repair, or modernize the building? One of terra cotta's great selling points was that it was virtually maintenance free, a material that will last forever. Why was this statement true in some cases and not in others? My goal in this section is to better understand the problems so solutions can be formulated to eradicate the problems.

The section on preservation and replacement develops the idea that rehabilitation of a building which includes terra cotta involves many variables. The first critical step is a thorough inspection of the terra cotta, which is often quite difficult. What are the methods available to inspect terra cotta, and how has technology improved these methods and made results more exact? Proper analysis of the results are then used to determine the condition of the

terra cotta. The decision to repair or replace damaged terra cotta is based on the test results and costs involved. If it is decided to replace the damaged pieces, there are several options. The replacement materials will be looked at to understand the strengths and weaknesses compared to the original terra cotta.

The section on the banks, the National Farmers Bank, Owatonna, Minnesota, and the Merchants National Bank, Grinnell, Iowa, will serve as study cases to understand the relationship between terra cotta and other building elements, and terra cotta and the building as a whole. These banks were chosen because they are excellent examples in terra cotta use, can be visited, and can be studied through literary sources.

The terra cotta project section of my thesis will encompass what I have learned in the preceding research. The research will be the basis for my project of remaking pieces from the Grinnell Bank. I believe that to understand terra cotta as an element, you must work with it in three dimensional form and not just write about it. I feel that thus I obtain a greater insight into many of the questions that have arisen during my research, and that the process will explain the various aspects of terra cotta manufacturing.

I will briefly look at terra cotta today. Is it being

used as in the past, or are there new methods of application for terra cotta? Is there a future for terra cotta, and if so can technological advances meet these demands?

In the conclusion I will reflect back upon various aspects of what I have learned and discovered during the written portion of my thesis. I will also discuss the project portion of my thesis - not only what I learned, but the problems and frustrations that arose while working with the material. In addition the conclusion, besides reflection upon the written and project portions, will emphasize the relationship between the two.

The appendices are included to explain a few major portions of my thesis. The first two will cover some selected additional information on Sullivan's banks in Owatonna and Grinnell, including additional photographs to explain the banks. The third appendix will be a brief "how-to" explanation of the steps followed in my manufacturing process. Each step will include a written statement and drawing. The fourth appendix will be a glossary containing important definitions associated with terra cotta.

TERRA COTTA EARLY HISTORY

Terra cotta in its broadest definition has been called "... undoubtedly the oldest building material known to history, other than wood." Nearly all the ancient civilizations--Etruscans, Greeks, Romans, Persians, Indians, Chinese, and Central American Indians--left large numbers of works in sun-baked or burned clay (Jandl, 1983, p. 117).

The broadest definition of terra cotta, which is Italian for "baked earth", includes pottery, statuary, and bricks. Non-architectural uses of terra cotta have included ordinary eating utensils, soldier's breast plates, and the sarcophagi of the Etruscans which were cast in terra cotta. Architectural terra cotta is defined as a fine grade of clays combined together which are then molded or cast into hollow blocks to be used as ornamental or cladding materials.

The use of terra cotta does not appear in architectural forms before the time of the Greeks. It appears first in the gutters of the Greek temples; the cymation or upper moulding was made of terra cotta because of its great durability. The Greeks also in some cases blocked out a main cornice in stone, and then neatly fitted on a veneer of ornamental terra cotta plaques. The Romans

used terra cotta to protect both stone and wood from the weather as well as to decorate both interiors and exteriors of their buildings. Many of the reliefs associated with Roman architecture, in fact, appear to have been pressed in molds (Jandl, 1983, p. 117).

The downfall of the Roman Empire in 409 A.D., caused terra cotta to be virtually abandoned as a building material until the 12th century. However, builders during the Byzantine period were known to have used terra cotta for window frames with the glass inserted and fastened with cement. Terra cotta was also occasionally used as a roofing tile by the Byzantine builders.

During the 15th century, a sophisticated terra cotta building technology developed in Italy. The area around Faenza, Italy, was particularly known for its fine work; indeed, especially fine terra cotta was known as "faience" from the name of the city (Jandl, 1983, p. 118).

In ancient times, terra cotta was unglazed and had a range of colors limited to the earth tones resulting from natural pigments, such as iron. Thus, the minerals in the clay deposits had added variety to the clay surface before glaze technology was developed. However, this new polychromatic glazing technique technology that developed allowed for a range of permanent colors never before obtained in architecture outside of stained glass. The

variety of colors and there application was largely developed by the Della Robbias.

Luca della Robbia was the leader of the della Robia family of sculptors, potters, and workers in enamels and glazes. Desiring a material which would be subtle and stimulating, to which color could be applied in places, Luca centered his attention to facile and responsive clay, glazing it with a hard enamel, an opaque body which invited a picturesque and vivacious handling to which he added color (Howe, 1911, pp. 179, 180). The family in succeeding generations raised the production of enamelled glazes to an artistic plane previously unattained, and in the opinion of many people, their masterworks have never been equaled.

The use of terra cotta gradually spread over western Europe from Italy. Terra cotta was used primarily in architectonic applications such as lintels, beltcourses, and window surrounds. The development of the Tudor style gave impetus to the use of brick and terra cotta in England, as exemplified in the great manor houses; during the unrest following the Reformation, however, terra cotta again fell out of favor in England, primarily because of reduced trade with Italy (Jandl, 1983, p. 118).

The decline of terra cotta as a building material lasted until the 18th century, when terra cotta was revived in England and Germany, where it was prized for its cost

effectiveness, ease of modeling, resistance to industrial pollutants, light weight, and durability. The best known of the terra cotta manufacturers from this period was the Coade establishment, which ran from around 1790 until about 1850 (Jandl, 1983, p. 118). As terra cotta use increased, competition became more keen as more manufacturers developed the ability to produce terra cotta.

During this time period many immigrants were coming to America, and some brought with them the knowledge needed to produce architectural terra cotta, knowledge which up to this time, was very limited in the United States. For example, in eastern Pennsylvania, the German settlements used terra cotta as flat roofing tiles during the 18th century, but that was the extent of its use as a building material until the next century.

Small scale production of terra cotta had begun in America in the 1840s and 1850s. Massive lintels and corbels made of terra cotta were used as replacements for heavier stone. In New York, architect James Renwick used terra cotta for the belt courses and the cornice of the Tonine building, the ornamental work on the St. Denis Hotel, and on three houses on 9th Street, between 5th and 6th Avenues (Croly, 1905, p. 88). Richard Upjohn, another architect who pioneered terra cotta use, painted terra cotta to resemble brownstone in the design for the Trinity

Church (1852).

Much of the earliest terra cotta produced was attempted by ceramic companies accustomed to working with clay in the form of vessels or sewer tile. These companies did not understand that, as a building element, terra cotta must have the strength required to carry building loads. This lack of understanding and inadequacy of kilns and consequent inability to standardize production caused many early pieces of terra cotta to lack durability and fail. These early terra cotta failures resulted in the decline of terra cotta as a building material for 20 years until the Chicago Fire of 1871.

1870: THE RISE IN POPULARITY

The devastation of the Chicago Fire (October 1871) brought to the attention of building owners and contractors the importance of fire-proof construction techniques. Inspection of the ruins showed that buildings using terra cotta as a fireproofing material or in the facades withstood the fire. Stone, iron, and brick were commonly believed to be fireproof building materials, but stone walls had crumbled, iron columns twisted and melted, and bricks were broken. Terra cotta was the material that had survived and the Chicago Fire helped to fuel the subsequent rapid growth of the city.

Beginning in the 1800s, the use of terra cotta as a building material increased rapidly. A very significant factor in the growth of terra cotta was the passage in 1886 of a Chicago city ordinance requiring all buildings over 90 feet tall to be absolutely fireproof. To be in compliance with the ordinance, builders turned to terra cotta. Terra cotta was the "right material at the right time" as far as tall building construction was concerned. Terra cotta, whether used as a structural element or as a fireproofing material, was the material that would protect a building from the ravages of fire.

Structural terra cotta was used in walls as load-

bearing units laid up in mortar and requiring little additional anchoring, and was often used as ornamental units in conjunction with stonework or brickwork. Structural terra cotta was associated with Gothic, Romanesque, Queen Anne and other revival movements where it was used particularly for ornamental detail such as string courses, capitals, and window moldings. Two early examples of the blending of structural terra cotta with other materials were at Dearborn Street Station (Dearborn at Polk Street, Cyrus L.W. Eidlitz, 1885) and the Rookery (209 South LaSalle, Burnham & Root, 1886) (Berryman and Tindall, 1984, p. 2).

Terra cotta used as a fireproofing material was designed to protect metal-frame buildings. Fireproof terra cotta was extruded in a variety of hollow shapes that could be used to encase columns or beams, or as a subflooring to prevent the vertical spread of fire. In the design of the Kendall Building in Chicago (1872) John Van Osdel used iron I-beams and columns that were encased in terra cotta tiles in conjunction with elongated tiles that were joined together to form arched ceilings, partitions, and floors. This was the first totally fireproof terra cotta building built in Chicago.

The development of structural metal-frame construction created the need for a terra cotta cladding. By the

1890s, metal-frame construction with terra cotta cladding had effectively replaced structural terra cotta which was now used only in smaller load-bearing masonry projects and for partitions.

Terra cotta cladding was extremely popular from the 1890s through the first third of the twentieth century. It sheathed the early skyscrapers of the Chicago School of Architecture, the set-back structures of the Art Deco Movement, the commercial buildings on neighborhood and Main Street business strips and opulent movie palaces (Berryman and Tindall, 1984, p. 2).

Advantages

Terra cotta as a building element had many advantages over other building materials. As stated before, terra cotta was able to survive the effects of the fires where wood, stone, and iron were not, because terra cotta was fired to such a high temperature during manufacturing, that the temperatures in a building fire did not affect it. Stonework, besides being affected by fire, was very expensive. The lack of skilled workers in the carving and finishing of stone kept the price of stonework very high. The fire dangers of lightweight wood construction are obvious, and although iron is a fire manufactured material, the temperatures reached during its manufacturing are lower

than that of most building fires.

Terra cotta buildings tended to stay fresh-looking longer than stone buildings. This was important in cities where tons of coal were burned daily, and the smoke and dirt in the air would collect on porous surfaces turning them black and unattractive. The ordinary acid gases contained in the atmosphere of cities had no effect upon it [terra cotta], and the dust which gathered on the moldings was usually washed away at every rainfall (Warren, 1905, p. 10).

Builders of skyscrapers found terra cotta a very attractive medium because of its light weight and ease of molding into decorative elements. A cube of solid terra cotta one foot on each edge would weigh approximately 120 pounds. Since the blocks were made hollow, terra cotta as used in building actually weighs only 60-75 pounds per cubic foot. By comparison, sandstone weighs approximately 150 pounds per cubic foot, and granite weighs approximately 175 pounds per cubic foot (Jandl, 1983, p. 147). Terra cotta retained its crisp details longer than other building materials, and could be used by architects to embellish their structures economically with original ornament. Thus safety, economy, and appearance were all factors that gave terra cotta an advantage over other materials.

The ease with which repetitive pieces could be

produced was another advantage terra cotta had over other materials. Once a mold was produced, numerous pieces of identical terra cotta could be manufactured. With stonework, each piece had to be hand carved. This was an element of terra cotta use that greatly reduced its cost and led to its popularity.

In summary, the growth in the use of terra cotta was greatly increased by its being a fireproof material, by its ability to reduce building costs by lowering the total weight of the building, by the ease and economy of repetitive detail, and by the ability to retain a fresh new appearance.

Stock Ornament

The cost advantage in terra cotta was greatly increased when a large proportion of the pieces could be cast in a mold. The cost to produce the mold became minimal when spread over numerous pieces. To promote terra cotta as an economic alternative for even limited budgets, manufactures began to produce stock ornament.

For modest buildings, architects and builders often minimized the expense of terra cotta by employing "stock" designs kept on hand at the manufactory. These were uniformly sized and pre-priced, allowing the contractor to determine not only the scale but the price of the completed

ornament (Darling, 1979 pp. 186-187).

Manufactures made stock ornament very economical and convenient by keeping large numbers of the pieces in stock, and having the molds ready so they could manufacture more at a short notice and at less expense than for ordinary terra cotta.

After the turn of the century the use of stock ornament increased greatly. Construction techniques became standardized, and architect and building owners often used terra cotta to add a personal touch to an otherwise undistinguished building.

Integration into the Wall

When terra cotta was used for tall office buildings in the early 1880s, it was often in the form of a crest of large, heavy ornament along the roofline (Darling, 1979, p. 175), and was very rarely integrated into the wall surface. The terra cotta remained quite separate in most instances until after 1890s when, as in the work of Sullivan, the concept of overall sheathing in terra cotta was established (Floyd, 1989, pp. 35 and 36). The integration of terra cotta into the wall system was a major fact contributing to the use of terra cotta to clad buildings, and to create building exteriors that became a more unified whole.

The development of terra cotta in America was very rapid. Its introduction to the building trade had been handicapped by a restricted knowledge of its technical possibilities. Due to the rapid increase in terra cotta use during the late 1800s, many firms began to produce terra cotta without understanding the problems associated with its manufacturing. Manufacturers began to undercut each other when bidding a project and subsequently produced an inferior material. This led to a bad reputation for terra cotta and harmed the manufacturers producing a high quality material.

The terra cotta industry recognized the need to organize as early as 1886 when the Brown Association was formed by New York companies. It was followed by the Manhattan Materials Company in 1896 and the Terra Cotta Manufacturers Association in 1902. Finally, in 1911, the National Terra Cotta Society, which remained active until 1934, was created (Tunick, 1989, p. 45).

The organization of terra cotta companies worked to produce a uniform quality standard that anybody belonging to the organization and producing terra cotta was to meet. The organization worked to eliminate the problems that had arisen by the production of inferior quality terra cotta, and promoted terra cotta and its advantages.

The National Terra Cotta Society produced "Terra

Cotta: Standard Construction." This standard gave a brief synopsis on the manufacturing process, recommended details, and included a standard specification for the manufacture, finishing and setting of terra cotta.

The work of the societies greatly increased the reputation of terra cotta as a building material, by working at a national level to promote the use of terra cotta in the building industry.

LOUIS H. SULLIVAN: HISTORY AND THEORY

While Chicago's terra cotta skyline may have "symbolized" commercial enterprise and culture, it directly reflected the work of architects like William LeBaron Jenney and Henry Ives Cobb and firms such as Holabird & Roche, Burnham & Root, and Adler & Sullivan. Under the guidance of Daniel Burnham and John Welborn Root the firm of Burnham & Root could claim responsibility for many of the massive brick and terra cotta skyscrapers which dominated Chicago's Loop. However, it is with the firm of Adler & Sullivan that the use of terra cotta is now most often associated (Darling, 1979, p. 180).

During a productive fifteen-year association, lasting from 1880 through 1895, Dankmar Adler became known for his technical ingenuity while Louis H. Sullivan earned praise for his imaginative decorative designs (Darling, 1979, p. 180). Sullivan who was responsible for the ornamentation, favored motifs based on and derived from botanical inspirations.

In 1874 Louis Sullivan left the office of Frank Furness in Philadelphia and moved to Chicago. While working for Furness, Sullivan was introduced to the idea of multi-material building surfaces in the design of the Pennsylvania Academy of Fine Arts which combined diaper-

patterned and tar-dipped brick with glass mosaic and carved stone. Although terra cotta was not an element, the concept of combining materials, especially brick with other elements was introduced to Sullivan, a concept with which he would become a master.

Sullivan arrived in Chicago and began experimenting immediately with the creative potential of clay for architectural ornament in his early Chicago houses and at the Troescher Building. On the former, he initially utilized plaques and discrete, ornamental details that evolve stylistically from the Revel Building (1881) or the Rosenfeld Building (1883) where the foliage is close to the stylized neo-Grec designs that Frank Furness customarily used (Floyd, 1989, p. 36).

Examples of terra cotta from Sullivan's early career, now in the extensive Richard Nickel Collection at the University of Southern Illinois at Edwardsville, suggest the evolution of Sullivan's ornament from the neo-Grec forms of the early 1870s to his own individual style (Floyd, 1989, p. 36).

The deep red terra cotta spandrels on the Troescher Building (1884), and the trim on the Ruben Rubel house (1884), both contain angular floral abstractions incorporating shells and snake-like spirals. Over the course of the next few years, Sullivan's terra cotta

ornamentation gradually evolved from botanical motifs and became more natural and luxuriant, taking the form of elongated buds, and leaves.

Sullivan's ornament thus was a combination of Byzantine and Moorish precedents along with his developing designs based on plant life. These designs were executed in clay, plaster, wood, and iron, but terra cotta was the material essential to the articulation of the building exteriors.

The transposition of design between materials is particularly notable on the Getty Tomb (1890), St. Louis, Missouri, where the upper walls of the rectangular structure are articulated as a field of repetitive ornament that would have lent itself ideally to molding in terra cotta although the building itself is actually of limestone. The same conditions were apparently also obtained at the Pueblo Opera House, Pueblo, Colorado, where quantities of fine ornament that, within a few years Sullivan would have been executing in terra cotta, were carved in stone. These critical years between 1886 and 1892 mark the point at which fired clay became the central medium for the expression of Sullivan's design potential (Floyd, 1989, p. 37).

As terra cotta became the central medium, the method in which terra cotta was designed by Sullivan continued to

evolve. The design of the ornament on the terra cotta became a combination of geometric and naturalistic forms.

Sullivan's ornament began to show geometric forms incorporated in with the botanical ornament during the 1890s. The Schiller Theatre (1892) shows further evidence of Sullivan's evolution in ornament by featuring large geometric forms intertwined with small clusters of curly leaves. Geometric patterns were also predominant in the design of the Chicago Stock Exchange (1893), especially in the arched entrance to the Trading Room.

Sullivan continued to combine geometric and naturalistic forms during the mid-1890s and up until his death in 1924. Combining forms was based upon beliefs of Sullivan and can be best understood by looking at Sullivan's metaphysical and aesthetic assumptions. Lauren S. Weingarden in her essay "The Colors of Nature," describes this association:

Sullivan's self-concept as an artist-prophet rather than merely an architect-decorator helped him to translate the language of metaphysics into the language of art. Sullivan believed that an absolute force, what he called the "Infinite Creative Spirit," manifested itself as cosmic rhythms generating and synthesizing the interaction between "objective" and "subjective" phenomena. Sullivan identified the objective with the visible appearances in nature and logical, rational analysis of human and natural conditions. Conversely, he equated the subjective with the intangible, vital essence of reality and emotional, spiritual responses to nature. Transforming linguistics into architectural symbolism, Sullivan represented the objective with the reductivist, geometric architectural masses and

structural elements. On the other hand, he created an "organic" style of ornament to symbolize the subjective component of his dialectical world view.

(Weingarden, 1985, p. 243)

Sullivan thus combined the objective (geometric) with the "subjective" (organic) in his terra cotta designs. Sullivan, by using terra cotta in his buildings, was able to translate these ideas of the metaphysical into works of art as would a painter with a brush or a poet with a pen.

The word "poet" appears repeatedly in Sullivan's writings as the highest goal to which an architect can aspire. This suggests that Sullivan used terra cotta not as a decorative element, but as an expressive element, one with feeling.

While Sullivan's ornament design was evolving, application of terra cotta on buildings was also transforming. Sullivan's metaphysical beliefs translated into geometric and naturalistic forms, caused his terra cotta to become more three-dimensional and become important as an object. A tympanum from the Albert Sullivan House (1893) in Chicago illustrates the way in which his ornament changed, becoming highly undercut and more vegetal in form and with smaller unit parts by the 1890s. By the time of the Babson Residence in Chicago, another phase of ornamental design was clearly apparent. Instead of the ornament filling the whole field or segment of the building

on which it was placed, it was framed, clotted, and set off as separate from the walling, while tendrils of foliage escaped the frame to synthesize the clot to the surface (Floyd, 1989, p. 38). The framing with terra cotta and setting it off separately from the wall plane is very evident in Sullivan's designs after 1900 and especially in his bank designs.

Sullivan in his bank designs, starting with the National Farmers Bank in Owatonna, Minnesota, continued to use richly colored terra cotta that combined geometric and foliated forms. Although all the bank designs were different, Sullivan used a most intimate knowledge and masterful handling of building material and decorative ornament of a most personal nature, and the result is a living architecture that defies classification. At least, it only can be classified under one heading, and that is the architecture of Louis H. Sullivan. It is an architecture that is all embracing, derived from the source, and leaving no question open as to its authorship. It is conscientiously applied to all problems large or small (Rebori, 1916, p. 456).

