Material and Property Characterization of Eight Heritage Churches Declared as National Cultural Treasures

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ABSTRACT

Eight churches in the Philippines built during the Spanish period have been declared as National Cultural Treasures (NCTs). These are: (1) Church of San Agustin, Paoay, Ilocos Norte; (2) Church of Our Lady of the Assumption, Santa Maria, Ilocos Sur; (3) Church of Pope St. Gregory the Great, Majayjay, Laguna; (4) Parish Church of the Holy Cross, Maribojoc, Bohol; (5) Church of Our Lady of the Gate, Daraga, Albay; (6) Parish Church of St. John the Baptist, Jimenez, Misamis Occidental; (7) Church of the Assumption of Our Lady, Maragondon, Cavite; and (8) Church of the Immaculate Conception, Jasaan, Misamis Oriental. These are examples of unique structures with outstanding qualities that are considered highly significant to the country. Built during the Spanish era, these churches

represent a fusion of European and Asian influences with the use of local materials, showcasing Filipino artistry

However, throughout its existence, there have been indications of damage, decay, and deterioration. It is imperative that a thorough study must be done to establish a profile of each of the churches before further repair interventions. A comprehensive understanding of the component material properties of these NCTs through characterization would ensure material authenticity and compatibility in restoration undertakings.

This paper presents the results of phase one of the study on the material and property characterization of these heritage churches that was undertaken as part of a collaborative conservation program made possible through the National Commission for Culture and the Arts. The study aims to establish a comprehensive database of the churches' material profile and present condition with the use of a combination of in situ and laboratory testing techniques on representative samples. The study focuses on the evaluation of mechanical (compressive strength), physical (porosity and moisture content), and chemical (binder analysis and elemental analysis) properties of original as well as repair materials, using the least destructive sampling and testing techniques (rebound hammer and handheld XRF).

INTRODUCTION

Spanish colonial heritage churches are historical landmarks that continue to exert significant spritual and moral influences in the country. Some of these Spanish colonial churches have been declared National Cultural Treasures (NCTs) because of their outstanding historical, cultural, and artistic value, under the Republic Act 10066, National Cultural Heritage Act of 2009. These heritage structures are tangible expressions of the craftsmanship, expertise, and skills of local artisans and masons.

Philippine religious heritage structures showcase the abundance and richness of locally available masonry materials such as corals, adobe, bricks, plaster, and mortar. The behavior of these building materials varies depending on the structures' configuration, location, and environmental conditions. These centuries-old structures have survived despite the long-term effects of decay and devastations caused by natural disasters. This continuing vulnerability remains to be the predominant issue of restoration professionals in the protection of our built heritage.

The integrity of these heritage structures based on basic conservation principles is founded on the structural stability as well as the material authenticity of their component materials. Although some architectural surveys and engineering studies have been conducted on structural conditions, very few have performed material investigations on the original building materials with the aim of ensuring compatibility. This is despite the popularity of stone characterization in the international scientific community. Significant restoration undertakings have been implemented without initial knowledge of the material condition and composition of the structures. Lack of information on conservation practices, especially with regard to the use of incompatible contemporary materials, has led to inadequate interventions that may have caused the loss of the original components.[1] Substantial emphasis has been given to the scientific methods of characterization so that conservators and restorers can properly understand the behavior of materials in undertaking the much needed maintenance work.

With the increased vulnerability of built heritage, it is imperative that a thorough study be done to provide a profile of each of the churches before further repair interventions. To address these concerns, the National Historical Commission of the Philippines (NHCP), has taken the lead in administering the promotion and preservation of Philippine historical heritage through effective conservation campaigns. The NHCP has taken the initiative in conducting the material and property characterization of all heritage churches declared as NCTs.

This paper presents the results of phase one of a study that was undertaken as part of a collaborative conservation program made possible through the National Commission for Culture and the Arts. The study aims to establish a comprehensive database of the churches' material profile and their present condition with the use of a combination of in situ and laboratory testing techniques on representative samples. The study focuses on the evaluation of the mechanical, physical, and chemical properties of original as well as repair materials, using the least destructive sampling and testing techniques.

HERITAGE CHURCHES DECLARED AS NATIONAL CULTURAL TREASURES

This paper focuses on eight heritage churches declared as NCTs as examples of unique structures with outstanding qualities that are considered highly significant to the country. Built during the Spanish era, these churches represent a fusion of European and Asian influences with the use of local materials showcasing Filipino artistry.

These NCTs are located throughout the archipelago. Two are located in North Luzon, three in South Luzon, one in Central Visayas, and two in Northern Mindanao. These feats of construction and artistry are imposing; built as fortresses, they were designed to resist invaders, as well as to withstand environmental hazards like earthquakes and typhoons.

CHURCH OF SAN AGUSTIN, PAOAY, ILOCOS NORTE

The Church of San Agustin in Paoay, Ilocos Norte was built under the supervision of Augustinian Father Antonio Estavillo from 1686 to 1704. Several restoration works on the church were undertaken until its official inauguration on 18 February 1896. Fourteen carved, thick, massive stone buttresses ending with volutes and topped with pyramidal finials provide strong support, thus enabling the church structure to withstand frequent earthquakes.

The church's thick coral block walls were brick-faced with hard lime mortar. It has a three-storey coral stone bell tower with molave braces. The bell tower served as an observation post for the Katipuneros during the Philippine Revolution; it was also used by local guerrillas during World War II.[2] Across the street of the church is the brick convent built in 1719 and restored in 1884. Because of these unique characteristics and its historical value, the Church of San Agustin was declared a National Cultural Treasure on 1 August 1973 and a UNESCO World Heritage Site in 1993.

