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Investigation of the Deterioration of the Trompe L'Oeil Interiors of San Sebastian Basilica, Manila, Philippines

Christine N. Leggio

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Investigation of the Deterioration of the Trompe L'Oeil Interiors of San Sebastian Basilica, Manila, Philippines

Abstract
The Basilica of San Sebastian in Manila, Philippines, is one of few surviving all metal cathedrals in the world. It was built in 1891, after the previous three masonry churches on the site were destroyed in earthquakes. Originally, both the exterior and interior steel cladding panels were faux painted to create the illusion of cut stone. Trompe l’oeil figures painted by some of the country’s leading turn of the century artists decorate the interior dome and side walls. The structure is actively corroding, causing damage to the interior finishes. This study examines the original painting technique and diagnoses the specific causes of the deterioration of the interior finishes.

Keywords
san sebastian basilica, trompe l’oeil, corrosion, decorative painting

Disciplines
Historic Preservation and Conservation

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INVESTIGATION OF THE DETERIORATION OF THE TROMPE L’OEIL INTERIORS
OF SAN SEBASTIAN BASILICA, MANILA, PHILIPPINES

Christine N. Leggio

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CONTENTS

Acknowledgments i

1.0 | Introduction  1
  1.1 The Church of San Sebastian  1
  1.2 Significance  3
  1.3 Preservation  8

2.0 | Site History  12
  2.1 Explorers and Missionaries  12
  2.2 Churches of Stone  15
  2.3 Church of Steel  20
  2.4 Painting and Decoration  28
  2.5 Steel and Iron in 19th Century Ecclesiastical Architecture  37
  2.6 Maintenance and Repair History  42

3.0 | Literature Review  45
  Conservation of Original Finishes on Corroded Architectural Members  45
  Evaluation of Coatings for Iron and Steel  46
  Remedial Treatments of Finishes on Corroded Metal  55
  Conclusions  61

4.0 | Investigation of Deterioration  62
  4.1 Methodology  62
  4.2 Description of Finish Types  63
Appendix B

Appendix B.1 | Sample Schedule and Location  153
Appendix B.2 | Cross Sections and Instrumental Analysis  166

Index  225
FIGURES

Figure 1.1. View of San Sebastian Basilica, 1955.  1
Figure 1.2. Postcard illustrating the iron and steel church of San Sebastian, c.1900.  2
Figure 1.3. Detail: Trompe l’oeil painting of a Saint, painted in 1891 by Professor Don Lorenzo Rocha.  3
Figure 1.4. Religious carvings from the colonial period on display in San Augustin Museum.  4
Figure 1.5. Trompe l’oeil paintings by Professor Don Lorenzo Rocha.  6
Figure 1.6. Slight variations in technique and style can be read in the simulated stone finishes.  6
Figure 1.7. View of the elaborately decorated interior dome and cupola of San Sebastian Basilica.  7
Figure 1.8. Corrosion damage is visible in many areas of the Basilica.  8
Figure 1.9. The San Sebastian Basilica Conservation and Development Foundation.  9
Figure 1.10. San Sebastian Basilica from the street.  10
Figure 2.1 Map of the islands of the Philippines. 2012.  12
Figure 2.2 Map of Intramuros, c 1899.  15
Figure 2.3 Saint Augustin Church, Intramuros, after the earthquake of 1853.  18
Figure 2.4 Manila Cathedral, with destroyed bell tower, after the earthquake of 1880.  19
Figure 2.5 A test mounting of a portion of the Basilica’s framework, Belgium, c 1889.  20
Figure 2.6 Blueprints for Palacio’s steel church, c 1882.  21
Figure 2.7 As-built floor plan of the Basilica.  22
Figure 2.8 Interior of the Basilica, facing the altar, as seen from the choir loft. 2011.  22
Figure 2.9 Assembly of the Basilica, Manila, c 1889. 23
Figure 2.10 The attic of the Basilica.  24
Figure 2.11 San Sebastian Basilica, as seen from the street, c 1900.  25
Figure 2.12 The interior of the Basilica, c 1960.  26
Figure 2.13 A group photo at the front door of San Sebastian Basilica, c 1900.  28
Figure 2.14 The retablo designed by Guererro and carved by Eulogio at the altar.  29
Figure 2.15 The pulpit designed by Guererro and carved by Eulogio.  30
Figure 2.16 Faux marble ashlar painted on the cladding plates. 2011.31
Figure 2.17 A cast iron column capital, painted to simulate jasper. 2011.  31
Figure 2.18 (from left to right) Recollect Martyr, Recollect Martyr, Saint Monica, Saint Rita of Cascia, Saint Augustine, and Saint Nicolas of Tolentino.  33
Figure 2.19 Winged figures decorate the pendentives.  33
Figure 2.20 The Recollect coat of arms painted in an arched niche above the altar. 2011.  34
Figure 2.21 Diagram showing the location of figural paintings in the choir loft. 2012.  35
Figure 2.22 Scenes from hell, by Martinez. 2012.  35
Figure 2.23 Detail: scenes from hell, by Martinez. 2012.  36
Figure 2.24 Corrugated iron church, built 1868 in Haggerston, Hackney, London  37
Figure 2.25 Iron church, manufactured in England and sent to Jamaica, c 1840.  39
Figure 2.26 Iron church of San Marco in Arica, Chile.  40
Figure 2.27 The metal Iglasia de la Nuestra Senora de las Mercades, in Grecia, Costa Rica.  40
Figure 2.28 The iron and steel Bulgarian Church of Saint Stephen, Istanbul, Turkey.  41
Figure 2.29 Patches at the base of a column.  42
Figure 2.30 Note the repainting of the marble ashlar to the level of the top of the windows.  43
Figure 2.31 Choir loft ceiling, showing a previous painting campaign covered over by later marbling. 43
Figure 2.32 The repainting of the lower portion of the Saint Augustine Trompe L’oeil Panel. 2012.  44
Figure 4.1 Diagram by the author showing the finish types in the interior of the Basilica, by location.  45
Figure 4.2 The ceiling near the altar, showing painted ashlar blocks in the simulated marble finish. 64
Figure 4.3 Jasper scheme painted column showing evidence of deterioration at the seams. 65
Figure 4.4 The figures of Saint Augustine and Saint Nicolas are visible. 66
Figure 4.5 Figures of saints decorate the drum of the domed cupola. 67
Figure 4.6 A lancet-arched molded frame containing the painted image of Saint Matthew, the Evangelist. 68
Figure 4.7 The choir loft at the southern end of the church, above the main entryway. 68
Figure 4.8 Trompe l’oeil medallions in blue and yellow on the ceiling below the choir loft. 69
Figure 4.9 Survey area NE, an Augustinian Martyr and survey area NW. 70
Figure 4.10 Survey area SW. 71
Figure 4.11 Location of the figural trompe l’oeil paintings within the Basilica. 72
Figure 4.12 Location of the figural trompe l’oeil paintings within the Basilica. 73
Figure 4.13 Location of the figural trompe l’oeil paintings within the Basilica. 73
Figure 4.14 The areas covered in the condition survey. 74
Figure 5.1 Raman spectra showing the sample of corrosion from the Basilica. 82
Figure 5.2 Painting from the choir loft survey area. 85
Figure 5.3 The bottom most plate of the SW survey panel, located in the choir loft. 85
Figure 5.4 Trompe l’oeil painting from the NE survey area showing streaking from leaks. 87
Figure 5.5 Areas which have been retouched with rust inhibiting paint. 89
Figure 5.6 Trompe l’oeil painting from the NE survey area. 89
Figure 5.7 Image of the NW panel. 91
Figure 5.8 Cross section of sample NEb3. 92
Figure 5.9 Graphic showing the percentage of surface area affected by a particular condition. 94
Figure 5.10 Detail of survey panel NE. 96
Figure 5.11 Condition survey areas (left to right) NE, NW, and SW. 97
Figure 5.12 Interior of the domed cupola during a test mounting in Belgium in 1888. 98
Figure 5.13 Cross section with cracking through the stratigraphy, with corrosion migration. 100
Figure 5.14 Cross section with upwards crack, illustrating corrosion migration. 100
Figure 5.15 Detail of painting from SW survey area showing a haze on the surface. 102
Figure 5.16 Chart showing the average annual weather statistics for Manila. 104
Figure 5.17 Graph showing the interior climate of the Basilica’s choir loft. 104
Figure 5.18 Streaking from water runoff from leaks is visible above a window in the nave. 105
Figure 5.19 The interior of a column, water is visible at the bottom of the shaft. 105
Figure 5.20 Graph showing the interior climate of the Basilica over the period of one month. 106
Figure 6.1 Sample from an area of marble ashlar finish which is cracking but well adhered. 110
Figure 6.2 Sample from the background of the trompe l’oeil niche, exhibiting level 2 cracking. 110
Figure 6.3 Sample from the background of the painting in the choir loft, exhibits level 2 cracking. 111
1.0 | Introduction

