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**ARCHITECTURAL EXTERIOR FINISHES IN THE SPANISH CARIBBEAN.
CASE STUDIES: SAN GERONIMO AND SANTA ELENA POWDER
MAGAZINES**

Almyr M. Alba

A THESIS

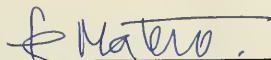
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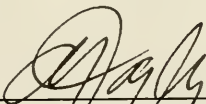
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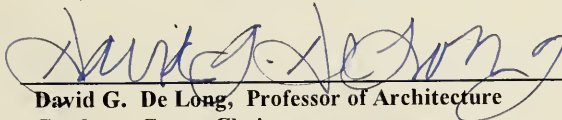
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DEDICATION

To my parents, Sofia and Ricardo, and my beloved Ramzi as their love, encouragement, and support have been a source of strength and inspiration which have made this work possible.

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INTRODUCTION

The architectural heritage of the Caribbean is broad and diverse. The Caribbean was the first part of the New World colonized by Spain, later becoming the connecting point between the mainland Iberian domains and the royal authority in Spain. The Caribbean was also the first military barrier to counteract British, French, and Dutch hostilities, and the center for exchange of goods produced in the New World and merchandise imported from Europe. As a result of its historic role, the Caribbean possesses some of the oldest and largest monuments constructed by the European powers, including several outstanding military complexes and numerous civic edifices.

Until recent years, efforts to conserve historic buildings in the Caribbean have ignored the significance of the outer skins of these early buildings. Exterior finishes can provide valuable evidence of materials, technology, aesthetics, and color preferences of a specific time, or on the evolution of a building over time. Many of the masonry walls of these monuments have been intentionally exposed assuming an "honesty of the noble materials" (i.e. stone) to be historically or aesthetically correct. This approach, in addition to jeopardizing the integrity of the historic structure, has led to erroneous interpretations of Spanish colonial architecture.

The goals of this study have been to research the technologies and materials of architectural surface finishes used in the Spanish Caribbean during the colonial period, and to explore possible regional variations in the Caribbean compared to those employed in Spain.

The research methodology consists of an initial review of the historical documentary sources including primary building treatises and secondary historical research. The initial approach was to establish the architectural literary sources utilized in

both Spain and the New Iberian World from the sixteenth to the nineteenth centuries. Once established, the principal references available for each century were studied and the general and specific architectural finish materials and described. The information derived from regional literature was employed later to illustrate the surface finish practices utilized in the Caribbean.

Complementary information about materials is provided in the second part of the study. The component materials of the stucco (e.g. lime, sand), paints (e.g. pigments), and additives, reported in the documentary sources, are described in terms of their chemical composition, physical appearance, properties, and behavior according to both original sources and contemporary knowledge.

The third component of the research is a case study of the analysis of architectural surface finishes from two eighteenth century Spanish military buildings: Santa Elena and San Geronimo Powder Magazines, both located in San Juan, Puerto Rico. The basic information on the architectural surface finishes of these buildings was derived from the Examination and Analysis of Exterior Finishes, Polvorin de San Geronimo and Polvorin de Santa Elena Report by Frank G. Matero and Joel Snodgrass. This report was produced in January 1990 for the restoration project of Santa Elena and San Geronimo Powder Magazines which was directed by Otto Reyes, project architect.

Samples from the exteriors of both buildings were analyzed using a variety of methods including optical microscopy, microchemical analysis, scanning electron microscopy (SEM) and energy dispersive X-ray fluorescence analysis (EDX) to establish the microstructure and composition of the samples. The results are compared with the information gleaned from the documentary sources to establish differences between actual practice and theory, and to determine the possibility of regional variations in the surface finishes and the treatment of buildings in the Spanish Caribbean and Spain.

It is understood that the case study buildings represent a very specific building type (powder magazine) constructed by the colonial state for military purposes and therefore cannot be considered architecturally representative. Nevertheless, the control and formulaic representation of this building type by Spanish royal military engineers in Spain and its colonies allows for the comparison of two original expressions of this building type against each other and in contrast to the practices as described in the European based treatises.

Chapter 1: Documentary Sources.

A. Architectural Treatises in Spain (Sixteenth to Nineteenth Century).

In the sixteenth century during the Spanish conquest of the New World, guild masters (*maestro de obra*), engineers, and architects (*alarifes*) journeyed along with the *conquistadores* and clergy to the New World. The design principles of these professionals were based on Italian treatises popular in Europe in the sixteenth century. During the first half of the century the most frequently published and therefore popular treatises in Spain were: Diego de Sagredo's *Medidas del Romano*, 1564; and Sebastian Serlio's *Tercero y Quarto Libro de Architectura*¹ (1552, first Spanish translation). In the second half of the sixteenth century other works followed, including: Leon Bautista Alberti's *Diez Libros de Architectura*² (1582, first Spanish translation); Juan de Arfe y Villafane's *De Varia Comensuracion para la Escultura y la Architectura*, 1585; Cristobal de Rojas' *Teoria y Practica de la Fortificacion*, 1598; Giacomo Vignola's *Regla de las Cinco Ordenes de Architectura*³ (1593, first Spanish translation); and Marcus Vitruvius' *Diez Libros de Architectura*⁴ (1564, first Spanish translation). Among these books, Vitruvius' treatise was the most significant and its influence pervaded the work of Spanish Renaissance architects and Spanish building treatises written during the Renaissance.

During the seventeenth century only new four major works were published: *Libro Primero de la Arquitectura*⁵ by Andrea Palladio (1616, first Spanish translation), *Arte y Uso de la Architectura* by Lorenzo de San Nicolas, 1633; the military treatise *El Architecto Perfecto Militar* by Sebastian Fernandez de Medrano, 1687; and the artist's paint essay *Arte de la Pintura* by Francisco Pacheco, 1638. The remaining works in circulation were reprints or adaptations of books issued in the previous century.

During the eighteenth century, the printing industry in Spain reflourished, and a wide number of architectural treatises were produced. Alberti, Arfe y Villafane, Palladio, San Nicolas y Vignola's works were reprinted. Also, new theoretical works such as *Escuela de Arquitectura Civil* by Brizguz y Bru, 1738; and *Critica y Compendio de la Arquitectura Civil* by Manuel Losada, 1740; and the military treatise *Principios de Fortification* by Pedro de Lucuze, 1781 were published in this century. In addition to the theoretical treatises a large number of practical handbooks were also edited. Among these handbooks were three specialized books on architectural finishes (stucco and paints): *Arte de hacer el Estuco Jaspeado* (The Art of Marbleizing) by Ramon Pascual Diez, 1785; *Disertacion sobre las Argamasas que Gastaban los Romanos* (Discourse on the Roman Mortars) by Lloriot, 1776; *Secretos de las Arte Liberales y Mecanicas* (Secrets of Liberal and Mechanical Arts) by Bernardo Monton, 1734; and *El Museo Pictorico y la Escala Optica* (Painting and Proportions) by Palomino de Castro y Velazquez, 1724.

During the nineteenth century Spanish publications shifted from the traditional emphasis on theoretical design books to treatises oriented toward practical matters in architecture. Several volumes were devoted to masonry and stucco work, including the following volumes intended to illustrate the art of revetments: *Manual de Construciones de Albanileria* (Manual of Masonry Construction) by Pedro Celestino Espinosa, 1859; *Observaciones de la Practica de Edificar* (Observations and Edification Practices) by Manuel Fornes y Gurea, 1841; *Manual del Albanil-yesero* (Mason and Plasterer's Manual) by Ignacio Boux (editor), 1840; *Tesoro de Albanileria* (Masonry Treasure) by Pascual Perier y Gallegos, 1853; and *Arte de Albanileria* (The Art of Masonry and Plaster Work) by Villanueva, 1827. The major publications devoted to paint preparation and painting technique included *Secreto de Artes Liberales y Mecanicas* (Secrets of

Liberal and Mechanical Arts) by Bernardo Monton, 1814; and *Manual Teorico-Practico del Pintor, Dorador y Charolista* (Theoretical and Practical Manual for Painters, and Gilders) by Manuel Saenz y Garcia, 1872.

B. Architectural Treatises in Spanish the New World (Sixteenth to Nineteenth Century).

Information about architectural books sent to the Americas during colonial times has been based on trade invoices, wills, and library inventories of the period.⁶ These sources, reviewed by Torres Revello in his article *Tratados de Arquitectura Usados en Hispanoamerica* (1956), revealed that the major architectural books available in sixteenth-century Spain were also available in the New World toward the end of the century. The list included *Los Diez Libros de Arquitectura*⁷ (The Ten Books of Architecture) by Leon Bautista Alberti (1582's Spanish edition); *De Varia Comensuracion para la Escultura y la Arquitectura*⁸ (Commensuration of Sculpture and Architecture) by Juan de Arfe y Villafane, 1598; *Tercero y Quarto Libro de Arquitectura*⁹ (Third and Fourth Book of Architecture) by Sebastian Serlio (1565's Spanish edition); *Regla de las Cinco Ordenes de Arquitectura*¹⁰ (The Five Orders of Architecture) by Giacomo Vignola (1587's Spanish edition), and *Diez Libros de Arquitectura*¹¹ (Ten Books of Architecture) by Marcus Vitruvius (1582's Spanish edition). These books were primarily found in archives in Mexico City.

The treatises of Arfe y Villafane,¹² Vignola,¹³ and Vitruvius¹⁴ were also cited in Mexico City dating the seventeenth century. In addition to these books, new architectural treatises were recorded toward the second half of the century: *Arquitectura*¹⁵ by Fray Lorenzo de San Nicolas (1633 and 1663's editions), *De Architecture Anno 1625*¹⁶ by

Andrea Palladio (1625's Spanish edition); *De Architectura*¹⁷ by Bernardo Gamuzi (1565's Italian edition); and *De Architectura*¹⁸ by Giacomo Vignola (1593's Spanish edition).

In Lima, capital of the Viceroyalty of Peru, architectural books belonging to Limean master builders, architects and engineers were documented during the Colonial period. As in Mexico City, the well-known treatises of Arfe y Villafane,¹⁹ Serlio,²⁰ Vignola,²¹ and Vitruvius²² were recorded in use during the eighteenth century. In addition to the previously mentioned books, *La Arquitectura*²³ by Pietro Cataneo (1597's Venetian edition) was registered in the archives in Lima.

Apart from the theoretical treatises, some practical architectural handbooks were brought to in the New World Spanish territories in the second half of the seventeenth and eighteenth century. Among them were *La Carpinteria de lo Blanco*²⁴ (1633) about woodwork roofing techniques, by Diego Lopez de Arenas; *La Perspectiva y Espectacularia de Euclides*²⁵ (1685's Spanish edition) about perspective ; *Breve Tratado de Bovedas Regulares e Irregulares* (1661) concerning vault construction techniques, by Juan de Torrijas; and *El Arquitecto Prefecto en el Arte Militar*²⁶ (1700) a treatise on practical military architecture knowledge, by Sebastian Fernandez de Medrano.

In addition to these architectural treatises, Torres Revelo recorded three essays on painting found in Latin America during the colonial era: *Dialogo de la Pintura*²⁷ by Vicencio Carducho, 1633; *Arte de la Pintura* by Francisco Pacheco,²⁸ 1649; and *El Museo Pictorico y de la Escala Optica*²⁹ by Antonio Palomino de Castro y Velazquez, 1724. The affinity between some fine arts painting techniques and painted architectural finishes suggested that similar techniques and materials were also employed on buildings.

C. Treatises written in New Spain.

Until the 1960s, it was believed that no architectural literature was written or published in the New World. However, the discovery of two works on architecture:

Miguel de San Andres' Architectural Treatise of the early seventeenth century and the anonymous treatise *Arquitectura Mecanica Conforme a la Practica de esta Ciudad de Mexico* written circa 1794-1813³⁰ disproved this theory. San Andres treatise appeared as part of a compilation of San Andres' essays produced by Eduardo Baez Macias, entitled *Obras de Fray Miguel de San Andres*.³¹ While *Arquitectura Mecanica Conforme a la Practica de esta Ciudad de Mexico* was translated from Spanish into English by Mardith Schuetz, and published under the name "Architectural Practice in Mexico City, a Manual for a Journeyman Architects of the Eighteenth Century".³²

D. Surface Finish Technology in the Treatises.

Published information on surface finishes examined here will be restricted to descriptions found in sources available for this study. Due to limited access to the publications previously described, a discussion of stucco and surface finishes technology in the New World will be limited to one representative book for each century.

D. 1. Sixteenth Century

The Ten Books of Architecture (1st Century B.C.) Vitruvius

The Ten Books of Architecture was the most quoted source regarding stucco techniques prior to the introduction of cement based revetments.³³ Several descriptions of the process of plastering or stuccoing, found in other building treatises made reference to Vitruvius' method. Vitruvius' description covers information about materials, lime slaking methods, proportions of materials, and stucco application processes.

D. 1. 1. Stucco Work

Materials and Proportions

According to Vitruvius the basic materials for stucco preparation are: lime and sand. The lime should be white and obtained from porous limestone.³⁴ The sand should

be pit sand, river sand or sea sand; however, pit sand was cited as the best of the three. Sea sand, although similar to pit sand, was not recommended because it was believed to retard the drying process of the mix and produce efflorescence in the stucco.³⁵

Vitruvius recommended the general proportion of stucco ingredients as one part binder to three parts filler.³⁶ The primary stucco paste, composed of lime and sand, was recommended for both exterior and interior walls. On damp areas, a water repellent paste, composed of lime and brick dust was recommended instead.³⁷

Substrate Preparation.

Substrate preparation was recommended only for mud walls (wattle and daub) so as to avoid the formation of cracks after stucco application. The base wall was covered with two overlapping layers of reeds with a coat of mud plaster in between.³⁸

Application Procedure

The stucco paste was to be applied in three layers or more;³⁹ the first layer rougher and thicker than the other two. After this first layer dried, the second was applied. When the intermediate coat was dry, the third fine coat was spread on top of it. The overall thickness of the finishes was cited to be about "six digits," equivalent to 5 to 8 centimeters.⁴⁰ During the application process, special attention was given to the horizontal and vertical leveling, and squaring of the stucco mass to achieve sharp edges and even surfaces.⁴¹

D. 1. 2. Surface Finishes

After the stucco was applied, Vitruvius recommends the application of three coats of marble stucco to give a perfect polish (mirror-like) and impart strength to the surface.⁴² The application process was similar to the lime-sand stucco procedure. First, 1 unit of lime is mixed with 3 units of powdered marble. The paste is mixed profusely until it no longer sticks to the trowel. Then, it is applied in 3 layers. The first layer must have

coarse grain marble, the second a medium grain, and the third a very fine one. First a rough coat is applied. While this layer is still wet, the slightly finer second coat is laid on top, and rubbed down. Following this, a third fine coat is applied and profusely polished until a shiny surface is achieved.⁴³

As in fresco technique, color can be added to the white marble finish coats while still wet. The coloring matter is either natural or man made. The natural pigments included red earth, yellow ochre, burnt ochre, and purple "ostrum",⁴⁴ whereas the man made pigments included black,⁴⁵ cooper blue, white lead, vedigris, sandarac, and indigo.

D. 2. Seventeenth Century

***Arte y Uso de Arquitectura* (1633) Father Lorenzo de San Nicolas.**

The second treatise *Arte y Uso de Arquitectura* written by Lorenzo de San Nicolas, in 1633, is a valuable source for understanding seventeenth-century stucco techniques. San Nicolas' treatise was frequently published during this century (1633, 1665 and 1667) in Spain and also appeared in the records of books published in the Spanish New World. The stuccoing techniques (*jaharrar*),⁴⁶ described in the treatise were well known in Spain and its territories overseas. Complementary information about colors applied to exterior surfaces can be derived from the fine arts painting treatise *Arte de la Pintura* by Francisco Pacheco, 1638.

D. 2. 1. Stucco Work

Materials and Proportions

According to San Nicolas stuccos are made out of two basic binding materials and a filler material. The binders are lime or gypsum and the filler is river sand or mine sand. The lime must be white, and is usually obtained from porous stone;⁴⁷ while the gypsum can be either dark (*yeso negro*), "mirror" type (*yeso de espejuelo*), or white (*yeso blanco*).⁴⁸ Three types of stucco are derived from these two binders: lime stucco, gypsum

stucco, and lime-gypsum stucco. The first type is recommended for exterior walls, the second type for interior walls,⁴⁹ and the third type for walls located in damp areas.

The proportions of binder material to filler in the mixture is varied according to the type of sand used.⁵⁰ If river sand is employed, the amalgam requires a ratio of 1 unit of lime to 2 units of sand. While for mine sand, the composite requires 2 units of lime to 3 units of sand. The latter type must be mixed in two steps. First, 2 parts of sand are blended with 1 of lime. Then, 3 parts of sand are combined with 2 of lime.

Substrate Preparation.

Unlike other masonry walls, earthen and brick wall substrates need a preparation process prior to the application of stucco.⁵¹ The surfaces of earthen walls are first punctured to achieve adhesion. A watery stucco, similar to a whitewash, is then applied to the surface. Brick wall surfaces must be cleaned and wetted first, then a layer of lime stucco applied, followed by a final layer of gypsum stucco⁵².

Preparation

The stucco paste is simply made by mixing together the slaked lime and the sand in the appropriate proportions. The mixture must be prepared in advance; 7 days in advance during the summer time, and at least a month ahead of time in the winter. In both seasons, water must be added to the paste every day.⁵³

Application Procedure

Similar to Vitruvius' method, San Nicolas suggested a 3 layer application of stucco. The first layer is less uniform than the second, and the second less uniform than the third. The thickness of the layers varies in each particular situation, and the layers should be adapted accordingly. The last layer is only specified as a very thin layer. In order to achieve smoothness and a bright finish, the stucco was polished by rubbing down the surface with a river stone until dry.⁵⁴

D. 2. 2. Surface Finishes

A marble-like finish is obtained by adding bitumen prepared with a “little” gum mastic (*almastiga*) and a “little” wax which is melted in oil.⁵⁵ The resulting bitumen is applied to the wall and dried out by coal fire. In order to achieve the finest finishes, instead of using the regular sand stucco,⁵⁶ the final coat of the lime stucco is applied without sand.

Pigments suitable for lime substrates are reported in Pacheco's painting treatise *Arte de la Pintura* in the section about fresco techniques. The inorganic pigments derived from natural earths and minerals suggested by him included whiting (*blanco de cal*), yellow and burnt ochre (*ocre claro y oscuro*), deep red (*almagra*), dark red (*albin*), purple (derived from the combination of *albin* and *smalt*), and smalt (*azul esmalte*) which is the most troublesome color because of its instability when painted or mixed with lime⁵⁷ due to lime's high alkalinity.

D. 3. Eighteenth Century

Architectural Practice in Mexico City (c.1783-1810)

This anonymous Mexican treatise is one of the few known architectural books published in the New World. The information on stuccos and other surface finishes provided in this manual is condensed and refers to finishes used in New Spain [Mexico and Northern New Spain (United States Southwest)]. Nevertheless, this source is valuable because it describes regional variations in surface finish techniques utilized in the Spanish New World during the colonial period. In addition to the techniques reported in this treatise, it is complemented by information about eighteenth century color taste obtained from the artist's painting treatise *El Museo Pictorico y de la Escala Optica* by Antonio Palomino, 1724.

D. 3. 1. Stucco Work

Materials and Proportions.

The primary materials used for stucco are lime and sand which are mixed in a 1 to 1 ratio for the revetment. The best binder material is derived from stones that "makes much noise" when fired in the kiln.⁵⁸ This lime is obtained from limestone with a higher concentration of calcium carbonate than other sources of lime in the area. The best sand for stucco work is sand mine, free of dust and clay residues.

Paste Preparation

In this book a brief explanation is reported for the preparation procedure. The author simply states that the dry lime and sand must be mixed profusely and then sifted. According to other sources,⁵⁹ the dry mixture was most probably profusely sprayed with water until a homogeneous paste was obtained. No further information is provided about application, substrate preparation, or other matters regarding stucco technology.

D. 3. 2. Surface Finishes

The customary surface finishes employed in Mexico City were a limewash primer (*xalpaco*), and a whitewash (*lechada*).⁶⁰ The former is prepared by diluting lime stucco in water while the latter is made out of lumps of unslaked limestone. For the whitewash, the lime is first placed in a pot, buried underground and watered gradually to slake the limestone, and left to settle. The slaking time is unspecified, but "the longer the *lechada* is buried the better the quality is".⁶¹ The application technique of these finishes is unknown, but it is most likely that the watery *xalpaco* was first brushed on the surface, and later the dense *lechada* laid on the walls with a trowel.

Pigments most probably added to the limewashes during the eighteenth century are analogous to those suggested by Palomino in his treatise *El Museo Pictorico y de la Escala Optica* for fresco painting. Palomino advised the use of coloring matter derived

from earths and minerals. The earths included yellow ochre (*ocre claro*), burnt ochre (*ocre quemado*), red earth (*almagre*), deep red (*albin*), dark red (*pabonazo*),⁶² green earth (*tierra verde*), Venetian earth (*sombra de Venecia*), raw umber (*sombra de viejo*), and black earth (*tierra negra*). While the mineral pigments, some of them calcineted, included whiting (*blanco de cal*), marble white (*blanco de marmol*), *hornaza* (light yellow), vermilion (*bermellon*), *vitriolo romano quemado* (red), smalt (*azul esmalte*), and black charcoal (*negro carbon*).

D. 4. Nineteenth Century

Arte de Albanileria (Art of Masonry and Plaster Work) by Juan de Villanueva, 1827.

In his work Juan de Villanueva points out the importance of the stucco, and stating "even when the stucco does not impart strength to the fabric, it contributes infinitely to its conservation by preserving the materials against destructive weather effects".⁶³ This protective skin and visual layer of the building, requires special care during construction. The information needed to ensure durability of the *guarnecidos*⁶⁴ (stucco work and surface finishes) is provided in this treatise. This book covers detailed instructions about materials selection, mixture preparation, paste application, and the necessary tools for *guarnecidos* work.