Figure 1. (a) Church of San Agustin, Paoay, Ilocos Norte; (b) Church of Our Lady of the Assumption, Santa Maria, Ilocos Sur; (c) Church of Pope St. Gregory the Great, Majayjay, Laguna; (d) Parish Church of the Holy Cross, Maribojoc, Bohol; (e) Church of Our Lady of the Gate, Daraga, Albay; (f) Parish Church of St. John the Baptist, Jimenez, Misamis Occidental; (g) Church of the Assumption of Our Lady, Maragondon, Cavite; (h) Church of the Immaculate Conception, Jasaan, Misamis Oriental

CHURCH OF OUR LADY OF THE ASSUMPTION, SANTA MARIA, ILOCOS SUR

The Malong rebellion in 1660 caused the destruction of early structures of the Church of Our Lady of the Assumption in Santa Maria, Ilocos Sur.[3] To replace these, a chapel and tower were constructed in 1810. However, another massive fire burned the church in 1822. The church was then reconstructed in 1824, and restoration work was completed by 1889.[4] Built in the eighteenth century, the church is another exceptional example of Philippine earthquake-proof Baroque architecture. The facade is quasi-Romanesque with rounded arches and pediments. The walls have carved side entrances and strong buttresses. The convent was constructed parallel to the facade of the wall; there is a bell tower at the midpoint of the nave wall. Because of the simplicity of its geometric forms and its location, the church was declared a National Cultural Treasure and a UNESCO World Heritage Site.

PARISH CHURCH OF THE HOLY CROSS, MARIBOJOC, BOHOL

The coral stone church of Maribojoc, Bohol was the third structure built in 1852 by Fr. Manuel Plaza and completed in 1872 by Fr. Fernando Rubio.[5] This structure remained standing after the town fire during World War II. However, it was completely destroyed by the earthquake that hit Bohol Island on 15 October 2013. The wide and massive two-level facade of the Church of the Holy Cross held a bas relief of San Vicente Ferrer with a pyramidal roof originally made of *tisa*. The church ceiling was painted by a renowned church artist, Ray Francia, illustrating liturgical motifs in 1930. Exquisitely carved and painted neo-Gothic, hardwood retablos highlighted the interior of the church, along with a nineteenth-century metal pipe organ found at the choir loft. The bell tower was on the right side of the main church, which contained seven bells and a clock acquired from the Altonaga Company in Manila.[6] Behind the structure was the stone convent, built by Fr. Fernando Rubio, which had access from the sacristy. This Spanish-period colonial architecture was declared a National Cultural Treasure in 2009.

CHURCH OF POPE ST. GREGORY THE GREAT, MAJAYJAY, LAGUNA

An early structure made of bamboo and nipa was built by the Augustinians in 1573 but was destroyed by a fire three years later. A second church was built by Franciscan Father Juan de Plasencia in 1578. However, it was burned again in 1606. A stone church was constructed from 1616 to 1649, which burned again in 1660, and restored in 1707. In 1711–1734, the present church was built by Franciscan Father Jose de Puertollano. In place of the old roof, galvanized iron was used through the orders of Father Gregorio Platero in 1892. This church served as headquarters for the Americans during the Philippine-American War in 1902.[7] The bell tower stands on the left side of the church, which can be accessed through a *langit-langitan*. It has four small bells and one big bell. The interior of the church has well-preserved retablos and *azulejo*-tiled floors. The church's unique architecture and historical significance earned its place as a National Cultural Treasure in 1972.

PARISH CHURCH OF SAN JUAN BAUTISTA, JIMENEZ, MISAMIS OCCIDENTAL

This well-preserved coral stone church was constructed in the nineteenth century by the Augustinian Recollects. Its massive facade has a unique portico with three arched entrances. Above the portico are three niches with statues of saints. While the exterior of the church is plain without much decoration, the interior of the church is a showcase of locally crafted painted ceilings, sculptures, and metalworks that have been untouched for centuries. Its upper walls are *tabique pampango*. The dome has a trompe l'oeil painting on canvas mounted on the ceiling that was installed in 1898. This was later on discovered to be masking a mural painting on wood panels underneath. The paintings on canvas can also be found throughout the ceiling. The interior has exposed wooden pillars and original floor tiles. Due to its magnificent and unique cultural and heritage value, it was declared a National Cultural Treasures in Mindanao in 1972.

CHURCH OF OUR LADY OF THE GATE, DARAGA, ALBAY

The wreckage of the Cagsaua Church due to the eruption of Mayon Volcano on 1 February 1814, caused its parishioners to relocate to Daraga. In 1945, the church served as headquarters for the Japanese in World War II. It was reconstructed in 1971–1973 after parts of it were destroyed during the war.[8] Built by the Franciscans with influences of Baroque architecture, the present church has intricately carved facade, made from volcanic tuffs and coral stone. Local artists created ornamental designs, such as flowers, angels, medallions, religious seals, niches, and saints, on the walls and pediment. An octagonal bell tower also has religious carvings. Twisted columns of the sacristy continuing to the convent are exposed to demonstrate the original columns of the church. The National Museum recognized the church's bell tower, baptistry, and facade as archeological structures and declared the church as a National Cultural Treasure on 29 October 2007.

CHURCH OF THE ASSUMPTION OF OUR LADY, MARAGONDON, CAVITE

The first structure of the Church of the Assumption of Our Lady in Maragondon, Cavite was constructed in 1618 until 1633. Anticipating the arrival of Dutch forces, the church was demolished in 1649 by Governor Sabiniano de Lara. A year after, a wooden church was constructed. The present stone church was built in 1714. It played a crucial role in the Philippine Revolution, serving as a watchtower for the revolutionary force of Gen. Emilio Aguinaldo.[9] The church houses intricately carved retablos, depicting galleons and floral motifs, including the pulpit and antique church doors. The base of the bell tower and convent consists of river stones, making the structure sturdier—an example of early structural technology. This heritage church was declared a National Cultural Treasure in 1972 due to its distinctive cultural and historical value.