1.1 The Church of San Sebastian

Quiapo is a small district of Manila known today as the “University Belt,” this district is among the oldest of the city. Situated in the Plaza del Carmen, San Sebastian Basilica’s green and white spires stand out among the smaller, deteriorating historic buildings, elevated train tracks and University architecture which surround it.

Constructed between 1886 and 1891, San Sebastian Basilica, also known as the Iglesia del Carmen or the Church of Our Lady of Mount Carmel, is East Asia’s first prefabricated all metal cathedral. It was built by the Order of Augustinian Recollects as the final solution to the frequent destruction of masonry buildings.
brought by earthquakes in the region.

Earthquakes claimed earlier masonry incarnations of the San Sebastian Church in 1645, 1863, and 1881. Faced with rebuilding a fourth time, the friars and the city director of Public Works looked to steel and iron for the solution.

Manufactured in Belgium and shipped to Manila in sections by English ships, the gothic revival, metal church took ten years to complete from design to decoration.
1.2 Significance

The designers of the Basilica chose to disguise rather than showcase the building’s industrial identity, even though its steel and iron structure qualifies it as a marvel of architecture and engineering. Every surface of the Basilica was painted in a simulation of cut stone. Elaborate trompe l’oeil paintings of saints and other religious figures decorate the interior of the church.

The painting was carried out by the professors and students from Manila’s in 1891. More than just a novelty, the paintings have art-historical significance in their own right.

Filipino art was profoundly influenced by the presence of the Spanish colonizers in the 17th, 18th, and 19th centuries. While the indigenous population certainly
had artistic and artisanal traditions, such traditions were rooted in sculpture. The Spanish brought a demand for paintings, primarily of a religious nature to the islands (Gatbonton 1992).

While indigenous carvers were employed by the Spanish to produce various decorations for churches and architecture, Chinese artists and artisans who settled in Manila and who were experienced in traditional Chinese painting techniques produced the early religious paintings for European tastes. A Chinese mestizo master of painting, Quiotan, is credited with training an early 19th century Filipino master of painting, Damian Domingo y Gabor, who would go on to found Manila’s first art school in his home studio in 1821 (Gatbonton 1992).