D. 4. 1. Stucco Work

Materials and proportions

The basic components of stucco are sand, lime, and gypsum. Out of these materials four types of conglomerates are obtained: lime stucco, lime and gypsum stucco, gypsum stucco, and plain gypsum stucco.⁶⁵ The first three stucco types contain sand as filling material; whereas the fourth is made with binder alone. The proportion of the ingredients in the mixtures is not constant. Lime and sand content varies according to

each particular situation. But the common ratios are 1 to 2, and 1 to 3 parts binder to aggregate.⁶⁶

Preparation

The stucco paste must be prepared shortly after the lime has been slaked in the "Spanish way." Once slaked, the lime is first ground⁶⁷ and later mixed with sand in adequate proportions and piled outdoors. The surface of the pile is sprayed with water and a protective superficial crust created. The pile is left outdoors as long as desired. When the building is ready for stucco work, fresh water is added to the dry mixture, and mixed until the paste reaches a greasy consistency.⁶⁸

Application Procedure

The stucco mixture is laid on the walls in several layers called *jarrados*.⁶⁹ The first coat of stucco must be coarse to allow the adhesion of the following layers. After it has dried, a second coat is applied on top. The second coat is leveled with a rule or a line⁷⁰ guided by straight rules. This step must be repeated several times. During this process, the surface is wet to allow adhesion of new layers.⁷¹ The stucco can be polished without the application of surface finishes layers (*blanqueos*),⁷² but this must be planned in advance. In doing so, a fine aggregate must be employed in the final coat of the stucco. When this layer is almost dry, it is then polished. The polish is achieved by rubbing down the surface with a mushroom-shaped trowel (*fratas*).⁷³

D. 4. 2. Surface Finishes

After the stucco work (*jarrado*) has been properly laid on and leveled, surface finish coats (*blanqueos* and *revoques*) are applied.⁷⁴ The outermost skin is made out of lime or gypsum. Lime-based surface finishes are composed of lime and sand. The lime employed must be white, strong and slaked for a long time⁷⁵ and the sand fine and clean. Each component is first sieved separately, and then mixed together. The proportion of

the materials depends on the quality of the components.⁷⁶ Nevertheless, the average proportion is 1 to 1 binder to aggregate because too much sand will weaken the paste, and too much lime will generate cracks in this layer.⁷⁷

The paste is laid on the wall with two tools: a steel trowel or laying trowel (*llana*) and a wooden trowel or hand-float (*esparabel*).⁷⁸ The hand-float, on the left hand is used to keep a moderate portion of the paste; while the laying trowel, on the right hand, is used to spread out the paste. The paste is rubbed down in small portions, and later leveled and polished with the laying trowel until the entire surface is covered.⁷⁹ While still slightly damp, the surface is polished again either with a steel trowel (*llana*), or a small hawk (*fratas*), or water and a brush.⁸⁰ The entire process must be repeated two or three times, and the surface kept moist for the duration of the treatment.

E. Surface Finish Technology in Secondary Documentary Sources.

Detailed information about building technologies can also be found in original documents including trade invoices and building construction reports.⁸¹ This information, found in the *Archivo de Indias* in Seville Spain, or in the national archives of Caribbean countries, was inaccessible for this work. Therefore, secondary sources on the architectural history of the Spanish Caribbean were also consulted for this study.

Unlike many major Spanish buildings of exposed stone, colonial Caribbean buildings were stuccoed. Lack of suitable stone and possibly experienced labor may have limited the use of fine grained hard stones. Instead coral limestone and other soft stones, easy to extract with simple tools, became customary in several Caribbean locations.⁸² These stones are coarse grained with uneven surfaces; and were commonly used in conjunction with brick, gravel and lime for wall construction. The wall surfaces were irregular and exposed to weather deterioration of a very humid and salt-laden maritime

environment. The colonial craftsmen adopted for that reason, the practice of enhancing and protecting the surfaces by means of stucco work.

E. 1. Stucco Work

Stucco was primarily made of lime and sand,⁸³ however, in certain situations the filling material was replaced by brick dust or vegetable fibers. Brick dust was mixed with lime for stucco work applied to wet areas;⁸⁴ while the specific purpose of the use of vegetal fiber was probable for tensile reinforcement.

Stuccos made of lime and sand, lime and brick dust, and lime and vegetable fiber were mixed in a ratio of 2 parts of binder to 3 parts of aggregate. Whereas for stuccos prepared with lime, sand, and brick dust stuccos the ratio was 1 part binder to 1 part aggregate.⁸⁵ Descriptions about other procedures involved in the stucco work were not available in the literature reviewed for this research.

In places where the fuel to process the raw material or lime itself was scarce, mud stuccos were extensively used.⁸⁶ These stuccos were prepared with lime, clayey soils, and sand or mud, sand and straw. The use of soils with an elevated percentage of calcium carbonate for preparation of bedding mortars is reported in certain locations in Colonial Cuba.⁸⁷ These soils were possibly employed in the elaboration of stucco work.

E. 2. Surface Finishes

E. 2. 1. *Revocos*

The stucco work was finished with *revocos*, lime based finishes applied by means of a trowel to the wall. This outer finish was prepared either with lime and fine sand or lime and water. When the paste was ready, a first step was to moisten the stucco work. Afterwards, the finish coat was laid on with *fratas* (mushrooms-shaped trowels) three to four inches in diameter.⁸⁸ The superficial foam formed in the surface was removed with the steel trowel (*cucharrilla de bruñir*) and a second layer was laid on and polished. If

further polish was desired, a ball made out of cloth was used to rub down the surface. This ball was replaced as soon as it became damp to ensure good results.⁸⁹ The surface could also be polished by rubbing down the surface with a hot iron. The heat created a perfectly smooth and polished finishes with a crystalline barrier against moisture penetration.⁹⁰

E. 2. 2. Limewashes

According to several authors, limewashes (*lechada de cal*) were the usual exterior surface finishes utilized during the colonial period.⁹¹ These surface coatings were made of slaked lime, water, and some other additive materials. The limewashes were either white or colored. Contrary to the general belief that colored surfaces were not employed in the colonial architecture, the buildings were enhanced by polychromatic finishes. Color studies have proven that the colors utilized in the built environment related to the surrounding environment.⁹² Consequently, the colorful landscape of the tropics was reflected in its architecture. In 1840, a visitor described her first impression of Havana “its houses, painted with bright colors, blend with the blooming prairie, where they appear to be planted”.⁹³

Color in limewashes was achieved by adding vegetable or mineral pigments.⁹⁴ The color palette for exterior walls was composed of ochre, dark yellow, burnt light red, pink, light blue and pale green.⁹⁵ These colors were applied to the building selectively. Colored limewashes were painted on elements in relief such as cornices, and door and windows inframes. Whereas, in most civil architecture the flat walls were painted in white. In similar fashion, a pale yellow, color derived from gamboge,⁹⁶ was the dominant tone utilized in flat walls in the military architecture during the eighteenth century.⁹⁷

Table No. 1							STUCCO WORK CITED IN TREATISES AND SECONDARY SOURCES			
Source	Materials				Ratio	Coats				
	Lime	Sand type	Brick Dust*	V. Fiber						
TREATISES										
Vitruvio		unspec.			1 to 3	3				
Vitruvio					1 to 3	3				
Rojas		unspec.			1 to 3	Unspec.				
Rojas	poor q. lime	unspec.			1 to 1	Unspec.				
Rojas		mine			1 to 2	Unspec.				
Rojas		river			2 to 3	Unspec.				
Rojas		beach			2 to 3	Unspec.				
San Nicolas		mine			3 to 1	3				
San Nicolas		river			5 to 2	3				
Palladio		unspec.			2 to 1	3				
Villanueva		unspec.			1 to2	3				
Villanueva		unspec.			1 to3	3				
Mex. Arc. Pra.		unspec.			1 to 1	3				
SECONDARY										
Caribbean		unspec.			2 to 3	Unspec.				
Caribbean					2 to 3	Unspec.				
Caribbean					2 to 3	Unspec.				
Caribbean		unspec.			2 to 2	Unspec.				

Table No. 2 SURFACE FINISHES CITED IN TREATISES AND SECONDARY SOURCES						
Source	Materials				Ratio	Coats
	Lime	Sand	Mar. Dust	Bitumen*		
Vitruvio					1 to 3	3
Alberti					N/A	1
San Nicolas					N/A	1
Villanueva					1 to 2	2 or 3
Mex. Arc. Pra.					N. spec.	2
Caribbean					N. spec.	2

E. 3. Additives

The primary stucco mixture was generally improved by the use of additives. The most common additives were alum, vegetable oil, and animal blood.⁹⁸ Resins, banana, cactus glue, potatoes starch, honey, milk, rice starch,⁹⁹ gypsum, ashes, vegetal fibers, and animal excrement¹⁰⁰ were also used, but to a lesser extent. These additive materials were added to the mixture to impart strength, to accelerate setting, or to improve plasticity of the stucco work.¹⁰¹

F. Tools

Among the sources already mentioned, tools were described only in the nineteenth-century treatise *Arte de Albañileria*.¹⁰² According to Villanueva, the basic tools for stucco work were used to carry the paste, to level, to lay, and to polish the stucco work. A detailed list of the names and function of these tools (in Spanish) is included:

Cubos: (Pail). Cylindrical wooden container with a curved metallic handle. It is used as a container for carrying water and stucco paste.

Cuezos: Five by one and a half foot rectangular shallow wooden box container for the stucco paste during the application procedure.

Espárruel: (Hand-float). One foot long, thin, wooden, rectangular trowel with a straight handle perpendicular to the center of one of its faces, utilized to hold portions of the stucco at hand level during the laying of the paste.

Frata: Small wooden mushroom-shaped trowel with a handle perpendicular to the center of one of its faces. The *frata* leveled and polished the stucco work (*enfoscado*). It is ideal to smooth stuccos later covered with surface finishes, because the *frata* does not impart a perfect polish to the stucco.

Llana: (Laying trowel). Rectangular steel trowel with an "L" shaped or "U" shaped handle in one of its faces. It was used to apply both the lime stucco coats (*guarnecidos*) and the finish coats (*blanqueos*) to the wall.

Maestra: (Straight rule or straight edge). Lime stucco rule used to verify the evenness of the stucco finishes.

Paleta: (Gauging trowel). A triangular steel trowel with an "L" shaped wooden handle attached to one of the edges of the triangle, used to apply the stucco paste to the wall.

Plomada: (Plumb). A pointed metallic weight attached to a line, used to ensure the verticality of the surface.

Regla: (Rule). A simple wooden tool perfectly straight on all its faces. This tool was used to check the evenness of the stucco work.

Talocha: (Darby or slack float). Two feet long, thin, narrow, wooden device with a handle in the middle of it. As the *frata*, this tool is used to level and impart a smooth finish to the stucco work.

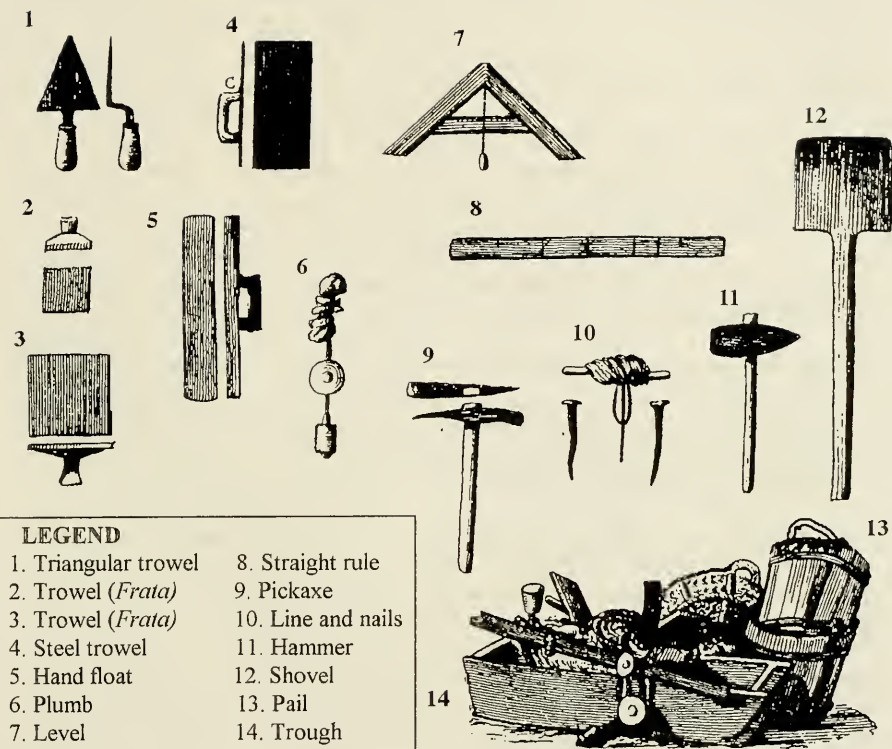


Illustration No. 1

Nineteenth-century plastering tools used in Spain. (*Arte de Albanileria*, 1827).

End Notes Chapter 1

1. Serlio's book was translated from Tuscan into Spanish by Francisco Villalpando in 1552. [*Bibliografía de Arquitectura, Ingeniería y Urbanismo en España*, Antonio Bonet Correa, ed.(Madrid: Turin Libros, 1980), p. 127].
2. Alberti's treatise was translated from Latin by Juan Fernandez de Espinosa, in 1582. [*Bibliografía de Arquitectura, Ingeniería y Urbanismo en España*, Antonio Bonet Correa, ed., (Madrid: Turin Libros, 1980), p.56].
3. Vignola's treatise was translated from Tuscan into Spanish by Patricio Caxesi in 1593.[*Bibliografía de Arquitectura, Ingeniería y Urbanismo en España*, Antonio Bonet Correa, (Madrid: Turin Libros, 1980), p.139].
4. Vitruvius' book was translated from Latin into Spanish in 1564 by Lazaro de Velasco, in 1564. Some later editions of the book changed the name to *De Architectura, Dividido en Diez Libros*, and *Compendio de los Diez Libros de Architectura de Vitruvio*. [*Bibliografía de Arquitectura, Ingeniería y Urbanismo en España*, Antonio Bonet Correa, (Madrid: Turin Libros, 1980), p. 144].
5. Palladio's book was translated from Tuscan into Spanish by Francisco Praves in 1596. [*Bibliografía de Arquitectura, Ingeniería y Urbanismo en España*, Antonio Bonet Correa, ed., (Madrid: Turin Libros, 1980), p. 101].
6. Jose Torres Revelo, "*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografía*, Vol. VI, 1956, p. 4.
7. Pedro Ochoa de Ondategui, who resided in Mexico City, imported from Spain two volumes of Alberti's treatise *Libro Primero de Architectura* in 1586. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografía*, Vol. VI, Jose Torres Revello, 1956, p.6]
8. Arfe y Villafañe's treatise *De Varia Comensuración para la Escultura y la Architectura* appears in trade invoices issued in Seville in 1586 and 1591 for Mexico City. In 1584, the same book was sent from Seville to Diego Navarro Maldonado in Mexico City. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografía*, Vol. VI, Jose Torres Revello, 1956, p.7].
9. *Tercero y Cuarto Libro de Architectura* written by Serlio was first imported by Diego Maldonado, from Mexico City, in 1584, and recorded in a trade invoice issued in Seville for Mexico City, in 1586. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografía*, Vol. VI, Jose Torres Revello, 1956, p.7].
10. In 1586 Vignola's treatise was sent in several occasions to Mexico, according to the records found in trade invoices issued in Seville.["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografía*, Vol. VI, Jose Torres Revello, 1956, p.6].
11. Vitruvius' book *Diez Libros de Architectura* was sent to Mexico in 1586 and 1591 according to trade invoices issued in Seville in the same years.["*Tratados de*

- Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p.7].
12. Martin de Ibarra from Veracruz Mexico, imported Arfe y Villafane book from Spain in 1600. It was also listed as part of the personal library of Diego Gonzalez Batres in 1614. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Jose Torres Revello, Vol VI, 1956, p.7, 10].
 13. Vignola's treatise appeared in a list of books sold at Paula Benavidez bookstore in Mexico City. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Jose Torres Revello, Vol VI, 1956, p.8].
 14. Vitruvius' book was recorded in the list of books that belonged to Diego Gonzalez Batres (1614), and years later (1655), in the library of the Mexican Architect Melchor Perez de Soto. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Jose Torres Revello, Vol VI, 1956, p.10-11].
 15. Lorenzo de San Nicolas' treatise was imported by Juan de Oviedo Cordoba, who lived at Mexico City, in 1660. In 1683, it was available at Paula Benavides bookstore, and in 1692 at Francisco de Rivera bookstore, both in Mexico City. In 1699, it was sent from Seville to Mexico to an unspecified consignee. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Jose Torres Revello, Vol VI, 1956, p.7,8].
 16. In 1661, Palladio book was available in Francisco de Rivera's bookstore in Mexico City. It was also recorded, in 1614, as part of Diego Gonzalez Batres personal library in San Miguel, Mexico. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Jose Torres Revello, Vol VI, 1956, p.8].
 17. Gamuzi's book *De Architectura* was listed among the books sold at the Agustin Santesteban and Francisco Lupercio bookstore in Mexico City. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Jose Torres Revello, Vol VI, 1956, p.8].
 18. Vignola's *Architectura* was available at the Agustin Santesteban and Francisco Lupercio's bookstore in Mexico City, in 1661. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Jose Torres Revello, Vol VI, 1956, p.8].
 19. Arfe y Villafane's treatise was recorded in 1758 among the books belonging to Santiago Rosales. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Jose Torres Revello, Vol VI, 1956, p.14].
 20. Serlio's book was recorded in 1758 among the architectural books belonging to Santiago Rosales. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Jose Torres Revello, Vol VI, 1956, p.14].
 21. Vignola's treatise was recorded in 1704 in the list of books belonging to Juan Ramon Conink, who lived in Lima since 1655. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p.14].
 22. Vitruvius' treatise was recorded in 1704 in the list of books belonging to Juan Ramon Conink, Flemish citizen, who lived in Lima since 1655. ["*Tratados de Arquitectura*

- Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p. 14].
23. Cataneo's book the *La Arquitectura* was recorded, in 1758, among the architectural books belonging to Santiago Rosales. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p. 14].
 24. Lopez de Arena's book was recorded in 1758 among the architectural books belonging to Santiago Rosales. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p. 14].
 25. Juan de Torrijas' book *Breve Tratado de Bovedas Regulares e Irregulares* was recorded in 1758 among the architectural books belonging to Santiago Rosales. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p. 14].
 26. Fernandez de Medrano book *El Architecto Perfecto* was recorded in 1758 among the architectural books belonging to Santiago Rosales. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p. 14].
 27. *Dialogo de la Pintura* by Vicencio Carducho was recorded in 1758 among the architectural books belonging to Santiago Rosales. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p. 14].
 28. *Arte de la Pintura* by Francisco Pacheco was available in three Mexican bookstores: Agustin Santesteban, Paula de Benavides y Juan de Rivera's bookstores, in 1655. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p. 15].
 29. *El Museo Pictorico y la Escala Optica* by Palomino de Castro was sent to Buenos Aires to an unspecified consignee from Seville in 1728. ["*Tratados de Arquitectura Usados en Hispanoamerica*", *Revista Interamericana de Biografia*, Vol. VI, Jose Torres Revello, 1956, p. 8].
 30. Mardith Schuetz, trans., *Architectural Practice in Mexico City*, (Tucson: University of Arizona Press, 1987), p. 3.
 31. Fray Miguel de San Andres' treatise was first published in 1969.
 32. The manuscript draft of the book was translated from Spanish to English by Mardith Schuetz and published in a bilingual version (English-Spanish) in 1987.
 33. Antonio Bonet Correa, ed., *Bibliografia de Arquitectura, Ingenieria y Urbanismo en Espana*, (Madrid: Turin Libros, 1980), p. 9.
 34. Vitruvius, *The Ten Books on Architecture*, Translated by Morris Hicky Morgan, (New York: Dover Publications, Inc, 1960), p. 45.
 35. Ibid.
 36. Ibid.
 37. Ibid., p. 209.

38. On top of the wattle and daub wall "nail rows of reeds to it ...then spread on the mud a second time, and, if the first row have been nailed with the shafts transverse , nail on a second set of shafts. ... then spread the sand mortar", (*The Ten Books on Architecture*, Vitruvius, Translated by Morris Hicky Morgan, [New York: Dover Publications, Inc, 1960], p.45).
39. Vitruvius, p. 206.
40. Ibid.
41. Ibid., p. 206.
42. Ibid., p. 207.
43. Ibid.
44. The purple color is obtained from a marine shellfish.
45. This black is obtained from the smoke produced by burning an unspecified resin.
46. San Nicolas termed *jaharrar* the entire stuccoing procedure, including the stucco and surface finishes. [*Arte y Uso de la Arquitectura*, Lorenzo de San Nicolas, (Madrid: Manuel Roman, 1736), p. 121].
47. Ibid., p. 37.
48. These types of gypsum were found in Spain. No reference to other locations appears in the treatise. [*Arte y Uso de la Arquitectura*, Lorenzo de San Nicolas, (Madrid: Manuel Roman, 1736), p.122.
49. Since this work is limited to exterior finishes gypsum stuccos are not described in this study.
50. San Nicolas, p. 121.
51. Ibid.
52. The preparation of gypsum stuccos is similar to lime stucco. The major differences between the two are that the gypsum requires a much lower calcination temperature (i.e. less fuel) and does not need previous maceration. The proportion binder to aggregate is 1:1. [*Arte y Uso de la Arquitectura*, Lorenzo de San Nicolas, (Madrid: Manuel Roman, 1736), p. 122].
53. Lorenzo de San Nicolas, *Arte y Uso de la Arquitectura*, (Madrid: Manuel Roman, 1736), p. 122.
54. Ibid.
55. Ibid.
56. The lime requires a special processing for this type of finish. The lime is, first, well-sifted and later soaked in water, mixed and deposited in a covered pool. The mixture is left in the pool for three of four months. After this period it takes on a greasy appearance.
57. Francisco Pacheco, *Arte de la Pintura*, facsimile edition, (Madrid: Instituto de Valencia de Don Juan, 1956), p. 50-51.
58. Schuetz, p. 22.
59. The author quoted and cited San Lorenzo, in several occasions along the book.
60. Schuetz, p. 31.
61. Ibid.