CHURCH OF THE IMMACULATE CONCEPTION, JASAAN, MISAMIS ORIENTAL

Built during the nineteenth century, the reconstruction of the Church of the Immaculate Conception in Jasaan, Misamis Oriental, was stopped in 1887 amid social upheaval during the Philippine Revolution. The Jesuit priests Francisco Rivera and Juan Cuesta wanted to emulate the urbanized design for the present church of the Immaculate Conception.[10] The facade has two contrasting designs. The lower portion is made of a thick wall of bricks. The upper portion, with twin wooden bell towers, has a modern design with symmetrical components and geometric lines. The parish bells dated circa eighteenth century are still intact. Excellent wood craftmanship reminiscent of a basket weave can be observed from the original ceilings of the interior. To the right of the church is the convent with massive wooden posts and long wooden panels to support the structure. Because of its unique architectural design with excellent ceiling woodwork, it was declared a National Cultural Treasure on 10 January 1974.

MATERIALS AND METHODS

To ensure appropriate and accurate characterization methodology, using multiple in situ and laboratory testing procedures, the use of proper sampling techniques is essential. This entails a careful selection of sample extraction locations and sampling size, which is important for the success of the tests to be conducted. Minimal but adequate dimensions of samples were extracted[11] to keep the original materials intact on the structure. Proper documentation of sampling was observed. Location points were marked to determine the condition and origin of sampling points. A total of 63 samples were tested from the Church of San Agustin, 92 from the Church of Our Lady of the Assumption, 71 from the Parish Church of the Holy Cross, 50 from the Church of Pope St. Gregory the Great, 51 from the Parish Church of St. John the Baptist, 106 from the Church of Our Lady of the Gate, 64 from the Church of the Assumption of Our Lady, and 103 from the Church of the Immaculate Conception.

Mechanical property tests include on-site compressive strength analysis. Selected testing points on existing bell tower, facade, exterior and interior walls of the churches and convents were performed in situ using a rebound hammer to measure the capacity of the structural material to withstand crushing forces. The rebound value is dependent on the hardness of the materials, with the unit of measurement of Mpa (Megapascal). Ten readings perpendicular to each location point were performed and averaged.[12]

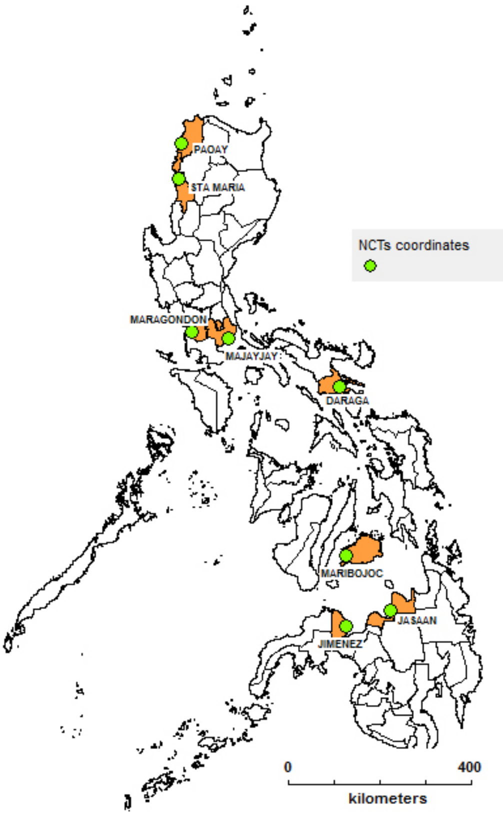


Figure 2. Location map of the eight heritage churches declared as NCTs

Physical property tests conducted in the laboratory include the determination of open porosity[13] and moisture content. A method of determining open porosity was adapted through established procedures[14] using indirect measurement of water absorption to provide an estimate. This method was used to measure irregular solids.[15] These were then immersed in water for twenty-four hours at 4˚C, and weighed again. Water displacement method was used to determine the volume (Va) of the solid material. Since density of water at 4˚C is 1 g/cm3, the value can also be considered as the volume of pores (Vp). Percent open porosity (%OP) is determined by the expression[16]

$$\%OP = \frac{[V(p)]}{[V(a)]} x100$$

Moisture content of the samples was determined to measure the amount of water retained. Moisture generally affects the mechanical and biological deterioration of building materials, thus it is important in the overall characterization of structural materials.[17] Samples were weighed before (Xa) and after (Xb) oven drying for twenty-four hours at 110˚C. Moisture content (%MC) was expressed by the equation

$$\%MC = \frac{[X(a) - x(b)]}{[X(a)]} x100$$

Elemental composition of materials was determined using handheld Skyray Pocket-III Genius X-ray fluorescence spectrometer (XRF).[18] This was performed to obtain approximate concentrations of Ca, C, and O on coral, plaster, and mortar samples; and Fe, Al, Si, and Mg on brick and adobe samples. Chemical analysis using acid digestion was used to determine the approximate binder/aggregate proportions of the mortar and plaster samples.[19] The method separated the binder from the aggregate components in their powdered form (using electronic pulverizer); effervescence test was conducted with the use of 14 percent HCl. In the determination of appearance and proportions of component materials, filtration method was introduced. Component weights were calculated based on the amount of material dissolved in the process.

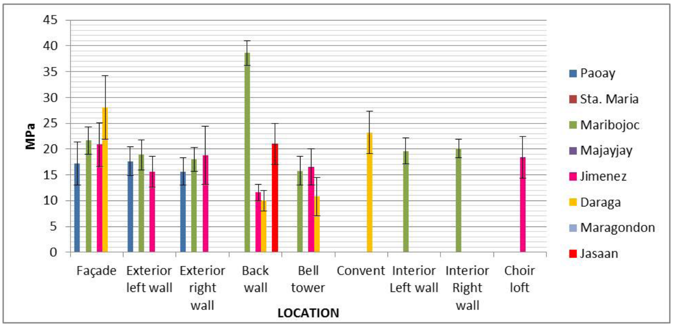
RESULTS AND DISCUSSION

Most of the churches in this study used corals, adobe, and bricks. These materials were tested using a combination of multiple analytical techniques, which were specified depending on the nature of the materials. Valuable information is gained with the combination of these techniques; doing otherwise would lead to inconclusive results. Determination of physical and mechanical properties[20] needs to be complemented with results from the chemical analysis in order to achieve complete characterization and to determine compatibility.[21]

MECHANICAL PROPERTY TESTS

Visual inspection of the condition and nature of the materials was done to determine the sampling points in compressive strength testing. Ten readings were averaged and evaluated based on the type of material. Crumbly, eroded, and loose materials were excluded as sampling points due to inconsistent data that these locations may generate. Sampling points consisted of the exterior and interior locations of the church complex. Data were segregated and evaluated based on the type of materials. Results of compressive strength analysis are illustrated in figure 3.