MANUFACTURING

Terra cotta manufacturing involves many steps, but the process basically consists of preparing the clay, modeling the clay into desired forms, drying, glazing, and then firing the terra cotta. These steps all rely upon the quality of the clay and the temperature at which it is fired. Understanding the process of producing terra cotta, from the receipt of raw materials to the shipping of completed blocks, is important in understanding the wide range of possibilities, and also the limitations, associated with terra cotta.

Terra cotta plants, like other plants that manufactured clay products, were originally located close to the source of raw materials. As the demand for terra cotta increased, terra cotta plants were then located near the population centers. The clay materials now had to be brought to the plant; this fact allowed plants to blend various clays together to obtain the desired degree of strength, plasticity, or color. Many of these new plants were designed to manufacture only terra cotta and became very efficient in its production.

The proper preparation of clays was essential to obtain a high quality terra cotta body. The lack of an understanding of clay as a building material led to many

failures. To meet the demand for huge amounts of terra cotta of uniform quality, manufacturers employed ceramic engineers to improve the quality of the clay. The terra cotta was now properly supervised from arrival of the clays until the finished pieces left the plant.

The clays arrived at the plant by railroad car and were dumped into clay cellars to "weather". This process helped to break down the clays prior to further processing; it also converted the pyrites in the clay to hydrated ferric oxide and reduced alkali content, thus reducing potential chemical changes following manufacture (Jandl, 1983, p. 131). The length of the weathering process, up to a year in some cases, depended upon the various types of clays and the manufacturer.

Next the clay was ground or milled to reduce the clay particles to a workable size. The crushed clay was then cleaned of foreign materials. Prior to 1893, this process nearly always involved "washing" the clay by mixing it with sufficient water to make a cream-like slip (Jandl, 1983, p. 131). The resulting mixture was allowed to sit so the stones and other impurities would settle out. The resulting slip was then passed through a strainer to create a uniform consistency and placed in a bin to dry. By the mid-1890s, this step had been replaced by machines that were developed to reduce most of the impurities. Although

the degree of purification was not as great, removing the impurities by machine allowed the clay to retain a workable consistency. When cleaned the clay was sent to a receiving bin.

The clays deposited in the receiving bin were placed in layers with layers of grog in between. Grog, which is made from clay that has already been fired and then finely ground, adds stability to terra cotta because, in contrast to unfired clay, grog does not shrink when heated. The receiving bin allowed the blending of various clays to obtain the degree of strength, plasticity, or color desired. The clays and grog were then mixed by taking vertical sections through the bin and mixing them in a pug mill. The pug mill was a machine with an auger in the center that mixed and compacted the clay to a uniform texture. The clay that came from the pug mill was then ready for the aging process.

The aging process, which was also called "souring", was not always thought to be necessary. Aging was done in a cool, dark place, generally for about 12 months although some plants aged their clays for twice that period (Jandl, 1983, p. 132). The aging process allowed time for the water in the clay to become evenly distributed and the air bubbles to dissolve. The clays that were aged were much more plastic and easier to press into molds or be molded.

Aging thus became a practice adopted by terra cotta manufacturers.

Block Design

Block design is the name for a period of time where the architect and the manufacturer work to produce the drawings showing the details of the pieces and joint locations and develop a setting plan. The architect's primary means of conveying information to builders was by architectural drawings showing plans, elevations, sections, and selected details. Elevation drawings, usually drawn at a scale of 1/4" or 1/8" to the foot, indicated where terra cotta was to be used (Jandl, 1983 p. 122). The plans and elevations also gave preliminary information pertaining to the degree of ornamentation and how it would be supported, and sufficient additional information to allow the terra cotta manufacturers to bid on producing it.

After the contract was awarded, the first action was to prepare shop drawings which analyzed construction, the size of individual pieces, the relation of the terra cotta to contiguous building materials, and the connections to the steel framing. Location of structural members was of particular concern to manufacturers since design of the structural members without thought to the terra cotta frequently dictated that the blocks be formed in odd shapes

to fit around the steel, thus weakening them (Jandl, 1983, p. 128). The terra cotta manufacturer would work with the architect to try and avoid these problem areas by moving or redesigning the steel.

The architect would then draw the details at a larger scale to show the form and detail of the terra cotta. These sections and elevations were usually drawn at a scale of 1/2" or 1" to the foot with full size details of the terra cotta.

The final block design was done by the manufacturer and at each step the drawings were sent to the architect for approval. If any problems arose they were resolved before the manufacturer proceeded to the next step.

The initial drawings produced by the manufacturer were similar to the architect's in scale, either 1/2" or 1". The manufacturer used these drawings to determine final joint location and to layout a numbering pattern to identify similar pieces.

Joint location was a major concern for two reasons. First, many designs were intended to simulate stone, but since terra cotta blocks were smaller than stone, there were more joints, and efforts were made to hide as many of the extra joints as possible. Second, many designs included large sculptural areas, and in these areas all the joints were made to be as unobtrusive as possible. In both

of these cases, the joints were concealed where possible by placing them at changes in the plane of the surface, thus hiding them behind the projecting portion. This process was referred to as back-jointing or back-checking (Jandl, 1983, p. 128).

Upon approval by the architect of the initial drawings, and agreement between architect and manufacturer on joint location and structural details, the manufacturer produced "shrinkage scale" drawings of each piece. Shrinkage scale drawings were necessary because terra cotta shrinks a certain percentage, usually 6-15%, from the time it is made until it becomes a finished piece. These drawings were made using a special ruler which was approximately 26" long but divided in 24 equal increments each representing an inch. These scale inches were then divided into eighths. Since there were clays with different shrinkage factors, the draftsmen would have a variety of scales.

Terra cotta blocks were generally designed to be fairly small. The blocks were made from 18" to 24" long, from 6" to 12" deep and of a height determined by the character of the work... (Warren, 1905, p. 13). It was economical for the manufacturer to make smaller lighter pieces because both replacement and installation costs were reduced. Terra cotta, whether plain or ornamental, is

always made of hollow blocks. Although they can be made solid, making them hollow requires less material, reduces the weight, and is less expensive.

Modeling

The final drawings approved by the architect were sent to the modeling shop. In the modeling shop, the highly skilled modelers turned the drawings into three-dimensional objects. The model was usually made from terra cotta clay, which has more character of its own than sculptor's modelling clay, inducing crisper, more vigorous modelling (Clute, 1931, p. 193). Each larger piece was created as a whole object without joints, which were put in later when the model was cut into convenient sized blocks.

The modeler must be highly skilled in understanding the properties of the clay body. A four-foot piece (pieces usually weren't this big) has considerable movement. The knowledge the model and mold maker has, therefore, is critical in dealing with the idiosyncrasies of the clay. The piece may not shrink the same amount in each direction... and the models and molds must be made accordingly (Kruse, 1989, p. 51). Therefore the modeler, besides being a highly skilled artist, must also have the technical knowledge to understand shrinkage and the effect it has on the piece.

The models were then inspected by the architect, or if that was not practical, photographs of the models were sent to the architect for approval. Upon the architect's approval, the next step was for the manufacturer to make molds of the repetitive pieces.

Molding

Molds were made from the original produced by the modeler. The molds were made of plaster of Paris which combined high strength and the ability to absorb water. These were important qualities because they reduced the amount of time the clay needed to sit in the molds.

The molds were produced in several interlocking sections so that the mold could be taken apart without damaging the terra cotta piece. With the mold in several pieces it would dry quicker allowing the manufacturer to reassemble the mold and produce another piece. Molds were usually reinforced with quarter-inch square steel rods, and the sides were bound with steel strap irons. This reinforcement was necessary to withstand the stresses involved in forcing the clay into the molds (Jandl, 1983, p. 132).

Pressing

Terra cotta had to be hand pressed into the molds, by pressers. The interior of the molds is covered with clay to a depth of 1". After the mold has been covered, strengthening walls of the same thickness are added about 6" apart. Another common practice was to roll the clay into slabs, to remove air bubbles, and then cut the slabs into shapes to be pressed into the molds.

The blocks were then allowed to stiffen in the molds for a few hours. This procedure allowed the block to gain enough strength to hold its own weight without deforming, and also the clay would shrink slightly in the time period releasing the block from the mold.

An alternative to hand pressing was extrusion. A steel die was cut to match the specific profile of the form and clay was squeezed through the die in an extruder. Machine extrusion allowed for the mass production of terra cotta veneer and terra cotta intended for fireproofing.

Finishing

The final finishing of the piece involved smoothing the edges, repairing imperfections, and removing any plaster particles that came from the mold. The pieces were given a smooth surface by rubbing with either a piece of leather or wood.

The finishing process also involved the adding of final detail to a piece-- very fine detail and any undercutting that was required. Pieces from the same mold could be varied at this time by adding or removing detail from a piece. Some terra cotta workers advised against working over the surface, other than smoothing and trimming, because they believed that carving disrupted the molecular patterns at the surface, resulting in a weaker piece (Jandl, 1983, p. 133).

Drying

Upon completion of the finishing, the terra cotta blocks were taken to the "drying room". The drying rooms were heated to approximately 30 degrees centigrade (85 degrees Fahrenheit) with steam heat. The drying process took approximately 48 hours to dry the free water (Jandl, 1983, p. 134).

The exterior of the blocks tended to dry more quickly than the interior causing warping and cracking in the blocks. Some manufacturers, to overcome this tendency, would dry the terra cotta first with a slow dry heat and then with steam heat. The goal in drying a piece was to obtain an even drying throughout the piece to allow the piece to shrink evenly and reduce warping.

After the piece had dried it was referred to as green-

ware and was ready to accept a finishing surface.

Glazing

The glazing process is one of the steps that makes terra cotta a unique material in that it can be produced with several hard burned, enduring colors on the same piece.

For exterior use, terra cotta nearly always needed a protective surface covering commonly referred to as "glazing". The glazing process includes the coverings known as slips, glazes, and engobes. The pre-1890s terra cotta was usually coated with a slip, while after this time the use of glazes became the more popular method. Either finish, slip or glaze, produced a form of skin for the terra cotta that protected it from the elements.

The terms "vitreous", "dull finish", "matte finish", "glazed", "semi-glazed", and enameled" are all used to designate the different surface finishes of terra cotta, and these terms are all sometimes incorrectly applied. As a matter of fact there are but two surfaces, one has a dull, vitreous finish, also called "standard finish" by the manufacturers, produced by the fluxing of metallic oxides and slip upon the surface of the terra cotta body, and the other has a bright porcelain-like, glazed or enameled finish, usually formed by a coating of slip covered with

another of glaze (Warren, 1905, p. 13).

A slip glaze is a thin form of the clay body applied to the terra cotta block which, during the subsequent firing process, develops into a thin protective glaze. The slip is largely made up of clay, making it prone to high shrinkage, so it is applied while the terra cotta is still leather hard. Thus, the ware and the glaze shrink together and the tendency to crack can be avoided. Slip glazes tend to have a color range limited to the natural occurring clay body colors: black, brown, buff, and red. Around 1895, other colors began to become more popular, and by 1895 slip colorings included buff, grey in several shades, cream, and pure white (Jandl, 1983, p. 135).

Although the Chicago Terra Cotta Works was using lead glazes as early as 1876, true glazes did not receive general development until around 1894, and the first large order was not produced until 1897 (Jandl, 1983, p. 135). Glazes were similar to slips in that they were a creamy mix of clays, but glazes included other materials, usually minerals, to produce a glossy surface available in a wide range of colors. By the turn of the century nearly any color desired was possible with glazes.

An engobe is a prepared slip that is between a glaze and a clay slip. It contains clay, feldspar, flint, flux and colorants. The engobes were used either alone as when

producing an imitation stone, or they serve under a glaze as a covering to hide the color of the clay body. In the later case they provide a buffer layer to provide a smoother surface and an intermediate in fusion between the body and the glaze.

Prior to 1888, slip was applied either by dipping the clay block into a vat containing the slip or brushing the slip onto the body. In 1888 a steam pressure method was developed to spray the slip onto the clay body; this was followed by a compressed air spray in 1893 (Jandl, 1983, p. 134). Following the glaze application, the terra cotta was ready to be fired.

Firing

Firing was the process of heating the terra cotta until the clay particles were knit together. Terra cotta was actually baked and not burnt, as it is never exposed to fire, but to heat radiated from brick ovens.

The total firing process lasted between eight and fourteen days, depending on the efficiency of the kilns. Slow fires were used until indication of moisture disappeared, generally about two days. Hot fires were run for about three days until the pieces reached the desired temperature. Cooling then lasted approximately three more days before the kiln was opened (Jandl, 1983, p. 135).

Historically, terra cotta firings have fallen into three temperature categories: high with cones 6-8, 2232-2305 degrees F., medium with cones 3-5, 2134-2185 degrees F., low cones 01-3, 2079-2134 degrees F. (Berryman and Tindall, 1984, p. 6). The firing process requires careful monitoring to assure a successful result. If the terra cotta is fired too rapidly, or cooled too quickly, excessive shrinkage, warping, and cracking of the piece could occur. If the terra cotta is not fired to the proper temperature, underburning can occur which will avoid warping but the terra cotta piece and the glaze will not properly adhere and the piece will also lack sufficient strength.

The job of firing the kiln was delegated to the "head burner". It was his responsibility to make sure the kilns slowly reached the desired temperature and when the temperature was obtained, the kiln properly cooled. Initially, the head burner was responsible for deciding when the proper temperature was reached, based on observation. Later, copper wires with iron washers were suspended in the kiln and observed until the wire melted.... Finally the " Seger cone" was developed (Jandl, 1983, pp. 135 and 136). These cones were manufactured of material similar to the glazes. The cones were designed to soften and bend when the kiln reached a certain

temperature. By utilizing cones of various bending points, the actual temperature within the kiln was known at all times.

Fitting and Numbering

When the terra cotta had cooled and before it was shipped, the manufacturers would lay the terra cotta out in the fitting room. This was the means of remedying mistakes which would cause trouble at the building site and which could easily and more economically be corrected at the plant. Overall dimensions were verified, and pieces were trimmed to assure the correct size. Edges were made true and square by grinding, rubbing, or sawing, until the pieces fit perfectly. Sometimes due to extensive warping a piece would have to be remade.

After the pieces were fitted, they were numbered according to the setting plan, in order that the men setting the material in the building used the correct pieces. The most commonly used numbering system included a large capital letter for each feature and individual numbers for each block within the feature. This numbering system reduced problems that might arise during erection at the building site.

Shipping

To transport the terra cotta to the building site, railroad cars were used. Terra cotta blocks were shipped in box cars rather than in open cars to provide protection to the pieces. They were laid in courses wedged against movement, and surrounded with hay or straw for additional protection (Jandl, 1983, p. 136). The ease of breakage of the pieces during shipping, and the lengthy time required for manufacturing replacement pieces, was a concern to the manufacturer. To prevent breakage great care was taken during the transporting process.

Installation

Installation was relatively simple because of the lightweight terra cotta, and the smaller size could be handled by one or two masons. An average mason working with the assistance of three or four laborers, could set approximately 12-13 cubic feet of terra cotta blocks per hour (Jandl, 1983, p. 136).

Up to the point of installation, terra cotta was manufactured and delivered to the building in strict accordance with the specifications. It was at this point that the supervision of the terra cotta producer ended, and also in many cases this was the end of the supervision of the architect and the engineer. To ensure accurate setting

and effective mortar joints, Chicago area manufacturers tended to hire their own masons to set the terra cotta. This helped to reduce the problems in installation because these masons became experts. By the turn of the century, terra cotta setting was considered a building specialty and subcontractors did most of the setting.

The installation of terra cotta was accomplished in two basic ways. The first pertained to structural terra cotta units. These were installed with masonry in load-bearing walls and employed little or no anchoring. The second applied to terra cotta cladding. This, in contrast, utilized a complex metal anchoring system to attach it to a metal frame.

Three different anchoring systems were used. In the first, hooks anchored to the supporting wall passed around a bar running between the ends of two blocks; in this system, anchor placement was critical, as adjustments were impossible. In the second system, a horizontal bar was fastened to the wall anchors, with a separate set of hooks running from the horizontal bar to holes in the tops of the blocks; horizontal adjustment was possible with this system. In the third system, the horizontal bar was placed in a recess in the supporting wall and was held in place with wires rather than hooks; the remainder of the fastening was similar to the second method (Jandl, 1983,

p. 137).

The metal anchors used to support the terra cotta were usually iron. Galvanized iron was the standard metal anchoring material and in pieces that were not backfilled needed to be protected against corrosion. Covering with asphalt, bitumen, or paint was possible for non-galvanized iron, while for very large individual pieces, bronze rods often were incorporated. Backfilling with concrete or brick was the most common solution to the question of how to protect the metal anchoring from corrosion. Backfill was intended to knit the blocks together and not actually support them. There was disagreement as to the best material for backfilling. Some preferred concrete, feeling that bricks were too soft, while those that used brick believed that concrete would expand at a different rate and cause stresses on the terra cotta.

The final step in the terra cotta installation was the cleaning of the exposed surface. It was important to remove any mortar drippings and especially any iron filings that would start to rust and blemish the terra cotta surface. Naphtha and a cloth or washing powder were used to remove any impurities from the terra cotta surfaces. Also stiff scrubbing brushes, without wire bristles, were used to clean the terra cotta because they wouldn't scratch the block finish.

DETERIORATION AND MAINTENANCE

A major cause of terra cotta failure is the lack of proper building maintenance. Other causes include original problems of manufacturing, design and installation, penetration of water into the clay body, improper attempts to clean, repair, or modernize, and inadequate continuous maintenance (Berryman and Tindall, 1984, p. 9).

The deterioration of glazed terra cotta is infinitely complex, particularly when used as a cladding material. As a terra cotta piece breaks down, a domino effect begins that breaks down the whole system: glazed units, mortar, metal anchors, and the backfill material. No other masonry system has a material failure potentially so complicated.

No one case of deterioration in glazed architectural terra cotta is ever identical to another, owing to the infinite number of variations with the material: original manufacturer, original installation inconsistencies, number of component parts, ongoing repairs, or the various types and sources of deterioration (de Teel Patterson, 1978, p. 3). However, certain general statements can be made about two problems that effect all terra cotta and are usually the cause of any deterioration that may happen.

Failures in Design

The root of deterioration in glazed terra cotta often lies in a misapplication of the material. Terra cotta is not a very forgiving material, unlike stone and brick which can take a certain amount of abuse, terra cotta doesn't allow that. In 1920, William Geer espoused popular opinion in his book, "The Story of Terra Cotta," when he said that terra cotta "...is without doubt the most durable material known. It is unaffected by age or climate change. Glazed and enamelled surfaces render it practically impervious to moisture, and dust and dirt may be removed at trifling expense with dry brushes or plain water." Unfortunately some building owners believed this hyperbole and neglected to maintain their buildings. Pieces of terra cotta fell, sometimes causing injuries; buildings became dirty and appeared dilapidated. Building owners and contractors also viewed terra cotta as a highly waterproof system needing neither flashing, weepholes, nor drips. This proved to be very untrue as serious water-related failure has occurred because the material was misapplied or detailed incorrectly for its architectural use.

Terra cotta as a material is very durable. Any problems related to the manufacturing of terra cotta usually occur in the relationship between the terra cotta body and the glaze. Ideally, the coefficient of expansion

of a glaze is less than that of the body so the glaze is always in a state of compression, most stable, and least likely to craze. When the build-up in pressure behind the glaze becomes great enough, a sheer exists at the interface between glaze and body (Berryman and Tindall, 1984, p. 9). The glaze then begins to crack and if enough pressure builds up the glaze then will blister and pop-off in pieces. The problem can begin as soon as the piece begins cooling after the firing, so careful attention to the compatibility of the glaze and the terra cotta body is essential to eliminating the problem. Decay of the terra cotta as a result of failures in the material is very unlikely, unless serious mistakes were made during the firing process. The temperatures reached during the firing process will burn out any organic material that might later decay. Therefore the problems that occur usually are the result of something besides the failure of the terra cotta body.

Construction methods in the later part of the 19th century were similar to those of the 18th century. Construction techniques that historically had been used on three story buildings were now being used on the new skyscraper designs. Relatively few, or even no, provisions were made for movement, whether caused by thermal fluctuations, moisture expansion, or wind loading. Forces

that were minimal in three story buildings were now becoming a major problem in high rise design.