62. Pavonazo was mainly used for interior painting in Spain in the eighteenth century. In exterior locations, it was utilized to darken vermilion, because when directly applied on the substrate it was oxidized by the lime. [*Artes de la Cal*, Ignacio Garate, (Madrid: ICRBC, 1993), p. 109].
63. Juan de Villanueva, *Arte de Albanileria*, facsimile edition of the original printed in 1827, (Madrid: Ediciones Velazquez, 1977), p. 71.
64. *Guarnecidos* is the term used by Villanueva to designate both the stucco work (*jarrado*) and surface finishes (*blanqueos y revocos*).
65. Villanueva, p. 72.
66. *Ibid.*, p. 15.
67. According to Villanueva, in Spain the lime was not macerated by immersion in water. It was only sprayed with water until soften, and afterwards pulverized. (*Arte de Albanileria*, facsimile edition, Juan de Villanueva, [Madrid: Ediciones Velazquez, 1977], p. 15).
68. *Ibid.*, pp. 15-16.
69. Villanueva defines the three basic layers of stucco as *jarrados*. Other authors called the stucco work *enfoscado*.
70. The use of a line (*cuerda*) is recommended if the stucco is made out of lime. (*Arte de Albanileria*, facsimile edition, Juan de Villanueva, [Madrid: Ediciones Velazquez, 1977], p. 71).
71. *Ibid.*, p. 79.
72. *Ibid.*
73. *Ibid.*, p.75.
74. *Ibid.*
75. The slaking time is not specified. The lime, Villanueva only said, must be old and evenly slaked in the pools. (*Arte de Albanileria*, facsimile edition, Juan de Villanueva, [Madrid: Ediciones Velazquez, 1977], p. 78).
76. Villanueva, p. 78.
77. *Ibid.*
78. *Ibid.*
79. *Ibid.*
80. *Ibid.*, p. 79.
81. Torres Revelo, p. 4.
82. The military engineer Bautista Antonelli was the first Spaniard to use coral stone in the Caribbean. During the construction of Portobello, Antonelli faced difficulties to extract the hard basaltic stone nearby. Instead, he decided to employ the abundant and softer coral stone in the construction of Portobello's fortifications. [Bautista Antonelli, *Las Fortificaciones Americanas del Siglo XVI*, Diego Angulo Iniguez, (Madrid: Hauser Menet, 1942), p. 21].
83. Sand and lime are reported as the basic materials for stucco in several secondary sources consulted in this study.
84. In accordance with Vitruvius' principles which recommended to replace the sand by burnt brick dust for finishes applied in damp areas. [*The Ten Books on Architecture*,

- Vitruvius, Translated by Morris Hicky Morgan, (New York: Dover Publications, Inc, 1960), p. 209].
85. Juan Zapatero, *Historia del Castillo de San Lorenzo del Real de Chagres*, (Madrid: CEHOPU, 1985), p. 27.
 86. Albert Macuncy, "Building Materials in Colonial San Augustin", *El Escribano*, Vol. 20, 1983, p. 60.
 87. Francisco Casal, "Insolita tradicion de Tapial en Cuba", *ADOBE 90, 6th International Conference on the Conservation of Earthen Architecture*, (Los Angeles: The Getty Conservation Institute, 1990), p.20.
 88. Ibid.
 89. Zapatero, p 24.
 90. German Tellez and Ernesto Moure, *Arquitectura Domestica, Cartagena de Indias*, (Bogota: Universidad de Los Andes-Escala, 1982), p. 41.
 91. A sequence of limewashes layers have been found in Colombia (Cartagena), Mexico (Veracruz), Dominican Republic (Santo Domingo), and Cuba (Havana) on colonial buildings. [*Arquitectura Domestica, Cartagena de Indias*, German Tellez and Ernesto Moure, (Bogota: Universidad de Los Andes-Escala, 1982), p. 41].
 92. Ignacio Garate, *Artes de la Cal*, (Madrid: ICRBC, 1993), p. 25.
 93. Historical reference of the trip of the Merlin countess to Havana in 1840, [*La Arquitectura Colonial Cubana, Siglo XVIII* Joaquin Weiss Sanchez, (Havana: Ediciones Letras Cubanas, 1979), p. 25].
 94. The lime attacks vegetable pigments; the lime either affects their intensity or oxidizes them during the carbonation process. Hence, most probably mineral earth pigments were preferred to vegetable coloring matters.
 95. Tellez, p. 41.
 96. Zapatero, p. 27.
 97. Tellez, p. 41.
 98. Ibid.
 99. Mario Ceballos, "*Restauracion de Edificios Coloniales de Antigua Guatemala*", *Adobe 90*, (Los Angeles: The Getty Conservation Institute, 1990), p. 24.
 100. Tellez, p.41.
 101. Tellez, p.41
 102. Villanueva, pp. 19-23.

Chapter 2: Materials Description

A. Stuccos

Stuccos are exterior covering materials applied to the wall to level and smooth irregularities of the substrate, and to protect the structural elements of the building from impact and deterioration caused by weather. This artificial conglomerate is a combination of an active binding material, and an inert aggregate, mixed with water and occasionally some additives.¹⁰³ The binding materials have properties that remain inactive until water is added to the dry components; simultaneously, the mixture is transformed into a plastic and workable paste. The filler agent, customarily sand, is used to increase volume and eliminate contractions due to stress in the material. The additive component both modifies the basic properties and/or imparts new properties to the stucco paste.

The stucco is applied in several layers to ensure adhesion and to distribute gradually the stress between the substrate and the finishes. The number of layers varies from one to three depending on the binder material and the function of the stucco. But in general, the stucco is applied in three layers: 1. base, 2. intermediate, and 3. finish coat. The first is applied tightly on the masonry substrate to support the subsequent layers. The second absorbs deformations in the first coat, under strain originated in the structural members of the building; and on the finish coat, exposed to stress provoked by environmental agents. The finish is both a smooth, flat and polished decorative layer, and a crystallization front which protects the stucco from moisture penetration.

A.1. Lime base stuccos

A.1.1. Non Hydraulic Lime Stuccos.

Lime was the principal binder material for interior and exterior stuccos and mortars before cement was produced industrially. The lime base stucco consisted of lime, and sand; in a basic ratio of one to three (1:3) or one to two (1:2).¹⁰⁴ The type of lime appropriated for plaster work according to Vitruvius, later quoted by San Nicolas, was a porous limestone; while the mine sand, free from impurities, was considered the best.

A.1.1.1. Lime

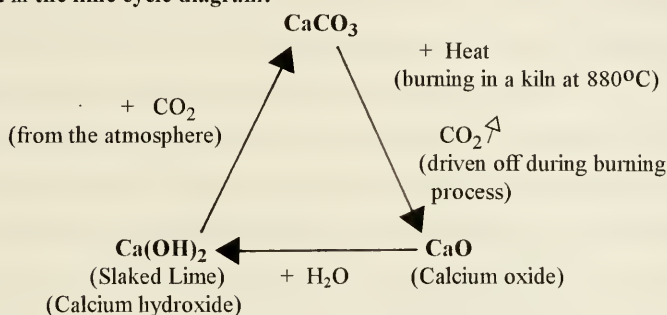
The lime is obtained from limestone, coral or shells, composed of calcium carbonate (CaCO_3) and/or magnesium carbonate (MgCO_3), and calcinated, in kilns at high temperatures to drive off water and carbon dioxide present in it. The resulting material is calcium oxide (CaO) or magnesium oxide (MgO) or a combination of both.

The caustic unslaked lime (*cal viva*) is slaked to produce CaOH (slaked lime) a suitable lime for stucco work. In Spain, in the period between the sixteenth to the nineteenth century two methods were employed: slaking by immersion (*apagado*) and by aspersion. In the former, lumps of lime were placed in a pit, water added enough to immerse the lime, covered and left during four months to macerate.¹⁰⁵ Every day the carbonation layer (milk lime) formed on top of the water was removed, the paste mixed, and covered again. The lime was ready when the paste reached a greasy consistency. The long slaking period favored the formation of portlandite¹⁰⁶ and improved the plasticity of the binder.

Later in the late eighteenth or early nineteenth century, the slaked method practiced in Spain changed to aspersion (*azogado*).¹⁰⁷ In this process, the lime lumps are sprayed with water to hydrate the material until it softens and turns into powder. The process is repeated two or three times, and shortly afterwards the lime is placed in a

protected place. During the slaking process the calcium dioxide in the burned lime (quicklime) is transformed into hydroxides of calcium and/or magnesium hydroxide.

The process of the transformation of the raw limestone into a man made cement is summarized in **the lime cycle diagram**:¹⁰⁸



The readily available coral limestone, sea shells, and coral were the primary materials for the elaboration of lime in Cuba, Puerto Rico, Cartagena, Florida, and Panama and other Caribbean locations¹⁰⁹. These raw material with a high content of calcium carbonate and some magnesium carbonate¹¹⁰ produce a white, high quality lime for mortars and plaster work.

A.1.1.2. Aggregate

The aggregate must consist of non-reactive materials such as quartz sand, to ensure dimensional stability of the paste during and after the setting process, and increase the volume of the mixture. Dimensional changes are due to the cementitious materials, which remain active, in the case of lime and Portland cement, even after setting. The lime tends to contract and expand in the presence of humidity and changes in temperature, generating cracks in the material.

The sand is predominantly composed of quartz and silica, and to a lesser degree feldspar, mica clay and other less representative impurities. Mine sand and beach sand

are composed of less reactive minerals such as quartz and silica; while feldsparic river sand, in addition to silica, contains aluminum and potassium.

The stability of the aggregate materials can be altered by the presence of impurities including chemical and organic material adhered to the sand. In that regard, the aggregate must be free of silt, salt and organic particles that reduce the strength of the paste, causes efflorescence and could deteriorate the masonry substrate.

Another important characteristic of the aggregate, which affects directly the performance of the stucco, is grain size and particle shape. In this regard, the ideal aggregate composition should be heterogeneous in size to ensure an even distribution of the aggregate, and to produce a compact stucco. On the other hand, a homogenous coarse aggregate produces a porous, weak, and non plastic paste with large spaces and low contact among particles. While a uniformly fine aggregate results in an unevenly packed aggregate, and contractions followed by cracks. In terms of the shape, irregular, angular or subangular particles produce a strong paste; whereas a rounded and even particle, yields a weak stucco mass.¹¹¹

In addition to the river and beach sand, in the traditional architecture in the Antilles and Central America the aggregate was composed of brick dust and brick fragments, fibrous matter, ashes, lumps of old mortar, fragments of coral, and calcareous sand.¹¹²

A.1.1.3. Water

Water is added to the dry components of the mixture to activate the binding properties of the binder and to bring the mix to a plastic consistency. The water, also, combines chemically and mechanically with the binder during hydration, and induces the carbonation or hardening of the mass.

Generally, the amount of water added to the mix relates to the required workability of the paste. In addition to plasticity, others factor determining the quantity

of water include drying conditions, porosity of the substrate, and the binder component. However, a balance should be established since too much water reduces the cohesive strength, and produces excessive shrinkage in the mix during the first stages of the setting process

The water added must be fresh, clean, and free of salts to avoid deterioration due to efflorescence and/or disturbances in normal setting-time of the stucco work. This previous statement appeared in the architectural treatises of the Renaissance and Baroque period, but according to historic information fresh water was not employed all the time in mortars in the Spanish New World. There was the belief, among some eminent colonial engineers, that salty water must be employed in buildings located near the shore. About this Bautista Antonelli, the chief military engineer of the Spanish crown in the New World, wrote in 1590:

*... "por experiencia se que donde bate la mar se han de hazer las mezclas con agua de mar, pues la dulce es contraria a la agua de mar" ...*¹¹³ (by experience I know that in the mortars for buildings fabric exposed to the sea, salty water must be used because fresh water is not compatible with sea water).

In addition to this assumption, fresh water was scarce in many colonial towns, and therefore reserved for human consumption.¹¹⁴ Hence, salty water was probably used in buildings other than those located near the sea.

A.1.2. Hydraulic Lime Stuccos

Hydraulic mortars and plasters, set without air and resistant to the water damage, were known since Roman times. The Romans discovered that some volcanic materials when added to the lime mortars imparted hydraulic properties to the amalgam. These composites are generically called "pozzolanas", because they were first made with volcanic ashes from the Neapolitan town of Pozzuoli.

The hydraulic mixture is produced by mixing slaked lime with volcanic ingredients, containing high percentages of active silica and alumina, and water.

The reactivity of the volcanic silica and aluminum is due to their exposure to very high temperatures released during volcanic eruption. A fast initial molten state followed by a rapid cooling of bubbling material yields a vitreous and irregular particles with large surface area which ensure good adhesion. When added to lime, the pozzolanic material forms a needle-like network of crystal that results in a very hard artificial conglomerate.¹¹⁵

Aggregate with parallel composition, silica and aluminum oxides, were employed to produce hydraulic mortar and plaster. Crushed brick and iron slag were widely employed in the Classical Antiquity and brought to light again in the Renaissance by the renewed interest in Vitruvius'. Nevertheless, the actual hydraulic properties of this material are dubious since the oxides, silica and aluminum are not in a very reactive state.¹¹⁶

In Puerto Rico the use of hydraulic mortars made with crushed brick is reported in the Historic Structure Report of the Fortifications of San Juan National Site.¹¹⁷ Brick as an aggregate component is also suggested in several contemporary works on the history of colonial military architecture in the Spanish Antilles by Juan Zapatero.¹¹⁸

Hydraulic plasters could be, as well, with naturally occurring hydraulic limes which contain clays in addition to the basic calcium and magnesium carbonate. When burned to high temperatures, the silica and alumina contained in the clays reacts with the calcium producing calcium aluminate and silicates. These lime lumps when finely ground yield a grayish cementitious compound resistant to moisture penetration.

A.2. Clay-based Stuccos

Mud plasters have been largely utilized to protect earthen walls (cob, pise, daub) because the likeness of both materials ensures the adhesion of the finishes to the substrate. The primary constituents of these stuccos are clay soils, sand or straw, and some additives. The materials are mixed in proportions of 2 to 3 soil to sand, some straw to provide tensile strength lack by the soil, and enough water to form a thick paste.¹¹⁹ Before application of the paste, the surface is scored and moistened to encourage effective bonding of the stucco to the substrate. Once ready, the stucco is applied in two to three layers, by hand or by trowel, and polished with river stones.

Since clay is the binder in soils, clays must be present in earth used for stuccoing. However, the ideal concentration of clays should range between 15% to 18%. Higher concentrations of the clays produce an extremely soft paste with a slow setting process; and lower concentrations of it, a paste lacking adhesive power.

Clays are constituted by silica and alumina, the cementing materials that appear in the form of wafers arranged in random fashion in the soil. When water is added to the dry and non plastic soil, the random particles are reorganized into a well defined layers structure that is plastic and a suitable paste for stucco work.

During colonial times, in areas where lime was scarce (e.g. Florida), clayey earth was blended with lime to extend the efficiency of mixture. The use of soils with a high content of calcium carbonate called *coco*, is reported in Colonial Cuba, for preparation of mortar employed in masonry walls. Possibly, similar soils were utilized to produce stucco pastes for surface finishes.¹²⁰

A.3. Additives

Diverse natural materials (organic and inorganic) have been used as additives, at least since Roman times, to mortar and stucco mixtures to improve their basic properties

including: strength, durability, plasticity, and waterproofing. The additives can be divided into air entraining, setting retardants, setting accelerators, plasticizers, and tensile reinforcement.

Air entraining additives improve the capability of the plaster to resist the stress produced by crystallization of water or soluble salts present in the material. These agents generate small bubbles in the mixture, while in a plastic state, providing space for any expanded salt or frozen water that could form in the stucco work. Setting retardant additives decelerate the hardening process of the mix by delaying the evaporation of the water contained in the mix. In doing so, stress provoked by a fast set is eliminated from the stucco. Waterproofing additives prevent water movement and/or reduce permeability in the stucco.

Additives to improve plasticity help reduce the amount of water necessary to create a workable paste, and prevent the accumulation of excess water that could weaken the stucco. Fibers add tensile reinforcement to the stucco which work primarily in compression and counteract the deformation produced by external agents such as temperature changes. Other admixtures enhance the adhesive qualities of the binder, acceleration of the setting time when climatic conditions are inappropriate, and the hardness of the stucco for improved resistance to impact and durability.

The traditional additives used as air entrainers include malt, beer, urine, and keratin. The additives added to improve the strength of the binder included gelatin, animal glues, rice starch, rye starch, gluten, casein, blood, album, egg yolk and white, keratin, pine resins, manila, Arabic gum and sugar. The tensile reinforcement additives include straw, elm tree bark, agave, jute, cotton, and sisal. Plasticity additives were sugar, milk, egg white, cow's dung, glycerin, glucose, mineral oils, resins, pine resins, and figs. The

waterproofing agents included animal glues, bitumen, wax emulsion, animal oil emulsions, bees wax. And the setting retardants were blood, egg white, sugar, gluten and borax.¹²¹

The Spanish New World counterparts included animal glues, banana glue, bitumen, cactus glue, and plant resins for waterproofing properties; sugar, cow dung, glucose, honey and resins for improving plasticity; rice and potato starch for accelerating setting-time; alum and resins for hardening; and banana tree fibers, agave, and cotton for tensile reinforcement.

Waterproofing Additives (Spanish New World)

Animal glues: Animal glues and gelatins are made out of skin, bones and tendons of mammals which are composed of collagen, a water soluble protein composed of keratin, elatin, mucin, and chondrin. According to primary sources, the animal glues were prepared by boiling rabbit, baby sheep or calf skins until a thick paste formed. For stuccos the calf skin was preferred over the others.¹²² Animal glue and gelatin are quite similar. The differences between them depend on the purity of the product (glues are less pure than gelatins). The imparted properties of them are flexibility, viscosity and gel forming capabilities, usually as an adhesive agent and paint medium.

Banana mucilage: Banana glue is produced by boiling the leaves and stem of the banana tree (*musa paradisiaca*) until a thick paste forms.

Bitumen: Bitumen is a natural combustible, mainly consisting of heavy hydrocarbons, derived from petroleum. This material is characterized by high combustibility and black color. Bitumen has been commonly used as a waterproofing agent and pigment.¹²³

Cactus mucilage (*baba de nopal*):¹²⁴ Derived from the tuna cactus *O. tuna* or *O. megacantha*, primarily composed of sulfuric acid esters, the cactus glue is produced by either by boiling the leaves of the plant until a thick substance is formed or by cold

extraction of the cactus sage. During the colonial period this glue was employed in New Spain as a vehicle component for tempera paints, and as a binder for stuccos.

Natural resins: Resins are viscous exudations produced by secretory glands in the stem structure of certain trees. Their function is to heal and seal wounds in tree bark. Their composition is very complex and varies widely from one another, but the basic constituents are di and triterpenes (carbon isoprene).¹²⁵ Based on their essential constituents, natural resins have been classified as Aromatic acids, aliphatic acids, resinols and resino-tannols, resin acids, resences, and essential oils.

Plasticity Improvement Additive (Spanish New World)

Cows dung: Used exclusively in mud plaster, the cow's dung, works as a set retarding agent. The mucus present in the cow's dung, when mixed with lime, forms a gel that traps moisture during the setting process of the stucco. Also, during the process the lime and the sand are held together in the soil and the clayey minerals in the soils stabilized.¹²⁶

Glucose: Glucose is derived from grape and corn sugar, and naturally found in plants and blood. It is colorless or white, granular, soluble in water, and partially soluble in alcohol. It is used in several industrial processes including, among others, wine, and infant food production.

Honey: Primarily composed of the sugars dextrose and levulose, several other compounds, and about 20% of water. It retains water when added to water-soluble substances.

Natural resins: (See description in waterproofing additives)

Sugar: Table sugar belongs to the group of sucrose sugars that is derived from cane and beet sugar and naturally occurs in honey and maple sap. It appears as hard, white, dry crystals, in lumps or powder and is totally soluble in water and slightly soluble

in alcohol. Among many other uses, sugar is utilized as an emulsifying agent in industrial manufacturing.¹²⁷

Setting Acceleration Additives (Spanish New World)

Starches: Starches constitute the principal carbohydrate found in plants, and are synthesized by them from carbon dioxide and water. They consist of carbon, hydrogen, and oxygen, found in two polymers called amylose and amylopectin with the empirical formula $(C_6H_{10}O_5)_n$.¹²⁸ Starch concentration in plants varies from one plant to another. The major concentrations are found in wheat, rice, potatoes, and bananas. Among other uses, starches are used in paint media and as an additive for stucco.

Hardening Additives (Spanish New World)

Alum: Alum is constituted by aluminum and potassium sulfate derived from Alunite (a composite of aluminum and potassium). It is a white salt with an astringent powder obtained from some rocks and soils by dissolution and crystallization. It was traditionally used to purify contaminated water.¹²⁹

Natural resins: (See description in waterproofing additives)

Tensile Reinforcement Additives (Spanish New World)

Vegetal fibers: Vegetal fibers are colloidal bodies, found in numerous types of plants of diverse characteristics. Their basic components are cellulose and by-products of cellulose. Fibers are obtained from the tissue of woody plants (bark and wood), dicotyledons (straw, jute, sisal), and from certain seeds (cotton).

Agave: Agave, also called henequen, maguey, pita and sisal, is primarily obtained from fibrous strands of the leaves of *Agave Americana* cactus. The stalks of the plant are cut and stacked to dry and cure until the fibers harden. It was used for rafters of thatch roofs and after further processing, for mats and fabric.¹³⁰

Cotton: Cotton belongs to the group of seed hairs fibers, characterized by fibers occurring as individual cells. Unlike bast and wood fibers, cemented together, the cotton cells occur individually. Due to easy separation of the cotton fibers, cotton is the preferred source of fibrous material in the manufacturing industry.

B. Architectural Paints

Paints can be broadly defined as suspensions of finely ground colorants (pigments) in a liquid or plastic medium.¹³¹ The pigment and medium are the basic components and determine the physical, mechanical, and chemical characteristics of the paints. However, individually each component functions in a very distinct way. The colorants provide coloration, texture, gloss, and determine the opacity or transparency of the material. The medium or vehicle gives initial fluidity and later adhesion of the film to the substrate.¹³² Sometimes the qualities of the material are improved or new properties are supplied to it by the use of additives. The basic types of admixtures are dryers, preservatives and fungicides.

B.1. Limewashes

Limewashes (*lechada de cal*) are one of the most simple paints and were widely used as architectural surface finishes in the Old and New World, because of their low cost, availability and its biocidal properties. In addition to regular use in interior and exterior walls, limewashes were the preferred paint type for kitchens, because they counteracted the corrosive effects of the smoke.¹³³

Limewashes are a kind of liquid plaster, made out of slaked lime diluted in water, or from the carbonated water (milk lime) formed during the slaking process of the lime.¹³⁴ Both types have almost transparent coloration while in liquid state and turn to opaque

white when totally dry. Limewashes were traditionally mixed with common salt to ensure durability.

Before application, the surfaces should be cleaned and moistened to ensure adhesion of paint on the substrate, whereupon limewashes are painted with a thick brush in two to four coats. To guarantee paint coverage, each coat should be painted when the previous coat is totally dry.

In terms of color, limewashes are either off white, or colored, when pigments are added to it. Nevertheless, the range of pigments added to the lime is limited to those derived from inorganic pigments because the alkalinity of the material affects many organic pigments.

B.2. Organic Binder

References to organic based architectural paint the Spain or the Spanish New World is limited to very general information about the addition of unspecified fatty matter to the limewashes.¹³⁵ The addition of the greasy material improved binding properties of the medium preventing the separation of the pigment by pulverization when the medium dried out. These fatty limewashes were presumably similar to the lime-casein and lime-tallow broadly used in the British territories in North America,¹³⁶ prior to the twentieth century.

B.3. Pigments

Pigments are fine solid particulates of coloring matter, in suspension in the paint medium, used to impart add coloration and opacity to the material. Pigments are derived from a large variety of organic and inorganic, and natural or man made substances. They can be classified based on their color, chemical composition or origin. However, the most common way of classification is based on their chemical composition which divides them into two major groups: organic pigments and inorganic pigments.

Information about specific pigments used in the Spanish New World was limited to one coloring matter called gamboge (*gutugamba* or *goma gutta*).¹³⁷ Additional information was obtained on the fresco technique, painted on a lime stucco substrate, in the artistic painting treatises *El Arte de la Pintura* (1638) by Francisco Pacheco and *El Museo Pictorico y la Escala Optica* (1724) by Antonio Palomino.

B.3.1. Organic Pigments

Organic pigments are compounds of carbon with hydrogen, oxygen, nitrogen, sulfur and other elements mainly derived from vegetal sources and man made chemicals. These pigment types are characterized by their unstable behavior and tendency to fade upon exposure to light. Among them, few are quite stable including black charcoal and black lamp.