(A)



(B)

(C)

(D)

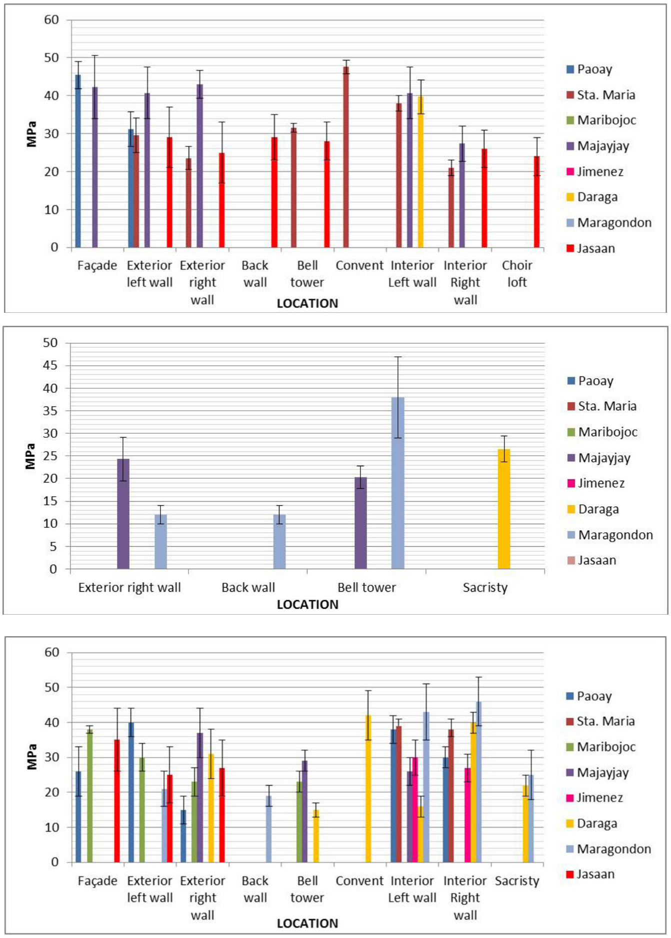


Figure 3. Compressive strength of coral (A), bricks (B), adobe (C), and plaster (D) measured at different points in the exterior and interior location points

Corals used as stone blocks were found to have a normal range of compressive strength from 13 Mpa to 25 MPa. Critical areas as well as high variations in data were found on the blocks from the back wall of Jimenez Church (12 MPa) and Daraga Church (10 MPa); meanwhile the highest strength was also found on the back wall, except for Maribojoc Church (39 MPa).

Bricks exhibited higher compressive strength than coral blocks as building materials. Bricks were found to have a normal range of compressive strength of 25 MPa to 41 MPa. Critical areas were identified on the interior walls of the Santa Maria Church (21 MPa) and Jasaan Church (24 MPa). High variations in data were observed on bricks from Majayjay Church and Jasaan Church.

Compressive strength analysis of adobe was conducted only on Majayjay, Maragondon, and Daraga churches. Average compressive strength of tested adobe materials was 22 MPa. Adobe materials on the exterior walls of Maragondon Church were critical, while those found on the bell tower were of stable condition.

Generally, plaster from the interior walls of the churches tested was found to have relatively higher strength than that from the exterior walls. Critical areas include Paoay Church's exterior right wall (15 MPa), interior left wall (15 MPa), and exterior bell tower walls (16 MPa). The plaster compressive strength of the following location points was found to have significantly higher readings than the corresponding building materials underneath (exterior left wall of Paoay Church, underneath coral and bricks; interior right wall of Santa Maria Church, underneath bricks; all exterior walls of Maribojoc Church, underneath corals; exterior right wall and bell tower walls of Majayjay Church, underneath adobe; interior walls of the church and convent walls from the Daraga Church, underneath corals; and facade of Jasaan Church, underneath bricks).

PHYSICAL PROPERTY TESTS

Several methods in the determination of percent moisture content and percent open porosity were performed in the laboratory of the Materials Research Conservation Division of the National Historical Commission of the Philippines. Samples subjected to these analytical techniques were identified to be representative of the physical properties of the materials in specific locations where they were retrieved. Minimal sampling was a concern for the testing of irregular and nonstandard samples. Each sample was selected based on its capability to endure water absorption and drying while still retaining its original shape and form. Due to this, some churches either do not have the material or do not have usable data to form conclusions.

The amount of moisture retained in the building materials was evaluated and compared against its percentage open porosity. Significant amounts of moisture were observed to have been retained by coral blocks from Maribojoc and Jimenez churches, while corals from Paoay, Daraga, and Jasaan churches were relatively dry. These coral blocks were found to have a percentage porosity of 37–44 percent with low variation. However, it was noted that coral from Daraga Church exhibited significantly low porosity, considering the natural characteristics of the material. Representative bricks retained the highest amount of moisture with the lowest percentage of open porosity, when compared to coral and adobe. Adobe as a building material was able to retain high amount of moisture. The porosity of materials from the two locations, however, vary significantly. Plaster samples from Paoay and Daraga churches were relatively dry although the amount of open porosity of plaster from Daraga was higher than those from Paoay. Mortar retrieved from Paoay and Jasaan churches were the driest while those from Paoay were the most porous.

Plaster and mortar samples have generally high amounts of retained moisture with the mortar being more porous than plaster. The amounts of moisture present on plaster and mortar of each church were consistent, while the porosity of these materials were indirectly proportional, except for Jimenez and Maragondon churches. All building materials collected from Maribojoc Church exhibited consistently high moisture.