In 1823, the Real Sociedad Económica, a Spanish organization formed to
promote intellectual and economic development in Spain and its colonies, founded an art academy. In 1826, Damian Domingo was made the professor of the new academy, fusing the institutions (Gatbonton 1992, p28). Domingo had accepted the position on the condition that the school accept and treat equally students of both indigenous and native descent. After Domingo’s death in 1834, the school was closed due to a lack of cohesive leadership. It was reopened in 1850. The newly formed school was called the Academia de Dibujo y Pintura and it no longer adhered to Domingo’s requirement of equality and segregated its students by creating separate sections for Spaniards and students of Indio and mestizo heritage (Gatbonton 1992, p40). In 1857, faced with a staff shortage, one of the school’s most talented students, Lorenzo Rocha y Icaza was appointed president. His classmate, an Indio, Lorenzo Guerrero y Leogardo, volunteered to serve without salary as his assistant, in charge of the indio students, without salary. The two Lorenzos had won awards the previous year – for the best paintings by a Spanish and native student – Rocha for his likeness of the queen and Guerrero for a portrait of Magellan (Gatbonton 1992, p40).

Many years later, in 1891, the school, still headed by Rocha and Guerrero, would participate in the decoration of the Basilica of San Sebastian. Many student hands painted the faux graining of the marble and jasper stone schemes covering the walls of the Basilica. Rocha and a star pupil, Felix Martinez, painted the figural trompe l’oeil panels which decorate the dome and side walls of the church interior (Salvatierra 1993). Martinez, on his own, is credited with the painting of the figures in the choir loft. (Zaragoza 1894). Professor Guerrero is credited with designing the sculptural retablos as well as the confessionals and
Figure 1.5. Trompe l’oeil paintings by Professor Don Lorenzo Rocha in the octagonal cupola of San Sebastian Basilica. 2011.

Figure 1.6. Slight variations in technique and style can be read in the simulated stone finishes which decorate the ceiling and walls of the church. 2011.
pulpit. These were carved by a student, Eulogio Garcia. (Salvatierra 1993, p42).

The work of the many hands of the students is legible in the faux stone work at the Basilica. Variations in scale, brush work, and design both enhance the naturalistic quality of the simulated stone as well as demarcate sections completed by individual students.

The paintings in the Basilica are significant for their quality, scale, and for being the last remaining work of Lorenzo Rocha. Painted on the cusp of an artistic (and national) revolution, these paintings are a record of the end of the Spanish Colonial religious dominance in Filipino art. Completed just a few years before the end of Spanish occupation, they are a final relic of the papal and monarchic influence on art and architecture.
1.3 Preservation

San Sebastian Basilica was placed on the World Monuments Fund’s Watch List for the first time in 1998, and was relisted in 2010, because the rapid deterioration of the building’s steel, cast, and wrought iron structure was recognized as a potent threat to the longevity of the significant architectural and engineering expression. The entirety of the building is actively corroding.

Corrosion is affecting almost every feature of the building, including the intricate faux finishes and more than 140 figural trompe l’oeil paintings in the Basilica. The result has been losses of applied cast iron ornamentation, such as moldings, handles, scrolls, and other such elements. Loss in areas of the steel cladding panels on the interior and exterior of the Basilica in the form of holes has affected
many areas of the church. Loss, staining, and other damage to the painted decorations are extensive. The corrosion has threatened the stability of the structure as a whole.

While the threat of physical instability of the Basilica as a result of the corrosion of its structural members obviously poses the greatest threat to the building’s long term preservation and urgently requires attention in its own right, this study is focused on the deterioration mechanisms at work on the decorative interior finishes. The reason for this is that the structural stability of the Basilica is currently being studied and addressed by an international team of volunteer professionals, while the deterioration of the interior finishes has never been systemically addressed.

Figure 1.9. The San Sebastian Basilica Conservation and Development Foundation was established in 2010 to oversee the conservation of the Basilica.
The San Sebastian Basilica Conservation and Development Foundation (SSBCDF), is planning for the conservation of the Basilica. The Foundation hopes that the conservation of the Basilica will serve as an example of best practices in preservation in a country which is just beginning to take stock of its cultural heritage.

This study investigates and seeks to (1) identify the specific pathologies affecting the interior finishes, (2) assess the extent of damage to selected paintings of the Basilica, (3) diagnose the cause of the deterioration, and (4) establish a framework for research and testing of future remedial treatments. By building upon previous research and investigation of the SSBCDF, it aims to contribute to an understanding of the deterioration of painted finishes on ferrous substrates and to serve as a basis for determining conservation options in the Basilica’s

Figure 1.10. San Sebastian Basilica from the street. 2011.
cultural and economic context.
2.0 | Site History

2.1 Explorers and Missionaries

The history of San Sebastian Basilica is closely intertwined with the history of the Spanish colonization of the Philippine Islands. That history begins with the expedition led by Magellan in 1521. Upon landing on the small southern island of Cebu, he claimed the lands for Spain and named them “Islas de San Lázaro.” Many expeditions to these newly claimed islands took place in the following
decades. In 1543, Ruy López de Villalobos led an expedition to the Philippines and named two of the islands “Las Islas Filipinas” in honor of the prince of Spain, Philip II. This name would eventually be applied to the entire archipelago.

The nation known today as the Republic of the Philippines is a collection of more than 7,000 islands, only some 2000 of which are named. The largest of these islands is Luzon, located in the northern part of the archipelago, followed by Mindanao, to the south. Between them lie a cluster of smaller islands which form the central portion of the chain, known as the Visayas. Of these, the central island of Cebu was traditionally the hub of trade and commerce (Francia 2010).