Organic pigments were absent from the color palette for fresco technique during the modern era in Spain. In the Spanish-Colonial possessions in the Caribbean, however, a yellow pigment derived from a plant extract called *gutugamba* (gamboge) is reported in the literature.

Gamboge (*Gutugamba*): It is a yellow gum-resin extracted from several species of *Garcinia* tree native to India, Ceylon, and Cambodia in the Far East, where it was employed since ancient times. The use of gamboge was expanded to the rest of the world in the seventeenth century when introduced to Europe. There was constant use during the 1750-1850 period.¹³⁸ Probably during this century some species of *Garcinia* were introduced to the tropical areas of the New World. The resin was employed in cartography maps and in the limewashes of military buildings.¹³⁹ Gamboge is extracted from the trees by means of artificially incisions on the bark of the tree, which yields a yellowish brown opaque liquid that hardens when exposed to air. The raw material is

processed and appears in its commercial form as yellow lumps with a superficial layer of yellow dust.

B.3.2. Inorganic Pigments

The inorganic pigments are chemical compounds derived from raw earth and grounded minerals in the form of carbonates, oxides, phosphates, silicates, sulfates, and sulfides from which the basic color of a particular pigment is produced. Their color range could be expanded by calcination of the raw materials¹⁴⁰ to produce a wider quantity of tones or even totally different colors out of the same compound. The most representative inorganic pigments included the naturally occurring yellow, red and brown ochre, and the pigments made synthetically from metals.

Inorganic pigments suggested by Pacheco and Palomino were derived from earths and minerals. The earths included yellow ochre (*ocre claro*), burnt ochre (*ocre quemado*), red earth (*almagre*), deep red (*albin*), dark red (*pavonazo*),¹⁴¹ green earth (*tierra verde*), Venitian earth (*sombra de Venecia*), raw umber (*sombra de viejo*), and black earth (*tierra negra*). While the mineral pigments, some of them calcinated, included whiting (*blanco de cal*), marble white (*blanco de marmol*), *hornaza* (light yellow), vermilion (*bermellon*), *vitriolo romano quemado* (red), smalt (*azul esmalte*), and black (*negro carbon*).

B.3.2.1. Earth Pigments

Yellow Ochre (Ocre claro)($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$): Yellow ochre is derived from two hydrated forms of iron hydroxides, limonites and goethites, present in some natural earths which are mainly composed of silica and clays. In addition to these iron oxides, the yellow ochre is composed of some clay, sand, chalk, and gypsum barytes. The concentration of iron oxides determines the opacity and resistance of the pigment. Those with higher percentage

of iron oxide are transparent and strong; while the those with more clays are opaque and weak.¹⁴²

Burnt Sienna (*Ocre quemado*)(Fe_2O_3): Dark yellow color produced by calcination of natural raw Sienna. The name derived from the place where the active earth was first employed. However, earth with analogous compositions are found in many other locations in the world. It is a very stable pigment, but when mixed with lime tends to bleach.¹⁴³

Natural Red Ochre (*Tierra roja, Almagre, Sinopia*) (Fe_2O_3): Red ochre is obtained from earth with a very high content of iron oxide, from which derives the characteristic red color of this pigment. Other components of the raw earths are silica and clays. If the earths are prepared by thorough washing and levigation, the resulting pigments will be one of the most long-lasting coloring matters.

Green earth (*Tierra verde, Tierra de Verona*): Green pigment made out of green clayey soils found in Verona, Italy.¹⁴⁴ These green earths originated from marine clays with a complex chemical composition, but are characterized by predominance of glauconite and celadonite (composites of hydrous iron, magnesium, and aluminum potassium silicates). The green color is produced by iron in a ferrous state present in the clays.¹⁴⁵ This pigment yields a beautiful green color, but when applied in a lime substrate tends to discolor due to formation of iron hydroxide (yellowish).

Sombra de Venecia, Sombra de Italia: Light-brown color derived from dark Venetian earth. It is used to paint shadows in fresco painting, but tends to bleach after dry.¹⁴⁶

Raw Umber (*Sombra de Viejo*) ($\text{Fe}_2\text{O}_3\cdot\text{MgO}$): Brown color obtained from coarse dark earth and used to paint shadows in temple and fresco painting.¹⁴⁷ Umber consists of iron oxide, silica and aluminum, present in other earthen pigments, manganese dioxide and hydrous ferric oxide which gives its dark color. The soils, found in many parts of the

world, are characterized by a basic reddish brown color with some greenish undertones. The careful manufacturing of the pigment, by grinding and levigation, produces a stable and enduring pigment.¹⁴⁸

Tierra negra (Black) (unknown composition): Black mineral color with some clayey impurities.¹⁴⁹

B.3.2.2. Mineral Pigments

Whiting (*Blanco de cal*) (CaCO_3): The basic component of whiting is slaked lime diluted with water. According to Palomino, the lime must be slaked first by aspersion (spraying the lime lumps with fresh water) and when the lime crumbles, by immersion (immersed in water and profusely mixed). The carbonated film (milk lime) which forms on top of the water is removed every day. After four months the slaked lime is sieved in a very fine sieve and diluted with fresh water. The resulting paint is similar to milk.

Blanco de Marmol (CaCO_3): White pigment, similar to whiting, but made out of marble. It is prepared with very white marble crushed in a metal mortar, sieved and grounded again in a hand-operated mill.¹⁵⁰ Palomino recommended its use to replace whiting, when the time is scarce to macerate the lime during four months.

Hornaza (unknown composition): Light yellow color, prepared in a pottery kiln and used for glazing and fresco painting.¹⁵¹

Pavonazo or Almagre (FeAlO_2): Dark red color of mineral origin, used in fresco paint in Spain to replace the organic carmine.¹⁵² It is obtained from Ferric Aluminum oxide.¹⁵³

Vermilion (*Bermellon*) (HgS): Vermilion is a compound of mercury and sulfur, found naturally in the mineral cinnabar, available in Spain, China, Japan, Mexico Peru, Germany, Austria and California. Cinnabar is rarely found pure enough to produce the pigment. As a result, it is manufactured directly from mercury and sulfur. The two elements are processed either by the wet method or the dry method. In the wet method, the mercury

and sulfur are grounded simultaneously in the presence of water. The resulting black compound is mixed with a warm solution of caustic potash or potassium sulfide and stirred for several hours until it yields vermilion. In the dry method, 84 parts by weight of mercury are profusely combined with 16 parts by weight of sulfur, until a black powder is obtained. Finally, the powder is processed by sublimation producing vermilion pigment crystal.¹⁵⁴

Vitriolo calcinado (unknown composition): Red color derived from burnt or calcinated *caparrosa* (slag found in cooper mines).¹⁵⁵

Smalt (*Azul esmalte*) ($\text{CoO} \cdot \text{K}_2\text{O} \cdot \text{SiO}$): Blue color traditionally made in Spain out of grounded glass. It is primarily a Cobalt glass derived from the fusion of cobalt oxide with potash silicate. The product is a deep blue glass that is finely ground and washed to create the pigment. Smalt is unstable in the presence of hydrochloric and sulfuric acid and reacts with carbonic acid in the air. Palomino stated that *esmalte* even though a troublesome pigment, was the only blue pigment suitable for fresco paint.

Morado (FeAlO_2) + ($\text{CoO} \cdot \text{K}_2\text{O} \cdot \text{SiO}$): Purple color is obtained from the combination of *smalt* (*azul esmalte*) and either *pavonazo* or *almagre*.¹⁵⁶

Negro carbon¹⁵⁷ (C): Black pigment produced by grinding charcoal of Holm oak wood. The wood must be burnt without the bark.¹⁵⁸

B.4. Paint Additives

Paint additives were employed to improve the strength of the paint itself or to stabilize certain pigments that tended to deteriorate when exposed to environmental agents. Strength was achieved by the addition of salt and animal glues, while unstable pigments, including smalt and some greens, were mixed with cow's milk if used in interiors or goat's milk when painted on exterior areas.¹⁵⁹

Salt: Common salt (table salt) is a sodium chloride compound found in sea water and in deposits left by millenary oceans. It is a transparent or white crystalline powder, soluble in water and glycerol and partially soluble in alcohol. It has a wide range of application, but in distemper paints is utilized as a hardening agent.

Animal glues: Animal glues are made out of skin, bones and tendons of mammals composed of collagen, a water soluble protein composed of keratin, elatin, mucin, and chondrin. Traditionally the animal glues were prepared by boiling rabbit, baby sheep or calf skins until a thick paste formed. Afterwards, garlic and honey were added to impart adhesive strength and elasticity to glue. The glues are flexible and viscous materials with gel forming capabilities, usually used as an adhesive agent and paint medium.¹⁶⁰

Milk: Heterogeneous liquid produced by mammary glands of mammalian females. The most common source of milk is cow's milk which is composed of water, emulsified fat and fatty acids, casein, lactose, serum proteins, phosphorus, potassium, iron, copper and several vitamins. The composition of other animals milk is similar to cow's milk; the major differences lie in the type of fat and proteins present in the milk. In terms of chemical composition, milk is considered a complex system with several levels of dispersion (from molecular to colloidal). It has been extensively use in artistic and architectural paints because of its emulsifying properties.¹⁶¹

End Notes: Chapter 2

103. John Diehl, *The Manual of Lathing and Plastering*, (New York: Mac Publishers Association, 1960), p.342.
104. Ignacio Garate, *Artes de la Cal*, (Madrid: Instituto de Conservacion y Restauracion de Bienes Culturales, 1993), p. 139.
105. Vitruvio, San Nicolas, Palladio, Alberti recommends this slaking method.
106. Giorgio Torraca, *Porous Building Materials*, (Rome: ICROOM, 1981), p. 69.
107. Juan de Villanueva, *Arte de Albanileria*, facsimile edition of the original edition printed in 1827 in Madrid (Madrid: Ediciones Velazquez, 1977)], p.13.
108. John and Nicola Ashurst, *Plasters, Mortars and Renders in Conservation, Practical Conservation*, English Heritage Technical Books, (Aldershot: Gower Publishing Co., 1988), p. 2.
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Chapter 3 Case Study: San Geronimo and Santa Elena Powder

Magazines

A. History of the Buildings

The possibility that the war between Spain and England would extend to the Spanish colonies in the Caribbean Sea was clearly evident by the second half of the eighteenth century. British pirate attack of the Spanish colonies in the West Indies increased daily. Puerto Rico, the westernmost Spanish settlement in the Antilles, neighboring the British and Netherlands possessions, held a strategic position for the protection of Spanish Caribbean possessions. In response to this need, the Spaniard Monarchy sent the Field Marshal and military buildings inspector Alejandro O'Reilly to the island in 1764. As a result of his strategic and technical study presented in 1765, a comprehensive plan for the expansion and reinforcement of the San Juan's existing fortification system was proposed by military engineer Thomas O' Daly in the same year.¹⁶² Prior to 1765 plan, the primary function of San Juan's military post was to protect the island. The O'Reilly-O'Daly plan transformed Puerto Rico into an entry port for goods and people coming from Spain, and a major Spanish maritime base in the Caribbean, earning it the royal title of "the guard of the Antilles and the Spanish outpost of the Mexican Gulf."¹⁶³

The O'Reilly-O'Daly plan included reforms of the existing fortifications, construction of new military buildings, the rebuilding of the city walls, and the edification of four accessory gunpowder magazines. Santa Elena, San Geronimo, Santa Barbara, and Miraflores Powder Magazines were strategically located to serve the entire military system in the urban and surrounding areas. The former

three were built on San Juan Island, while the latter was in Isla Grande, an islet in the entrance of the city bay.

These powder magazines were designed by Thomas O'Daly and built by the military engineer Juan Francisco Mestre who collaborated in the execution of the renovation plan for the city. The four gunpowder storage buildings were built at different dates according to the requirements of the fortified post. Due to the urgency to provide gunpowder to all the fortresses located in the western zone at the outskirts of the city, San Geronimo was first erected in 1768 at the edge of the walled area. Miraflores was built in 1776, to store the provisions of the nearby islands. Santa Elena was constructed in 1783, to serve the forts located on the north wing of the capital.¹⁶⁴ And Santa Barbara was finished in 1787, to provide gun powder to El Morro, Ochoa and Santa Barbara Batteries in the core of San Juan's fortified belt.

Santa Elena and San Geronimo powder magazines were both typical examples of Spanish colonial military architecture. The original design of these powder magazines corresponded to models adopted during the seventeenth and eighteenth century by the Spanish Military Academies, particularly to those employed for the Spanish New World known as *La Escuela Fortificacion Abaluartada en America*.¹⁶⁵ The seventeenth-century powder magazine type was a massive rectangular building with load bearing walls and steeply inclined gable roof supported by an interior vaulted structure. In the eighteenth century, the edifice was moderately changed. Three features were appended to improve the basic gun storage edifice: lateral buttresses, window openings, and a periphery wall. The first element was added to reinforce the vaulted roof structure, the second to generate interior ventilation to keep the explosive material dry, and the third to protect the building from enemy assault.

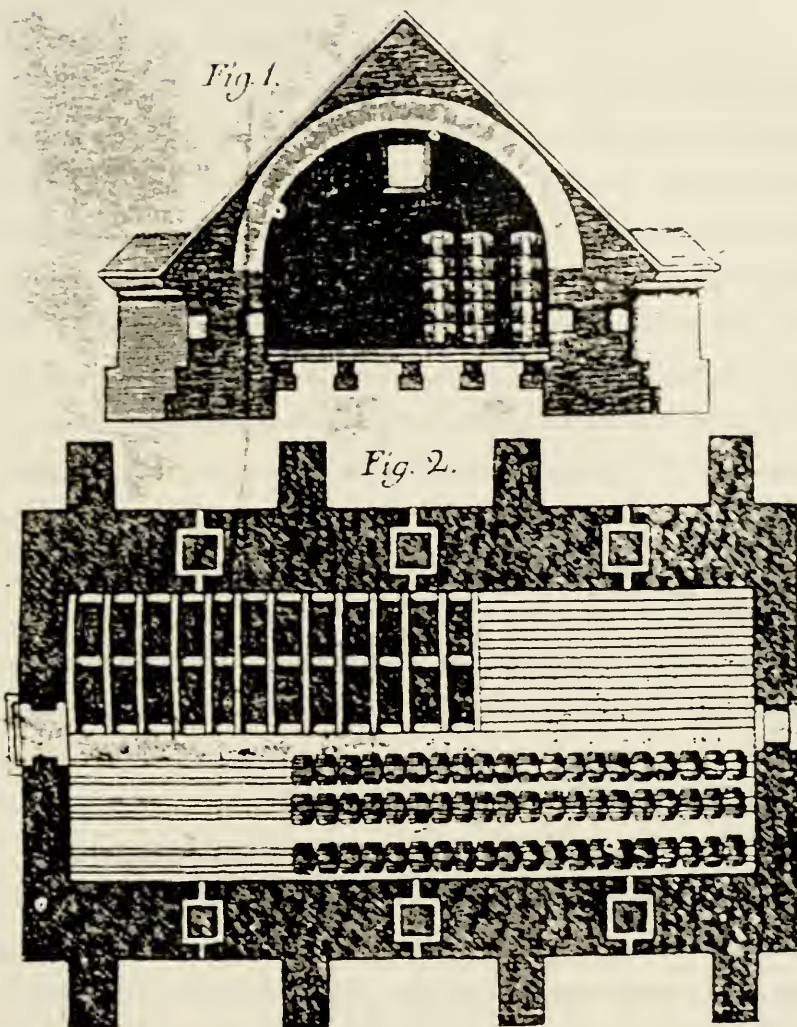


Illustration No.2

Eighteenth-century model of a powder magazine building presented in the treatise *Tratado de Fortificacion*, Barcelona 1768 (in *La Fortificacion Abaluartada en America*).

B. Architectural Description of the Buildings

B.1. San Geronimo Powder Magazine.

San Geronimo "bomb proofed"¹⁶⁶ powder magazine is a massive building with a rectangular plan of 190 feet long by 30 feet wide with two symmetrical axes. The original edifice had three interior spaces: two ante-chambers, located in the front and rear entrances of the building respectively, and a central room for the storage of the gun powder. The front gable facade is a flat wall with one main door, a high ventilation window, a decorative cornice and finial in the roof line. The rear gable facade is flat and solid, and decorated on the top with a cornice and finial. Each lateral facade is composed of a main flat wall complemented by ten projecting buttresses that reinforced the thrust of the roof structure and eighth small slit vents built into the main wall. The buttresses were crowned by a decorative molding

Twelve feet away from the powder magazine proper, is a ten foot high perimeter wall with two cylindrical sentry boxes, each crowned with a dome roof on the southeast and the northwest corner. Years later, due to intense atmospheric moisture¹⁶⁷, truncated pyramidal ventilation chimneys were added on the north and south faces of the periphery wall. The purpose of this addition was to improve air circulation, necessary to keep the gun powder dry.

The main building was constructed of a local calcareous sandstone and brick rubble masonry (*mamposteria*) laid with a bedding mortar of crushed brick, lime, and sand. Cut sandstone was employed as reinforcement at corners, openings, and the principal cornice. Ventilation chimneys were built with brick laid with lime bedding mortar, while the roof structure was of brick and lime mortar. All walls were covered with a white stucco and the brick gable roof was left entirely exposed.

The perimeter wall and sentry boxes were built in rubble masonry, similar to the main building. In the sentry boxes, the cornice and roof cap were constructed of sandstone, whereas the coping of the perimeter wall was made of lime, crushed brick and sand stucco. The walls, dome roof, and decorative elements were stuccoed similar to the principal building.

In contrast to Santa Elena, a large number of openings, for windows and doors, were cut into the walls of San Geromino, in the 1940s, when the building and the surrounding area were converted for a zoo¹⁶⁸.

B.2. Santa Elena Powder Magazine.

Santa Elena "bomb proofed"¹⁶⁹ powder magazine is a massive building with a rectangular plan of 150 feet long by 45 feet wide with two symmetrical axes. The original edifice had a single interior space for the storage of the gun powder. The front gable facade is a flat wall with a main door, a high rounded ventilation window; and a decorative cornice at the roof line. The rear gable facade is a flat wall with a main door, high-central rectangular windows, and a cornice. Each lateral facade is a main flat wall with ten 5'x5' projecting buttresses that reinforced the roof structure, and eight small slit vents built into the main wall. The buttresses were crowned by a low inclination hipped roof. Like San Geronimo, years later, truncated pyramid ventilation chimneys were added to the north and south facades, in the space occupied by two of the buttresses. These ventilation devices were attach to the main building to improve the air circulation, necessary to preserve the gunpowder. Twelve feet away from the main building, a high perimeter wall with two domed sentry boxes on the northwest and southeast corners, was added.

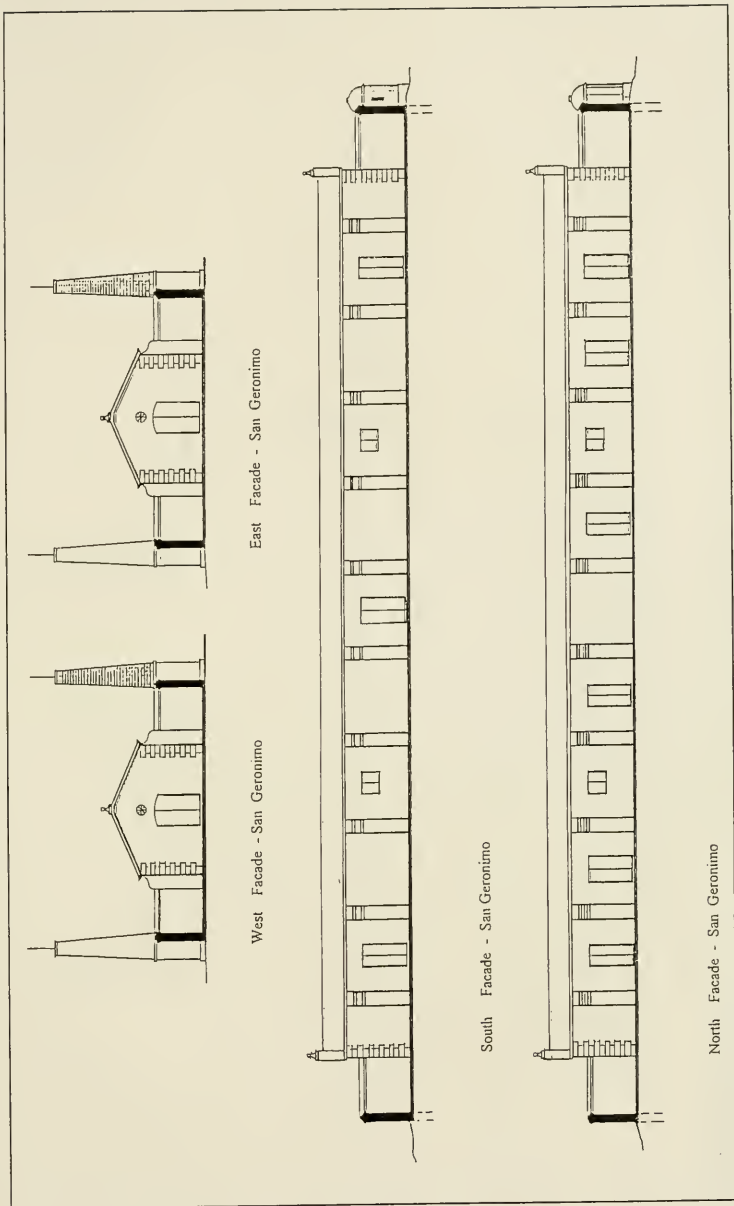
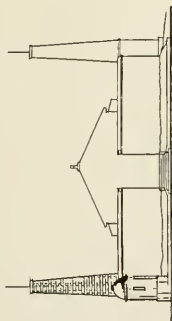
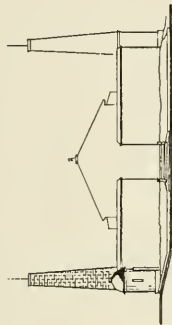


Illustration No. 3

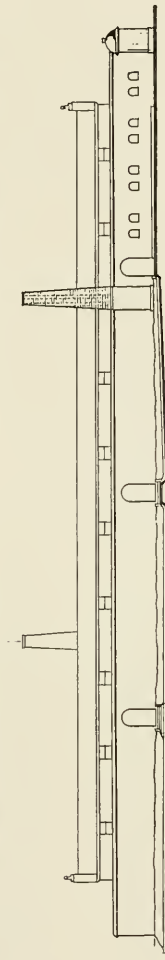
FACADES - SAN GERONIMO



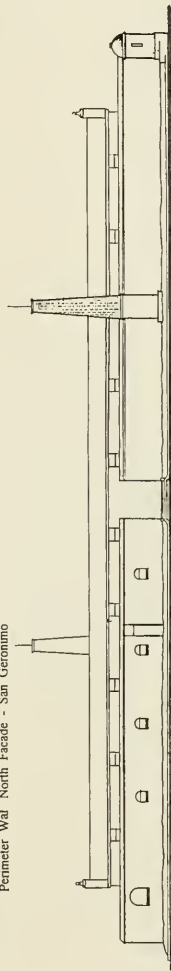
Perimeter Wall East Facade - San Geronimo