The movement of buildings-- thermal expansion and contraction and shortening of steel frames under loads-- was less well understood, and the phenomena were not considered in design. When terra cotta cladding was installed on metal hangers, few provisions were made for relieving the stresses of weight and normal material and building movement (Berryman and Tindall, 1984, p. 9). This resulted in structural failures, vertical cracks, bulges in piers, spalls at joints, and falling units.

Stress problems also occur in a building from the effect of one-time expansion. One-time expansion occurs as a result of moisture, a phenomena experienced by all fired clay materials, including brick. The effects and impact of this one-time expansion are very substantial, especially when the expansion is contained.

The evolution of stress-relieving details (flexible joints, shelf angles, etc.) occurred late in the development of American building construction; most early continuously clad High Rise buildings (c.1900-1920) had little or no provision for normal material and building movement in their original design. Cracks running through many units or stories or large areas of material deterioration often indicate stress-related problems

(de Teel Paterson, 1978, p. 5).

Mortar joints and their deterioration has always been important in the survival or failure of a terra cotta system. The need to keep the internal system dry is important in terra cotta, and deteriorated mortar joints are a major source for water infiltration.

There are five major reasons for mortar joint failures: weathering action, settling, temperature cycles, poor original design and materials, and a lack of exterior maintenance (Tindall, 1987a, p. 25). Weathering action in joints is inevitable. Masonry mortar is purposely soft to allow for movement in the wall. Wind, rain and pollution eat away at this softer mortar and without proper maintenance can eat it away. Uneven settling of the building can cause mortar to crack and break loose from the terra cotta blocks. The temperature cycle is another natural occurring event that works to weaken the mortar. Moisture that enters a bad joint can freeze and expand, causing a section of the mortar to break loose. The seasonal cycle of hot and cold causes the terra cotta and mortar joints to expand and contract at different rates, eventually breaking the bond between the mortar and the terra cotta. Poor original design usually results in the inability of a mortar joint to shed water. Also if the mortar specified was too hard it will have shrunk, causing

excessive cracking, or if too soft it will result in premature weathering action. The problems associated with mortar joint failure can be the most severe in terra cotta, but with regular maintenance can be prevented.

Water-Related Damage

There are many ways in addition to faulty mortar joints by which moisture can find its way into the wall of a building: defective construction, leaky roofs, and faulty flashing. Terra cotta systems are highly susceptible to deterioration by water and can develop problems such as crazing, spalling, and metal anchor deterioration.

Crazing, or the formation of small random cracks in the glaze, is a common form of water-related deterioration in glazed architectural terra cotta. When the new terra cotta unit first comes from the kiln after firing, it has shrunk to its smallest possible size. With the passage of time, however, it expands as it absorbs moisture from the air, a process which may continue for many years (de Teel Paterson, 1978, p. 3). The crazing is caused by a build-up of differential stresses between the terra cotta and glaze. The differential stresses are the result of the glaze going into tension because it has a lesser capacity for expansion than the more porous terra cotta body. If the expansion in the terra cotta becomes too great and the

strength of the glaze is exceeded, cracks will begin to form on the face of the terra cotta.

Crazing is a natural phenomenon. Nothing is to be done about it. It is the extent and configuration of the crazing that is the measure for concern. Craze lines that are parallel and concentrated in one area or radiate from a single point are symptomatic of structural stresses in the unit. They foreshadow the failure of the unit. On the other hand, crazing that resembles spider webs is the result of overall growth in the units; it is common and to be expected (Kruse, 1989, p. 48). Unless the cracks visibly extend into the porous body below, crazing should not be considered a serious problem. Visible cracking into the terra cotta body presents a very serious problem and will cause the bonding between glaze and terra cotta body to fail, resulting in separation, called spalling.

Spalling, the partial loss of the masonry material itself, like crazing, is caused by water and is usually a result of not only air-borne water but more commonly of water trapped within the masonry system itself (de Teel Patterson, 1978, p. 3). Pieces of the glaze, about the size of silver dollars, pop-off the terra cotta body. This is caused by water getting into the terra cotta wall system, from which it tends to migrate outward and become trapped by the impervious glaze, which acts as a water

barrier. The trapped water builds up pressure, especially in the presence of widely fluctuating temperatures, expands and pushes itself and the glaze free of the terra cotta body. This loss of glaze from the terra cotta piece is known as glaze spalling.

Glaze spalling leads to a more serious spalling problem known as material spalling. Material spalling causes wholesale destruction of portions of the glazed terra cotta unit itself. Material spalling is a particularly severe situation. Not only is the visual integrity of the detailing impaired, but a large area of the porous underbody, webbing, and material anchoring is exposed to the destructive effects of further water entry and deterioration (de Teel Patterson, 1978, p. 4).

As crazing goes unchecked and becomes more serious it leads to spalling which leads to serious water problems within the terra cotta wall system. High amounts of moisture within the wall system leads to deterioration of the metal anchoring system.

The detrimental effects of corrosion of anchors and support steel are probably the most serious circumstances that can affect terra cotta cladding. Often the failure is blamed on the terra cotta when in actuality the culprit is the steel work.

Deteriorated anchoring systems are perhaps the most

difficult form of glazed architectural terra cotta deterioration to locate or diagnose. Often, the damage must be severe and irreparable before it is noticed in even the most intense "prima facie" examination. Partial deterioration results in staining and material spalling. Total deterioration and the lack of any anchoring system may result in the loosening of the units themselves, threatening the architectural or structural integrity of the building (de Teel Patterson, 1978, p. 4).

The metal anchoring and support systems usually were coated with some form of rust-inhibitor. This protection often lost its effectiveness over a period of time and left the steel exposed to the effects of moisture.

As the steel and iron members began to rust from water intrusion, the expansion of the rust produces something in the neighborhood of 7000 psi, expanding to about ten times its original size. As the terra cotta is usually placed right on the steel, it cracks and gives way when the steel begins to swell and push out (Kruse, 1989, p. 54).

Material failure is most often the result of water-related problems. Other problems, less frequent though no less severe, include damage caused by later alterations and additions, or inappropriate repairs.

Inappropriate Alterations

Adjoining materials can prompt deterioration of terra cotta because of alterations or inappropriate repairs. Many terra cotta buildings were "modernized" during the 1950's by being covered with metal siding, signs, and marquees. These installations often were attached to the building by boring bolt holes into the terra cotta. As the bolts and caulking deteriorated, or the additions removed, holes existed that allowed the water to enter the terra cotta wall system.

During the modernization period, terra cotta was often painted. Paint does not damage terra cotta, but its removal may burn or destroy the surface. The use of abrasive cleaning techniques can damage the surface, allowing greater water absorption.

Building Maintenance

A proper maintenance plan is critical to preserving terra cotta. The above problems can be prevented if noticed and rectified early. A comprehensive maintenance plan should include a systematic record of deterioration or other problems observed and repairs made (Berryman and Tindall, 1984, p. 10).

Close up inspection of terra cotta cladding is necessary since hairline cracking can be indicative of a

major structural defect. In the Preservation Briefs #7, six methods of inspection are listed: prima facie analysis, tapping, infrared scanning, sonic testing, metal detection, and laboratory analysis (de Teel Patterson, 1978, pp. 5 and 6).

Prima facie analysis is a unit by unit, hands on inspection of the terra cotta. Visible surface deterioration can be identified during this step. Tapping tends to be an inexact, but reliable method of determining internal problems. The terra cotta units are struck by a wooden mallet. Undamaged units give a pronounced ring, deteriorated units produce a flat hollow sound. Infrared scanning is used in locating deteriorated internal material. Broken or loose internal terra cotta pieces have a less firm attachment than sound pieces and therefore emit a different temperature that can be detected by the infrared scan. Sonic testing is an excellent method for detecting interior failures. Sound waves penetrate the material and bounce back in different patterns for undeteriorated material or failed material. Metal detection is a useful way in locating the position of internal metal anchoring. A metal detector is used to determine if the anchoring exists or has dissolved. The final inspection method requires samples of removed material to be analyzed by a laboratory. The tests can be

used to find glaze absorption, permeability or glaze adhesion, or to evaluate the material for porosity (de Teel Patterson, 1978, p.5 and 6).

Implementing a proper maintenance plan is a necessary approach to protection of a terra cotta building. Catching a problem while it is still minor will prevent further problems from arising.

PRESERVATION AND REPLACEMENT

Keys to Success

Preservation of a building which includes terra cotta involves many variables. The degree of deterioration in terra cotta can be very difficult to detect and improper repairs will damage it further. An architect or other professional with experience in working with terra cotta must be involved from the outset.

The architect and building owner must set priorities for the project. Whatever the decisions, the work must equal the spirit, attention to detail, (Fig. 1) and pride in craftsmanship associated with the original production of terra cotta. If inferior materials and workmanship are allowed, the building will suffer.

The approach to terra cotta is a familiar one in preservation: if it ain't broke don't fix it (Tindall, 1987, p. 51). On the other hand, if units have failed, the first objective is to discover why they failed and if adjacent or similar units are about to fail. Where severe damage has caused structural problems, a structural engineer should be hired to analyze the condition of the steel anchoring system. Such structural deterioration must be stopped before any repair work can begin (Figs. 2 and 3).

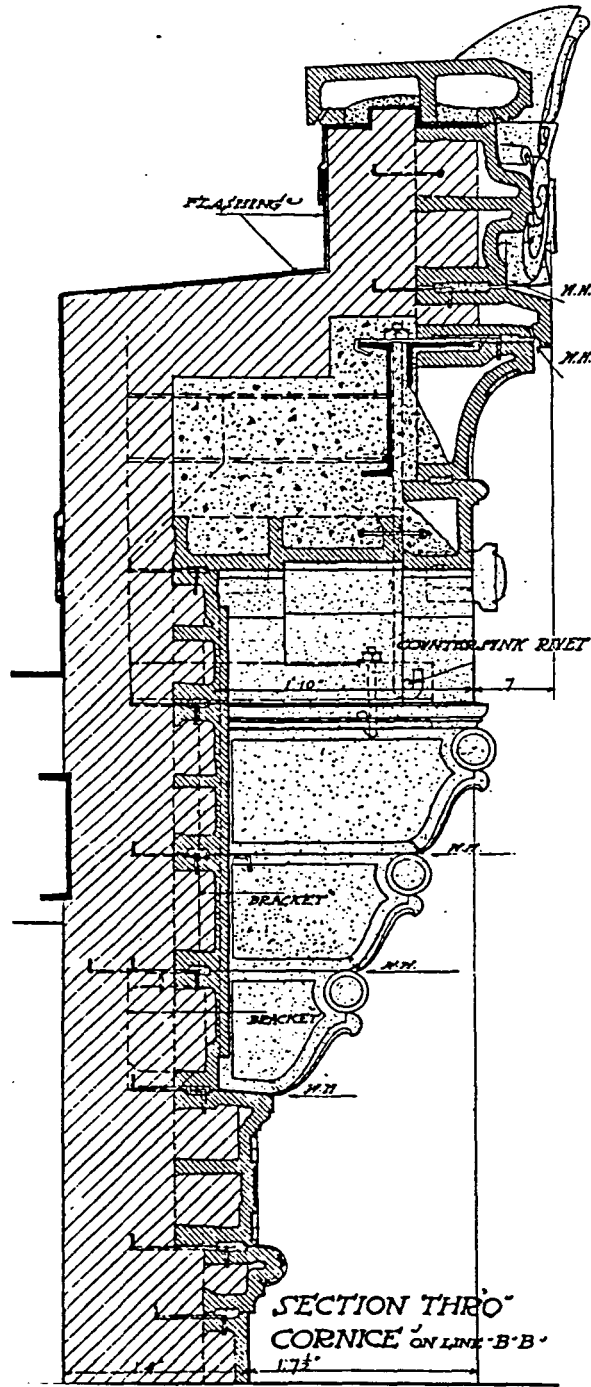


Figure 1. Section through Cornice
(National Terra Cotta Society, 1927, plate 24)

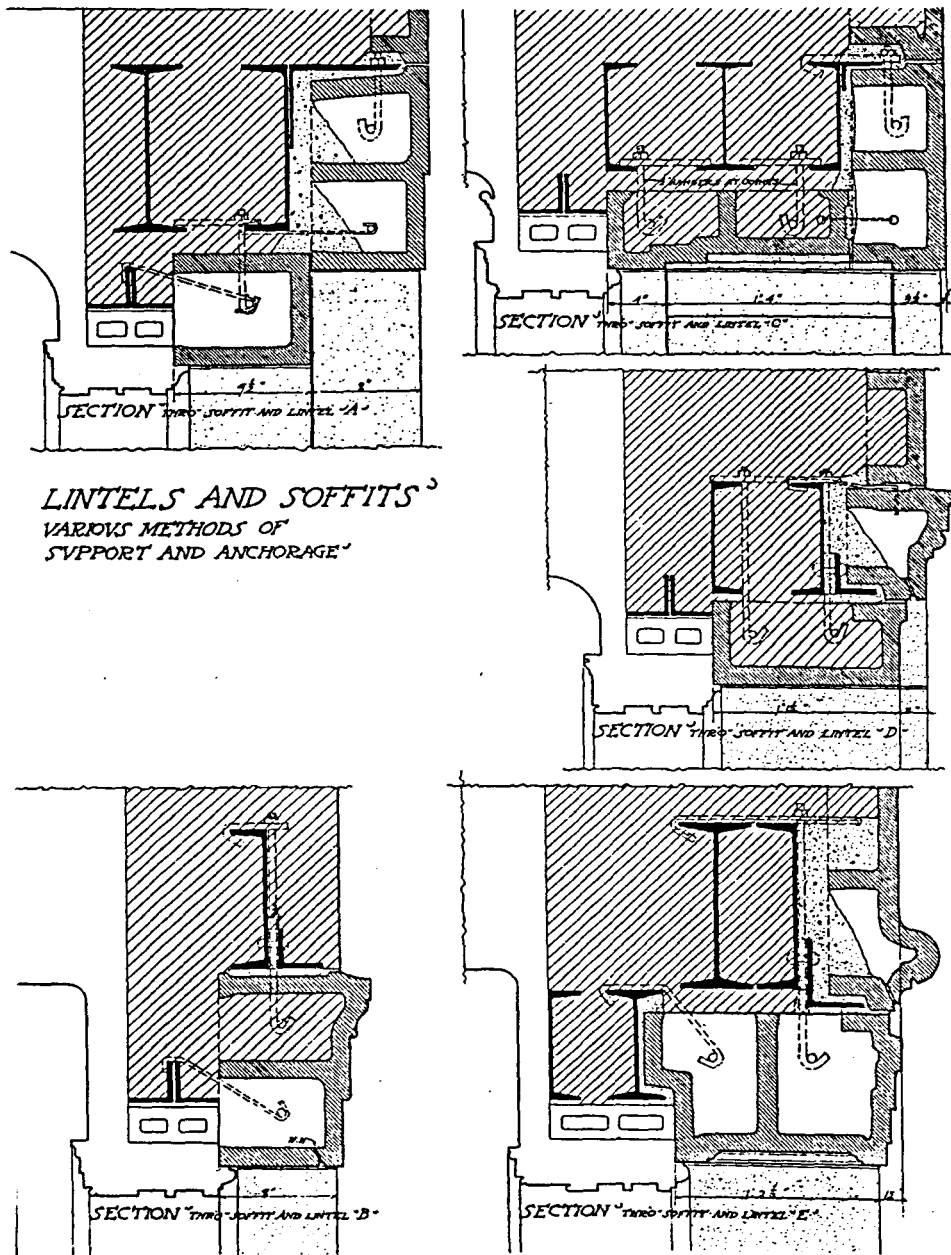


Figure 2. Lintels and Soffits
(National Terra Cotta Society, 1927, plate 35)

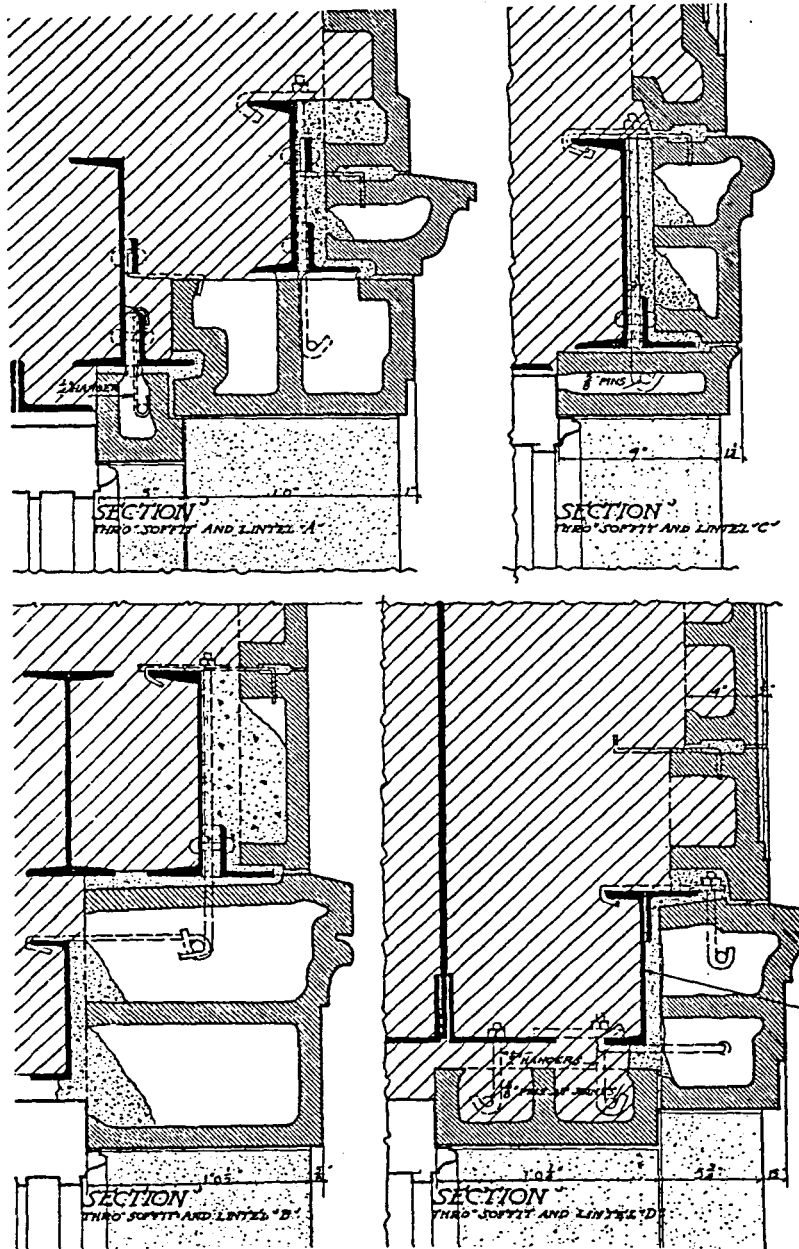


Figure 3. Lintels and Soffits
 (National Terra Cotta Society, 1927, plate 36)

Terra cotta that poses a hazard to safety must be permanently or temporarily removed or stabilized in place (Berryman and Tindall, 1984, p. 14). A nylon netting held in place with metal straps can be used to hold pieces until a permanent solution is determined. If there are openings where terra cotta units are missing, these openings must be made weathertight to prevent further deterioration to adjacent units.

Inspection

Inspection of terra cotta in buildings is very important. Most problems can be prevented if noticed and rectified early. An eyeball inspection can easily be accomplished with binoculars from the ground or an adjacent building. Some items to look for: (1) missing units, (2) deteriorated or missing mortar, (3) large cracks running through multiple units, (4) material failures, (5) presence (or absence) of water-shedding devices, (6) bulges in the terra cotta, (7) rust stains from anchors, (8) efflorescence from excessive moisture. If any of these symptoms are present, a more thorough, hands-on investigation of the terra cotta is necessary.

A close up inspection of terra cotta will help reveal what is causing the problem. In the Preservation Briefs #7, six methods of inspection are listed: *prima facie*

analysis, tapping, infrared scanning, sonic testing, metal detection, and laboratory analysis. These inspection methods are described in the section Building Maintenance in the chapter Deterioration and Maintenance.

Analyzing the test data, decisions can be made for correction of causes of present deterioration and prevention of any further problems.

Cleaning

Cleaning and testing are usually done simultaneously. Cleaning will uncover many defects which were previously hidden by dirt. As an area is cleaned, a detail analysis should be conducted using the methods described above.