Though profoundly influenced by 333 years under Spanish Colonial rule, the island nation was also influenced by many other cultures in pre-colonial times. Rich with mineral, botanical, marine, and forest derived resources; the islands have seen a cyclical flow of seafaring nomadic peoples from as early as the first millennium BCE. By the third millennium, settlements of these peoples had sprung up in the Philippine archipelago. These settlements, called barangays after the vessels which carried the nomadic clans over the waters, created a network of trade related societies which had little inclination to organize into formal nation-states until the influx of the Spanish colonizers who would appear and exert influence beginning in the 16th century, CE (Francia 2010).

The Philippine archipelago was situated in a significant Southeast Asian trade circle which ranged from the Persian Gulf to Southern China and was at its peak of activity from the seventh through the ninth centuries CE, but lasted through the beginning of the 15th century. For most of this time, the seas were dominated by the Chinese Treasure Fleet, which trolled the waters for goods and natural
resources and was the major player in the trade circle until the Chinese ports were closed during the Ming Dynasty in the 15th century (Francia 2010). This void left by the Chinese was soon filled by the fleets of the Portuguese, looking for conquest and materials in the early 16th century. It was Magellan who first brought the Islands of the Philippines to the attention of the Spanish.

Spanish colonization began to take hold in 1565, when Miguel López de Legazpi, the first Governor-General of the Philippines, arrived from New Spain on the Philippine island of Cebu and established the first permanent settlement in the archipelago.

At the same time, the Augustinian Recollect movement was gaining strength in Spain. A sect of Catholicism dedicated to the veneration of Saint Augustine, the Recollects had a strong belief in the importance of missionary work. In 1605, the Recollects were authorized to establish missions abroad. The first group set out from Spain in July of that year and reached Manila in May of 1606.

There they established a convent in Intramuros', the walled Spanish settlement which included Fort Santiago and is the oldest part of the City of Manila, in 1608. Along with others over the years, they would go on to found the convent and parish of San Sebastian in 1621 (Salvatierra 1993).

i “Within the walls.”
2.2 Churches of Stone

San Sebastian Church was established in 1621 on land donated to the religious order by Don Bernardino de Castillo Maldonado y Rivera, Maestro de Campo of the Royal Infantry Battalion and commander of Fort Santiago, and his wife, Doña Maria Enríquez de Céspedes. The couple, who had earlier funded the construction of San Nicolas Church in Intramuros, donated their estate in the barrio of Calumpang to the order on the condition that they establish a church and convent dedicated to Saint Sebastian (E. L. Romanillos 2001, p170,178).
Situated in a low-lying, flood prone area outside of Intramuros, Calumpang was a sparsely populated area home to roughly three hundred residents in thirty homes in unsavory condition. The Recollect Friars quickly recognized the potential for establishing a retreat for the missionaries in the area and perceived a need for spiritual attention among its residents (Romanillos 1991, p2). In February of 1691, the Archbishop of Manila, Msgr. Miguel Garcia Serrano OSA, authorized the foundation of the new church and convent, which would come to have four incarnations (Romanillos 1991, p2).

Shortly thereafter, the donated house was converted to a convent, and a new stone church was erected beside it with further financial assistance from Don Bernardino de Castillo. This church has been described by various historians and chroniclers as "curious," "well built," and of "medium" size (E. A. Romanillos 1991, p3).

The church was inaugurated on the 5th of May, 1621. The same day, a statue of the Virgen del Carmen, a gift to the Recollects from the Discalced Carmelite nuns of San Jose monastery in Mexico City, was enshrined in the church, making it the first Carmelite shrine in the Philippines. A miracle ensued. In 1621 the Dean of Manila Cathedral, Msgr. Juan Vélez, was gravely ill and was documented as having been miraculously cured when the holy image of the Virgen del Carmen was brought to his bedside (E. L. Romanillos 1991, p11-12).

This first church was not to last. Besieged by looting and arson in the Sangley Uprising of 1639, it would finally succumb to the devastating San Andreas

\[\text{Romanillos 1991, p2.}\]

\[\text{Romanillos 1991, p3.}\]

\[\text{E. A. Romanillos 1991, p11-12.}\]

\[\text{E. L. Romanillos 1991, p11-12.}\]
earthquake of 1645. The quake, which fell on November 30th, the feast of Saint Andrew the Apostle, is regarded as the most destructive quake to occur during the Spanish occupation. It claimed San Nicolas Church and over one hundred other masonry buildings in the city, prompting one Spanish Father to remark that “nothing was left of Manila but its shadow” (E. L. Romanillos 1991, p34-35).

Left to minister in a temporary *nipa* church, the Recollect fathers demolished the ruins and quickly endeavored to erect a larger, more ornate church on the site (Salvatierra 1993, p21). Constructed again of stone, the second church is described as being composed of “one nave with a transept which served as the main church, and a very spacious presbeteria” with “ten large glass windows facing the street, five doors, confessionals made of *tindalo*, the pews of *molave* and *tindalo*.” (E. L. Romanillos 1991, 36-37).