Perimeter Wall West Facade - San Geronimo



Perimeter Wall North Facade - San Geronimo



Perimeter Wall South Facade - San Geronimo

Illustration No.4

PERIMETER WALL FACADES - SAN GERONIMO



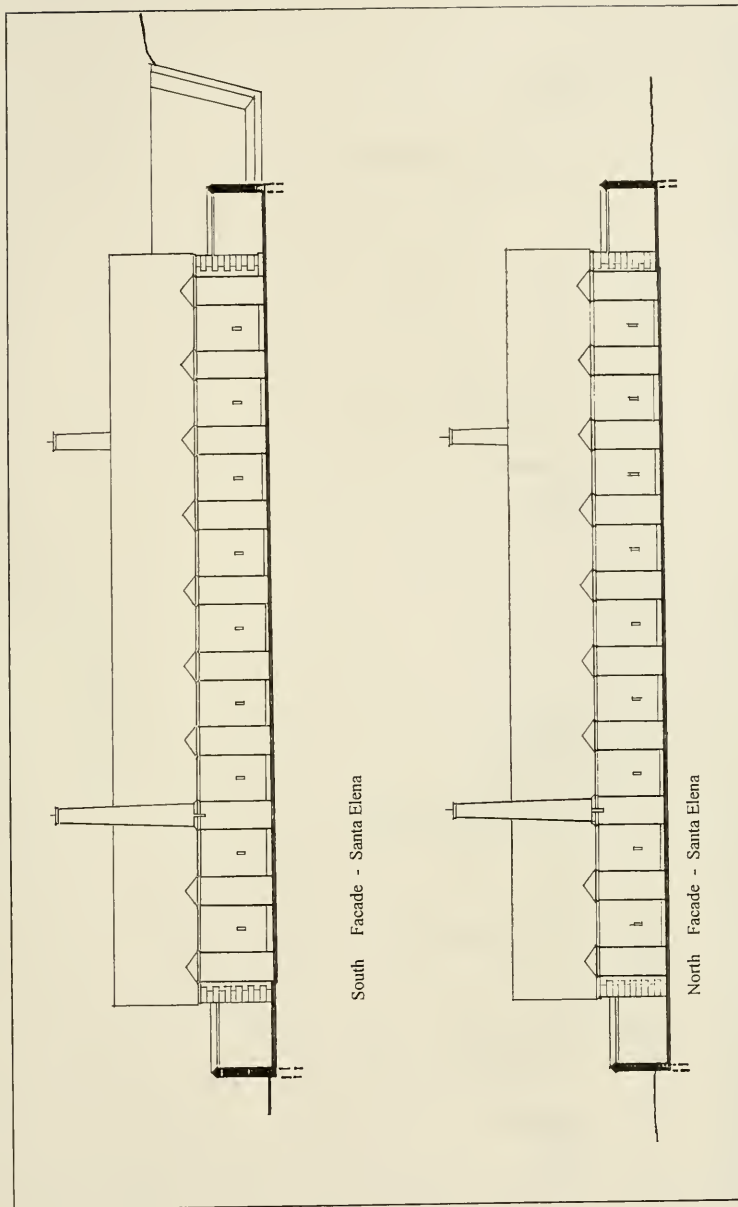
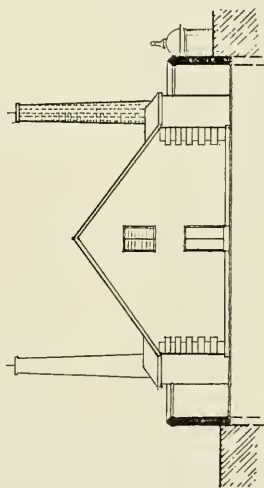
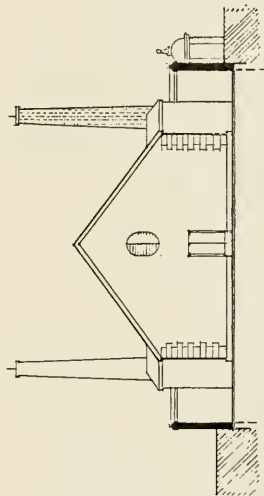


Illustration No.5

FACADES - SANTA ELENA



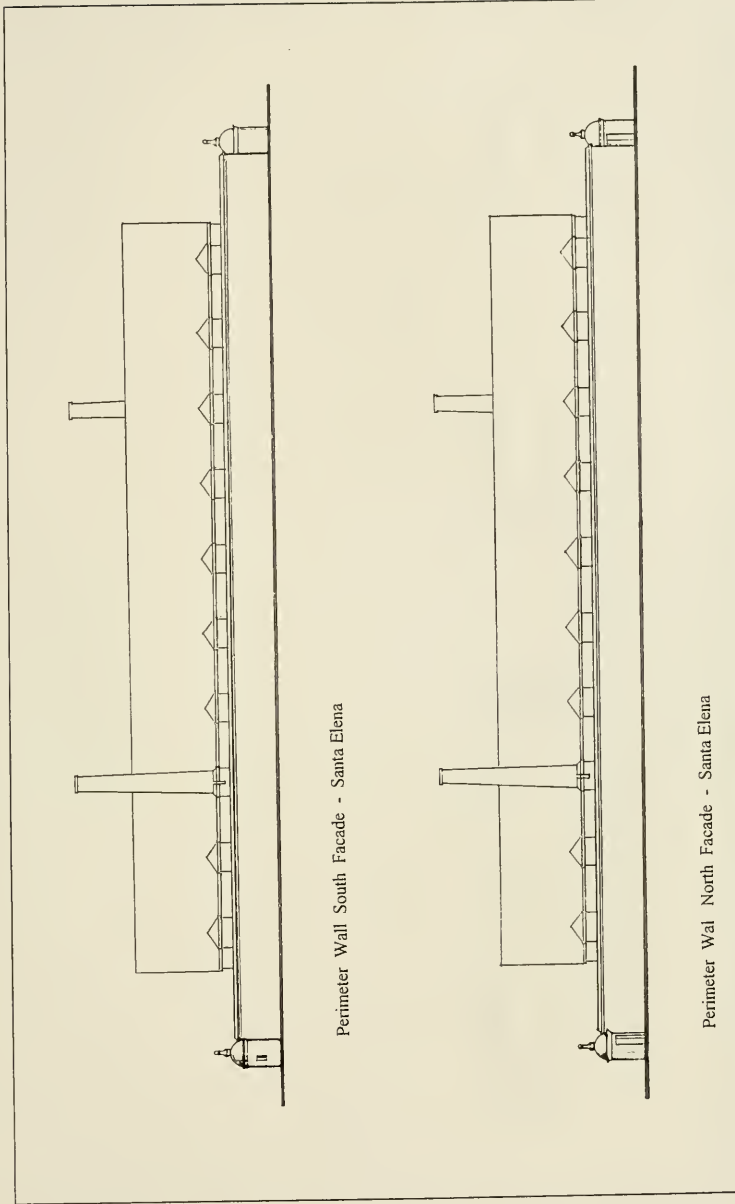
East Facade - Santa Elena



West Facade - Santa Elena

Illustration No. 6

FACADES - SANTA ELENA

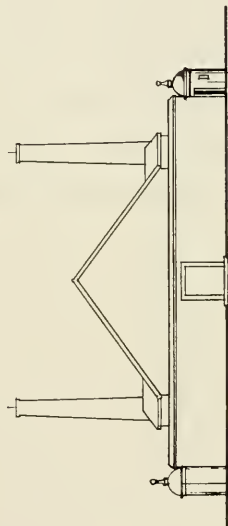


Perimeter Wall South Facade - Santa Elena

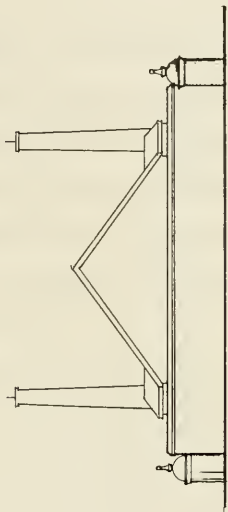
Perimeter Wall North Facade - Santa Elena

Illustration No. 7

PERIMETER WALL FACADES - SANTA ELENA



Perimeter Wall West Facade - Santa Elena



Perimeter Wall East Facade - Santa Elena

Illustration No. 8

PERIMETER WALL FACADES - SANTA ELENA

C. Sample Description

Samples from the buildings were examined to compare period documentary sources with actual construction practice in the Spanish Caribbean context. The specimens analyzed were collected in 1989 by Frank Matero during an earlier study of the building for restoration and are now part of the Building Materials Collection of the Architectural Conservation Laboratory of the University of Pennsylvania. Twenty-two samples of the exterior stucco (ten samples from Santa Elena and twelve from San Geronimo) were examined for this work.

Sample selection for analysis was based on two criteria: well preserved samples (i.e. where no or few post colonial interventions occurred), and similar locations in both buildings for comparison. In Santa Elena, finishes were obtained from the wall of the main building (base, junction and medium high); from the sentry box (wall, the dome cap, the dome, and the door frame); and from the perimeter wall (coping and body wall). At San Geronimo specimens were taken from the northwest sentry box (slit window, dome, and wall); the northwest sentry box (cornice); the south face of the perimeter wall (arch opening, coping, wall, top of the buttress); the south ventilation chimney (base); and the southeast sentry box (roof cap, dome, and body wall).

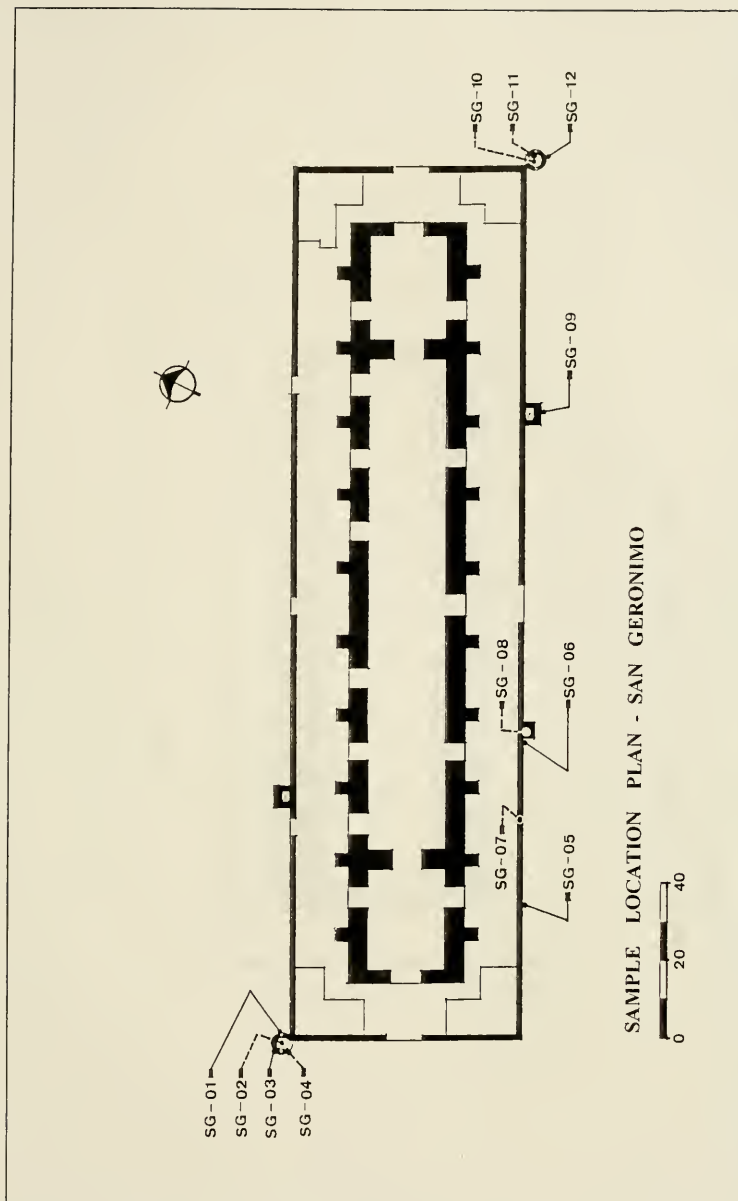


Illustration No.9

SAMPLE LOCATION PLAN - SAN GERONIMO

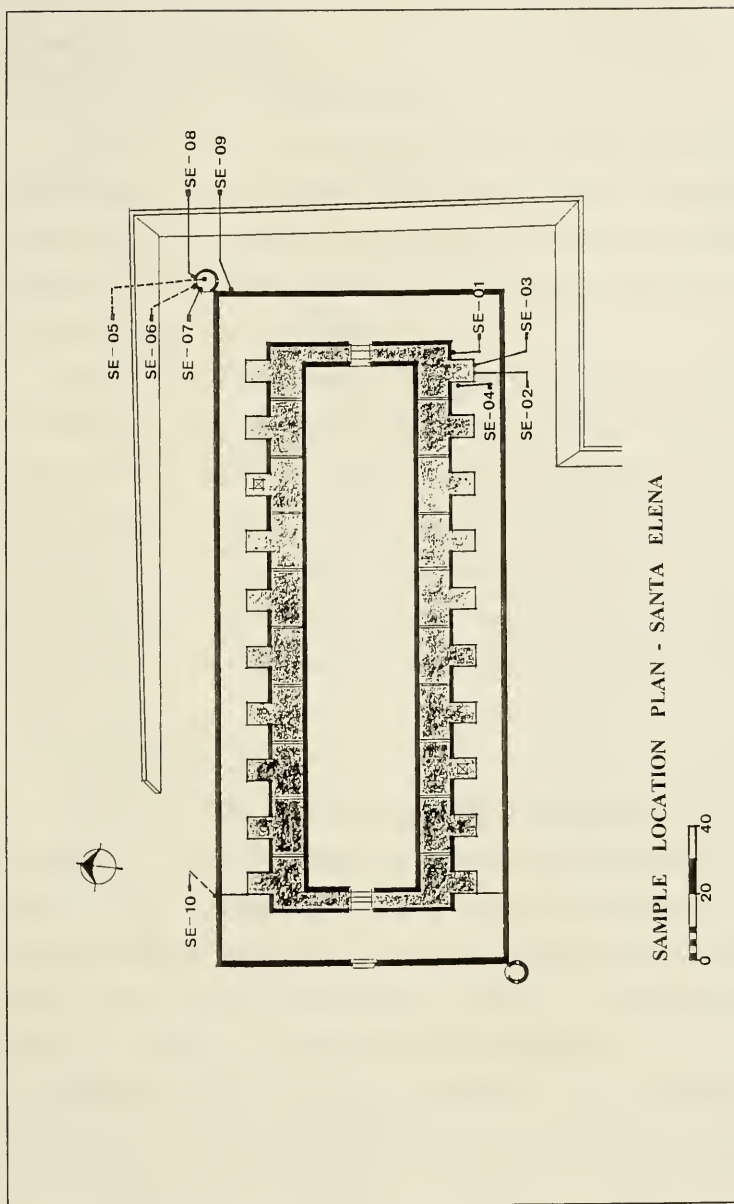


Illustration No. 10

SAMPLE LOCATION PLAN - SANTA ELENA

D. Sample Characterization.

D. 1. Examination and Analytical Methods

Optical microscopy was employed to characterize the layer structure and micromorphology of cross-sectioned and thin-sectioned samples. Material composition was determined by microchemical tests, scanning electron microscopy (SEM) and energy dispersive X-ray fluorescence analysis (EDX). Gravimetric analysis was not performed because of the small size of the samples.

Due to the specimens friability, all were first treated with stone consolidant Conservare OH, applied by capillary absorption for one week prior to sectioning. Samples then were embedded in a polyester-acrylic resin¹⁷⁰ and hardened under a tungsten light. The mounted specimens were then cross-sectioned with a circular micro-saw,¹⁷¹ and polished with fine grain abrasive paper (No. 400 and 600) and deionized water. Only those samples chosen for examination by optical microscopy were further burnished using a felt cloth with a suspension of alumina powder,¹⁷² deionized water and a drop of acetone.

D.1.1. Optical Microscopy

Gross layer structure and micromorphology of the samples were observed with a stereo binocular microscope (Nikon SMZU) with reflected illumination. The specimens were viewed under magnifications of 12.5x to 25x; and photographed at 3.5x, and 4x. The microstructure of individual layers and their components was later examined with a polarized light microscope (Nikon Optiphot 2) fitted with reflected and transmitted illumination. Samples were observed under magnifications of 50x to 100x, and individually photographed at 12.5x and 25x magnification. This provided information on layer structure, paste color and texture; and aggregate distribution, color, size, and

shape. Additional information on the presence of fractures, cracks, voids was also recorded.

Further examination and analysis was performed on thin sections using polarized light microscopy. For the stucco and surface finishes this was an effective tool to describe detailed stratigraphic features, micromorphology, and the mineralogy of the constituents. Thin sections were prepared by mechanically grinding specimens to a standard thickness of 0.03 mm, then polished and mounted on a microscope slide.

D. 1. 2. Qualitative Microchemical Analyses.

Qualitative microchemical analyses are simple micro-chemical techniques used to provide basic information about the elemental constitution of a wide range of materials. An unknown element is identified by visible reaction between the acid-dissolved substance and a standard chemical reagent, which causes a specific chemical transformation in the presence of certain materials. The outcome of this reaction is the formation of a new substance detected by color alteration, crystallization, gas formation, dissolution, and heat liberation.

Micro-chemical tests were performed to identify the basic components of the red, pale- yellow, and white colored on surface finishes. Red finishes in SG-09 were tested for: iron oxide, red lead, and vermilion. SE-02 and SG-06¹⁷³ were also tested, for these pigments and gamboge¹⁷⁴ (*gutugamba* or *goma guta*), a colorant known to have been used from historical accounts.¹⁷⁵ SG-08 was also analyzed for calcium, white lead, zinc white, and gypsum. The tests of each sample were repeated five times to confirm the results.

Red pigment. ¹⁷⁶

The selected paint layer was first removed from the surface and treated with sulfuric acid (H_2SO_4) [1:5 (V/V)] (or any other mineral acid) to separate the pigment from the media. A drop of sodium sulfide (Na_2S) is then added to the mixture to test for

lead (Pb) or mercury (Hg). The formation of a black precipitate indicates the presence of both elements. If positive, confirmation test for the identification of lead is accomplished by heating the acid-treated sample until the acid evaporates. Then a drop of water is added to dissolve the precipitated crystals. Once dissolved a crystal of potassium iodine (KI) is added. The formation of a yellow coloration is an indication of lead.

Vermilion (composed of Hg and S) confirmation is performed by adding a drop of water to the acid-treated specimen, followed by a drop of sodium azide/ Iodine. To test for iron the sample is heated first, and once the acid is evaporated a drop of potassium ferrocyanide ($K_4 [Fe (CN)_6]$) is added to the residue. The formation of a blue color is an indication of the presence of iron (Fe).

White Pigment.¹⁷⁷

The selected paint layer was first removed from the surface and treated with a drop of nitric acid (HNO_3) [1:1(V/V)]. The presence of lead and calcium carbonates (whiting) is detected by gas liberation; whereas the presence of gypsum and zinc is indicated by gas absence. A confirmation test for lead requires first, to heat the acid treated sample to evaporate the acid, followed by the addition of a drop of water to the precipitated crystals. One crystal of potassium iodine (KI) is then added to the mixture. The formation of a yellow color is an indication of the presence of lead. Whiting is tested by adding sulfuric acid (H_2SO_4) [1:5 (V/V)] to a nitric acid-treated specimen. The presence of carbonates is detected by the formation of needle-like crystals. Confirmation is done by heating the acid -treated sample; the formation of needle-like crystals confirms gypsum. Zinc is confirmed by the addition of a drop of sodium hydroxide to the acid-treated sample, followed by addition of few drops of dithizone solution. A red color formation is an indication of the presence of zinc.

Gamboge.

The sample is first removed from the substrate and a drop of dilute sulfuric acid is added. A drop of caustic soda (NaOH) [1:2 (V/V)] is added. A positive reaction is verified by the change of color to a deep red, followed by solubility of the colorant in NaOH.¹⁷⁸ Further testing is performed by heating the pigment in an open flame. If the sample burns and copious smoke is produced, and an aromatic smell of resin occurs the reaction is considered positive.¹⁷⁹

D.1.3. Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Fluorescence Analysis (EDX)

Scanning Electron Microscopy is used for surface analysis of the microstructure of a material. During examination a small portion of the specimen is placed in a high vacuum chamber and exposed to an electron beam. The interaction of the electrons in the beam with the sample have several responses and each one provides information about a particular micro-characteristic of the sample (morphology, composition, crystalline structure).

Accurate chemical composition and elemental distribution within the sample is obtained by Energy Dispersive X-ray Analysis (EDX). The X-ray is generated in the SEM vacuum compartment by the electron beam and collected by a cryo-cooled SiLi crystal. A multichannel examiner device computes the amount of X-rays generated at different energies. Elements are recognized by their inherent energy, and their concentration is determined from the calculated rate of energy counts released.¹⁸⁰

This application produces a qualitative analyses represented by a X-ray spectrum and/or a X-ray dot mapping. The X-ray spectra are used to determine the elements present in the examined material. The resulting diagram shows a sequence of peaks, each one representing an element in the sample. Since every element has a characteristic

peak wavelength, the results are compared to energy/wavelength tables and the identity of the element can be established.

X-ray element dot map can be constructed by selecting and mapping the energy emitted from a particular element in a specific zone of the sample. SEM uses the output of the X-ray spectrometer which has already separated and recognized every element in the material. Each constituent is displayed in a “window” which is a base-image that shows the location and concentration of the selected element within the examined surface of the scanned material. The location is marked by white dots and the concentration is depicted by the brightness of spots.

From representative specimens (SE 02, SE 09, SG 03 and SG 10) were analyzed at 20 kv energy in a JEOL JSM 6400 Scanning Electron Microscope at 10x, 22x and 25x magnification respectively. Sample SE-02 (from Santa Elena) is a white stucco with a yellowish-red paint; while SE-09 is a white and reddish stucco, a *revocos* and yellowish-red paints. SG-03 (from San Geronimo) is a reddish, and a grayish stucco and yellowish-red paint; whereas SG-10 is only a reddish stucco. One specimen SE-02 was gold coated, for possible detection of carbon particles in resin; the rest were carbon coated.

The binder component of the white stucco was tested for calcium, magnesium, and sulfur which could suggest either the use of use of gypsum, or calcitic or dolomitic lime. The reddish stucco was scanned for calcium, sulfur, iron, magnesium, and aluminum which could suggest the use of any of the following materials: brick dust, gypsum, and calcitic or dolomitic lime. The aggregates in all the samples were examined for silicon aluminum, potassium and calcium to determine whether the materials were quartz sand, feldspar, and lime. Paints were also tested by SEM-EDS for the presence of iron, sulfur, and carbon, which are the basic minerals present in the suggested sources of red, and yellow colorants.