ELEMENTAL ANALYSIS

In situ elemental analysis on varying location points interior and exterior to the church was carried out. Element analyzer Genius X-Ray Fluorescence (XRF) was the equipment used as a form of nondestructive testing to determine the elemental composition of plaster, mortar, and stone blocks. The XRF was calibrated to determine the calcium content of samples from different locations within the church.

Table 1 shows the elements present and their quantity on representative coral samples. Exposed coral location points were collected from the exterior walls of the five churches (Paoay, Maribojoc, Jimenez, Daraga, and Jasaan). Varying amounts of calcium were present on these corals according to the geographical location of the church and also the condition of the materials. Corals from Paoay exhibited the most amount of calcium, while the least was observed from the facade of Jimenez Church. Trace amounts of titanium and iron were also detected on most of the corals tested.

Interior and exterior location points were selected for testing bricks and adobe. Elements present on bricks were mainly iron, aluminum, silicon, and calcium with traces of potassium and titanium, while adobe was composed mostly of calcium. Bricks from the interior and exterior location points of Majayjay Church exhibited almost consistent amounts of elements present. The amount of iron present was consistent on all bricks; however, the amounts of potassium and calcium were notably higher on location points from Majayjay Church. Aluminum and silicon, which are major components of clay, were also detected, in minimal amounts, on bricks of Daraga and Jasaan Churches. Distinct compositions of bricks provide an elemental signature that can be compared against new materials for compatibility and durability.

Table 1. Percent of Elements detected in coral tested and their relative composition measured on-site by XRF Spectrometry (See page 59 for list of the Elements)

ELEMENTS	PAOAY		MARIBOJOC			JIMENEZ				DARAGA	JASAAN	
	EXTERIOR		EXTERIOR			EXTERIOR				EXTERIOR	EXTERIOR	
	LEFT WALL	RIGHT WALL	LEFT WALL	RIGHT WALL	BELL TOWER	LEFT WALL	RIGHT WALL	FACADE	BELL TOWER	RIGHT WALL	RIGHT WALL	BACK WALL
K	-	-	-	-	-	0.305	0.796	1.076	0.117	-	-	-
Ca	89.185	83.988	83.101	55.543	78.508	20.571	27.554	20.588	34.755	21.264	32.291	45.872
Ti	0.076	0.067	0.049	3.507	0.125	0.035	0.081	-	-	0.017	0.249	0.020
Mn	0.802	0.662	-	-	-	-	-	-	-	-	-	-
Fe	0.010	0.007	0.311	1.568	0.756	0.147	0.209	0.129	0.078	0.253	1.234	0.023
Co	-	-	-	-	-	-	-	-	-	0.001	0.002	0.001
Ni	0.044	0.045	0.020	0.006	0.014	-	0.001	-	-	-	0.006	0.002
Cu	0.099	0.092	0.038	0.015	0.031	-	0.001	-	-	-	0.016	-
Zn	0.242	0.211	0.069	0.888	0.015	0.005	0.003	0.002	0.009	0.004	0.472	0.002
As	0.023	0.021	0.057	0.053	0.087	-	-	-	-	-	-	-
Rb	-	-	0.010	0.000	-	-	0.001	-	0.001	0.001	0.000	-
Sr	-	-	-	-	-	0.650	0.657	0.502	0.539	-	0.721	0.871
Zr	-	-	0.207	0.154	0.171	-	-	-	-	-	0.097	0.102
Cs	-	-	-	-	-	-	0.006	0.020	0.018	-	-	-
Ta	-	-	0.022	-	0.009	-	-	-	-	-	-	-
Pb	0.135	0.132	0.134	0.903	0.129	0.006	0.015	0.023	0.025	-	0.183	-
Bi	-	-	-	0.034	0.010	-	-	-	-	-	0.002	-
Mo	0.143	0.150	0.164	0.145	0.183	-	-	-	-	-	-	-

(-) <2ppm

Table 2. Percent of Elements detected in brick and adobe tested and their relative composition measured on-site by XRF Spectrometry

ELEMENTS	MAJAYJAY		DARAGA	JASAAN					DARAGA
	EXTERIOR	INTERIOR	INTERIOR	EXTERIOR			INTERIOR		ADOBE
	LEFT WALL	FLOOR	LEFT WALL	BACK WALL	LEFT WALL	FACADE	RIGHT WALL	LEFT WALL	FACADE
K	2.971	2.477	0.168	0.539	0.297	0.262	0.486	0.267	-
Ca	6.052	5.230	0.225	0.220	0.374	0.322	0.365	0.496	39.961
Ti	0.489	0.287	0.470	0.547	0.416	0.523	0.540	0.528	0.037
Mn	0.234	0.096	-	-	-	-	-	-	-
Fe	13.678	11.881	13.556	13.355	11.197	12.206	12.216	9.613	0.044
Co	0.004	0.008	-	-	-	-	-	-	-
Cu	0.071	0.060	-	-	-	-	-	-	0.001
Zn	0.519	0.217	-	-	-	-	-	-	0.009
As	0.061	0.049	-	-	-	-	-	-	-
Rb	-	-	-	-	-	-	-	-	0.001
Sr	-	-	-	-	-	-	-	-	0.083
Zr	0.026	0.032	-	-	-	-	-	-	-
Nb	-	-	-	-	-	-	-	-	-
Ta	-	-	-	-	-	-	-	-	-
Pb	0.055	0.161	-	-	-	-	-	-	-
Mo	0.148	0.164	-	-	-	-	-	-	-
Mg	-	-	-	-	-	0.025	-	0.006	-
Al	-	-	3.620	2.715	3.525	1.953	3.048	1.715	-
Si	-	-	4.580	3.495	2.760	2.657	1.912	2.248	-