This church would last far longer than the previous one, and would survive at least ten intense earthquakes before undergoing an extensive renovation and expansion which added two rows of columns to the center of the nave and raised the height of the ceiling in 1859-61. The refurbished church stood

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the number of residence permits fixed at 3,000. The commercial profitability of the issuance of residence licenses to Chinese immigrants and traders led to their rapid increase in population and their eventual uncontrollability. Thus when the 6,000 Sangleys in Binan and Calamba of Laguna province who were conscripted in 1639 to provide rice for the support of Spanish forts, rose up in arms against the abusive mayor, the governor-general and other colonial officials were initially helpless. The other Chinese residents in Binondo … in no time joined the revolt. Thereupon, they resorted to pillage and plunder of town halls and churches. Father Andres del Espiritu Santo lamented that San Sebastian church which was located outside the scutted walls of Manila was not spared. A year after, in 1640 the bloody uprising was finally quelled by the combined forces of Spaniards, Tagalogs and Pampangos. The horrifying aftermath was 22,000 to 24,000 massacred Sangleys.” (E. L. Romanillos 1991, p34).

iii A traditional indigenous construction technique using bamboo and *nipa* palm leaves.

iv *Molave* and *tindalo* are hardwood species indigenous to the Philippines.

v As described by Frederick H. Sawyer, English engineer and supervisor of the assembly of San Sebastian Basilica, in his 1899 “Inhabitants of the Philippines.”
for two more years before toppling in 1863 in another devastating earthquake. This quake caused the entire roof of the Manila Cathedral to cave in on the prebendaries as they chanted the vespers of Corpus Christi, caused the crack that took the tower of San Augustin Church in Intramuros, and dashed nearly every other building in the city to the ground (E. A. Romanillos 1991, p39). The catastrophic earthquake claimed four hundred lives and wounded more than two thousand.

Once again the Recollects hastened to demolish the ruins and rebuild. The reconstructed church was opened to the public on January 20, 1867. The third incarnation of San Sebastian Church would last thirteen years before being damaged beyond repair – its stone walls severely cracked in the earthquake of 1880, and furthermore its wooden structural members perniciously damaged by

Figure 2.3 Saint Augustin Church, Intramuros, after the earthquake of 1853.
termites and weevils. It was condemned by Don Genaro Palacios, Director of

Faced once more with the prospect of rebuilding, Fr. Esteban Martinez, prior,
insisted upon building a church that was capable of housing the miraculous
image of the Virgen del Carmen, one that would withstand earthquakes
where the others failed (Zaragoza 1894, p30). They looked to new materials to
provide a basis for the construction of a church with the stability and flexibility to
withstand the islands frequent quakes.
2.3 Church of Steel

Don Genaro Palacios recommended building the new church of metal and was soon commissioned to produce designs for a gothic revival cathedral that could be made entirely of precast steel and cast iron parts (E. L. Romanillos 1991, p52). “What more appropriate abode befitting the holy Mother of God than a temple of solid steel, on that would symbolize their firm faith and resilient character, one that would defy the three fatal foes of Asian edifices: tremors, termites, typhoons.” (E. L. Romanillos 1991, p47).

Placios’ design was approved by the Recollect Provincial Council on June 14, 1883. After many bids, the Societe Anonyme d’Enterprises de Travaux Publics

Figure 2.5 A test mounting of a portion of the Basilica’s framework, Belgium, c 1889.
of Brussels, Belgium was awarded the contract for the manufacture of the prefabricated church (Salvatierra 1993, p22).

The steel and iron components manufactured in Belgium were delivered to Manila by eight separate ships, beginning with the William Burkitt in 1888 and ending with the Cicero in 1890. The order totaled 1,527 tons and included both structural and decorative components. Steel components included sheets for interior and exterior cladding. Wrought ironwork included supports and framework. Cast iron components included column plinths, door and window

Figure 2.6 Blueprints for Palacio's steel church, c 1882.
Figure 2.7 As-built floor plan of the Basilica.

Figure 2.8 Interior of the Basilica, facing the altar, as seen from the choir loft. 2011.
jambs and frames, arches, finials, friezes, crenellations, and column capitals. Also included in the order was galvanized iron sheeting for the roofing. An additional 500 tons of ironwork grills, balusters, and other elements were acquired from shops in Manila (Zaragoza 1894, p22).

The earthquake proof design was carefully planned to have a low center of gravity, with a sunken foundation and sturdy buttresses to support the walls of the nave. The foundation, two meters deep, is a network of iron plates and chains
that tie the supports for the columns of the outer walls to the supports for the columns of the central nave. This network was filled with a mixture of lime, sand, hydraulic cement, and gravel sourced from the river Pasig to form a foundation of reinforced concrete (E. L. Romanillos 1991, p63).

This foundation supports the church which measures 50 meters long by 22 meters wide. The bell towers are 52 meters high, while the top of the dome is 33 meters high. Fifty-seven columns composed of an interior support system of angled iron plates support the elaborate groin vaulted ceiling and side walls, which are tied together with iron cross bracing for stability. A system of iron king post trusses supports the roof and is hidden by the vaulted ceiling panels and ribs. The central columns support a network of cast iron tracery which forms the groins of the vaulted ceiling and dome. Fluted cladding hides the interior support of the
columns, while the cross bracing of the side walls are clad in sheet steel. Cast iron ornamentation in the form of architectural embellishments such as column capitals, window frames, and decorative friezes help to conceal the junctures in the cladding panels.

The seismic-resistant design proved effective. Belgian specialists sent by the manufacturer to aid in the church’s assembly in Manila wrote to Palacios in 1899, describing an earthquake which rattled the structure under construction on May 26th of that year. The structure had suffered no damage at all (E. A. Romanillos
The final result is a gothic revival church, fronted by two spired bell towers and adorned with an octagonal cupola at the transept, which is the same width as the nave. The interior is composed of a central nave, separated from two side naves by rows of fluted columns. At the north end is the main altar with four supporting altars, each dedicated to a different saint. At the south end, the choir loft spanned the central nave above the narthex, at the level of the start of the

Figure 2.12 The interior of the Basilica, c 1960.
vaulting, and was later extended across the entire width of the church. Spiral staircases in the bell towers add stability and provide access to the choir loft.