Cleaning will visually enhance a building by uncovering fine details lost under years of accumulated dirt. It may reveal previously unknown colors or materials and facilitate matching of mortar, bricks, and replacement units and afford the opportunity to preform a hands-on inspection of damaged units (Berryman and Tindall, 1984, p. 15).

The benefits of proper cleaning can be great if done correctly. There is also the potential for irreparable damage if done incorrectly.

Cleaning should not take place when either the air temperature or building surface temperature is less than

40 degrees F. or on windy days (Berryman and Tindall, 1984, p. 16). Many chemicals will not be as effective in cold weather, and with the addition of high concentrations of water during cleaning, damage from freezing can occur.

A reasonable goal is to aim for 85% clean. Most of the damage associated with cleaning - bleaching (burning) of the masonry, etching of glazes, dissolution of colors, etc.- occurs while removing the last 15% of dirt (Tindall, 1987b, p. 51). The idea of making it look "good as new" will cause damage which will create new problems.

Test panels should be cleaned first to determine the effect of cleaning procedures on terra cotta. Toxic chemicals can be released during cleaning. Polychromatic terra cotta is extremely sensitive to acid attack, which will etch the glaze, removing most of the surface color. Because of potential damage caused by cleaning, a small area should be cleaned and then analyzed to determine the effect of the cleaning and extent of the damage.

There are three accepted methods of cleaning terra cotta: (1) mechanically with water, (2) plain water, (3) chemical cleaning (Tindall, 1987b, p. 51). Mechanically uses high-pressure water to blast away the dirt particles. Water pressure around 500 psi is recommended to remove dirt without removing the terra cotta surface. The plain water system includes steam cleaning and sprinkler hoses to

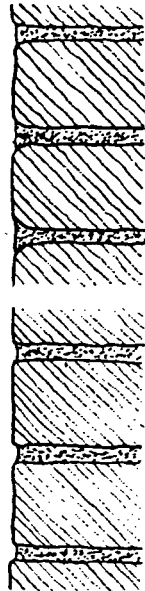
soften the dirt, which is then scrubbed or flushed away. This system is successful on watertight, mildly dirty buildings, and especially on glazed terra cotta. Chemical cleaning is usually a blend of acidic ingredients and wetting agents. Chemical solutions, if mishandled, can do extensive damage to the terra cotta and surrounding building materials.

There are certain cleaning techniques not recommended which will damage the surface of the terra cotta. These include: all abrasive cleaning measures (especially sand blasting), the use of strong acids (particularly fluoride-based acids), high-pressure water cleaning and the use of metal bristle brushes. These methods of cleaning will remove the protective glaze and expose the porous tile body to the damages of water infiltration.

It is important to remember that terra cotta was designed to be cleaned easily. This was a major selling point of terra cotta and should be remembered when cleaning a building.

Tuckpointing

Tuckpointing of mortar that has deteriorated is one of the most useful preservation methods. Tuckpointing not only improves the buildings appearance but seals areas of water penetration (Fig. 4).



Joints filled to full

Wide feather edge
susceptible to spalling

Joints slightly recessed

Incorrect

Mortar joint cleaned out to
a sufficient uniform depth

Edges of brick damaged by
tool or grinder, creates a
wider joint

Correct

Mortar cleaned out to a
uniform depth - about 1"

Undamaged edges of brick

Figure 4. Repointing Mortar Joints

Tuckpointing should be done with a mortar that matches the original physically and has a compressive strength lower than the adjacent masonry unit. Portland cement or coarsely screened mortars can cause point loading and also prevent the outward migration of water through the joints, thus damaging the terra cotta.

The mortar joint should be raked out by hand to a minimum depth of one inch. It is recommended that it be done by hand because mechanical grinders will damage adjacent edges of terra cotta. After the joint is raked out, new mortar is built up in layers. The final layer is flush with the terra cotta and tooled to compact the mortar and provide a suitable joint profile.

Waterproofing

One of the primary agents of deterioration in terra cotta is water. Therefore, water-related damage can be repaired only when the sources of water have been eliminated.

In an effort to stem water-related deterioration, architects and building owners often erroneously attribute water-related damage to glaze crazing when the source of the deterioration is, in fact, elsewhere: deteriorated caulking, flashing, etc.

The prime sources of exterior infiltration are

failures in water shedding design elements: gutters, downspouts, flashing, and mortar joints. If these elements have failed, or are working improperly, they need to be replaced or repaired.

Water that migrates from the interior of a building must be allowed to pass through the wall to the exterior where it can evaporate. Normal terra cotta induces a capillarity action to remove interior water. The addition of sound mortar joints and weepholes will permit adequate evaporation. Nonporous coatings, and hard portland cement mortars prevent essential migration of water.

A building should not be treated with a waterproofing compound unless the surface of the terra cotta is so damaged there is no alternative. Cementitious paints are expensive to apply, need regular maintenance and are difficult to remove. Usually, they are unacceptable aesthetically. Silicones are damp proofers since they change the size of the pores of the terra cotta and create negative capillarity (Berryman and Tindall, 1984, p. 19). Silicones are not completely effective and contribute to the addition of soluble salts.

Holes caused by structural cracking, sign anchors, or slots for steel need to be sealed. There are two types of holes, static (nonmoving), and dynamic (moving and active).

Static cracks should be caulked with butyl sealants

or acrylic latex caulks. Dynamic cracks need a caulking that will allow movement and still remain watertight. Usually a polysulfide caulking is employed. These caulks are available in a number of commercially available waterproof caulking compounds. These caulking compounds should be used only to repair holes within the terra cotta unit and not as a repointing material.

Anchor Replacement

Where water problems have existed for some time, corrosion of the metal anchoring system has probably taken place. In severe cases, terra cotta pieces can be removed by pulling on the piece.

New metal anchors should be of a rust-proof material. Stainless steel is the most durable, but high cost often prohibits its use. Hot-dipped galvanized and epoxy-coated steel are more economical materials. Sizes and shapes of anchors depend upon the original design and when possible should be the same as the original. Existing anchors should never be reused.

When possible and where applicable, replacement units should be anchored in a manner similar to the original (Fig. 5). Both structural and visual compatibility are major considerations when choosing replacement materials.

Reanchoring can be a very difficult task. The

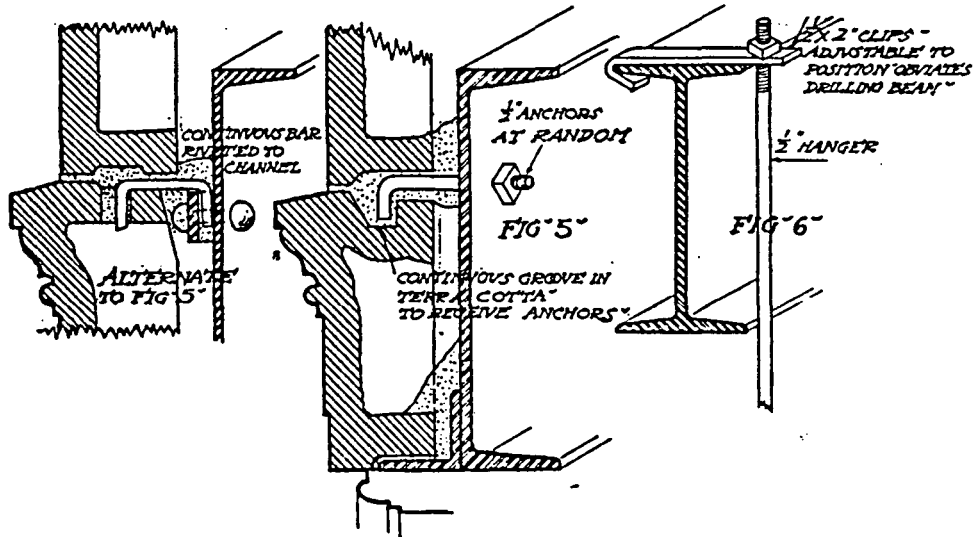
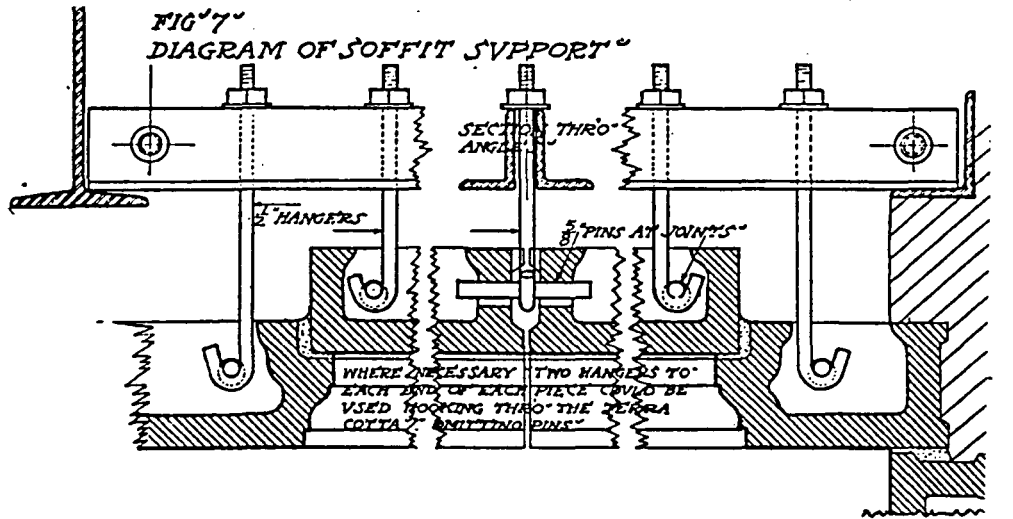


Figure 5. Anchor, Hanger, and Strap Details
(National Terra Cotta Society, 1927, plate 67)

complexity of the interlocking system of masonry units, backfill, and metal anchoring often cause damage to the piece to be reanchored or to adjacent pieces. If care is not taken during reanchoring, the terra cotta piece as well as the metal anchoring will need to be replaced.

Damaged Piece Replacement

Replacement of severely damaged or missing terra cotta elements is difficult. If the original material is available it should be used. Terra cotta is the best replacement for terra cotta when considering color, texture, durability, and uniformity over the long run. Sound terra cotta units from the back of the building can be relocated to the front. New terra cotta units can be manufactured to replace the damaged pieces and with an increase in manufacturers of terra cotta, it has become easier to find someone with the skills required to produce terra cotta.

Terra cotta produced today is often superior to terra cotta produced at the turn of the century. The clay bodies used in the past often failed to meet what are known today as standard tests of rates of absorption, freeze/thaw cycles, compressive strengths, thermal expansion, and saturation coefficients (Kruse, 1989, p. 53). Today's clay bodies have developed with less absorption, a higher

compressive strength, and a lower saturation coefficient. The terra cotta bodies of today are often run through a series of tests to assure quality before manufacturing.

Higher quality standards produce a material that is permanent and will continue to match the surrounding terra cotta. Other replacement materials weather differently from the original terra cotta and after time will no longer match the originals.

Although terra cotta is the ideal replacement, the decision of replacement materials depends on cost, availability, and compatibility of materials. Another major consideration is the question of delivery time. The time required to manufacture replacement terra cotta is often quite lengthy.

There are many alternatives available to the architect faced with replacing deteriorated terra cotta. If a material other than terra cotta is used, it should be physically and visually compatible with the existing terra cotta. Physically the strength of the substitute material needs to be equal to or less than the surrounding terra cotta. If it is significantly stronger it can cause excessive pressure on surrounding pieces causing them to fail.

The composition of the substitute material should be chemically compatible with terra cotta. The presence of

minute quantities of some acids, salts, and alkaline materials can cause corrosion or decomposition of adjacent materials (Berryman and Tindall, 1984, pp. 23 and 24).

Visually substitute materials need to match the original terra cotta in color, texture, profile, and size. Substitute materials should not detract from or add to the overall design of the building, they need to become an integral part of the whole building and not individual pieces.

In *Progressive Architecture*, November, 1977, John Morris Dixon lists six options available to architects: (1) stucco-like material, (2) precast concrete, (3) fiberglass-reinforced plastic, (4) fiberglass-reinforced concrete, (5) cut stone, (6) new terra cotta units (Dixon, 1977, p. 101)

A stucco-like material is used to patch a piece that has suffered surface damage such as spalling. The texture and color of the original terra cotta is difficult to match which often leads to painting of the patch. The patch and paint weather differently from the terra cotta causing an incompatibility between the two materials.

Precast concrete shows promise as a replacement for terra cotta. Concrete has no significant shrinkage, therefore molds can be made from existing pieces. The concrete can be cast as hollow units to reduce weight, but there is a greater unit weight with concrete than with

terra cotta that can cause unwanted stresses. Matching of color and texture is often difficult. As concrete weathers the aggregate becomes exposed discoloring the surface. There are acrylic finishes that can be applied to match terra cotta, but these surfaces require periodic recoating.

Fiberglass-reinforced plastic units, like precast concrete, can be easily molded from existing pieces. It is also very light, weighing less than terra cotta, so it requires simpler anchoring techniques. Fiberglass must be painted to avoid ultraviolet and weathering deterioration, as well as to match the existing terra cotta. The color coating must be reapplied often to protect the fiberglass. Fiberglass-reinforced plastic is not sufficiently fire-resistant and violates fire codes in many cities and is therefore unacceptable.

Fiberglass-reinforced concrete units can be cast using molds from existing pieces. The castings can be made hollow thus reducing the weight, making it comparable to terra cotta. As with other replacement materials it is difficult to match the original color and texture of terra cotta, and questions of cost and long-term performance in such situations are still being investigated.

Stone can be carved into virtually any size or shape and with any detail available in terra cotta (after all, terra cotta was often used to simulate stone) (Tindall,

1987b, p. 51). Stone is an extremely durable material and aesthetically is compatible with terra cotta. The disadvantage of stone is cost. Complex stone carving is labor-intensive, and like terra cotta work, very few craftsmen exist today. Stone also is heavier which creates problems of weight and anchoring.

The object of restoring a terra cotta building must be to preserve as much of the original fabric as feasible, then replace what cannot be saved by the best means for the situation. There is a tendency today to replace damaged ornamental work with simpler and cheaper materials. It is the job of the architect to make sure that the integrity of the building is not diminished by the removal of the ornament.

OWATONNA AND GRINNELL

Louis H. Sullivan designed and built eight banks between 1906 and his death in 1924. Of these banks, the National Farmers Bank, Owatonna, Minnesota, and the Merchants National Bank, Grinnell, Iowa, are the best examples of terra cotta, brick, stone, and stained glass being integrated to satisfy both the functionalist and decorative conditions of the project.

In both banks Sullivan was able to fuse a functional, structural, and artistic solution because of his mastery in the relationship among art, technology, and nature.

Owatonna and Grinnell will both be examined to understand how various building materials are combined with terra cotta to achieve an overall harmonious effect. The bank's terra cotta will also be studied to show that the terra cotta was not used as a decorative element but as an expressive element, conveying Sullivan's metaphysical beliefs.

At the time that Sullivan was designing his banks, many of the banks being built were in a Greek or Roman style with big columns and a feeling of mystery, reserve, dullness and frigidity. Sullivan's banks were attractive and inviting and brought into prominence that banking is a

function of society and not a secluded mystery. Sullivan was also able to suggest the qualities of strength and security and thus inspire confidence in the bank users and directors.

The National Farmers' Bank (see Appendix A) and the Merchants National Bank (see Appendix B) both were designed around a "democratic" floor plan (Figs. 6 and 7). The plan can be called "democratic" in that it is open and the officers are in plain view and easily approached. This is the modern "human" element of the plan as it tends to promote a feeling of ease, confidence and friendship between officers, employees, and customers. The vault location was situated at the end of the room on direct axis with the bank's entrance. The large open door of the vault inspired confidence in the strength and security of the bank.

Sullivan used a basic floor plan in all his banks, making only minor changes as required by the program. In Grinnell, the bank is entered through a vestibule into a central public space.

On the left side were the special facilities: the women's room, a special room for women to do their banking, savings department and men's room. In the center of the bank was the vault and deposit boxes with a customers room and teller space in front. To the right of the public