(-) <2ppm

Table 3 shows the elemental composition of plaster samples tested from the interior and exterior walls of all eight churches. Plaster location points consisted mainly of calcium and iron, with traces of titanium, zinc, and lead. The largest amount of calcium in plaster was exhibited from the bell tower of Santa Maria Church (97.875 percent), while the least was observed in plaster found on the facade of Jasaan Church (13.342 percent). Varying amounts of calcium in plaster tested from the same church may indicate differences in the plaster mixture used and the date of introduction to the wall. Inner layers of plaster were observed to have more calcium content than the outer layers. The amount of calcium in the inner plaster layer on the right wall of the Maribojoc Church was twice as much as that in its outer layer. The plaster from the interior walls has lesser calcium content than that from the exterior walls of Santa Maria and Daraga churches, while the opposite was observed in Jimenez and Jasaan churches. Lower amounts of calcium were observed on Jimenez, Daraga, Maragondon, and Jasaan churches, when compared to Paoay, Santa Maria, Majayjay, and Maribojoc churches. High amounts of titanium detected on the plaster may suggest the presence of paint on testing points.

The presence of calcium on mortar and plaster location points was examined. Plaster was observed to contain more calcium than mortar from the bell tower of Santa Maria and Maragondon churches and from the left wall of Jasaan Church. High amounts of calcium was observed on both mortar and plaster from the Santa Maria Church bell tower. The difference in their calcium composition was significant. This was also noted on plaster and mortar from the bell tower of Maragondon Church. The mortar from the left wall of Majayjay Church, the back wall of Jasaan Church, and the right and back walls of Maragondon Church contained more calcium than their plaster location points.

Table 3. Percent of Elements detected in plaster tested and their relative composition measured on-site by XRF Spectrometry

ELEMENTS	PAOAY		SANTA MARIA			MARIBOJOC			MAJAYJAY	
	EXTERIOR		INTERIOR		EXTERIOR	RIGHT WALL		EXTERIOR	EXTERIOR	
	LEFT WALL	RIGHT WALL	LEFT WALL	RIGHT WALL	BELL TOWER	OUTER LAYER	INNER LAYER	BELL TOWER	LEFT WALL	RIGHT WALL
K	-	-	-	-	-	-	-	-	3.848	-
Ca	70.001	50.280	53.001	31.077	97.875	41.692	88.914	75.339	22.641	58.604
Ti	0.135	0.176	0.074	24.099	0.036	0.068	0.042	0.085	0.166	0.070
Mn	0.014	0.044	-	-	-	-	-	-	0.242	-
Fe	4.077	6.606	1.757	2.992	0.143	2.068	0.343	1.360	8.157	2.828
Co	-	-	-	-	-	-	-	-	-	0.004
Ni	0.003	0.003	0.017	0.013	0.009	0.007	0.004	0.003	0.002	0.002
Cu	0.038	0.040	0.037	0.034	0.040	0.070	0.040	0.034	0.044	0.045
Zn	0.009	0.103	0.034	0.060	-	0.031	0.019	0.026	0.029	0.064
As	0.013	0.032	0.077	0.029	-	-	-	0.115	0.045	-
Rb	-	-	-	-	-	-	-	-	-	-
Sr	-	-	-	-	-	-	-	-	-	-
Zr	-	-	-	-	-	0.024	0.186	0.076	0.069	0.057
Nb	-	-	-	-	-	-	-	-	-	-
Cd	-	-	-	-	-	-	-	-	-	-
Ta	-	-	-	-	-	-	-	-	-	-
Pb	0.107	0.097	0.122	0.131	0.126	0.113	0.125	0.204	0.152	0.128
Bi	-	-	-	-	-	-	0.002	-	-	-
Mo	0.155	0.159	0.171	0.165	0.129	0.155	0.159	0.164	0.203	0.143

(-) <2ppm

Table 3. Percent of Elements detected in plaster tested ... (*continued*)

ELEMENTS	JIMENEZ					DARAGA					
	INTERIOR			EXTERIOR		EXTERIOR			SACRISTY		
	LEFT WALL	RIGHT WALL	SACRISTY	BELL TOWER	FACADE	LEFT WALL	BACK WALL	BELL TOWER	OUTER LAYER	INNER LAYER	BAPTISTRY
K	0.583	-	0.295	0.382	0.703	-	-	-	1.269	0.027	0.779
Ca	19.003	27.005	31.243	15.669	24.534	17.408	42.923	34.740	16.852	20.025	21.213
Ti	0.026	0.024	0.024	0.009	0.019	0.035	0.036	0.024	0.053	0.094	0.562
Mn	-	-	-	-	-	-	-	-	-	-	-
Fe	0.185	0.027	0.028	2.371	0.246	1.214	0.006	0.048	1.484	0.830	0.154
Co	-	-	-	0.002	-	0.003	-	-	0.002	0.003	-
Ni	-	-	-	-	0.001	0.011	0.001	-	-	0.007	-
Cu	-	-	-	0.001	-	-	-	-	0.003	0.004	-
Zn	0.007	0.001	0.005	0.079	0.009	0.002	0.002	0.003	0.006	0.023	-
As	-	0.003	-	-	-	-	-	-	-	-	-
Rb	-	-	-	-	-	-	-	-	-	-	-
Sr	-	-	-	-	-	-	-	-	-	-	-
Zr	-	-	-	-	-	-	-	-	-	-	-
Nb	-	-	-	-	-	-	-	-	-	-	-
Cd	-	-	-	0.018	0.011	-	-	-	-	-	-
Ta	-	-	-	-	-	-	-	-	-	-	-
Pb	0.006	-	0.003	0.038	0.036	-	-	-	-	0.010	-
Bi	-	-	-	-	-	-	-	-	-	-	-
Mo	-	-	-	-	-	-	-	-	-	-	-

(-) <2ppm

Table 3. Percent of Elements detected in plaster tested ... (*continued*)