D.2. Results

D. 2. 1. Stucco

Two original stucco types are represented by the samples: lime stucco, and a combination of powdered brick and lime stucco. A third type of stucco found in the San Geronimo specimens is not likely of colonial origin because it is located in an area restuccoed during the 1940's.¹⁸¹ In the two primary stucco categories, subdivisions were found based on the variations of the binder-aggregate ratio; aggregate constituents and grain-size distribution; stratigraphic structure, and paste color. Whether the primary stucco types and their variations are related to the function and/or location of particular architectural elements will be explored in the this section.

D. 2. 1. 1. Stucco: San Geronimo

D.2.1.1.1. Lime stucco

The samples identified as lime stucco had two main constituents: lime and sand, and an overall color range of white to light gray. The sources of the basic materials as identified by SEM and thin section examination appear to be coral limestone for the binder material, and quartz and feldspar sands for the aggregate. This stucco type was found in the dome roof of the southeast sentry boxes, and in both body wall and coping on the south side of the perimeter wall.

Three layers or coats were observed for the lime stuccos: 1. base, 2. intermediate, and 3. finish. The first one is close to the substrate and is a rough textured layer with an approximately equal proportion of binder to aggregate. The intermediate layer has slightly smaller aggregate than the first coat and the percentage of binder to aggregate is moderately higher. The third coat, is fine-textured and thinner with a higher proportion of binder and reduced percentage of aggregate. The average thickness of the layers was 2.0 mm,¹⁸² 3.50 mm, and 0.45 mm respectively.

The aggregate component is heterogeneous in regard to composition, color, and size. It basically consists of sand of several colors (pale brown, red, yellow, and white) and sizes; lime lumps are white and coarse; wood particles are pale brown and gravel size, with other unidentified fine black particles. However, the predominant aggregate is a white clear quartzitic sand, medium to coarse in size, of trapezoidal subangular shape.

Yellowish-red irregular particles were observed in the majority of the samples, but in low concentration and randomly distributed in the paste. These particles were identified by microchemical testing as gamboge and iron oxide. The historical accounts have suggested that gun-resins were used as strength-imparting additives in the stuccos.¹⁸³

D.2.1.1.2. Lime and Powdered Brick Stucco

Information about stucco stratigraphy and strata dimensions was obtained from microscopical observation of cross and thin sections. A well defined stucco stratigraphy was found in the material extracted from the walls. In other locations no differentiated layer structure was observed. In the walls the lime-powdered brick stucco was applied in two layers: a base, and finish coat. The first layer is thick with coarse to medium size aggregate, and a larger amount of aggregate than binder. The second coat is thin with fine aggregate, and a higher concentration of binder. The average thickness of the base and finish layers are 5.0 mm, and 1.0 mm respectively. According to the observations, the number of campaigns of colonial stuccos was limited to one.

The lime-powdered brick stucco is composed of lime, as a binder; brick dust, as an hydraulic additive; and sand, and larger brick fragments as aggregate. The use of brick dust in stucco mixtures is mentioned in the pre-nineteenth century building treatises.¹⁸⁴ With regard to color this type ranges between several hues of reddish-yellow whose intensity depends on the concentration of the brick dust in the mixture.

This type of stucco was primarily used in high weather-exposure elements such as cornices, copings, door frames, and window sills. A secondary use of it was in body walls. Unlike the lime stuccos, this type was mainly utilized on the north side of the complex, but was also found in the southeast sentry box dome cap, again probably for its improved durability to moisture.

Grain size distribution and the ratio of binder to aggregate ranged widely in the samples. The concentration of powdered brick most probably relates to water exposure of the element in which it was employed. The examination of the two samples, which represent the maximum and the minimum brick dust content confirmed this practice. The specimen with the highest concentration of brick dust was extracted from a cornice. The lowest concentration was found in a wall which is rain protected.

Sand, lime lumps, brick fragments, and a composite of dark red material and sand, are the aggregates of the powdered brick stuccos. They vary in size, concentration and distribution. Three variations were observed in the aggregate component. First, predominantly white, clear quartz sand, medium-sized, trapezoidal-shaped, and subangularly-edged aggregate. Second, prevalent brick fragments, coarse to gravel-sized, square-shaped, and subrounded aggregate. Third, predominant white opaque lime lumps, coarse-sized, spherical-shaped, and rounded. The binder material is calcitic lime obtained from coral limestone.

D. 2. 1. 2. Santa Elena Stuccos

D. 2. 1. 2. 1. Lime stucco

The stucco grouped under lime stucco type were composed by two main materials: lime and sand, and their color ranged from white to light gray, and cream. The sources of the basic constituents as identified by SEM and thin section examination

appear to be coral limestone for the binder material, and quartz and feldspar sands for the aggregate.

The lime stucco showed a very characteristic pattern of use in Santa Elena; that is predominantly used in the walls. It was also used in the dome roof of the northeast sentry box. For this stucco classification, three differentiated coats were observed: 1. base, 2. intermediate and 3. finish. The first coat is closest to the substrate and is a rough textured layer with an approximately equal proportion of binder to aggregate. The middle layer, has slightly smaller aggregate than the first coat and the percentage of binder is moderately higher than aggregate. The third one is fine textured and thinner with a higher proportion of binder than aggregate. The average thickness of the base, intermediate, and finish coats are 1.80 mm¹⁸⁵, 4.00 mm, and 0.40 mm respectively.

The aggregate component is heterogeneous in regard to composition, color, and size. It basically consists of sand of several colors (pale brown, red, yellow, and white) and sizes; lime lumps (white and coarse); wooden particles which are pale brown and gravel size, and other unidentified fine black particles. However, the predominant aggregate is a white clear quartz sand, medium to coarse in size, of trapezoidal shape, and subangular edges.

The primary paste was white to light gray in color. Another type, found to a lesser degree, was a cream color. The primary paste was very dense, while the cream color samples were cohesively poor and had numerous cracks. The lime employed in the first group was probably pure and those of the second group were either adulterated by the addition of clayey material or clayey sands to the mixture.¹⁸⁶

Traces of yellowish-red irregular particles were observed in several samples, but randomly distributed and in low concentration. These particles were identified as

gamboge and red iron by microchemical testing. The historical accounts have suggested that gum-resins were used as strength imparting additives in the stuccos.¹⁸⁷

D. 2. 1. 2. 2. Lime and Powdered Brick stucco

The lime-powdered brick stucco mixture was composed of lime, as a binder; brick dust, as hydraulic additive; and sand, and brick fragments as aggregates. The use of the brick dust for hydraulic set and added durability in stucco mixtures is mentioned in early building treatises.¹⁸⁸ With regard to color this type ranges between several hues of red-yellowish whose intensity depends on the concentration of the brick dust in the mixture. It was found in the pavement¹⁸⁹ of the Southeast corner of the complex (SE 04), in the cornices and door frame of the northeast sentry box (SE 06, 07); and in the wall and copings of the perimeter wall (SE 09,10).

The grain size distribution and brick dust content and the ratio of binder to aggregate varied in the samples. Three sub categories of lime-powered brick dust stucco were established based on the predominant aggregate type: first, predominantly white clear quartz sand, medium-sized, trapezoidal-shaped, and subangular; and a roughly equal binder to aggregate ratio (SE-09, SE-10); second, brick fragments, fine to medium-sized, irregular-shaped, and subrounded, and a slightly higher ratio of aggregate.(SE-04, SE-07); third, predominantly white opaque feldspar sand, finely-sized, subrounded, and a higher proportion of aggregate.

In Santa Elena both the amount of brick dust and the grain size of the aggregate are related to water exposure and the required durability of the stucco. The aggregate is primarily gravel size in the pavement, while for the wall it is smaller. Whereas concentration of brick dust is higher in the cornice samples than in the perimeter wall samples.

Differentiated base, intermediate and finish coats were identified on the body wall. The first, is rough textured with medium-sized aggregate, and a higher proportion of aggregate to binder. The intermediate coat is thick, with medium-sized aggregate, and equal proportions of binder to aggregate. The last coat is thin with a fine aggregate and a greater proportion of binder to aggregate. The average dimension of the layers are 2.00 mm¹⁹⁰, 3.95 mm, and 0.40 mm respectively.

Two stucco campaigns were recorded in the samples from the confining wall. The first one is composed of three stucco layers and a surface finish, and the second is composed of a thick coat of lime stucco. In the remaining samples a sole stucco campaign was recorded.

D. 2. 2. Surface Finishes

Limewashes and *revocos* were the original surface finishes applied to the surfaces of Santa Elena and San Geronimo Powder Magazines. Colored and uncolored limewashes were observed in both buildings; while the *revocos* were only found in Santa Elena. These finishes were customarily use to protect the stucco work and to enhance the appearance of the building. The results of the observations and analytical tests are analogous to the practices reported in the colonial era architectural treatises and contemporaneous historic literature. According to these sources these finishes were common place architectural surface treatment employed during colonial times in Spain and the Spanish New World.

D. 2. 2. 1. Surface Finishes at San Geronimo Powder Magazine.

Limewashes of various colors were the surface finish materials employed on San Geronimo's walls during the Spanish tenure of the building. A limited color palette was composed of white, a range of yellowish-red hues, red and gray. These colors were made

out of lime, gamboge¹⁹¹ and iron oxide, charcoal, and brick dust¹⁹² as identified in selected samples (SG-02, SG-06, and SG-09).

Paints were selectively applied to the walls to create plain colored surfaces, decorative elements, protected areas, and to accentuate raised elements. Plain colored surfaces were achieved by using one color on the flat body walls (white and pale yellow). Decorative elements were achieved by painting a scored quoining, white with black joint lines, on the four corners of the main edifice. The protective areas consisted of a reddish-yellow scored band (9 inches wide) and recessed black line (one inch wide) painted on the base of the main building. Relieved elements such as cornices, dome roof cap, main gate frame, and the base of the ventilation duct were emphasized with red yellow and red finishes that contrasted with the pale wall background. A special color application was the use of a gray limewash on the dome roof of the Northwest sentry box dome roof.

Examination of the paint layers has established that paints were applied on top of a thin limewash primer (SG-02, SG-03, SG-06, SG-08). Absence of fractures between these two layers has suggested that outer coats were laid on shortly after primer application. These films were painted either when the stucco base was totally dry or much later in time.¹⁹³ Painting campaigns were limited to one in all areas of the building except for the confining wall in which a whitewash was applied on top of the yellowish-red wash. Additional data with regard to average dimension of the paint layer was recorded. The primer measured 0.055 mm; and the paint finishes 0.050 mm.

In addition to its color imparting characteristic, the gum-resin gamboge was also probably employed as a water repellent additive in lime based paints, as currently practiced in some tropical countries.¹⁹⁴ Most probably the colonial builders wanted to achieve a stronger moisture-resistant film by the addition of this native produced resin.

Gambole forms in a limewash medium an acid compound¹⁹⁵ and due to its flake-like microstructure a dense compact film with very few pores. The obtained paint is thus an impermeable and strong moisture repellent that protects the outer skin of the building.

D. 2. 2. 2. Surface Finishes at Santa Elena Powder Magazine.

Colored limewashes and *revocos*¹⁹⁶ were the surface finishes utilized in Santa Elena Powder Magazine. These finishes were applied to protect the stucco work, to generate smoother wall finishes, and/or to impart color. The chromatic schema of this building is more limited than in San Geronimo. Three basic colors were identified for this building: yellowish-red, black, and red-orange. However, the predominant color is a gradation of yellow-red tonalities. The first color was produced from a combination of gambole and iron oxide; the second from charcoal; and the third from fine lime-powdered brick stucco.

The analysis of the paint layers has established that paints were applied on top of a limewash primer (SE-01, SE-02, SE-03, SE-05, SE-08, SE-09). Absence of fractures between these two strata have suggested that colored films were painted on shortly after primer application. Additional data obtained from the examination was in regard to layer width and painting campaign. The average thickness of the primer and the paint film were 0.11 mm, and 0.04 mm respectively, while the number of painting campaigns was limited to one.

Colors were selectively applied to the walls to create plain colored surfaces, decorative elements, and protected areas, and to emphasize raised elements. Plain surfaces were achieved with one color, yellow-red, applied to the walls. Decorative elements were articulated with two colors (white with black lines) painted to imitate a scored quoining in the four corners of the main edifice. The protective area, was painted with two colors (reddish yellowish and black) at the base of the wall of the main building.¹⁹⁷

Localized color applications were used to differentiate raised features from the main wall surface. Projective elements such as cornices, the dome caps, windows and main gate frames¹⁹⁸ were finished in a red yellow color in contrast to the pale background. The cornices and the dome cap color were produced by exposed lime-powdered brick stucco.

Revocos are lime-based surface finishes applied with trowels on top of the stucco work. This finish type was identified in two thin sections from the base wall of the main building and the body wall of the perimeter wall (SE-02 and SE-09). It is possible that this surface finish was employed in other areas of the building, but its identification was cumbersome in cross sections. In both samples, they appeared as early finish campaigns of the building. Absence of fractures between this outer layer and the stucco coat have suggested that the *revocos* were applied while the previous coat was wet. The dimensional width of the layer was 0.30 mm.

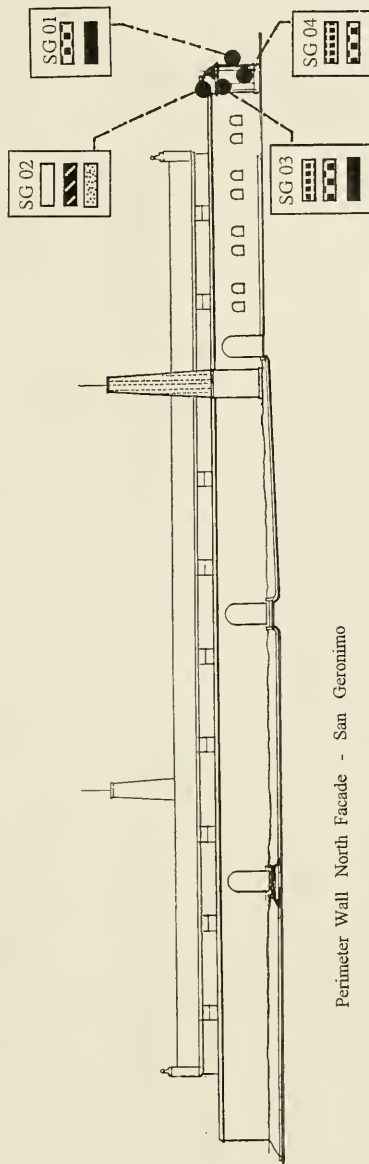
The results of the analyses of the paint finishes revealed the influence of material availability on the painting practices in Puerto Rico. Adaptation of readily available resources to conform with academic and practical knowledge brought from Spain appear to have been the rule. Even though the use of colored limewashes was of common knowledge since ancient times, the colonial builders limited the color schema to pigments available in the area (e.g. gamboge, lime, charcoal). Some of the coloring materials were employed as in the old world traditional methods, and some others in an innovative way, inherent to the particular conditions and materials of the New World.

FINISHES CHARACTERISTICS/ TYPOLOGY											
TABLE No.3											
SAMPLE	CHARACTERISTICS									LOCATION	USE
	1	2	3	4	5	6	7	8	9		
SG 01										Northwest sentry box, window sill	opening
SG 02										Northwest sentry box, dome roof	roofing
SG 03										Northwest sentry box, wall	body wall
SG 04										Northwest sentry box, cornice	dec. element
SG 05										South perimeter ext. wall, wall (next arch open.)	body wall
SG 06										South perimeter ext. wall, wall (next to buttress)	body wall
SG 07										South perimeter ext. wall, coping	dec. element
SG 08										South perimeter ext. wall, wall (top of buttress)	body wall
SG 09										South vent stack, wall	base wall
SG 10										Southeast sentry box, roof cap	dec. element
SG 11										Southeast sentry box, dome roof	roofing
SG 12										Southeast sentry box, wall	body wall
SE 01										Southeast corner, left of quoin	body wall
SE 02										Southeast corner, buttress base	wall base
SE 03										Southeast corner, buttress	body wall
SE 04										Southeast corner, floor	pavement
SE 05										Northeast sentry box, dome roof	roofing
SE 06										Northeast sentry box, cornice	dec. element
SE 07										Northeast sentry box, door frame	opening
SE 08										Northeast sentry box, wall	body wall
SE 09										South perimeter wall, wall (near sentry box)	body wall
SE 10										North perimeter wall, coping	dec. element
Characteristics Legend											
1. Lime stucco											
2. Lime & powdered brick stucco											
3. Cement stucco											
4. Uncolored limewash											
5. Yellowish-red limewash											
6. Red limewash											
7. Gray limewash											
8. Wood particles											
9. Additive											

Table No.4					
SURFACE FINISHES					
SAMPLE	SUR. FINISH	COLOR	MUNSELL #	LOCATION	USE
SG 01	Limewash	yellow-red	10YR 9/4	Northeast sentry box, window sill	opening
SG 02	Limewash	gray	5PB 6/1	Northwest sentry box, dome roof	roofing
SG 03	Limewash	yellow-red	10YR 9/4	Northwest sentry box, wall	body wall
SG 04	L/pb stucco	red-yellow	10Y 5/2	Northwest sentry box, cornice	dec. element
SG 05	Limewash	yellow-red	5YR 6/6	South per.ext.wall,wall (next arch opening)	body wall
SG 06	Limewash	white	~ 5Y 9/1	South per.ext.wall, wall (next buttress)	body wall
SG 07	Limewash	white	~ 5Y 9/1	South per. ext. wall, coping	dec. element
SG 08	Limewash	white	~ 5Y 9/1	South per. ext. wall, wall (top buttress)	body wall
SG 09	Limewash	red	2.5YR 5/6	South vent stack, wall	base wall
SG 10	L/pb stucco	red-yellow	5YR 8/6	Southeast sentry box, roof cap	dec. element
SG 11	Lime stucco	white	~ 5Y9/1	Southeast sentry box, dome roof	roofing
SG 12	Lime stucco	white	~ 5Y9/1	Southeast sentry box, wall	body wall
SE 01	Limewash	yellow-red	10YR 8/4	Southeast corner, left of quoin	body wall
SE 02	Limewash	yellow-red	7.5YR 8/8	Southeast corner, buttress base	wall base
SE 03	Limewash	yellow-red	10YR 8/4	Southeast corner , buttress	body wall
SE 04	L/pb stucco	red -yellow	5Y 6/8	Southeast corner, floor	pavement
SE 05	Limewash	yellow-red	10YR 7/6	Northeast sentry box, dome roof	roofing
SE 06	L/pb stucco	red-yellow	5YR 6/1	Northeast sentry box, cornice	dec. element
SE 07	L/pb stucco	red-yellow	10OR 5/8	Northeast sentry box, door frame	opening
SE 08	Limewash	yellow-red	10YR 7/6	Northeast sentry box, wall	body wall
SE 09	Limewash	yellow-red	10YR 7/6	South per. wall, wall (near sentry box)	body wall
SE 10	Limewash	yellow-red	10YR 7/6	North perimeter wall, coping	dec. element









Table No. 5 LAYERS AVERAGE WIDTH			
SAN GERONIMO	Width (mm)	SANTA ELENA	Width (mm)
Lime Stucco		Lime Stucco	
Base Coat	2	Base Coat	1.8
Intermediate Coat	3.5	Intermediate Coat	4
Finish Coat	0.45	Finish Coat	0.4
Lime-brick dust stucco		Lime-brick dust stucco	
Base Coat	5	Base Coat	2
Intermediate Coat		Intermediate Coat	3.95
Finish Coat	1	Finish Coat	0.4
Surface Finishes		Surface Finishes	
		Revocos	0.3
Primer	0.55	Primer	0.11
Limewash	0.5	Limewash	0.04

FINISHES TYPOLOGY - SAN GERONIMO

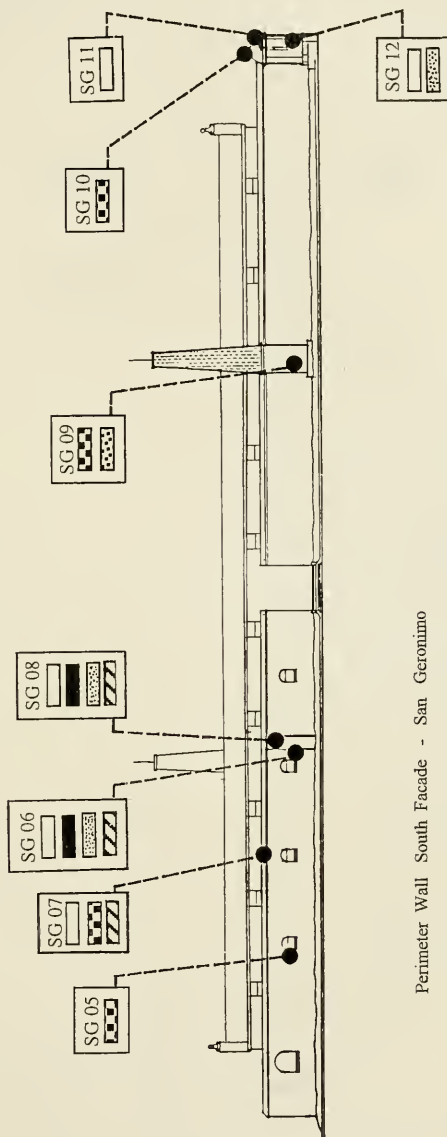


Perimeter Wall North Facade - San Geronimo

LEGEND

	Lime stucco		Yellowish-red limewash		Red limewash
	Lime & pow. brick stucco		Whitewash		Additive
	Cement stucco		Gray limewash		

FINISHES TYPOLOGY - SAN GERONIMO

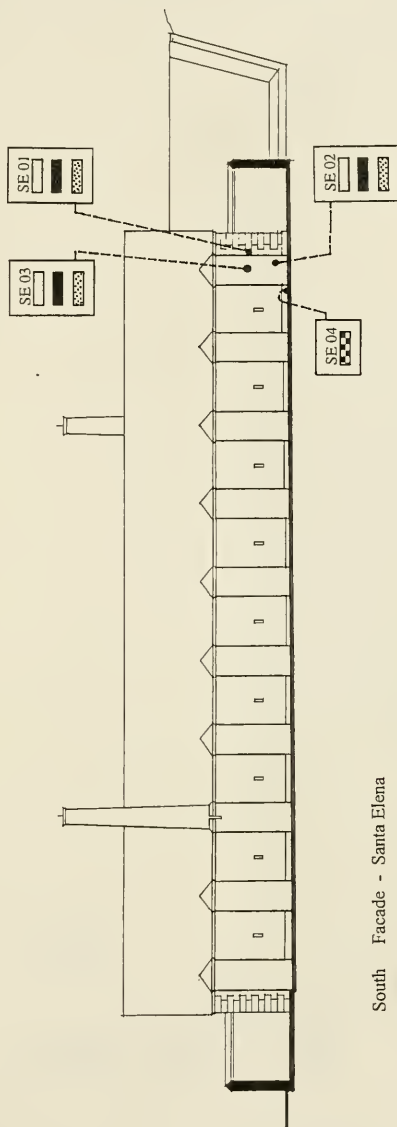


Perimeter Wall South Facade - San Geronimo

LEGEND

	Lime stucco		Yellowish-red limewash		Red limewash
	Lime & pow. brick stucco		White wash		Additive
	Cement stucco		Gray limewash		