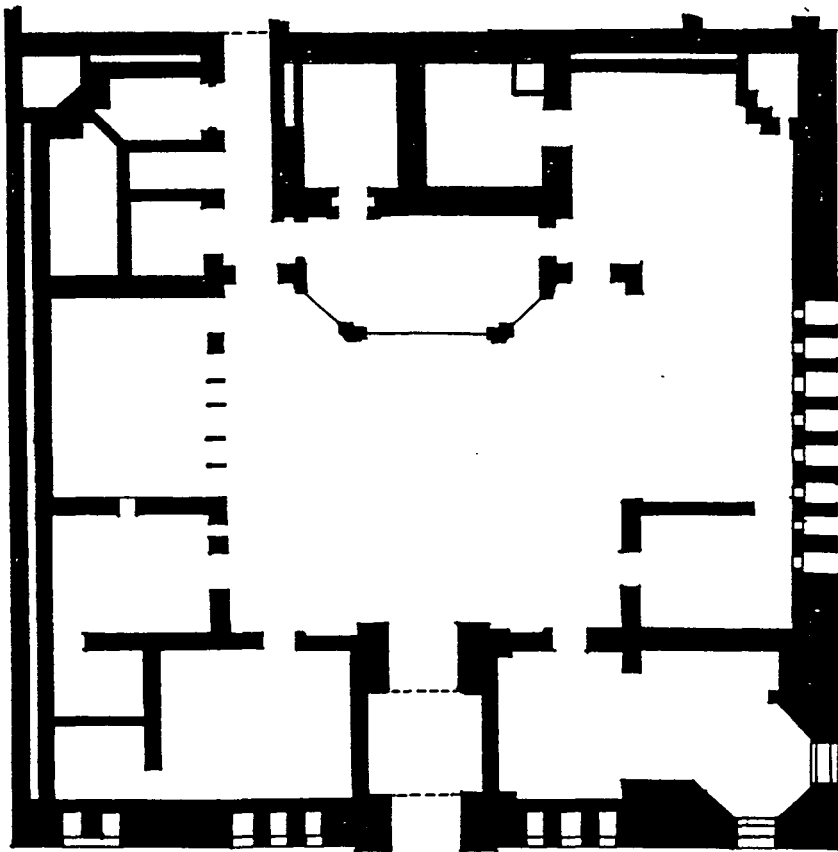


Figure 6. Farmers' National Bank, Floor Plan

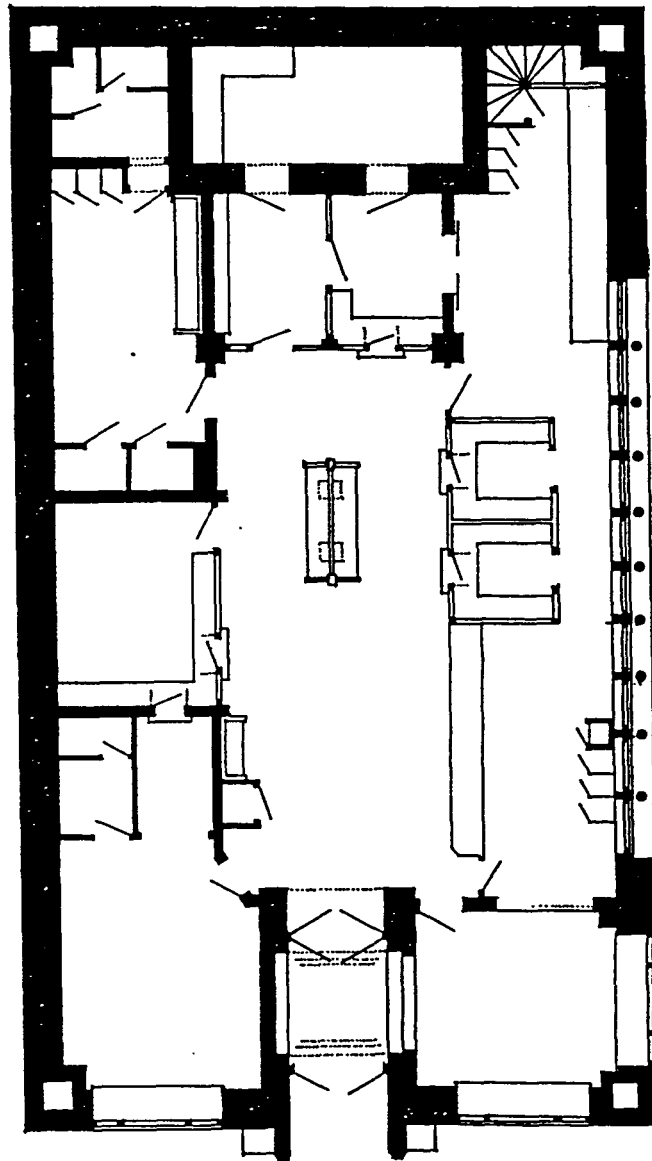


Figure 7. Merchants National Bank, Floor Plan

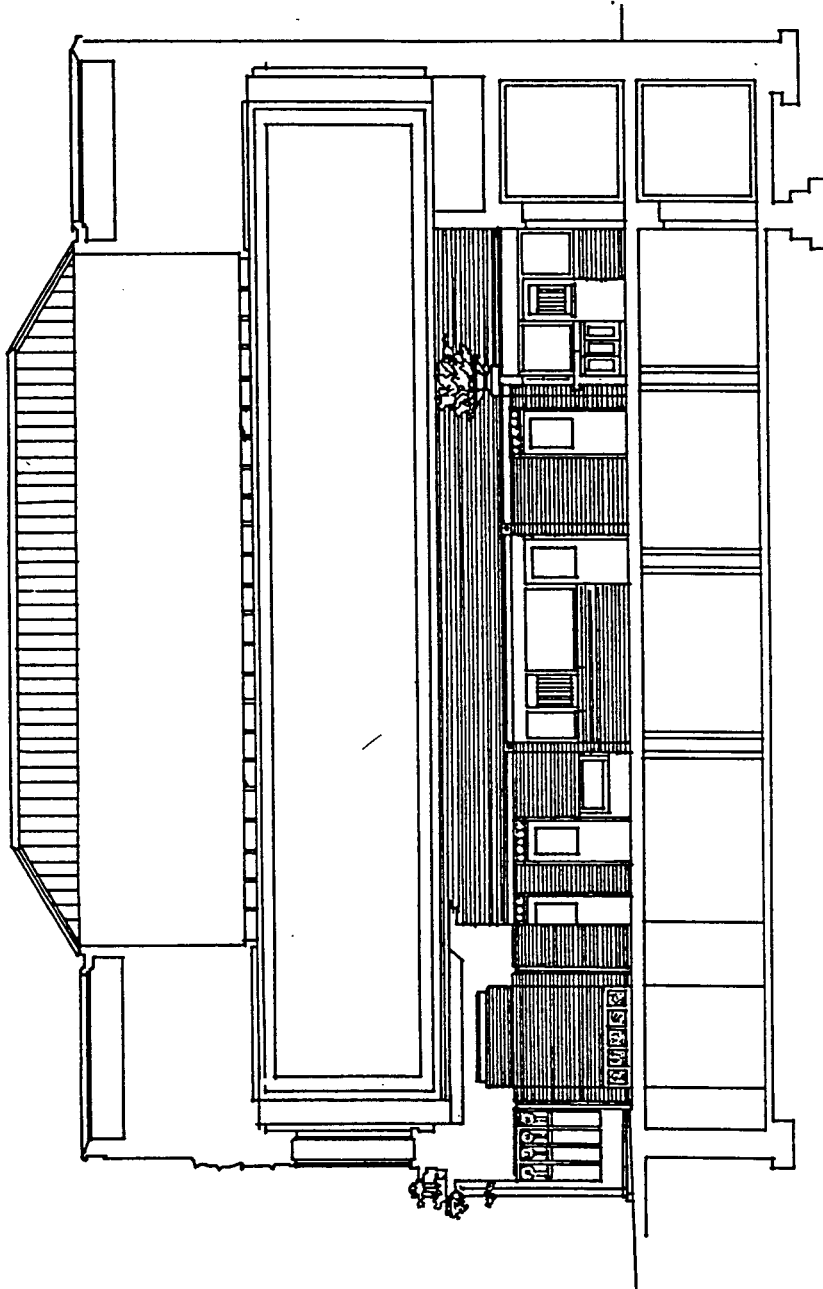


Figure 8. Merchants National Bank, Building Section

space, from front to back, the directors room, officers platform, space for two tellers, and a bookkeepers work area. As in all of Sullivan's banks, the interior had a very open feeling, a feeling of friendship between bankers and patrons.

The exterior of the Owatonna bank is richly decorated. The facades are divided into three horizontal layers: a base of pink Portwing sandstone; a central layer of brick and terra cotta around a large, semi-circular window; and a brick and terra cotta cornice (de Wit, 1986, p. 180). Sullivan suggests an organic source that is making the building grow, while at the same time creating a tension between upward movement and downward pressure (Fig. 9). The sandstone base has small punched windows that suggest a solid, strong base, on top of which are the earth tones of the brick, the green terra cotta, and blue mosaic, which represent the colors of the surrounding framing community which supports the bank.

The bank in Grinnell is a pristine brick box featuring a terra cotta frieze and a massive ornamented entrance (Fig. 10). The entrance ornament in the form of superimposed circles, squares, and diamonds surrounds a large circular window; such a synthesis between geometry and natural forms is the essence of Sullivan's objective - subjective symbolism of ornament and architecture.

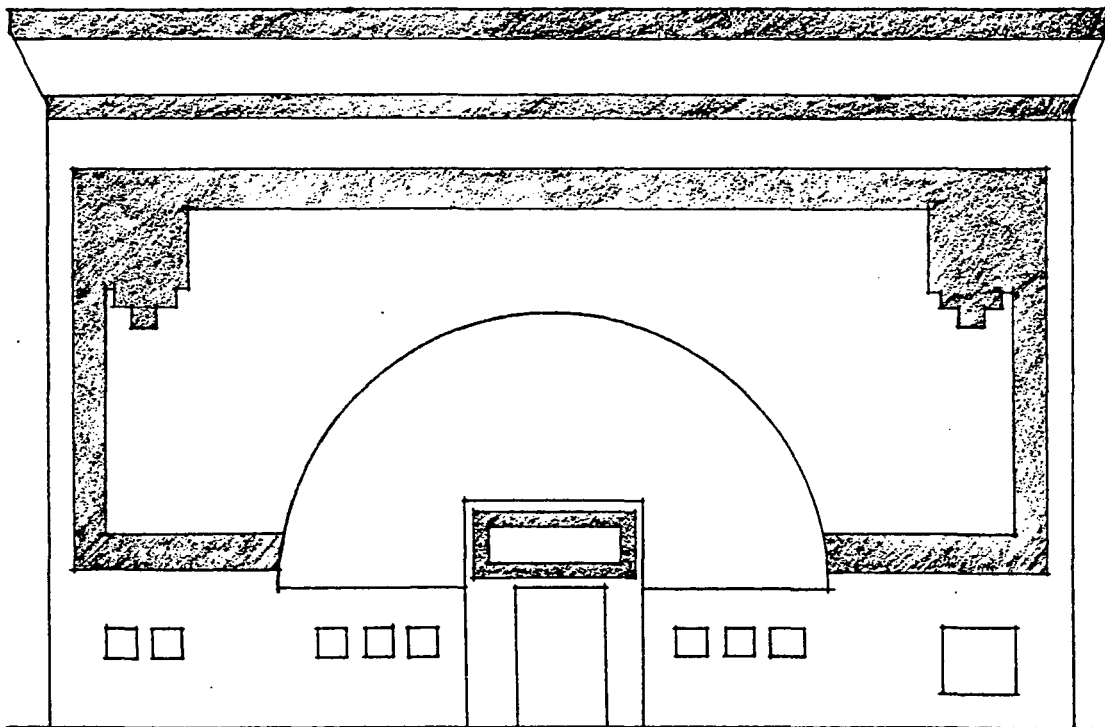


Figure 9. National Farmers' Bank. Relationship of terra cotta to building mass.

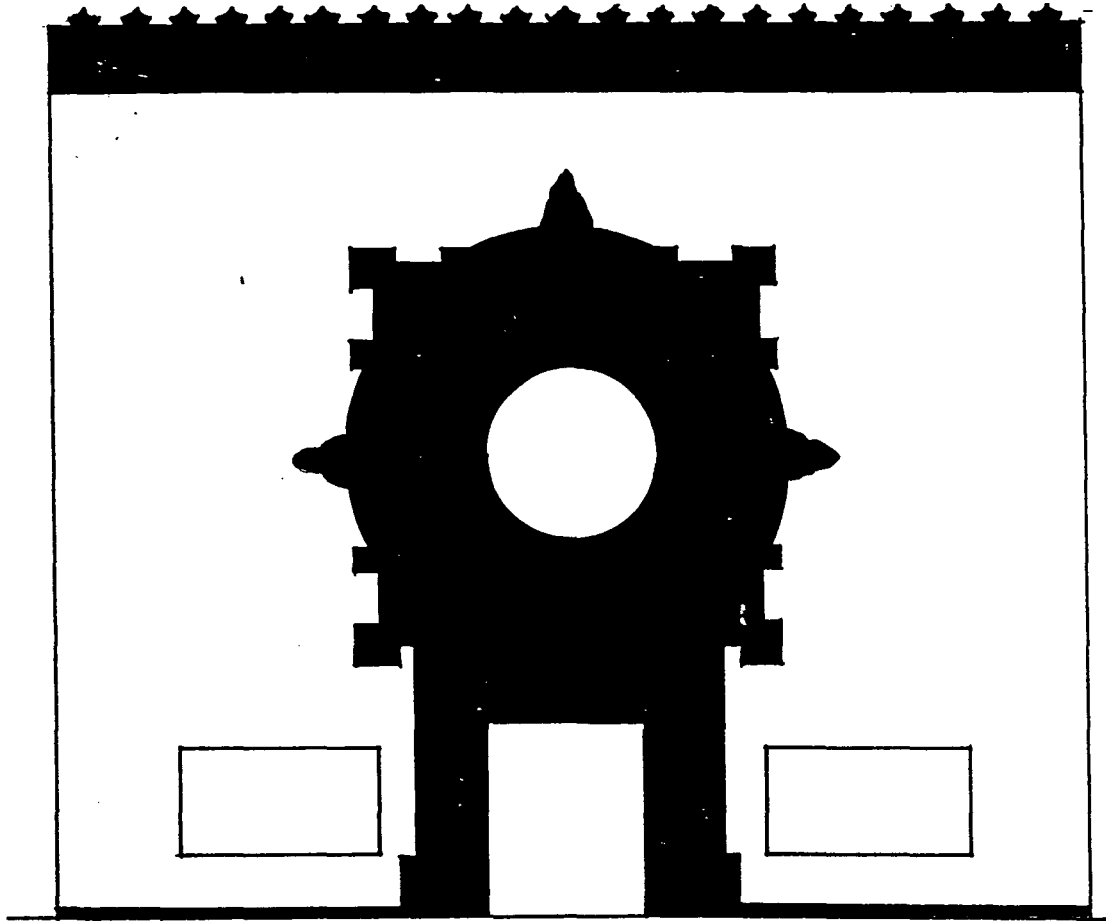


Figure 10. Merchants National Bank. Relationship of terra cotta to building mass.

The long brick east wall has two openings, both are cut sharply into the surface, a large window above the tellers, and a small window in the directors room. The plainness of the exterior at Grinnell is contrasted with the elaborate ornament placed at the entrance and the cornice line.

The exterior material of both banks is predominantly what Sullivan called a "tapestry brick". These bricks as they came from the kiln showed a veritable gamut of colors from the softest pinks through reds, yellows, browns, purples, and blacks. When laid up promiscuously, the general tone is one of an oriental rug.

A wall of "tapestry brick" lended itself admirably to associate with other materials susceptible to color selection because of its broad, supporting neutrality.

In Sullivan's banks the brick became background material, allowing the other materials, mainly terra cotta, to rise from and stand out of the building plane.

The Owatonna bank exterior is dominated by the reddish tapestry bricks which give a feeling of autumn, while on the inside a more springlike bluish green predominates.

The interior has more than 240 shades of contrasting and analogous hues of yellow, red/orange, and green. These colors are used on the fresco patterns, terra cotta, and in the stained glass windows. The natural light coming in the stained glass windows affects and changes the interior

colors from day to day and season to season. Sullivan conceived the bank as a "color symphony" which could bring the outdoor and indoor environment together.

The bank in Grinnell does not have the same color effect of Owatonna. Fewer colors were used but the general feeling is still the same. The exterior is predominately tapestry brick with a reddish brown terra cotta cornice and base band. The rose window and entrance are surrounded with a buff-toned terra cotta. The large stained glass window opening is divided by very slender gilded columns that reflect the early morning sun. Once in the interior, the light is, as in Owatonna, changed by large expanses of stained glass. The interior colors are reduced to tapestry brick, natural wood and terra cotta in earth tones. The contrasting colors come from the stained glass and rose windows.

In both banks, terra cotta was an important material on the interior and exterior. As explained in the chapter on Louis Sullivan, he combined the objective (geometric) with the "subjective" (organic) in his terra cotta designs and used this as an expressive element. In the banks, Sullivan subordinated his organic mode of ornament to the simple geometric contours of the mass composition. At the same time, he increased the scale of the ornament so that the organic imagery begins to compete with the geometric

simplicity of the cube (Weingarden, 1987, p. 59). Sullivan exploited this contrast and composed a complementary relationship that produced surface tension and dynamic balance between the primary elements of his symbolic representation. Thus in the banks, this combination of the objective and the subjective was not limited to just within the terra cotta but also between the terra cotta and the building itself.

The primary terra cotta on the exterior at Owatonna is a band plantlike green in color that enframes the two big arched windows. This green band could have been intended by Sullivan to symbolize the agrarian wealth upon which the bank depended. There are also four monumental medallions that visually anchor the upper four corners of the elevations.

On the interior terra cotta is used in two ways. A very ornamental, green (teco green) band runs along the top of the brick walls. This band sits on top of reddish brick and acts as transition between the lower bank volumes and the great upper space. In the upper space there are four large chandeliers. These chandeliers provide the artificial light and resemble stylized plants growing down from the ceiling.

Like the terra cotta at the Owatonna bank, that at Grinnell conveys a sense of upward movement, suggesting the

organic growth of the building. The entrance is located between two blossoming terra cotta columns joined by a cornice. Above this opening and spreading outward around a rose window are intertwined circles and squares of terra cotta through which natural forms are allowed to burst forth. The rose window medallion is predominantly buff-toned with green added to receding planes and gilding to high relief surfaces. This combination brings life to the medallion by using complementary color contrast and adds a chromatic richness to the whole building. Visually the medallion also moves upward from the ground and outward from the wall surface to create a tension with the flat wall surface.

The entrance medallion is the dominant theme for the exterior and interior reliefs. Thus, throughout the entire design, Sullivan used the concave, hexagonal, shield-like form that results from overlapping circles and squares (Weingarden, 1987, p. 92).

A reddish brown cornice with finials is the other major use of exterior terra cotta. The cornice creates a solid band that caps the building and the finials subtly breakdown the geometric cube of the bank.

On the interior, terra cotta is used as a decorative band above the vault area towards the back of the bank. This terra cotta is set against the blank back wall and

echoes the cornice on the exterior.

The terra cotta at Owatonna and that at Grinnell are very similar. The company that produced it, The American Terra Cotta Company, and the man that made the pieces, Kristian Schneider, were the same. To better understand terra cotta use, the next chapter will detail my process of examining the Grinnell bank and the remaking of pieces that were hypothetically damaged.

TERRA COTTA PROJECT

To better understand the process of manufacturing terra cotta and the problems that can arise, I decided as the project portion of my thesis to remake some terra cotta pieces from an existing building. The building chosen was the Merchants National Bank in Grinnell, Iowa (see preceding chapter and Appendix B).

The manufacturing process was very similar to the steps outlined in the Chapter on Manufacturing. The steps required to produce terra cotta have not changed significantly during the past century, but instead the changes have occurred within the steps. Clays are no longer used directly from the ground but instead are mixed according to an exact formula. Various clays are combined with other ingredients to form a clay body suitable for a specific need. The firing process is more exact with kilns that burn more efficiently and have better temperature controls. These improvements and others will be discussed as references to them arise.

The first step was to decide upon a clay body formula which meets the piece requirements. The piece needed to be made of an exterior grade, load-bearing clay that resisted warping, and had minimal shrinkage. The clay body decided upon met these requirements (Fig. 11) and had a shrinkage

TERRA COTTA BODY FORMULA

ORIGINAL FORMULA		REVISED FORMULA	
AP Green	30	30	
OM4 Ball Clay	10	10	
Goldart	10	--	
Redart	25	35	
Wollastonite	10	10	
Talc	10	10	
Frit #3819	5	5	or #3124, #3110
Grog			
Calamo 35	12	12	
Calamo 50	8	8	
Red Iron Oxide	8	4	
Barium Carbonate	1/2	1/2	
Bentonite	2	2	
Nylon Fibers	(Handful)		

5 gallons of water/vinegar mix
 (Numbers represent percentage of total mixture)

Start with water/vinegar mix and add bentonite and nylon fibers first. Follow with materials by adding largest amount first working down to the smallest.

Figure 11. Terra cotta formula

factor of approximately 10%.

The second step was to mix the various ingredients together. In a sonar mixer, the water, bentonite, and nylon fibers were mixed together. The nylon fibers are an additive that has gained popularity in the past few years. The nylon, about 1/4" long, adds strength when the clay is in a plastic state, when fired the fibers melt and become a flux that aids in the firing process. The rest of the materials are added starting with the ingredient of largest volume. The clay is removed from the mixer and stored in an air tight container. I had the best results if the clay was allowed to age before use. Even if the ageing process was only for a week, the clay became more uniform and was much easier to work with. While the clay is ageing, the next steps can take place.

The project was to remake some existing pieces instead of making ones of new design. Because of this the process is slightly different than designing a new piece. Instead of working with an architect to make a new design, the piece must be made to match an existing one.

At the initial stages of the project, careful measurements were made of the existing piece. Since no pieces were available to be removed from the building, measurements, field sketches, notes, and photographs were made (Fig. 12). Also the discovery of the original terra

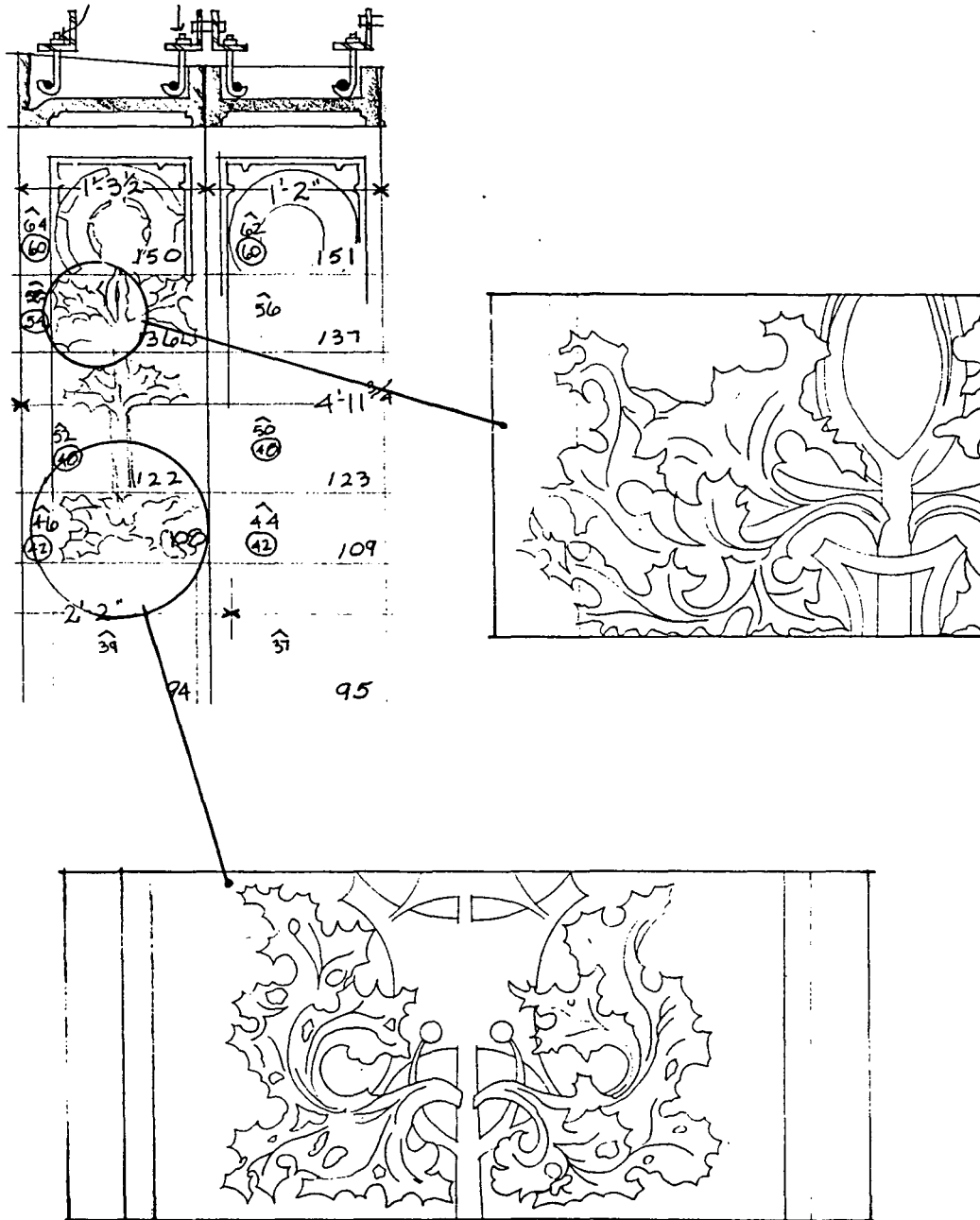


Figure 12. Terra cotta piece sketches

cotta setting drawings aided in obtaining exact measurements (Fig. 13 and 14).