ELEMENTS	MARAGONDON				JASAAN		
	EXTERIOR				EXTERIOR		INTERIOR
	FACADE	RIGHT WALL	BACK WALL	BELL TOWER	BACK WALL	FACADE	LEFT WALL
K	0.358	1.573	0.215	-	0.981	0.737	0.689
Ca	19.679	16.029	15.063	35.619	19.865	13.342	23.489
Ti	0.037	0.056	1.268	0.024	0.106	0.241	0.175
Mn	-	-	-	-	-	-	-
Fe	1.124	0.482	0.851	0.131	2.394	9.900	5.198
Co	0.001	0.001	0.001	-	0.003	0.003	0.003
Ni	-	-	-	-	-	0.009	0.008
Cu	0.003	0.001	0.008	-	0.006	0.004	0.003
Zn	0.005	0.005	0.080	0.002	0.104	0.021	0.005
As	-	-	-	-	-	-	-
Rb	-	-	-	-	0.004	0.002	0.002
Sr	-	-	-	-	0.358	0.048	0.247
Zr	-	-	-	-	0.079	-	0.069
Nb	-	-	-	-	0.003	0.002	0.001
Cd	-	-	-	-	-	-	-
Ta	-	-	-	-	-	0.003	0.010
Pb	-	0.009	0.012	-	0.009	-	-
Bi	-	-	-	-	-	-	-
Mo	-	-	-	-	-	-	-

(-) <2ppm

The calcium compositions of mortar on two location points of the Maragondon Church were almost consistent, suggesting that the mortar may be from the same mixture or may have been composed of the same materials.

Pigments on paintings, statues, and floor tiles were tested to determine the elemental spectrum. The presence of certain elements can help determine the nature of the pigments and may also indicate the period when it was manufactured. High amount of calcium was observed on the floor tiles from the Santa Maria Church; however, the amount of calcium present varies depending on the color of the tile. Titanium was found in pigments from Santa Maria and Jasaan churches. Iron was found to be the main component of pigments from the sacristy and altar wall of Daraga Church, while the pigments from Jasaan Church have lesser amount of iron. Three kinds of gold pigments were tested for each church, but have varying compositions and elements. Pigments with high amounts of titanium with traces of zinc indicate the use of modern paint.

BINDER ANALYSIS

Binder proportion analysis is done to determine the ratio of the three basic components of historic building materials. Acid digestion is used to separate the binder component (acid soluble, usually calcium carbonate), the fines (finely textured impurities such as clay), and the sand or aggregate. This is important in the preparation of repair materials compatible with the original. Mortar mixtures from Paoay (PY), Santa Maria (SM), Jimenez (JM), and Jasaan (JS) were composed of a binder aggregate ratio of 1-to-1 or one part binder with one part aggregates, while those from Maragondon (MR) have a binder aggregate ratio of 1-to-2 or one part binder with two parts aggregates. Mortar from Majayjay Church has the least amount of binder (10 percent).

Table 4. Percent of Elements detected in mortar tested and their relative composition measured on-site by XRF Spectrometry

ELEMENTS	SANTA MARIA		MAJAYJAY	MARAGONDON					JASAAN	
	EXTERIOR		EXTERIOR	EXTERIOR					EXTERIOR	INTERIOR
	CONVENT	BELL TOWER	LEFT WALL	FACADE	LEFT WALL	RIGHT WALL	BACK WALL	BELL TOWER	BACK WALL	LEFT WALL
K	-	-	-	0.397	0.405	0.570	0.006	-	1.391	0.408
Ca	53.146	64.010	61.671	17.809	8.861	20.185	26.909	20.873	26.543	18.961
Ti	0.114	0.114	0.073	0.073	0.063	0.045	0.036	0.076	0.154	0.056
Mn	0.018	0.019	-	-	-	-	-	-	-	-
Fe	5.497	6.753	6.322	1.611	5.626	2.275	0.666	0.820	2.457	2.464
Co	-	-	-	0.002	0.002	0.004	0.001	0.001	0.003	0.004
Ni	0.013	0.001	-	-	-	-	0.002	-	-	0.003
Cu	0.035	0.046	0.046	0.003	0.006	0.005	-	0.001	0.005	0.005
Zn	0.100	0.022	0.205	0.008	0.014	0.005	0.003	0.002	0.010	0.005
As	-	0.058	0.040	-	-	-	-	-	-	-
Rb	-	-	-	-	-	-	-	-	0.003	0.183
Sr	-	-	-	-	-	-	-	-	0.613	0.045
Zr	-	-	0.026	-	-	-	-	-	0.079	0.001
Pb	0.160	0.111	0.107	0.007	0.001	-	-	-	0.003	0.001
Mo	0.153	0.188	0.133	-	-	-	-	-	-	-

(-) <2ppm

Table 5. Percent of Elements detected in pigments tested and their relative composition measured on-site by XRF Spectrometry

ELEMENTS	PAOAY		SANTA MARIA						
	PIGMENT		TILES				PIGMENT		
	GOLD	ORIGINAL	OFF-WHITE	BROWN	YELLOW	WHITE	BLACK	WHITE	GOLD
K	8.093	4.611	-	-	-	-	-	4.809	-
Ca	1.832	2.048	83.449	69.211	77.576	74.564	22.210	0.735	14.876
Ti	0.379	0.244	0.074	0.090	0.047	0.020	7.089	17.730	26.889
V	-	-	-	-	-	-	-	-	-
Cr	-	-	-	-	-	-	-	-	-
Mn	-	-	-	-	-	-	-	-	-
Fe	3.921	0.825	1.011	8.087	0.848	0.307	1.584	0.575	1.399
Co	-	-	-	-	-	-	-	-	0.012
Ni	0.116	0.051	0.010	-	0.014	0.003	0.010	0.004	
Cu	13.017	0.458	0.035	0.033	0.043	0.031	0.094	0.030	0.081
Zn	1.073	0.211	0.015	0.008	0.006	0.005	0.001	0.006	0.238
As	-	0.049	0.096	0.034	-	-	0.062	-	-
Rb	0.099	0.022	-	-	-	-	-	-	-
Zr	0.047	0.038	-	-	-	-	-	-	-
Sb	0.004	-	-	-	-	-	-	-	-
Ta	-	0.165	-	-	-	-	-	-	-
Pb	0.491	0.245	0.116	0.101	0.122	0.104	0.143	0.128	0.465
Bi	0.093	0.106	-	-	-	-	-	-	-
Mo	0.199	0.323	0.138	0.117	0.159	0.157	0.168	0.180	0.200