Monumental stained glass windows help to light the interior. There are huge rose windows in the north and south walls, as well as on the east and west walls, at the transept. Twelve stained glass lancet arch windows with scenes from the life of Christ light the side walls on the first level of the church, while smaller lancet arch stained glass windows light the church at the level of the vaulting and the drum of the cupola.

After the arrival of the final shipment, it would be another year until the church was ready to open. The time was spent painting and decorating the interior and exterior of the church. Around this time, the church was awarded the title of “Basilica” by papal decree, linking it to Saint Peter’s Basilica in the Vatican (Salvatierra 1993).
2.4 Painting and Decoration

The painting of the church by the local art school was commissioned by the Provincial Council. Professor Don Lorenzo Rocha led the project and was assisted by students Felix Martinez, Isabelo Tampinco, Antonio Sanchez, Manuel Martinez, Clemente Parades, Manuel Espritu, and Simon Fortic. Professor Lorenzo Guerrero oversaw the design and execution of sculptural elements in the church: the retablos, confessionals, and pulpit.

The new church had five altars. The central and main altar is dedicated to the Virgen del Carmen. Two side altars beside the main altar are dedicated to the Sacred Hearts of Mary and Jesus. On the east wall is the altar of Saint Nicolas,
and on the west wall is that of Saint Joseph (Zaragoza 1894). The pulpit, altars and retablos, gothic in style, were designed by Don Lorenzo Guerrero and carved by Don Eulogio Garcia (Zaragoza 1894).

In addition to the altars, retablos, confessionals, pulpit, lighting, railings, and furnishings needed to decorate the interior of the church, the largest part of the project was the treatment of the walls and columns to disguise the industrial identity of the prefabricated iron church. Students of Manila's best art academy,
the Academia de Pintura y Dibujo, overseen by their professors Lorenzo Rocha and Lorenzo Guerro, painted every inch of the interior and exterior of the Basilica to give the impression of a stone church with sculptural niches. The result is a show case of painting technique: two schemes of faux stone marbling and graining, more than 100 figural trompe l’oeil paintings throughout the church, as well as faux wood graining on the doors, and trompe l’oeil depicting architectural details and religious symbols in relief on the ceiling of the

Figure 2.15 The pulpit designed by Guererro and carved by Eulogio at the altar, in front of the Basilica’s German stained glass windows. 2011.
CHAPTER TWO

Figure 2.16 Faux marble ashlar painted on the cladding plates. 2011.

Figure 2.17 A cast iron column capital, painted to simulate jasper. 2011.
The paintings were executed using a traditional oil painting technique of painting on a support with pigments suspended in a medium of drying oils, typically linseed oil. The paint was applied directly to the primed steel surfaces.

The flat steel cladding of the walls and ceiling vaults was painted in a scheme designed to simulated marble ashlar. Each ashlar block was carefully sectioned off by painting in shadows of mortar joints. The faux stone was painted in shades of green and tan, with darker veining and highlighting flecks of reds, yellows, and browns.

The fluted cladding of the columns engaged in the side walls and standing in the center of the church are painted in shades of red with highlights of green and yellow to simulate the stone jasper. This scheme also adorns the cast iron work details including the various ornamental friezes, the ribs of the ceiling vaulting, and the tracery that surrounds the windows and doors of the church.

Forty full figure paintings decorate the lower drum of the dome and depict Carmelite saints and martyrs. The eight walls of the octogonan cupola are sectioned in to six panels, the top center of which is a lancet arch window. The other five panels serve as niches for a single painted figure in each. Another sixty eight figures decorate the pendentives supporting the dome; twelve of these are full figure angels in tear drop shaped panels, and fifty six are cherubic faces on the frieze bordering the pendentives (See figure 2.18).

Six monumental full figure paintings in fully rendered trompe l’oeil niches decorate the walls behind and flanking the altar. Saint Augustine and Saint Nicolas de Tolentino flank the main altar, that of the Virgen del Carmen. Two
CHAPTER TWO

Figure 2.18 Winged figures decorate the pendentives. Note the arched frieze is decorated with cherubic faces. 2011.

Figure 2.19 (from left to right) Recollect Martyr, Recollect Martyr, Saint Monica, Saint Rita of Cascia, Saint Augustine, and Saint Nicolas of Tolentino.

Photos: Estan Cabigas, 2011
Recollect Martyrs flank Saint Joseph's altar on the east wall, and Saint Monica and Saint Rita of Cascia flank Saint Nicolas' altar on the west. These figures are painted standing in ornate trompe l'oeil sculptural niches. These niches are surmounted by scrolled gothic spires supported by columns resting on an ornate scrolled pedestal. Although not gilded, these painted pedestals are executed in shades of yellows and browns to mimic the look of gilt carved wood pedestal niches. All of the niche figures wear flowing black robes, and the Saints Rita and Monica also wear the nun’s habit. The figures of the Recollect martyrs hold palms, a symbol of their martyrdom (See figure 2.19).

Recollect and Carmelite coats of arms are painted in the molded lancet arches above the figures of Saint Nicolas and Augustine. The four evangelists are painted in the lancet arches above the niche figures of the side walls.

Figure 2.20 The Recollect coat of arms painted in an arched niche above the altar. 2011.
Figure 2.21 Diagram showing the location of figural paintings in the choir loft. 2012.

Figure 2.22 Scenes from hell, by Martinez. 2012.
Seventeen square panels framed in jasper scheme molding depicting scenes from hell arch over the rose window on the south wall in the choir loft (See figure 2.19). The panels show groups of human figures engulfed in flames. They are said to have been painted entirely by one student, Felix Martinez (Zaragoza 1894).