These drawings and photos were then taken back to the studio where full-scale drawings of all sides were produced. To counteract the 10% shrinkage in the clay body, the drawings were increased in size by 11%. Instead of using the scale rulers used at the turn of the century, a photocopier easily enlarged the drawings the required percentage. The enlarged drawings were then used to produce a model of the final piece.

To aid in making the original model, I transferred all scale drawings to chipboard. The chipboard became a template (Figs. 15 and 16) with which I transferred the design to the clay.

The clay used in the modeling process is the same clay that will be used in making the final pieces. Terra cotta clay is used because it has a character of its own that is unobtainable in modelling clay.

When the modeled piece was finished, it was allowed to become slightly stiff, so it would not deform from handling or from pressure of the plaster.

The form is usually made in 5 pieces, one for each face, that interlock to form the piece and break apart to release from the piece. I just made a mold for the detailed front face, and hand built the other sides. The

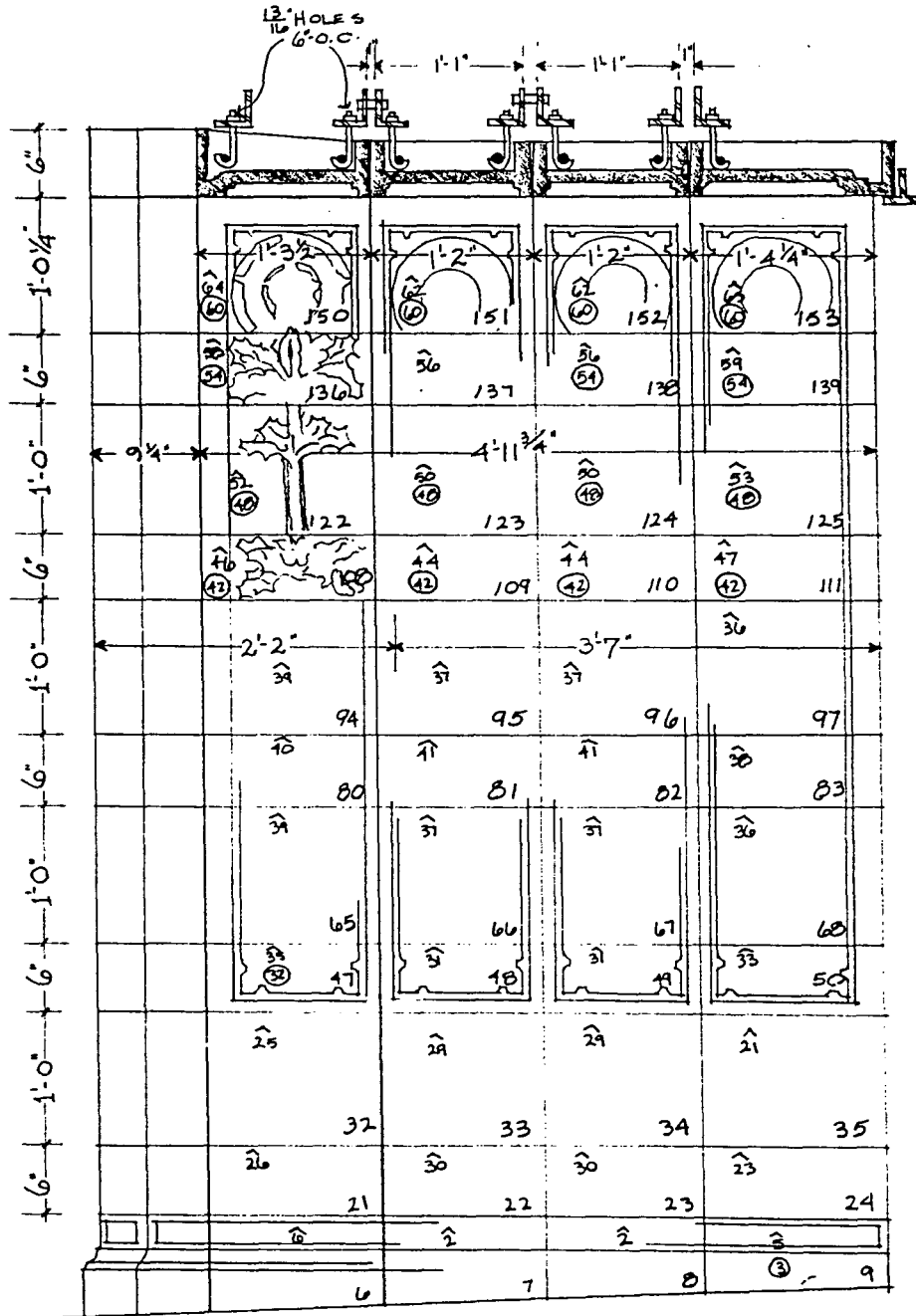


Figure 13. Original terra cotta setting drawings

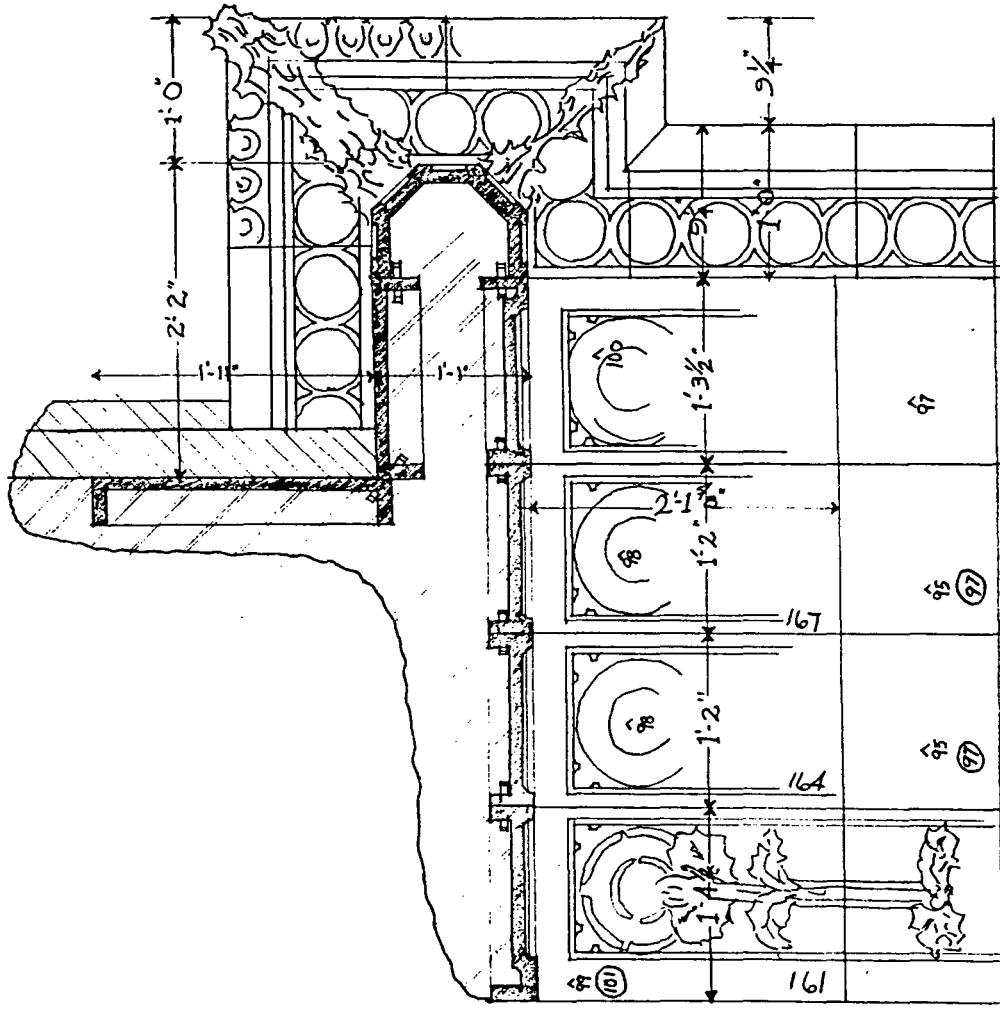


Figure 14. Original terra cotta setting drawings

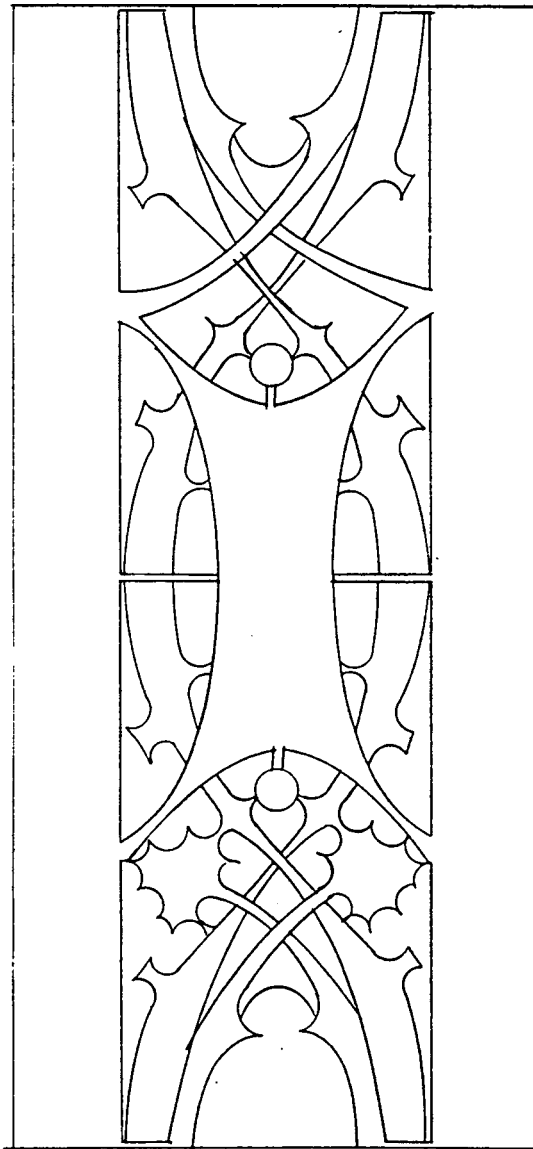


Figure 15. Terra cotta piece templates

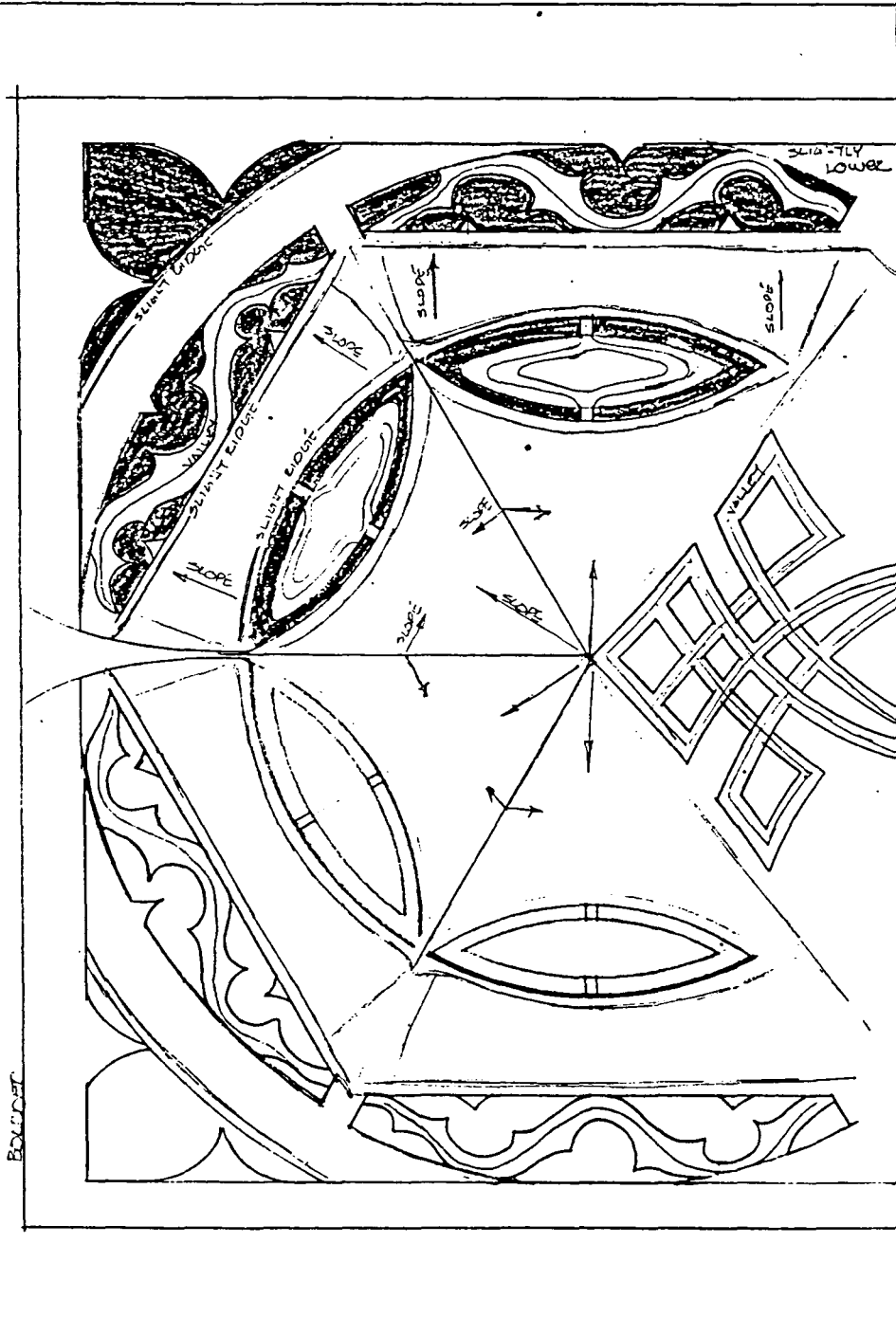


Figure 16. Terra cotta piece templates

disadvantage of this method is the many joints where problems with cracking and separation will occur during drying and firing.

To make the mold of the model, which is the negative of the model, plaster of paris or artists modeling plaster is used. I made a wooden form box out of 1" x 4" lumber, slightly larger than the model. The model is placed face-up on a flat surface with the box placed around it. All cracks between the joints in the box, the box and table, and the model and table are filled with clay. A form release soap was brushed on all surfaces to ease in separation and reduce absorption of water by the model from the plaster.

The plaster is mixed and poured into the mold, while the mold is tapped, to release any trapped air bubbles. The plaster gives off heat while it is hardening, so when the plaster cooled I removed the form work and turned the mold over. I removed the modeled piece a couple of hours later. The model should not remain in the mold until it becomes dry because it will damage detail in the plaster when being removed. I removed it when the clay was still leather hard and cracks were just starting to form between the clay and plaster. Because it is the mold that is wanted and not the model, I broke the clay in pieces so the mold would remain undamaged.

The mold was then cleaned and any minor damage repaired. The mold is cured by setting it aside for a few days to let any remaining water in the plaster escape.

When the mold has cured, the making of an actual piece can begin. A terra cotta clay slightly stiffer (less water) than what was used to make the model is used. The clay is hand pressed into the molds to insure complete filling of all the detail. I used fist-sized balls of clay that were pressed into the molds using the ball of my hand. After the mold was filled, I used a rolling pin to smooth the back, and ensure a uniform thickness in the piece. The clay and mold are then set aside to start the drying process.

The plaster mold absorbs water from the clay causing the clay to become stiff. The time period of this step varied greatly depending upon the conditions of the room. When the molds were placed in the kiln room, the piece could be removed in as little as two hours. If the molds were covered with plastic the piece could remain in the molds for up to a day without becoming too dry.

I found it was best to remove the piece when there was still some flexibility in the clay, but has enough strength to support its own weight. I took a knife and ran the edge between the piece and the mold before removing to break any existing bonds between the clay and plaster.

When the piece came from the mold, there were often slight imperfections. These blemishes were removed by smoothing the edges, removing any plaster particles, and patching small holes. The piece was then given a smooth surface by rubbing with either a piece of wood or leather. The terra cotta block was now ready for its final drying.

Historically drying usually took place in a drying room where the terra cotta could be dried with steam heat. I did not have a drying room so a process to ensure even drying throughout the piece was required. I placed the blocks on a piece of canvas and covered them with plastic. The canvas allowed the terra cotta pieces to move as they shrunk, and the plastic slowed the drying process so the interior and exterior dried at a uniform rate.

After the piece has dried it is known as greenware and is ready to be either glazed or fired.

In my process, the piece was fired, glazed, and then fired again. In most terra cotta companies, the piece was glazed and then fired only once.

The firing process has a few very critical steps that must be carefully monitored to ensure a successful firing. The first occurs after the kiln has been loaded and the firing started. The first firing is known as a bisque firing and is usually fired to cone 010-08. The first critical temperature in a bisque firing is from the start

of the kiln until it reaches 200 degrees F.. Water that remains in the clay, when heated, turns to steam and releases from the piece. If the steam is not allowed to exit the piece, pressure builds up and the piece will explode. To allow the steam the opportunity to escape, I left the door slightly open for the first few hours of firing. The kiln was slowly allowed to reach a temperature of 200 degrees F. at which point the kiln was closed and the temperature within the kiln allowed to rise gradually at the rate of 100 degrees F. an hour. The second critical temperature is 1064 degrees F., known as quartz inversion. During quartz inversion the terra cotta pieces rapidly expand in size causing great pressure on not only the joints, but the whole piece. Quartz inversion is detected by the color that begins to show in the kiln. After the kiln has passed quartz inversion, the temperature in the kiln can be raised at a rate of 150 degrees F. an hour.

The final temperature reached was approximately 2200 degrees F. To insure the temperature was reached, Orton Pyrometric Cones were used. These cones are made to melt at a certain temperature depending on the cone. Temperature gauges located on the kiln were used to give an approximate temperature. The approximation was close enough until the kiln reached the 1800 degrees F.-1900 degrees F. range, then the cone needed to be watched to

guarantee that the proper temperature was reached. When the cone started to fall, the kiln was shut down and allowed to slowly cool.

It is very important that the kiln be allowed to cool slowly, especially during quartz inversion when the piece rapidly shrinks. Both the piece and the glaze will crack if the kiln is opened too quickly. When the temperature has dropped to below 200 degrees F., the door is cracked open. A couple hours later the pieces can be removed, although still quite warm, without much problem.

The kilns I used were not large, and I did not load them fully. Thus the firing time required was greatly reduced. A typical firing schedule usually lasted about a day. The kiln would be loaded and fired slowly for a couple of hours, to remove any trapped water. The gas would then be turned up to increase the temperature to 2200 degrees F. This would take somewhere around 6-8 hours to reach. The kiln was then shut off and allowed to slowly cool for about 10 hours. The door would then be cracked open for a couple of hours and the pieces removed.

After the pieces had cooled, they were ready to be glazed. The oxide washes (stains) were applied using an air-sprayer to insure a more uniform covering of the piece.

Sample pieces were made to test different combinations of stains. The test terra cotta was divided into eights

with slight variations from section to section. Using a combination of stains and underglazes, I was able to obtain a close match to the existing. I also combined red iron-oxide and iron-chromate on other pieces to produce a dark red surface that gave the pieces an aged affect.