(-) <2ppm

Table 5. Percent of Elements detected in pigments tested ... (*continued*)

ELEMENTS	DARAGA			JASAAN			
	PIGMENT			PIGMENT			
	SACRISTY	BAPTISTRY	ALTAR WALL	GOLD	BLUE	OFF-WHITE	LIGHT BLUE
K	-	0.791	-	-	-	-	-
Ca	-	12.779	-	-	-	-	-
Ti	1.093	2.696	1.474	87.313	49.928	89.032	63.195
V	-	-	-	0.053	-	0.077	-
Cr	0.049	-	0.128	0.488	0.091	0.053	0.284
Mn	0.119	-	0.247	0.071	0.103	0.083	0.031
Fe	98.697	0.622	98.108	12.075	49.720	10.756	34.228
Co	-	0.001	-	-	-	-	-
Ni	0.042	0.003	0.043	-	-	-	-
Cu	-	0.028	-	-	-	-	2.221
Zn	-	-	-	-	-	-	-
As	-	-	-	-	-	-	-
Rb	-	-	-	-	-	-	-
Zr	-	-	-	-	-	-	-
Sb	-	-	-	-	-	-	-
Ta	-	-	-	-	-	-	-
Pb	-	0.021	-	-	-	-	-
Bi	-	-	-	-	-	-	-
Mo	-	-	-	-	-	-	-

(-) <2ppm

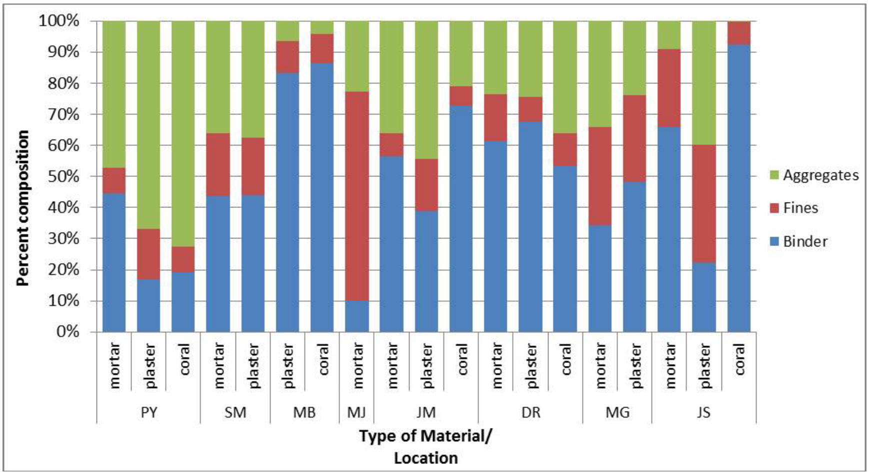


Figure 5. Binder aggregate composition of representative samples

Plaster exhibited less binder composition than the corresponding mortar in Paoay, Jimenez, and Jasaan churches, while the opposite was observed in Maragondon Church. Equal proportions of binder were observed on mortar and plaster from Santa Maria and Daraga (DR) churches. Coral, as expected, contained the most amount of binder; however, low amount of binder was observed from those retrieved from Paoay and Daraga churches.

CONCLUSION

Multiple intrinsic and extrinsic factors affect the behavior of materials on built heritage. This is the reason why a combination of physical, mechanical, and chemical analytical techniques were undertaken to provide a comprehensive understanding of the original materials. The characterization of these building materials can help ensure proper conservation practice. This will also provide valuable information on the history of restoration on the structure.

The combination of materials that have their own unique characteristics need to be understood as to their compatibility to ensure the safety of the heritage structure. Original materials, such as corals, bricks, and adobe, have their own properties that repair materials must complement. Considerations regarding the strength of materials need to be addressed since the behavior of stone blocks might further damage the original. Results of the study suggest that corals and adobe have low to moderate strength while bricks are stronger. Porous materials need to be maintained due to their ability to absorb and retain water. Indications of highly porous materials suggest the extent of deterioration of the material, which may be the result of salt crystallizations and recrystallizations. Relationships of original building materials, such as corals and bricks, vary greatly depending on environmental conditions that these materials have been subjected to. The geographical location of these structures may also be a significant factor in the behavior of these materials, on which further studies should focus.

Elemental and chemical analyses of original building materials and ancient mortars and plasters can help determine their composition and the authenticity of materials. Original building materials, which are mostly scarce, can be examined to determine the most appropriate and compatible repair materials. This is easier for bricks, wherein clay compositions can be tested with precision using different firing techniques. Ancient renders' binder aggregate proportions are determined with the use of simple methods such as binder analysis; however, these are just approximations,[22] while the qualitative and quantitative data can be obtained through nondestructive techniques and equipment. The use of this measuring device can provide evidence and validate recommendations that can be further evaluated through on-site experimental methods of mortar application.

NOTES

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4 Layug, A Tourist Guide to Noteable Philippine Churches, 18–19.

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6 Ibid.

7 Galende, Philippine Church Facades, 202.

8 Ibid., 231.

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LIST OF ELEMENTS

K	-	potassium	Sr	-	strontium
Ca	-	calcium	Zr	-	zirconium
Ti	-	titanium	Cs	-	cesium
V	-	vanadium	Ta	-	tallium
Cr	-	chromium	Pb	-	lead
Mn	-	manganese	Bi	-	bismuth
Fe	-	iron	Mo	-	molybdenum
Co	-	cobalt	Nb	-	niobium
Ni	-	nickel	Mg	-	magnesium
Cu	-	copper	Al	-	aluminum
Zn	-	zinc	Si	-	silicon
As	-	arsenic	Cd		cadmium
Rb	-	rubidium			