Today the paintings still remain in the Basilica. They are largely intact, and original. Repainting has been limited to retouching of severely corroded areas. Major repainting campaigns have been limited to a few areas of faux ashlar in the choir loft, a few columns in the nave, and the lower quarter of a trompe l’oeil in the nave.
2.5 Steel and Iron in 19th Century Ecclesiastical Architecture

While San Sebastian Basilica is a marvel of art and architecture, it is not unique in its all-metal composition. Metal houses of worship were at the peak of popularity in the 19th and early 20th century and varied in size, style, and cost.

Small churches made of corrugated, galvanized iron panels were popular throughout the United Kingdom as temporary houses of worship to be used until a more permanent masonry structure could be erected. Composed of a cast
iron framework clad in galvanized corrugated iron sheets, these “tin tabernacles” were often inexpensive and somewhat portable. The buildings were, on many occasions, sold second hand and moved to other locations when superseded by masonry iterations. Because of their economy and flexibility in design and transport, they also became widely used by missionaries in Australia and New Zealand, as well as parts of Africa and the Americas as early as the 1830’s. These metal churches were simple in design on both the exterior and interior. They also tended to be small in size, seating between 100 and 500 worshippers.

The Illustrated News of London reported in September of 1844 on the production of an iron church made in England and sent to Jamaica for assembly. Under the title “An Iron Church for Jamaica,” it states:

“A church has been sent out to Jamaica, as a specimen, as many of the kind are likely to be required. The pilaster supports are of cast iron, on which are fixed the frame-roof, of wrought iron, of an ingenious construction combining great strength with simplicity of arrangement; the whole is covered with corrugated iron and the ceiling formed of paneled compartments, covered with felt, to act as a non-conductor of heat. The body of the church is 65 feet by 40; the chancel, 24 by 12: a robing-room and vestry are attached. The windows are glazed with plate-glass, one eight of an inch in thickness; the two chancel-windows and four others are of stained glass.”

In the height of their popularity from the mid-nineteenth century and the 1920’s, thousands of these structures were erected across the United Kingdom. The rapid boom following the industrial revolution caused the growth of towns across the kingdom. These working class towns centered around industrial processes grew
quickly and their religion followed them in the inexpensive, quick to assemble, prefabricated corrugated iron structures (Momement and Holloway 2007).

In addition to these vernacular iron churches, more ornate examples exist. Almost invariably, these more ornate designs are credited to Gustave Eiffel. In most cases there is little definitive proof of such attributions. San Sebastian Basilica was suggested to have been designed by Eiffel, but it has not been proven. All Spanish documentation credits Genaro Palacios with the design of the church. The attribution to Eiffel is most likely based on record from Eiffel’s papers which reference designing a church in Manila in 1875.

Other church designs attributed to Eiffel include the Church of San Marco in Arica, Chile. Constructed circa 1870, it is made completely of prefabricated iron
components. There is also a metal church in Grecia, Costa Rica. Iglesia de la Nuestra Senora de las Mercedes is very similar in appearance to San Sebastian.

Figure 2.26 Iron church of San Marco in Arica, Chile.

Figure 2.27 The metal Iglesia de la Nuestra Senora de las Mercades, in Grecia, Costa Rica.
Basilica on the exterior.

Bulgarian Church of Saint Stephen, in Istanbul, is another grand church constructed entirely of steel and iron components and was designed in a Baroque style. The church was completed in 1898, constructed from parts prefabricated in Vienna between 1893 and 1896.

While metal churches were at one time common, no such church was ever as extensively decorated. San Sebastian Basilica is unique among these iron churches in its simulation of the appearance of stone.

Figure 2.28 The iron and steel Bulgarian Church of Saint Stephen, Istanbul, Turkey. Completed 1894.
CHAPTER TWO

2.6 Maintenance and Repair History

The restoration and treatment history of San Sebastian Basilica until the 1980s is limited to several exterior repainting campaigns which were additive – additional paint layers were applied but the previous failed coatings were not removed. In 1987, the exterior of the Basilica was fully restored. All layers of paint were removed completely until the bare metal was fully exposed. Badly corroded areas of the steel plates were cut out and patched with welded steel panel dutchmen repairs. Then the exterior was primed and painted with two coats of enamel paint.

In 1990, a campaign of restoration was undertaken in the interior. The treatments involved manually cleaning the surface dust from the painted surfaces,

Figure 2.29 Patches at the base of a column.
Figure 2.30 Note the repainting of the marble ashlar to the level of the top of the windows.

Figure 2.31 Choir loft ceiling, showing a previous painting campaign covered over by later marbling. Note the difference in color and style from the wall on the left.
retouching of the badly corroded areas with a rust inhibitor, and retouching some areas of stone veining (Salvatierra 1993, p101).

Although there is no archival record, the lower panels of the trompe l’oeil figure of Saint Augustine, to the right of the altar, were replaced with a single perforated steel panel. The lower third of the design was repainted on the replacement panel. This likely occurred during the restoration of 1987, though with no documentation, this is merely speculation.

See Appendix A for time line of repairs and alterations.
3.0 | Literature Review

Conservation of Original Finishes on Corroded Architectural Members: Literature Review

In order to form a complete understanding of what is known about the preservation of decorative finishes on corroding metal substrates, a review of the relevant literature was undertaken. The goal of the review was to identify studies which addressed the many aspects of finishes-on-metal conservation—from the evaluation of the causes and mechanisms of such deterioration, to the treatment and interventions undertaken to remediate the resulting conditions. In order to be comprehensive in approach, it was necessary to extend the search beyond the traditional conservation literature.