The pieces were now ready to be fired again. When a stain was used, care needed to be taken when loading the kiln to make sure that the stain was not accidentally brushed off. The stains tended to be much more fragile, when being handled, than other surface treatments.

The final firing is very similar to that described before. Since the piece had already been fired once, all the free water in the terra cotta had been driven off, the kiln could be closed and fired at a quicker rate.

The making of the pieces gave me an in-depth knowledge of terra cotta that I would never have gotten by just writing about it. Many questions that arose during researching and writing, were answered when I started to actually work with the material.

TERRA COTTA TODAY

Today, over 100 years after the birth of America's terra cotta industry, the large factories have vanished and only a handful of experienced terra cotta artists remain to pass the knowledge onto the next generation. Yet thousands of structures serve as testimony to the significant contributions of architectural terra cotta.

The 1940s and 1950s were very hard on terra cotta manufacturers. Only one company, Gladding, McBean and Co. of Lincoln, California, continued to be active during these years.... The outlook for Gladding, McBean and Co. began to brighten in the late 1970s, and over the last ten years they have produced various types of architectural terra cotta to fill nearly six hundred job orders (Tunick, 1989, p. 47). In recent years several new companies, along with individuals, have started to produce architectural terra cotta.

The renewed interest can be attributed to two factors. First, the recognition of an architectural heritage through historic preservation. People want to save the old, when possible, instead of always tearing it down. Terra cotta was a popular building material, and many of these old structures use it for cladding along with brick. The vast majority of architectural terra cotta presently

manufactured is for replacement pieces used in the restoration of historic structures (Tunick, 1987, p. 47).

A second factor leading to the growing popularity of terra cotta is the reintroduction of color, surface pattern, and ornamentation in today's architecture. This has led to a "rediscovery" of terra cotta as a building material for new buildings. One particularly innovative example by Hardy Holzman Pfeiffer, a firm that has used terra cotta in a number of projects, is the Ohio Theatre Expansion and Arts Pavilion in Columbus, Ohio. The decision was made to use plum-colored glazed terra cotta for a three story high interior lobby (Tunick, 1989, p. 48). Since terra cotta is historically thought of as an exterior building material, although it was used in interiors, this application helps open new territory for terra cotta in contemporary design.

Today with technical advances, terra cotta is being experimented with as a cladding material for tall buildings. Terra cotta has typically been made in blocks that use a metal anchoring system that attaches the terra cotta to the building frame. The cladding being experimented with today is similar to the ashlar veneer produced after the turn of the century, except today's veneer is much thinner and mixed with air to reduce the weight. The terra cotta is attached to a backing that is

attached to the building frame similar to stone veneer.

Terra cotta as a cladding material has advantages over stone. First, with the infiltration of air, the terra cotta weighs less, reducing the size of the anchoring system required. Second, terra cotta can be produced in any shape and with any degree of ornamentation desired. Third, the color spectrum of terra cotta is unlimited and a single piece can have multiple colors. Fourth, today's acid rain disintegrates granite and marble. Spalling, which normally took a thousand years to occur, now happens in sixty years. Scanning electron-microscopic studies clearly show decalcification of crystalline structure in stone due to acid (Kruse, 1989, p. 55). The glaze on terra cotta can make it impervious to the effects of acid rain.

The future for terra cotta is on an upswing. After 50 years of falling into disfavor, terra cotta is starting to make a come back. The biggest demand is for terra cotta to replace existing terra cotta, but the research that is taking place could open up new uses for the material. Terra cotta can be made cheaper and faster than stone, and, with our technology, can be made to last longer.

CONCLUSION

The purpose of this thesis was to investigate architectural ornamentation as it pertained to terra cotta. I started with a deep interest in the material, not a lot of knowledge, and many questions. As I conclude this thesis I have a greater interest in the material, some knowledge, and still many questions.

The historic overview of terra cotta until 1870 made me realize that terra cotta existed, and at times was used extensively before the Chicago Fire. In architectural history terra cotta has had periods of used followed by periods of little use. This made me realize that when the last, and probably greatest, period of use ended in the 1930's, terra cotta can return again as a building material.

The period between 1870 and 1930 is when terra cotta was used extensively and the period I was most familiar with. This was also the time period when experimentation with glazes was great. In 1870 most terra cotta was unglazed and came in earth tones, by 1900 almost all terra cotta was glazed and most colors were available.

The research into the history of terra cotta gave me an understanding of how terra cotta developed prior to 1870, and why it advanced so quickly in Chicago after 1870.

Terra cotta was indeed "the right material at the right time".

I chose next to look at Louis Sullivan's use of terra cotta because in his hands the material reached a unique level of creativity and expressive synthesis with construction. Sullivan was one of the pioneers in the use of terra cotta and one of the few to understand its full potential as a material. Sullivan's work showed that terra cotta, besides being fireproofing for steel structures, could at the same time be a beautiful element giving life and meaning to the building.

The research portion in manufacturing explained what happened during the various stages. I then took this information and applied it in the studio. I feel that this was the most important part of my thesis. Terra cotta is a three-dimensional material and to understand it you need to work with it in that form, and while working with it many questions brought about by the research were answered.

The manufacturing of terra cotta pieces gave me an insight into and a better understanding of terra cotta. The steps used a hundred years ago were basically the same that I used today. Technological advances have improved some of the steps and made them more exact and easier to control.

Clay bodies today are much better than what was used

fifty or a hundred years ago. Manufacturers often failed to meet what are known as today's standard tests of rates of absorption, freeze/thaw cycles, compressive strengths, thermal expansion, and saturation coefficients. In today's clay bodies, various clays and other materials are mixed together to form a clay that meets a specific requirement. This clay body can then be remade as required exactly like the original since each batch is rigidly controlled.

Working in the studio making terra cotta pieces gave me a knowledge and respect for terra cotta that I would not have obtained otherwise. Working with terra cotta made me realize that it is a very fragile material that if handled wrong will crack, warp, or explode when fired leaving a worthless piece. I also learned that if the manufacturing process is done correctly, and with care, you are rewarded with a beautiful piece of terra cotta that will last indefinitely. I experienced feelings of both frustration and joy when making the pieces. Frustration happened when the mold broke because I wasn't careful removing a piece; spending days trying to mold the leaves of a piece; opening the kiln and finding out the glaze didn't turn out as expected, or the piece had cracked or blown-up during firing. The frustration was easily overcome by the joy of a successful piece. The greatest feeling was when the kiln was opened and the piece turned out as planned.

I looked at this thesis as the opportunity to study and investigate architectural ornamentation as it pertained to terra cotta. Terra cotta, a building material, whose time, I hope, has come again.

APPENDIX A

NATIONAL FARMERS' BANK, OWATONNA, MINNESOTA

DATES

Final Plans: 15 January 1907

Interior Decoration: 1 April 1908

Official Opening: 16 July 1908

National Register of Historic Landmarks: 1976

DIMENSIONS

68 x 68 feet (main bank block)

COST

\$125,000

(Weingarden, 1987, p. 48)

"My whole spring is wrapped up just now in the study of color and out of doors for the sake of your bank decorations.... I want a color symphony and I am pretty sure I am going to get it.... There has never been in my entire career such an opportunity for a color tone poem as your bank interior plainly puts before me."

Louis Sullivan

Architect Louis Sullivan in these excerpts from a letter written to banker Carl Bennett, reveals the depth and intensity of feeling behind his design for the National Farmers' Bank.

Sullivan saw the function of a bank not merely as a place to store money or to gain financing for other ventures. He saw the bank as the financial heart and soul

of the community. The bank, as a symbol of security and prosperity, should celebrate the good things in the life of this small, but prosperous Midwest farming community.

The striking beauty of the Owatonna bank is a combination of many elements. The terra cotta, iron work, stained glass, and other ornament were the finest available at the time. A time when American craftsmanship excelled. Sullivan along with men like George Elmslie, his chief assistant; Louis Millet, a Chicago artist and colorist, who designed the great leaded glass windows and assisted Sullivan with the arch stencils and the interior color work; and Kristian Schneider, who sculpted all of the bank's ornament in clay from which were made molds for casting all of the terra cotta, cast iron and ornamental plaster in the building. These were the men responsible for the creation of this bank.

The bank stands today in celebration as a tribute to Sullivan's creativity.

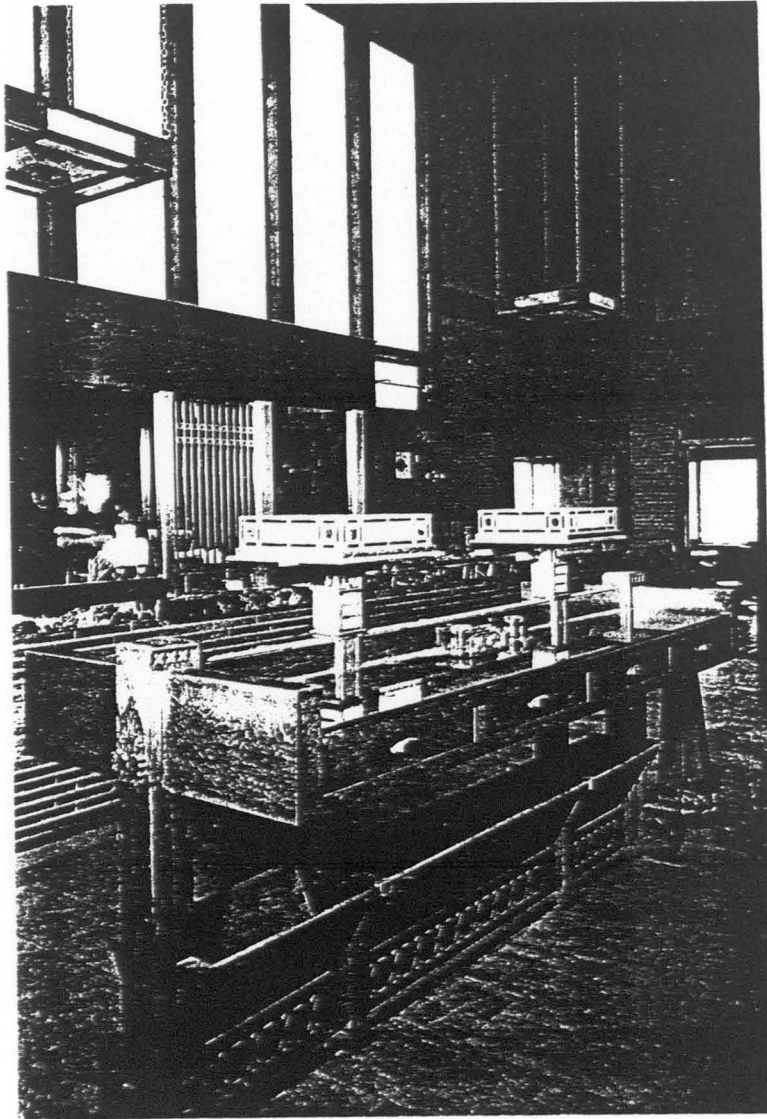


Figure 17. National Farmers' Bank.
Photo: Henry Fuermann, Chicago Architectural
Photographing Co.

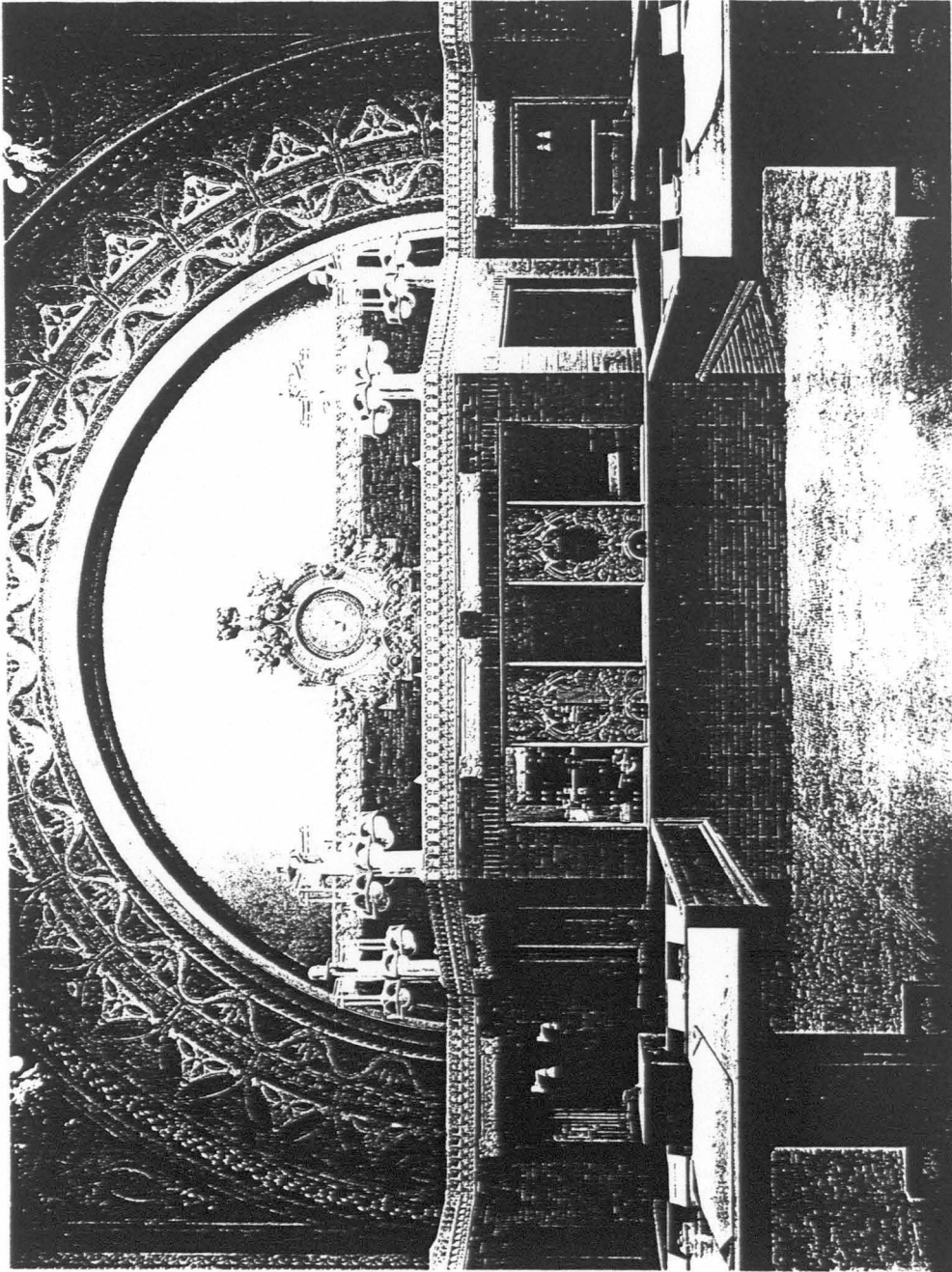


Figure 18. National Farmers' Bank. Banking room
Photo: Henry Fuermann, Chicago Architectural
Photographing Co.

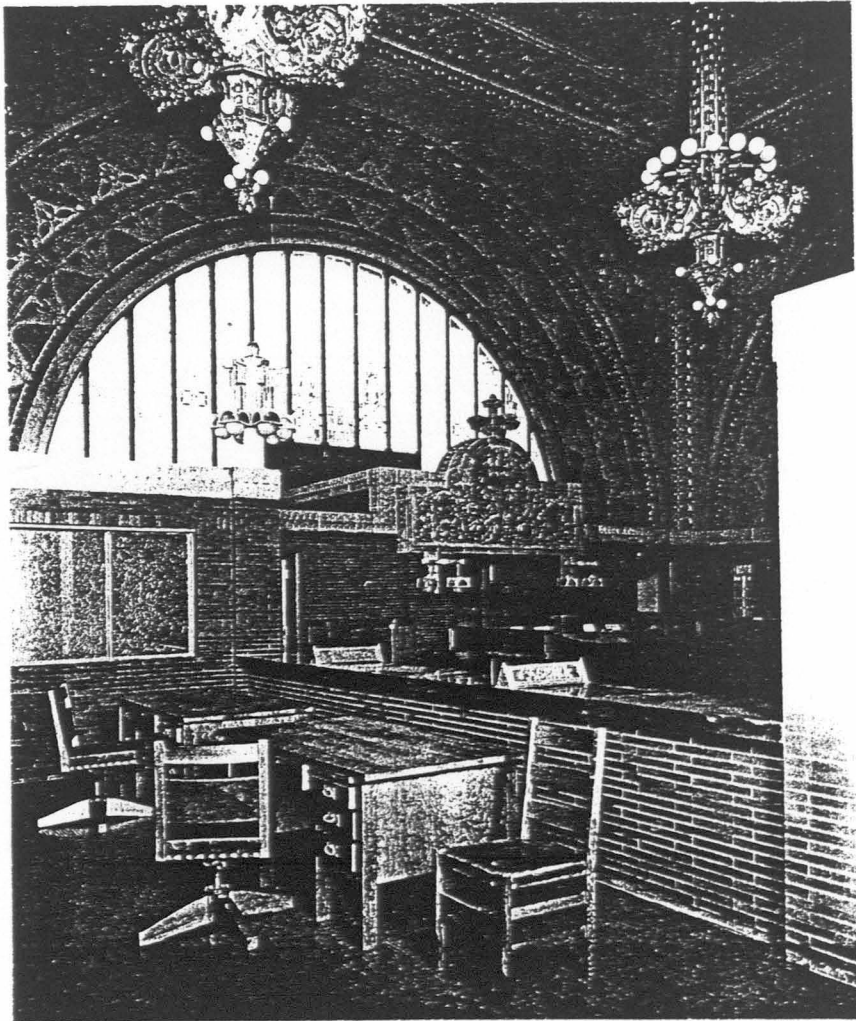


Figure 19. National Farmers' Bank. Banking room.
Photo: Henry Fuermann, Chicago Architectural
Photographing Co.

APPENDIX B

MERCHANTS NATIONAL BANK, GRINNELL, IOWA

DATES

Preliminary Sketches: November 1913

Working Drawings: February 1914

Official Opening: 1 January 1915

National Historic Landmark: 1976

DIMENSIONS

42 x 75 x 35 feet

COST

\$60,000

(Weingarden, 1987, p. 84)

The building, nearly cubical, is a pure suggestion of all the favorable connotations a bank could wish. Its monolithic solidity connotes security and stability; the tapestry brickwork, friendly warmth. The terra cotta ornament modifies any sense of the austere that the severely rectangular basic shape creates.

The center of visual interest, on the exterior, is a great circular stained glass window over the entrance with a startling design in buff and gilt terra cotta. The design around the window is in five layers, a circle, square, circle, diamond, and a third circle bound by square

bars. Other embellishing elements include heraldic griffins guarding the door and a decorative frieze.

The cornice along the top of the building is of rich brown terra cotta. Small finials rise against the skyline and give contrast to the otherwise clean-cut geometry of the building mass.

Sullivan carried the embellishing detail throughout the whole interior. The same pattern used for the building cornice is repeated at the rear of the bank in the form of a golden frieze.

The east wall is dominate in the interior with its great row of soaring stained glass windows, recessed behind heavy oak columns. The inserts in the center of each section are in peacock blue and green colors.

Sullivan used a subordinate color scheme that relied on natural materials that enhance the ambience of golden tones; verde antique marble counter tops; hickory stained wood; specked buff salt-glazed Roman brick; and pinkish-gray Tennessee marble floors.

Although not as ornamented as some of Sullivan's buildings, the effect is still the same. In this case, a bank that is simply efficient and beautiful.