FINISHES TYPOLOGY - SANTA ELENA



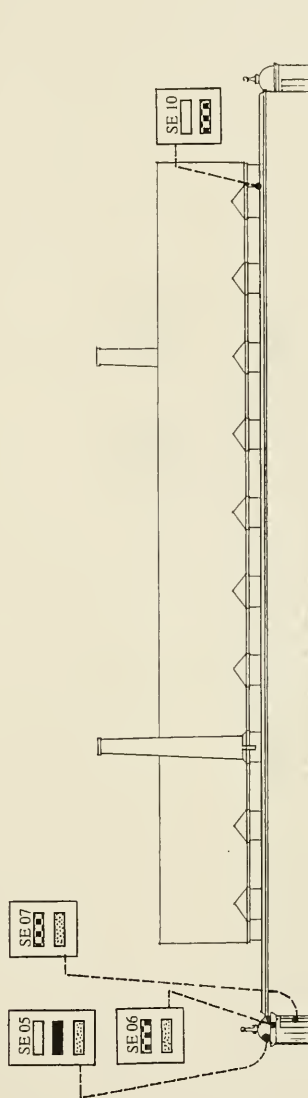
South Facade - Santa Elena

LEGEND

	Lime stucco		Yellowish-red lime wash		Red lime wash
	Lime & pow. brick stucco		White wash		Additive
	Cement stucco		Gray lime wash		









ILLUSTRATION No.14

FINISHES TYPOLOGY - SANTA ELENA

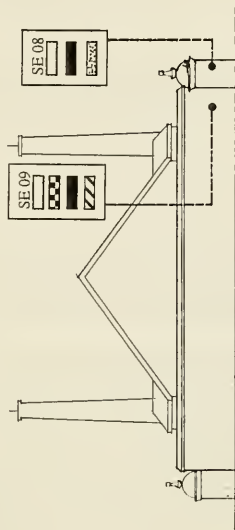


Perimeter Wal North Facade - Santa Elena

LEGEND

	Lime stucco		Red lime wash
	Lime & pow. brick stucco		Yellowish-red lime wash
	Cement stucco		Whitewash
			Gray lime wash
			Additive

FINISHES TYPOLOGY - SANTA ELENA



Perimeter Wall East Facade - Santa Elena

LEGEND

	Lime stucco		Yellowish-red limewash		Red limewash
	Lime & pow. brick stucco		Whitewash		Additive
	Cement stucco		Gray limewash		

End Notes Chapter Three

162. Juan Manuel Zapatero, "El Periodo de Esplendor en las Fortificaciones de San Juan de Puerto Rico", *Asinto*, Vol.5 (1959), p. 27.
163. Albert Macuncy and Ricardo Torres-Reyes, *The Forts of Old San Juan*, (Connecticut: The Chatham Press, Inc. 1973), p.67.
164. Adolfo De Hostos, *Ciudad Murada 1521-1898*, (Havana: Editorial Lex, 1948), p. 213.
165. According to Juan Zapatero the models adopted during the eighteenth century by the Caribbean military architecture were similar to those suggested by the French military treatise wrote by Vaudin. (*Escuela de Forticacion Abaluartada en America*, Juan Zapatero [*San Juan: Instituto de Cultura Puertorriquena*, 1978],p.178).
166. Ibid., p. 179.
167. De Hostos, p. 213.
168. *Informe para el Proyecto de Remodelacion del Parque Luis Munoz Rivera*, December, 1991, San Juan, Puerto Rico.
169. Zapatero, p. 179.
170. De Hostos, p. 213.
171. Boiplast™
172. Buehler Isomet™
173. Buehler Micropolish II™, 0.05 microm.
174. In those test that required heat, the acid treated sample pigmented particles turned dark first, and burned producing copious smoke and an aromatic smell of burnt resin.
175. The paint film observed in unembedded samples showed two distinctive components: red-orange nodules, randomly distributed; and fine yellow particles dispersed in limewash. When observed in cross-section the yellowish-red paints appeared as two distinctive strata. The first is a bright translucent and continuos yellow-red layer with few deep orange red particles. The second and outermost layer, appeared as a bright semi-translucent and discontinuous orange-red layer. In the stucco stratum it became visible as fine, irregular, and scarce yellowish-red particles randomly distributed in the paste.
176. Juan Zapatero, *Historia del Castillo de San Lorenzo del Real de Chagres*, (Madrid: CEHOPU, 1985), p. 27.
177. Advance Architectural Conservation Laboratory Exercises, Spring, 1994, University of Pennsylvania, Philadelphia.
178. Ibid.
179. F. W. Weber, *Artists' Pigments, and Their Chemical and Physical Properties*, (New York: D. Van Nostrand Company, Inc., 1923), p.57.
180. Rutherford Gettens and George Stout, *Painting Materials, A Short Encyclopedia*, (New York: Dover Publications, 1966), p.115.
181. Graham Lawes, *Scanning Electron Microscopy and X-Ray Microanalysis*, (London: Thames Polytechnic, 1987), p. 96.

182. *Informe para el Proyecto de Remodelacion del Parque Luis Munoz Rivera*, December, 1991. San Juan, Puerto Rico.
183. The dimension were recorded from embedded sample which are limited to the size of the mold.
184. Ignacio Garate, *Artes de la Cal*, (Madrid: Instituto de Conservacion y Restauracion de Bienes Culturales, 1993), p.124.
185. Brick dust is mentioned in the *Ten Books of Architecture* by Vitruvio as water repellent component lime plaster. The actual properties of the brick dust are unknown, but it hardly imparts hydraulic properties to the mix. Puzzolanas with same basic composition (silica and alumina) were use to made hydraulic artificial conglomerates, but these elements are there in very reactive form capable to generate truly moisture repellent mixture.
186. The dimension were recorded from embedded sample which are limited to the size of the mold.
187. Similar stucco paste, adulterated with clay material, were found in El Castillo del Morro in San Juan. (The Fortifications of San Juan National Historic Site. Historic Structure Report, 1991, National Park Service, USDI) p.16.
188. Garate, p. 124.
189. Brick dust is mentioned in the *Ten Books of Architecture* by Vitruvio as water repellent component lime plaster. The actual properties of the brick dust are unknown, but it hardly imparts hydraulic properties to the mix. Puzzolanas with same basic composition (silica and alumina) were use to made hydraulic artificial conglomerates, but these elements are there in very reactive form which is capable to generate truly moisture repellent mixture.
190. The dimension were recorded from embedded sample which are limited to the size of the mold.
191. Gamboge is a yellow gum-resin obtained from the *Garcinia* trees originally of India, Ceylon and Siam, and found in other similar tropical climates (e.g. Central America and the Caribbean area). It was probably use in another Puerto Rican Colonial fortresses according to the information reported in the Historic Structure Report of San Juan Historic Site, that states that the yellowish-red paints used in El Morro Batteries appeared to have an organic binder. (The Fortifications of San Juan National Historic Site. Historic Structure Report, 1991, National Park Service, USDI), p.31.
192. Brick dust was employed for red limewahses in Spain, as a cheaper alternative to pure red pigment. (*Artes de la Cal*, Ignacio Garate, [Madrid: Instituto de Conservacion y Restauracion de Bienes Culturales, 1993], p.113.
193. This assumption is suggested by the crystallization front present in the stucco coats underneath the colored limewashes.
194. R. Sengupta. "Use of Dammar as a waterproofing medium for painting at Bayiman", *Indo-Asia Culture* 4, Vol. XVII, October, 1968), in Maribea Beas, *Traditional Architectural Renders on Earthen Surfaces*, (Master Thesis, University of Pennsylvania, 1991), p.28.

195. F. W. Weber, *Artists' Pigments, and Their Chemical and Physical Properties*, (New York: D. Van Nostrand Company, Inc., 1943),p.57.
196. *Revocos* are fine stucco paste with very fine or no aggregate applied with trowels on top of the stucco work.
197. *Examination and Analysis of Exterior Finishes*, Polvorin de San Geronimo and Polvorin de Santa Elena, January, 1991, San Juan, Puerto Rico.
198. The only decorative element in the samples was the cornice. The information about the rest was obtained from the Report *Examination and Analysis of Exterior Finishes*, Polvorin de San Geronimo and Polvorin de Santa Elena, January, 1991, San Juan, Puerto Rico.

CONCLUSIONS

The rediscovery of certain Roman technologies such as plaster work during the Renaissance through the work of Vitruvius, renewed interest in these methods for their use on building exteriors. Documentary sources on surface finish technology from the sixteenth to the nineteenth century display similar techniques and materials to the Roman traditions. The primary stuccos or plasters were prepared with lime and sand, in a basic ratio of 1 to 3, and applied in at least three coats. A similar process of mortar preparation, using the same type of aggregate, are suggested by all the authors; however, there was a tendency to simplify the extremely elaborate processes. Evidence of this is San Nicolas' and Alberti's proposal for the use of bituminous materials to imitate the mirror-like finishes made out of marble dust suggested by Vitruvius. Also, during the nineteenth century, a better understanding of the materials is suggested by changes in the basic procedures and technologies for stucco preparation proposed by Villanueva.

Similar concerns are reflected in the fine arts treatises about the use of pigments. Unlike Vitruvius, who included some organic pigments as suitable for stucco painting, the Spanish sources on fine arts painting suggest that authors recognized the limitation imposed by the alkalinity of the lime substrate on the color palette. The pigments suggested by them was restricted to earths and minerals.

The basic technologies of exterior architectural surface finishes stated in the architectural literature from the sixteenth to the nineteenth-century were also found in the Spanish colonial Caribbean buildings analyzed in this study. The results of the analyses reflected to a considerable extent, the information reported in the treatises reviewed. Regional variations determined by availability of material, technology, and climate, nevertheless, appeared to influence the methods applied. The study of the stucco samples

suggests adaptation of readily available resources to conform with academic and practical knowledge brought from Spain. Instead of lime derived from limestone, in the Caribbean lime was obtained from shells and coral. Also some pigments such as gamboge traditionally use for fine arts oil painting in Europe was use in for architectural paints in the New World. The primary components used in the preparation of stucco - lime and sand- were the same in Spain and the New World. However, instead of the recommended limestone and mine sand, the lime appears to have been derived from shells and readily available corral, and the sand from beach sources. The layer stratigraphic structure of three coat stucco described in the treatises was the same as the stratigraphy of the wall stucco samples examined for this study. Also the recommended changes in aggregate type and the thickness of the coats was observed in the samples studied. However, unlike the lime stuccos, the lime-powdered brick stucco used primarily in elements exposed to severe weather conditions was laid in one coat.

The concern for the resistance of stuccos to deterioration caused by water penetration in an extremely humid climate was observed by the extensive use of a lime and powdered brick in the elements exposed to extreme weather conditions at San Geronimo and Santa Elena Powder Magazine such as cornices and window frames. This also suggests a direct connection between the type of finishes applied and the function of the building; since gunpowder dry environments.

The influence of the treatises can be recognized in the surface finishes as well. *Revocos*, the thin lime-based finishes suggested by Vitruvius and later described by Villanueva, were used in the first surface treatment finishes campaign. In later repaintings, colored limewashes were applied on top of the *revocos* in accordance with the finishes suggested in the colonial Mexican treatise *Architectural Practice in Mexico City*. The color scheme of the limewashes was limited to pigments available in the area and mostly

similar to the coloring matters suggested in the Spanish fine arts treatises reviewed. The present analysis of the Caribbean stuccos however, suggested that some adaptations of locally produced pigments were implemented in the New World. Exemplified in the adaptation of the gum-resin gamboge, traditionally use for oil painting, for architectural paints.

The use of color and the articulation of the overall coloring schema on the building was not limited to plain colored surfaces. Color was also used to imitate decorative elements, to create protected areas, and to emphasize in relief elements. Decorative elements were articulated with two contrasting colors painted to imitate ashlar scored quoining in the corners of the main edifice. The protective area was painted with two colors at the base of the wall of the main building. Relieved elements such as cornices, dome caps, and main gate frame were finished in a red-yellow color in contrast to the pale background.

Additive agents as well as the finish materials were either the same or similar to the admixtures employed in Spain. Resins, natural fibers, milk and animal glues among others, were added to the stucco work or architectural paints to improve the performance of these surface finishes. New additive agents produced from native materials such as cactus glue were used as well during the colonial era. The colonial builders employed materials that resembled the properties of the materials already known to them, or adopted the materials from the traditional building practices of the indigenous people of the area.

RECOMMENDATIONS

The study of the technology and materials of exterior surface finishes in the Spanish Caribbean during the colonial period is a complex topic; however, until now, research in this area has been limited. The intention of this study has been to contribute to an understanding of the surface finishes in the region. The case studies, however, were limited to two buildings in the Caribbean, and a review of treatises on surface finish technology. It is recommended to carry out further historical and analytical research on the following:

- Investigation of primary documentary sources in the national archives of the Spanish Caribbean countries, and The Archives of the India in Seville, Spain. Trade invoices, building reports, inventories, legal information, building specifications, construction drawings, wills, construction inspection reports, governor reports to the crown, and custom bills should be examined.
- Additional study of architectural surface finishes technology in architectural treatises and trade treatises on stucco and painting technology other than those consulted for this study.
- Additional examination, description and analysis, of actual samples from other representative buildings from Puerto Rico and other Spanish Caribbean countries.
- Examination of finishes by building type (e.g. religious, domestic, public, and military buildings) to establish possible differences based on the function of the building.
- Application of analytical techniques such as gas chromatography-mass spectroscopy, infrared spectroscopy or Fowrier Transform infrared microscopy to identify organic components in stucco, paint binders, and additives traditionally used in surface finishes.

- Implementation of quantitative analysis of stucco components by differential thermal analysis (DTA) and mass spectrometry for quantitative and qualitative analyses.
- Test the performance of the original stucco recipes by facsimiles.

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APPENDIX I: SAMPLE SHEETS

Exterior Surface Finishes: Phase I Examination

Site: Polvorin de Santa Elena,

Campo del Morro, San Juan, Puerto Rico

Sample Location: S.E. corner, but base, wall juncture

Substrate: Calcareous sandstone + brick rubble mas.

Sample No. SE-02

Illum. A: Ref. Light

Mag. A: 4x

Illum. B: Pseu Dark

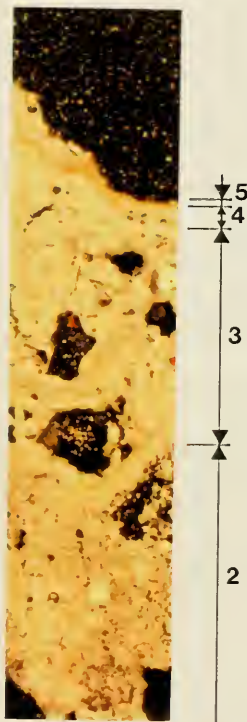
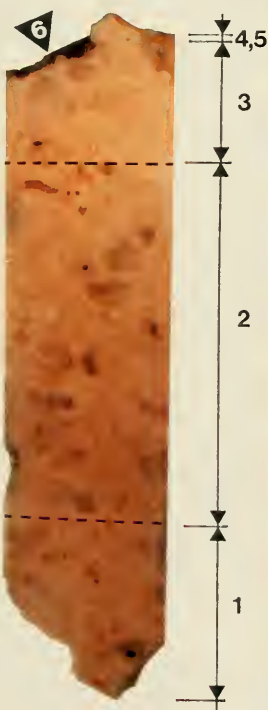
Field

Mag. B: 12.5x

Stratigraphy:

A

B



1. Stucco (1.80mm)
2. Stucco (4.0 mm)
3. Stucco (0.55mm)
4. Primer (0.20mm)
5. Paint (0.04mm)
6. Dirt/ Org.Growth
7. _____
8. _____
9. _____
10. _____

Sample No. SE-02

Observations:

- Layer 1:** Color (2.5 Y 8/2). Matrix: light gray homogeneous color w/ very small vacuole.
(Stucco) Aggregate: - White: clear, coarse, medium/ trapezoidal, irregular, elongated, squared / subangular, subrounded; - three-colored (black, yellow, gray): coarse/ ellipsoidal/ rounded; yellow reddish: translucent, very fine, irregular. Well graded aggregate, mainly white clear, medium, trapezoidal, and subangular, concentrated on the bottom of the layer. The percentage of binder material is greater than the aggregate, and the width is uneven (ranges from 2.0 mm to 1.60 mm). The layer is not clearly differentiated.
- Layer 2:** Color (2.5 Y 8/2). Matrix: light gray, sugary appearance, w/ fine voids.
(Stucco) Aggregate: - white: clear, very fine, fine, medium, coarse/ triangular, trapezoidal, spherical, elongated, squared/ subangular, subrounded; - white opaque: coarse/ elongated, spherical/ rounded; -yellow: translucent/ fine/ elongated, ellipsoidal/ rounded, subrounded. Heterogeneous and evenly distributed aggregate, and primary white clear, medium, triangular, and subangular. Equal proportion of binder to aggregate, and even thickness are also characteristic of this not very distinct layer.
- Layer 3:** Color (2.5 Y 9/2). Matrix: light gray homogeneous color. Aggregate:- clear: coarse/ elongated/ trapezoidal, irregular/ subangular, subrounded; yellow reddish: very fine, translucent, irregular. Aggregate is primarily white, clear, medium and subangular concentrated on the top of the layer and proportionally greater than the binder. Air vacuoles and cavities due to particle lost present on the matrix. It is no clearly differentiated from the previous layer, but very distinct from the next one because of the crystallization layer that occurs on top of it. Uneven width ranging from 0.50 mm to 0.60 mm
- Layer 4:** Color (2.5 Y 8.5/2). White opaque continuous and width in a range of 0.19
(Primer) to 0.23 mm.
- Layer 5:** Color (7.5 YR 8/8). Semi translucent red-orange, with scarce deep orange,
(Paint) particles, and uneven width in a range of 0.06 mm to 0.02 mm.
- Layer 6:** White, discontinuous and uneven width in range of 0.10 to 0.13 mm.
(Effl.)
- Layer 7:** Dirt or organic growth, discontinuous and irregular width.
(Dirt)

Exterior Surface Finishes: Phase I Examination

Site: Polvorin de Santa Elena,

Campo del Morro, San Juan, Puerto Rico

Sample Location: South wall, near s box, body wall

Substrate: Calcareous sandstone + brick rubble mas.

Sample No. SE-09

Illum. A: Ref. Ligh

Mag. A: 3.75x

Illum. B: Pseu. Dark
Field

Mag. B: 12.5x

Stratigraphy:

A

B



1. Stucco (2.00mm)

2. Stucco (3.95mm)

3. Stucco (0.40mm)

4. Sur.Fin. (0.30mm)

5. Stucco (1.25mm)

6. Primer (0.08mm)

7. Paint (0.01mm)

8. _____

9. _____

10. _____

Sample No. SE-09

Observations:

Layer 1: Color (2.5 5/10). Matrix: bi-color, dark red-brown and orange yellow.

(Stucco) Aggregate: -white: clear, translucent/ medium to medium-fine/ elongated, trapezoidal, triangular/ subangular, subrounded. Evenly distributed aggregate, but primarily white, clear, medium, trapezoidal and subrounded. A roughly equal proportion binder to aggregate and even width, are also characteristics of this layer.

Layer 2: Color (5 YR 7/6). Matrix: light orange, non homogeneous, w/ very fine red-

(Stucco) brown, white, and black particles. Aggregates: - white: clear/ very coarse to fine/ elongated, squared, trapezoidal, spherical/ rounded, subrounded, angular, subangular; - white: opaque/ fine, coarse/ squared, trapezoidal, ellipsoidal/ subrounded, subangular; - dark red orange: very fine to fine/ trapezoidal/ subrounded; -dark gray: coarse/ trapezoidal/ subrounded. Heterogeneously graded and well distributed aggregate, but primarily white, clear, trapezoidal, and subrounded. The representative features of this layer are a higher proportion of aggregate than binder material, and irregular width.

Layer 3: Color (5 YR 8/4). Matrix: Yellow-red homogeneous color, and evenly textured

(Stucco) paste. Aggregate: White : clear/ fine, medium/ triangular/ elongated/ trapezoidal/ subrounded, subangular, angular. Evenly distributed aggregate and predominantly white clear, medium, trapezoidal, and subangular, and higher percentage of binder than the aggregate, are characteristic of this layer.

Layer 4: Color (10 YR 9/1). Matrix: bright white homogeneous. Aggregates: White:

(Stucco) clear/coarse/ trapezoidal/ subangular; -white: opaque/ medium/ elongated/ rounded. A fine crystallization line is located on the outside section of the layer.

Layer 5: Color (5 YR 9/1). Matrix: Bright white, and unevenly textured. Aggregate:

(Sur. Fin.) -white: clear/ very fine, fine, medium, coarse/ elongated, irregular, trapezoidal, squared/subrounded, subangular. Evenly distributed aggregate; but predominantly fine, trapezoidal, and subangular, higher binder proportion than aggregate, a crystallization layer on top is characteristic of this layer.

Layer 6: Color (5 YR 9/1). Bright white, opaque, homogeneous, continuous and even
(Primer) width.

Layer 7: Color (10 YR 9/4). Nearly homogenous light red-yellow, bright, semi-,
(Paint) translucent w/very fine red particles, and constant width measurements.

Exterior Surface Finishes: Phase I Examination

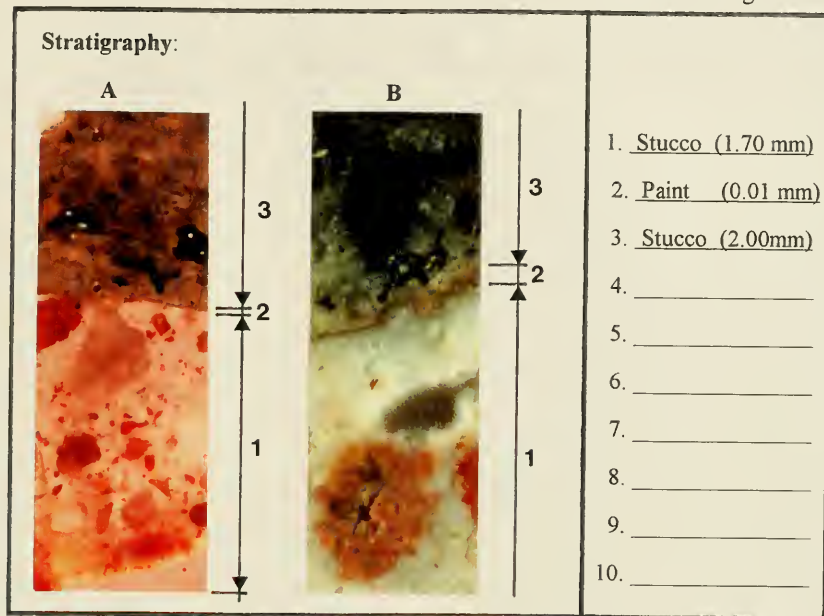
Site: Polvorin de San Geronimo,
Parque Luis Munoz Rivera,
Puerta de Tierra, San Juan, Puerto Rico
Sample Location: N.E. Sentry box, body wall stucco
Substrate: Calcareous sandstone

Sample No. SG-03

Mag. A: 10x

Mag. B: 25x

Illum.: Ref. Light



Observations:

- Layer 1:** Color (2.5 YR 8/4). Matrix: bright white w/ reddish and white translucent (Stucco) very fine particles. Aggregates: - white: clear/ fine to coarse/ triangular, ellipsoidal/ rounded, subrounded, subangular; -white: fine to very fine/ squared, elongated, trapezoidal/ rounded, subrounded, angular, subangular; - orange red: clear/ coarse to very fine/ elongated, trapezoidal/ subrounded, subangular. Heterogenous and evenly distributed aggregate. The proportion of aggregate is greater than the binder. Uneven width ranging from 2.40mm to 1.00mm.
- Layer 2:** Color (10 YR 9/4). Brigh yellow-red, mostly homogenous in color, uniform (Paint) width, and continous layer.