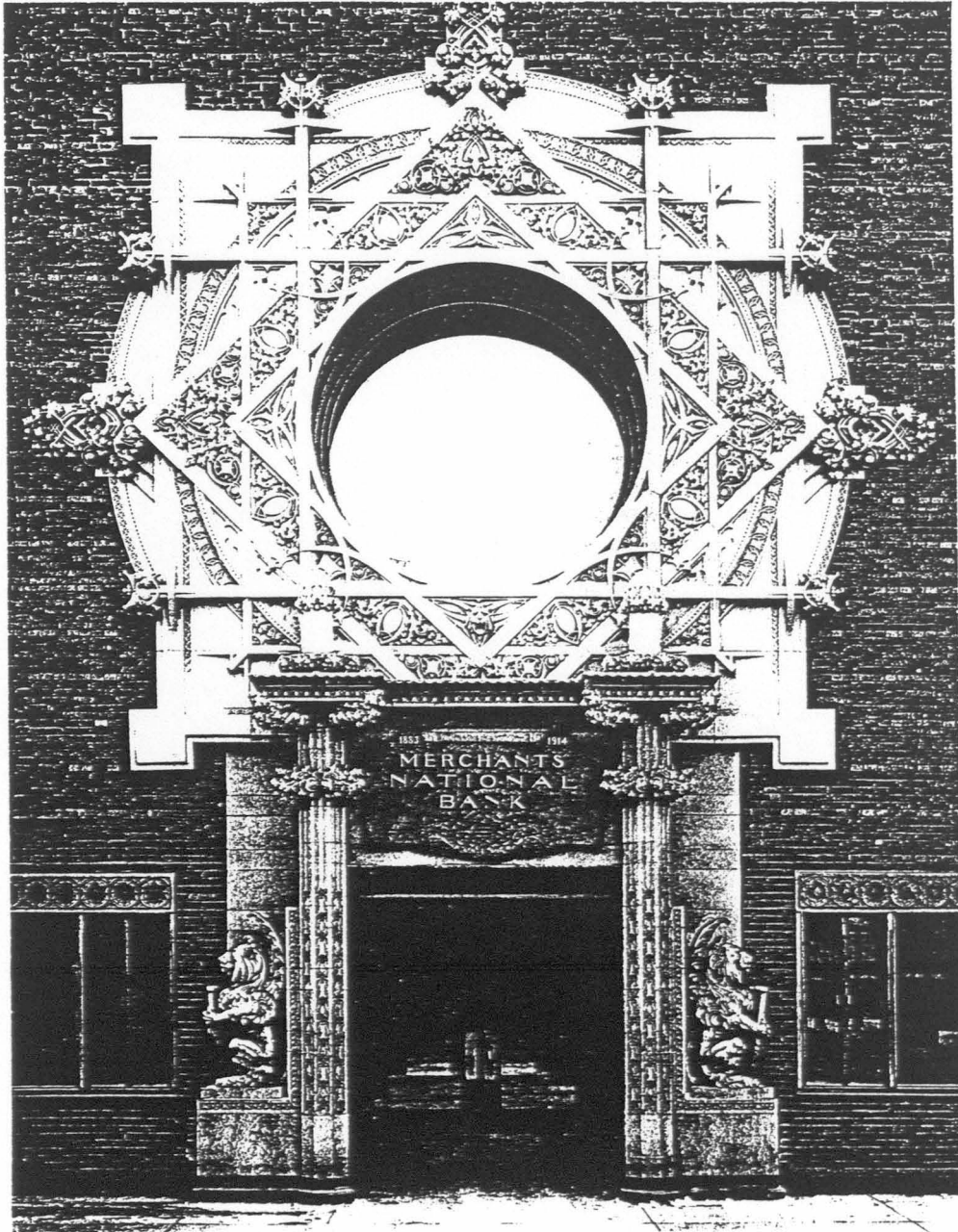


Figure 20. Merchants National Bank. Detail of Entrance.
Photo: Henry Fuermann, Chicago Architectural
Photographing Co.

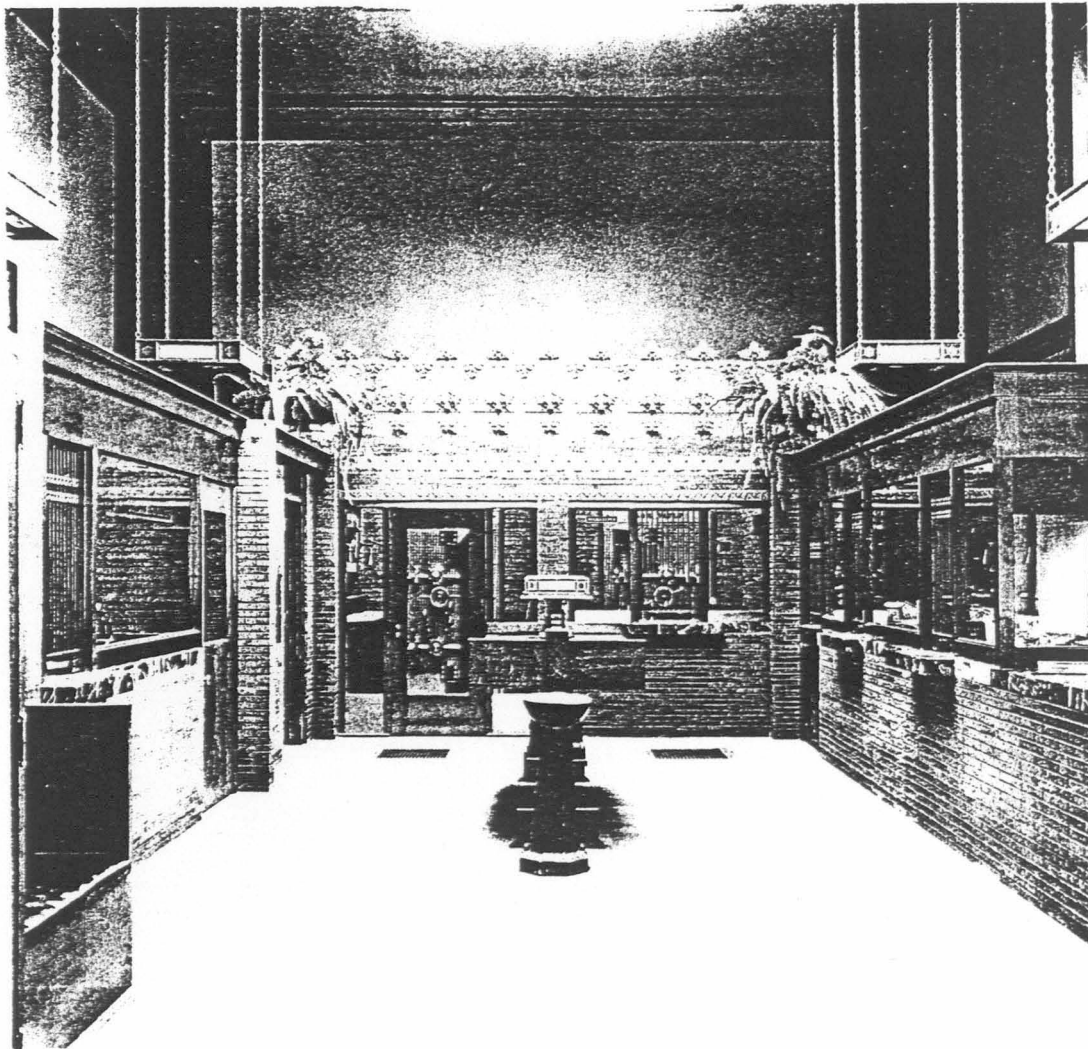


Figure 21. Merchants National Bank. View towards vault.
Photo: Henry Fuermann, Chicago Architectural
Photographing Co.

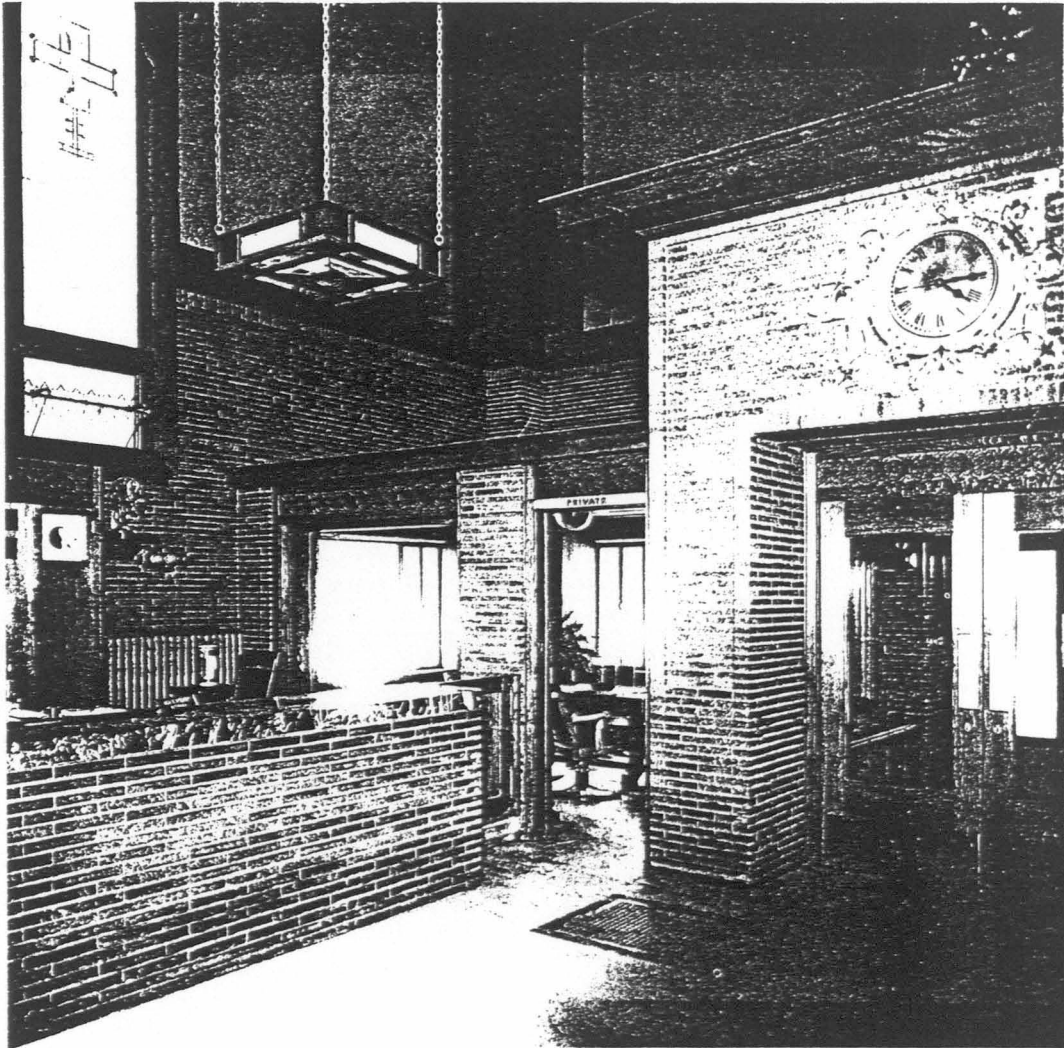
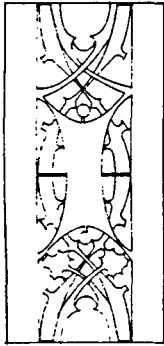
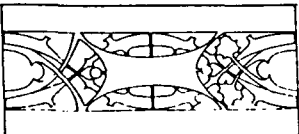
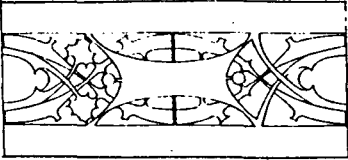


Figure 22. Merchants National Bank. View towards director's room. Photo: Henry Fuermann, Chicago Architectural Photographing Co.

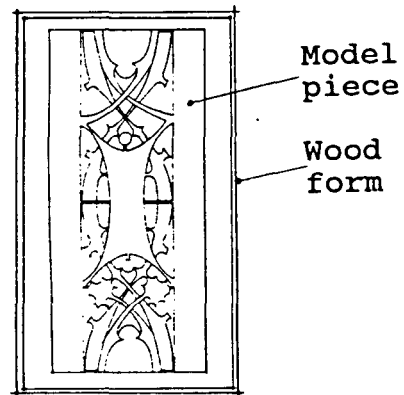
APPENDIX C

STEP BY STEP PROCESS

<p>STEP 1)</p> <p>Careful measurements of the existing piece are made. I made field drawings and notes, and photographed the piece.</p>																			
<p>STEP 2)</p> <p>Choosing a clay body formula. The formula contains various clays to produce a terra cotta body meeting the specific needs of the piece. These ingredients are mixed together to form a workable clay.</p>	<table border="0"> <tr> <td>AP GREEN</td> <td>30</td> </tr> <tr> <td>OM4 BALLCLAY</td> <td>10</td> </tr> <tr> <td>REDART</td> <td>35</td> </tr> <tr> <td>WOLLASTONITE</td> <td>10</td> </tr> <tr> <td>TALC</td> <td>10</td> </tr> <tr> <td>FRIT #3819</td> <td>5</td> </tr> <tr> <td>GROG</td> <td>20</td> </tr> <tr> <td>RED IRON OXIDE</td> <td>4</td> </tr> <tr> <td>BENTONITE</td> <td>2</td> </tr> </table>	AP GREEN	30	OM4 BALLCLAY	10	REDART	35	WOLLASTONITE	10	TALC	10	FRIT #3819	5	GROG	20	RED IRON OXIDE	4	BENTONITE	2
AP GREEN	30																		
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FRIT #3819	5																		
GROG	20																		
RED IRON OXIDE	4																		
BENTONITE	2																		
<p>STEP 3)</p> <p>Using the measurements from step 1, a model of the piece is made at a scale slightly larger than the original to allow for shrinkage in the clay.</p>	 <p>11 PERCENT LARGER</p> 																		

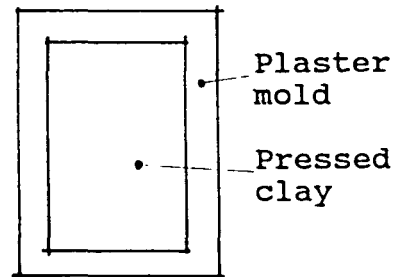
STEP 4)

I then made a wooden form work, slightly larger than the modeled piece, in which to set the model. Plaster of paris is poured covering the piece to a depth of 1". The modeled piece is then removed, and the finished mold is cleaned.



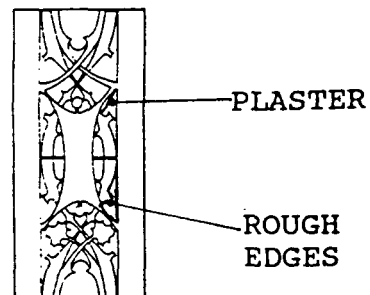
STEP 5)

The clay is then pressed into the molds. The clay is left in the molds until it stiffens, usually a few hours. When the clay can support its own weight the mold is removed.



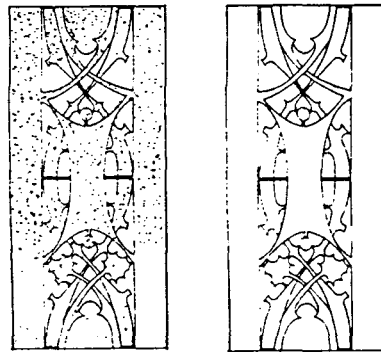
STEP 6)

The cast is then finished to remove imperfections and add detail. This is done with various ceramic tools and smoothing the piece with pieces of wood and sponge.



STEP 7)

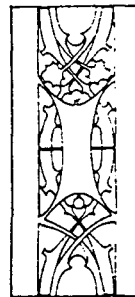
After the piece is finished, it is allowed to dry. Placing the piece in the kiln room caused a quicker and better drying.



Wet Piece Dry Piece
(lighter color)

STEP 8)

Glazing can be done either before or after firing (step 9) depending on the stain or glaze used. I used a combination of stains applied after the first firing and then refired to fuse the stain to the piece.



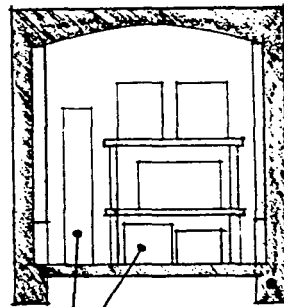
GLAZE

STAIN

BRUSHED OR SPRAYED
ON SURFACE

STEP 9)

The final step is to fire the piece. It is loaded into the kiln and heated to between 100 F. and 200 F. for a few hours to drive off any existing water. The kiln is then closed and fired to a temperature of 2200 F. The flame is then shut-off and the kiln allowed to cool. The finished piece is then removed from the kiln.



TERRA COTTA KILN

APPENDIX D

GLOSSARY

ASHLAR FACING. Solid units of clay, usually rectangular, which are larger than brick size. Terra cotta ashlar are plain pieces with no ornament. They are typically open in the back with "egg crate" webbing.

BISQUE FIRING. Preliminary firing to harden the body prior to glazing and subsequent glaze firings.

CERAMICS. Made of or pertaining to fired clay.

CLADDING. An external covering or sheathing applied to a structure for aesthetic or protective reasons which does not form an intrinsic supporting function for the wall.

CLAY. A hydrated silicate of alumina formed from the decomposition of granite into particles which are compact and brittle when dry, but become plastic and sticky when wet. They are classified into various types such as ball clays, fire clays, and slip clays.

CLAY BODY. A mixture of clays and other earthly mineral substances which are blended to achieve a specific ceramic purpose. A single clay may not have all the properties necessary for a specific need; it may lack plasticity, shrink to an excessive degree or warp too readily.

CRAWLING. Contraction of glaze coating on the surface of a clay body causing areas of exposed unglazed clay. This condition is caused by a too-heavy application of glaze or dirt, grease, etc., on the clay body.

CRAZING. An undesirable excessive crackle in the glaze which penetrates through the glaze to the clay body. These cracks may be present when the ware is taken from the kiln or may develop days or months later. Crazeing is caused when the glaze has contracted more than the clay, thus placing the glaze in tension.

Another type is moisture crazing. This is caused by exposure to the elements after firing. If a clay body is slightly porous moisture can enter causing a slight increase in size. This can cause the glaze to crack.

DUNTING. Cracking of ceramic forms caused by stresses which occur due to the cooling of the forms more rapidly than the material can accommodate.

EFFLORESCENCE. White powdery coating produced on masonry by the soluble salts of soda and magnesia rising to the surface as a result of water being absorbed by the masonry.

ENGOBE. A prepared slip that is between a glaze and a clay slip. It contains clay, feldspar, flint, a flux and colorants. It is usually applied to damp ware although may be used on bisque.

FAIENCE. In architectural ceramics, this is an alternative term for glazed terra cotta.

FLUX. A substance which causes or promotes melting.

FRIT. A partial or complete glaze that is melted and then reground for the purpose of eliminating the toxic effects of lead or the solubility of such compounds as borax or soda ash.

GREENWARE. Unfired ceramic ware.

GLAZE. A liquid suspension of finely ground minerals that is applied by brushing, dipping, or spraying on the surface of greenware or bisque-fire ceramic ware.

GROG. Hard-fired clay which has been fired and then ground into granules of more or less fineness. It can also be pulverized refractory materials such as broken ceramic forms, fire bricks, etc. It is used to open up clay bodies and/or reduce the shrinkage in ceramic products which, because of their thickness, have drying and shrinkage problems.

KILN. A furnace made of refractory materials for the firing of ceramic products.

LEATHER HARD. The condition of the raw ware when most of the moisture has left the body but is still soft enough to be carved.

MOLD. A form or box, usually made of plaster of paris, containing a hollow negative shape. A positive form is made by pressing moist clay into this hollow.

PLASTICITY. The quality of clay that allows it to be manipulated and still maintain its shape without cracking or sagging.

POLYCHROMED TERRA COTTA. Glazed with several or many colors. This term, when referring to colored terra cotta, is often used interchangeably with the term "faience."

SHIVERING. The cracking, buckling and separation of glaze from the body. It occurs when the glaze is under too great compression, the opposite of the cause of crazing.

SHRINKAGE. Contraction of the clay in either drying or firing.

SLIP GLAZE. A glaze which is made wholly or largely from clays of low fusion point. Since the glaze is largely made up of clay, making it prone to high shrinkage, the ware is usually glazed while it is still leather hard. Thus the ware and glaze shrink together and the tendency to crack may be avoided.

SPALLING. A term applied to the fracture or disintegration of a material. It can be caused by:

1. Rapid changes in temperatures during manufacture
2. Water damage occurring after the piece has been in use
3. Uneven temperatures caused by the sun which produces different expansion and contraction of the material in the same piece.

The types of spalling due to water-related problems are those of glaze spalling and material spalling. When the water builds up sufficient pressure to cause expansion of the clay body or expansion of its own volume in freeze-thaw cycles, the glaze will blister or separate from the clay surface (glaze spalling) or the clay body itself may fracture or disintegrate (material spalling).

VITREOUS. Pertaining to the hard, glasslike and nonabsorbent quality of a body or a glaze.

VITRIFICATION. The hardening, tightening and finally the partial glassification of clay achieved through firing at high temperatures.

(Berryman, 1984, p.26-29)

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