Sample No. SG-03

Layer 3: Color (10 YR 4/2). Matrix: gray greenish w/ very fine dark green and clear (Stucco) particles. Aggregates: - white: clear/ coarse/ trapezoidal, elongated, ellipsoidal/ rounded, subrounded, subangular; -light gray: fine/ elongated, trapezoidal/ subangular, subrounded; - yellow: translucent/ medium/ trapezoidal/ subrounded; - multicolored (light brown, bright white, black): very coarse/ ellipsoidal/ subrounded. Heterogeneously and evenly graded aggregate with a predominance of white clear ellipsoidal aggregate. A greater proportion of binder to aggregate, cavities and vacuoles, and uneven width are also characteristic of this layer.

Exterior Surface Finishes: Phase I Examination

Site: Polvorin de San Geronimo,
Parque Luis Munoz Rivera,
Puerta de Tierra, San Juan, Puerto Rico

Sample Location: S.E. sentry box, roof cap

Substrate: Sandstone

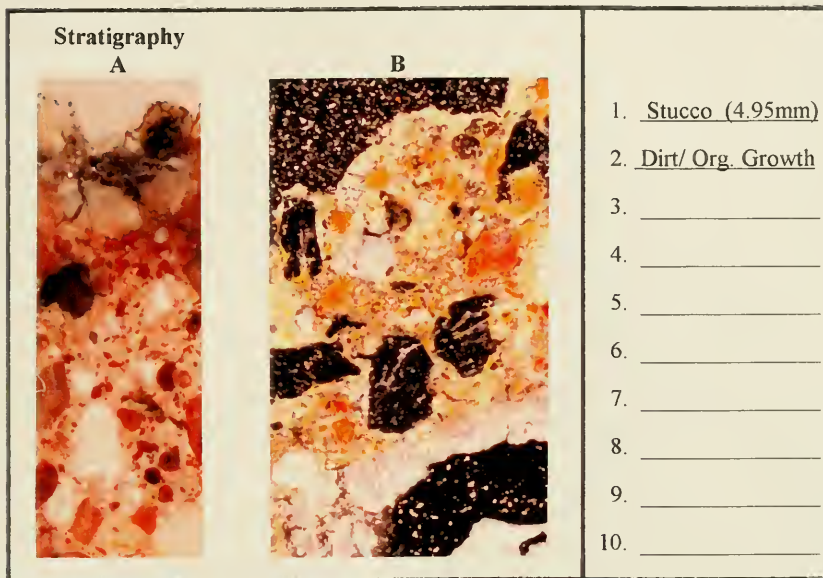
Sample No. SG-10

Illum. A: Ref.Light

Mag. A: 10x

Illum.B: Pseu. Dark Field

Mag. B: 12.5x



Observations:

Layer 1: Color (5YR 8/6). Matrix: bright white w/ very fine red and white clear and opaque particles. Aggregate: - white: clear/ fine to coarse/ elongated, trapezoidal/ subrounded; - bright white: opaque/ fine to coarse/ trapezoidal/ subangular, subrounded; - white: semitranslucent/ medium to coarse/ trapezoidal/ subrounded, rounded; - red: clear/ fine/ trapezoidal/ spherical/ subrounded, subangular; - red-orange: opaque/ fine to very coarse/ trapezoidal, irregular/ subrounded. **Heterogenously and evenly graded aggregate. Elongated cavities randomly distributed in the matrix, greater proportion of aggregate than binder, and uneven width, are also characteristic of this stucco layer.**

Layer 2: Dirt or organic growth.
(Dirt)

APPENDIX II: SAMPLE LIST

SAMPLE LIST

San Geronimo

Sample	Location	Use
SG 01	Northwest sentry box, window sill	opening
SG 02	Northwest sentry box, dome roof	roofing
SG 03	Northwest sentry box, wall	body wall
SG 04	Northwest sentry box, cornice	dec. element
SG 05	South perimeter ext. wall, wall (next arch open.)	body wall
SG 06	South perimeter ext. wall, wall (next to buttress)	body wall
SG 07	South perimeter ext. wall, coping	dec. element
SG 08	South perimeter ext. wall, wall (top of buttress)	body wall
SG 09	South vent stack, wall	base wall
SG 10	Southeast sentry box, roof cap	dec. element
SG 11	Southeast sentry box, dome roof	roofing
SG 12	Southeast sentry box, wall	body wall

Santa Elena

SE 01	Southeast corner, left of quoin	body wall
SE 02	Southeast corner, buttress base	wall base
SE 03	Southeast corner, buttress	body wall
SE 04	Southeast corner, floor	pavement
SE 05	Northeast sentry box, dome roof	roofing
SE 06	Northeast sentry box, cornice	dec. element
SE 07	Northeast sentry box, door frame	opening
SE 08	Northeast sentry box, wall	body wall
SE 09	South perimeter wall, wall (near sentry box)	body wall
SE 10	North perimeter wall, coping	dec. element

APPENDIX III: Energy Dispersive X-ray Fluorescence Analysis (EDX) Results.

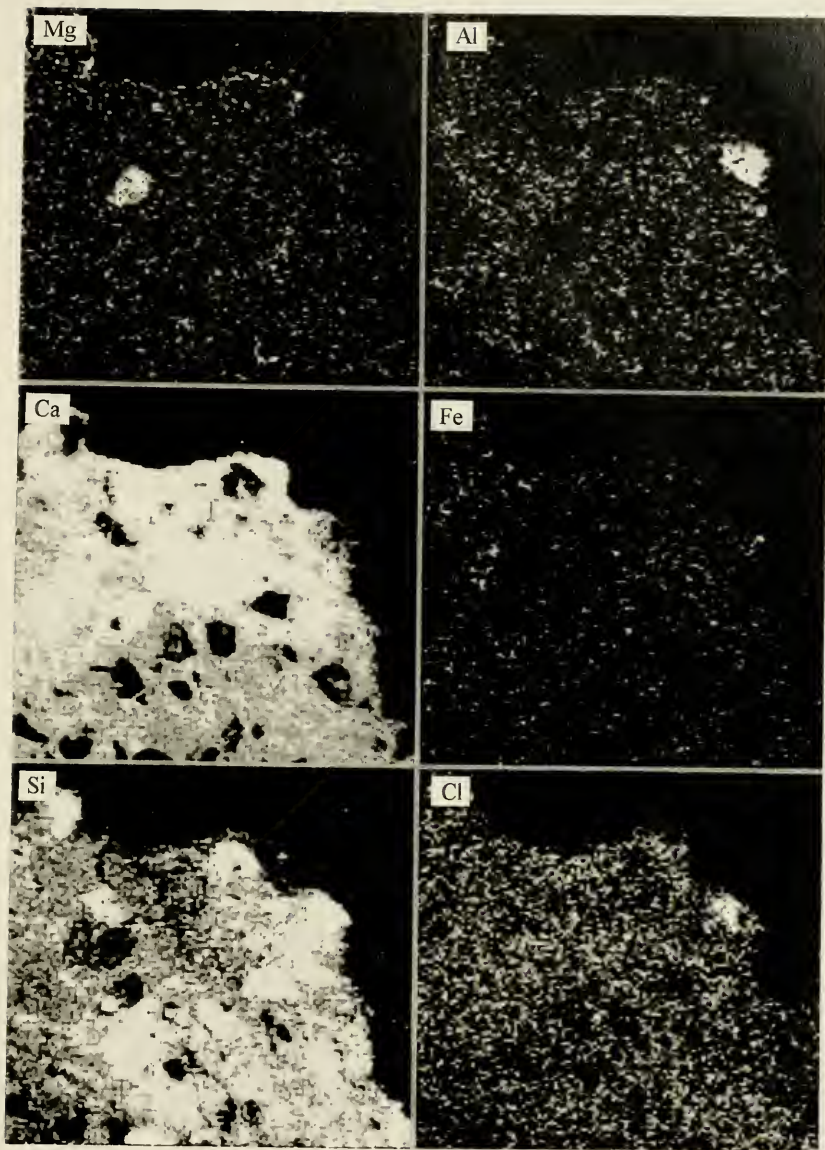


Illustration No. 16: Sample SE-02 X-ray element dot map showing elements found in higher concentration.

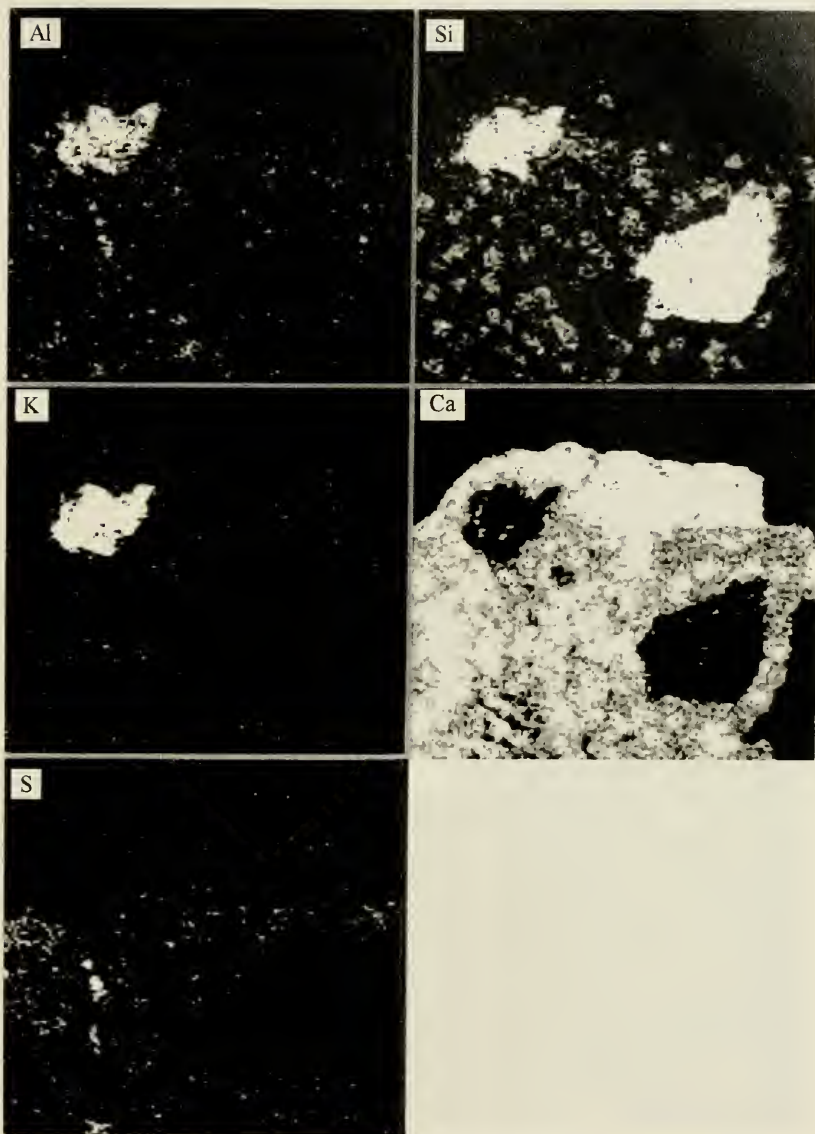


Illustration No. 17: Sample SE-09 X-ray element dot map showing elements found in higher concentration.

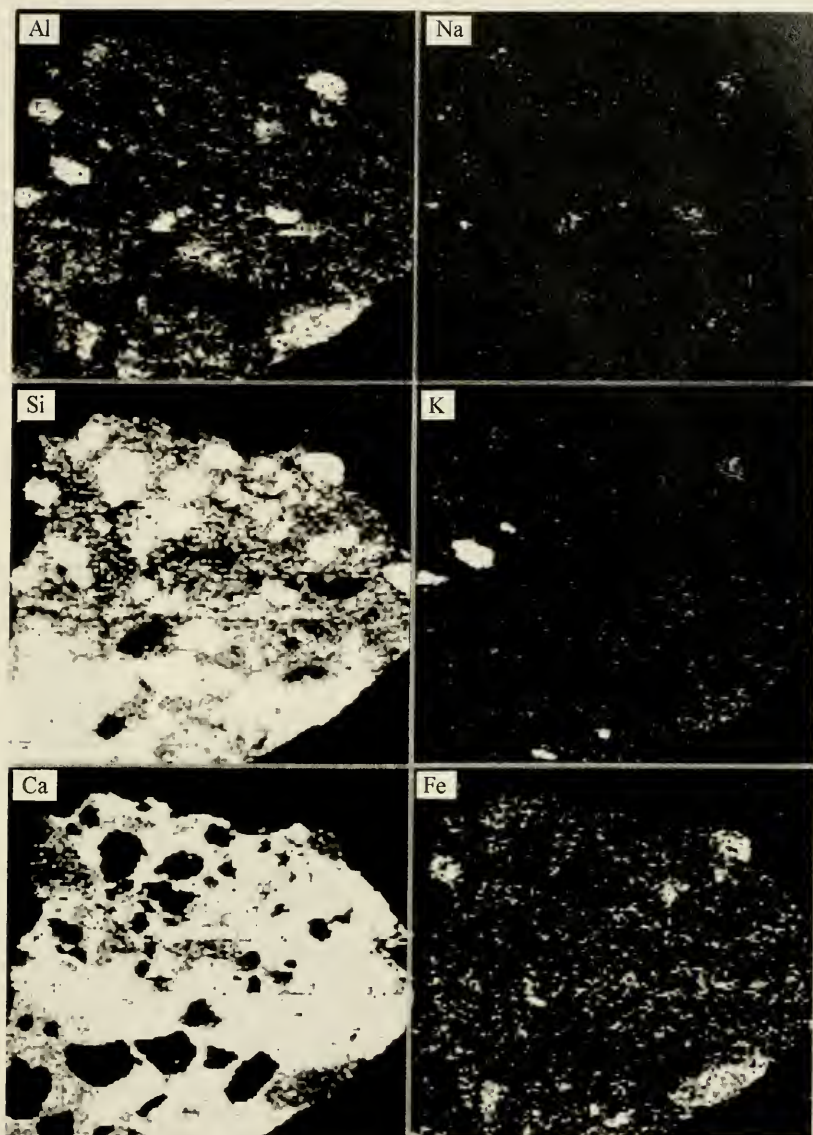


Illustration No. 18: Sample SG-03 X-ray element dot map showing elements found in higher concentration.

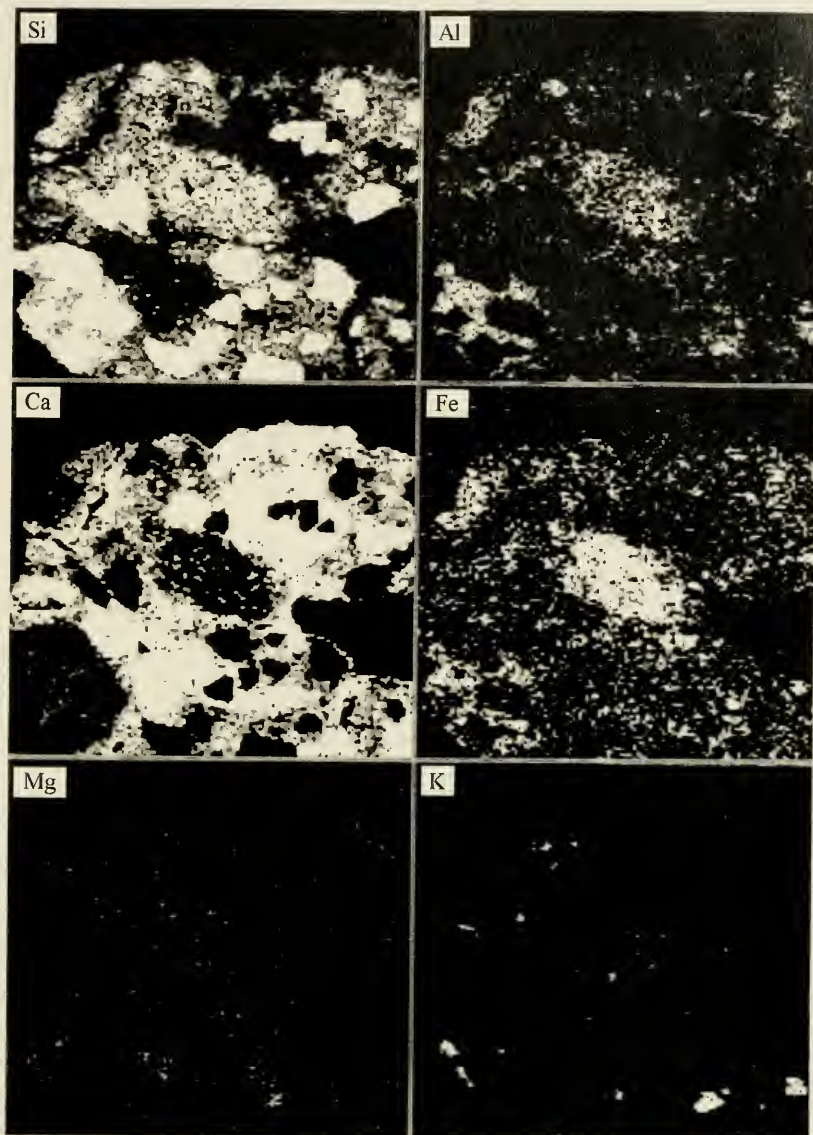


Illustration No. 19: Sample SG-10 X-ray element dot map showing elements found in higher concentration.

**APPENDIX IV: San Geronimo and Santa Elena Powder Magazines
Photographs.**



Illustration No. 20: San Geronimo main facade.



Illustration No. 21: San Geronimo main facade.



Illustration No. 22:
Santa Eleua main facade.



Illustration No. 23: Santa Elena lateral facade.



Illustration No. 24: Santa Elena northwest sentry box.



Illustration No. 25: Santa Elena north facade perimeter wall.

APPENDIX V: Glossary of Terms

Acabados: Finishing materials laid on masonry walls.

Aguada: Dye applied to the wall to remove the whiteness of the plaster coat.

Whitewash. (Sinon. *Lechada*)

Allanar: To level, to smooth or to flatten wall finishes or land. (Sinon. *brunir*, *aplanar*).

Apagar: To slake the lime lumps.

Aplanado: Plaster, plastering.

Argamasa: Mortar composed by lime, sand, brick dust and coconut fiber or calcareous sand.

Azogar: To slake the lime by spraying water to the lime lumps.

Azulaque: A kind of bitumen or mastic made out of vegetable fibers, lime, oil and slags grounded glass. It was employed to seal the joints of water pipes. (Sinon. Zulaque, betun)

Betun: A kind of bitumen or mastic made out of vegetable fibers, lime, oil and slags or grounded glass. It was employed to seal the joints of water pipes. (Sinon. Azulaque, zulaque).

Blanquear: To apply one or more coats of lime or gypsum wash to walls or building roofs. (Sinon. *Encalar*, *blanqueo*)

Blanqueo: To apply one or more coats of lime or gypsum wash to walls or building roofs. (Sinon. *Encalar*, *blanquear*)

Brunido: A polished finish.

Brunir: To burnish, to polish.

Cal: Lime.

Cal apagada: Slaked lime.

Cal grasa: Lime putty

Cal magra: Slaked lime

Cal viva: Unslaked lime.

Calcina: Mixture of lime and grounded stones.

Caliche: Limewash spalls.

Cascajo: Brick or stone fragments.

Complanar: To level, to smooth or to flatten wall finishes.

Encalar: To plaster with lime or a bitumen that has unslaked lime.

Enfoscado: First mortar coat or base coat applied directly on the substrate. It protects and levels the substrate surface.

Enfoscar: To cover with mortar holes in a new wall.

Enjarre: Plaster or stucco.

Enlucido: Plaster or plaster coat./ Rough paint made out of milk, lime, or gum, of neutral color, and applied with wide brushes on interior and exterior walls./ Bright finishes coat achieved by polishing the stucco with a wooden trowel.

Escayola: A kind of colored gypsum stucco, very resistant and adhesive, employed to imitate marble and other natural stones.

Esgrafiado: Sgraffito.

Estucco: Composite of gypsum, gum, and linseed oil, employed as decorative finishes on masonry walls.

Estucco de marmol: Mixture of cement, lime or gypsum, and pulverized marble or a coloring matter that is applied on walls to imitate marble.

Frates: Mushroom shaped trowel, similar in shape to a hawk, used to polish plaster and stucco finishes.

Fratesar: To polish and perfectly smooth a stucco finish with a mushroom shaped trowel (*frates*) right after the stucco has been polished with a regular trowel.

Guarnecido: First mortar coat or base coat applied directly to the substrate. It protects and levels the substrate surface. (Simon. *Enfoscado, jarrado*).

Hormigon: A composite of a conglomerate, sand and gravel.

Jaharrar: To polish a stucco finish.

Jalbegue: Whitewash made out of lime or fine white clays./ Limewash employed for a very smooth polishing of the stucco or plaster.

Jarrado: First mortar coat or base coat applied directly on the substrate. It protects and levels the substrate surface. (Simon. *Enfoscado, jarrado*).

Lechada de Cal: Limewash

Llana: Regular trowel.

Maestra: Screed, ground, girder.

Mortero: A mixture of a conglomerate, water and sand.

Palustre: Triangular trowel.

Pasta: A conglomerate diluted in water, but not watery.

Revoque: Finish coat applied on top of the *enfoscado*. It generally has finer aggregate than the *enfoscado* layer. It is the finish coat of the stucco. Pigments can be added to it to obtain a colored surface./ Exterior wall stucco. (Simon. *Revoco tendido, pintura or blanqueo*).

Zulaque: (Mex.) A kind of bitumen or mastic made out of vegetal fibers, lime, oil, and slag or grounded glass. It was employed to seal the joints of water pipes. (Simon. *Azulaque, betun*).

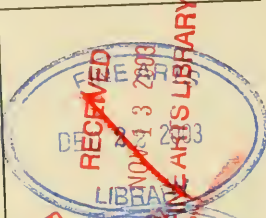
Xalpaco: (Mex.) Watery mortar used as an undercoat to the whitewash.

Anne & Jerome Fisher

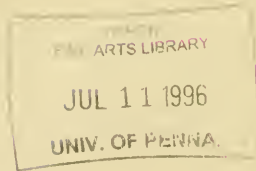
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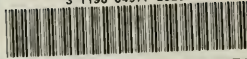


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