There are many industrial studies on corrosion prevention through the application of protective coatings to steel structures. Studies conducted on the effectiveness of preventing corrosion of steel through the application of protective coatings shed light on the potential reasons for their failures. These studies identify problems with surface preparation, potential contaminants that can affect the adhesion of paint films to metal substrates, and the effects of the environment and weathering on such systems, but have few suggestions for extending the life of already damaged materials. These studies tend to focus on the desired properties of protective coatings for iron and steel, preparation and methods of application, and on the failure and decay mechanisms of such coatings.
CHAPTER THREE

Technical publications relating to the evaluation of anti-corrosive paint systems on large steel structures such as bridges and industrial buildings were included and provided a great deal of information on the possible reasons for, and symptoms of, coating failure. Such technical studies do not address methods for treating a failed coating, but rather focus on the mechanisms of coating failure in order to prevent it from occurring in the future by adjusting coating formulations, as well as surface preparation and paint application methods for new structures.

Conservation case studies provide examples of treatments to remedy the physical appearance of coating failure and corrosion. These studies generally accepted the formation of corrosion on the painted objects as a result of improper storage and handling, and remedied that cause by placing the item in a controlled environment. In these cases the finishes are regarded as primarily ornamental, rather than as the front-line protection of the metal surface from aqueous or atmospheric corrosion.

Evaluation of Coatings for Iron and Steel

One important article by Pamela W. Hawke entitled “Paints for Architectural Cast Iron” proved to be an excellent starting point. The article describes the reasons for painting ferrous architectural members and outlines traditional methods of doing so.

Iron and steel are unstable in their purified form, and form more stable compounds (iron oxides, what is generally termed “rust”) in the presence of
moisture and oxygen through an electrochemical reaction known as corrosion. Painting the surface of the reactive metal with a protective coating can effectively shield it from the corrosive environment and prevent the reaction from occurring. Early coatings for steel and iron include oils, tar, and paints utilizing pigments such as red and white lead, iron oxide, and zinc. Linseed oil was the most commonly used binding media for such coatings. These coatings were applied in the shops where the components were manufactured because corrosion could set in even before the product could reach the customer.

Red lead was a common primer for the protection of iron and steel building elements. It is not surprising, therefore, that the first coat of primer found on components of San Sebastian Basilica. Red lead bound in linseed oil reacts as the oil polymerizes to form the metal soap, lead linoleolate, which makes for a durable, elastic, moisture-resistant coating.

An article by William H. Smyrl on the prevention of corrosion through the use of protective coatings states that the primary concern when studying corrosion is generally to reduce rate at which it occurs (Smyrl 1987, p609). The rate of corrosion may be controlled by the use of protective films composed of drying oils and pigments as long as they are well maintained.

“Evolution of Steel Protection: A Personal View,” by S.L. Lopata is another article which provides a brief history of the developments in the technology of protective coatings for steel. This article provided useful information about the historic use of red lead primers, the majority of the article discussed advances in the technology, including the development of high performance zinc based coatings as well as the development of water based and epoxy resin coatings,
as alternatives to oil based and metal solids containing coatings (Lopata 1984, 8).

Red lead primers bound with linseed oil, alkyd paints with iron oxide pigmentation, oil bound primers were the only widely used protective coatings for steel structures before World War II. Further developments included the development of “rust converters” in response to the need for primers which could be applied to already rusty surfaces in order to re-coat them without the need for sandblasting for adequate adhesion. Tannic acid treatments, which convert the oxides of the corrosion product to more stable tannates, followed by high zinc content coatings are now commonly used for such purposes (Lopata 1984, 7, 9). While tannic acid works well to arrest corrosion, it produces a dark black staining effect which would damage the aesthetic qualities of the finishes at San Sebastian Basilica.

Before the development of such high-tech coating systems, lead and linseed oil coatings were generally accepted as the best protection for architectural ironwork. Books such as John Fryer’s 1875 “Architectural Iron Work” provided specifications for the application of such coatings.

“Each casting thoroughly coated with paint on all surfaces, including bolt holes, to be painted before using. All bolts to be dipped in paint before being used, and all screws, rivets, etc., to be treated in this way as well; carefully scare away all burs, etc., after the drilling of holes. The joints made flush and true, and water tight.” (Fryer, 1875, p63).
And

“...all the exposed iron work to be painted two coats best white lead and linseed oil paint; outside the color to correspond with the present color of front; inside work painted white or such color as directed.” (Fryer, 1875, p138).

But while these coatings are effective in the protection of ferrous building components, aging and weathering affect their properties, particularly elasticity and durability. This can result in the failure of a coating.

“The Analysis of Coatings Failures” by George D. Mills, published by the American Society for Testing and Materials is an important article which relates to the evaluation of the performance of the coatings in San Sebastian Basilica. It is a comprehensive guide describing all of the factors which should be considered when trying to determine the reason behind a coating failure. Though the article is geared toward the examination of coatings of an industrial rather than decorative nature, the scale, materials, and substrate of such industrial structures has a strong correlation to the Basilica.

A coating is considered to have failed when it loses its ability to serve its specific function. Generally, coatings for steel structure serve a protective, utilitarian purpose first and an aesthetic function second. However, many coatings are also intended to have a particular aesthetic quality. In such cases, undesired change
in the coating’s visual properties also constitutes a coating failure. Common changes include changes in color, gloss, texture, as well as the appearance of biological colonization. The article states that such modes of failure are usually caused by reactions to the environment.

Failures may manifest in cracking, peeling, chalking, blistering, or delamination. These conditions may occur in tandem. Protective coatings for steel have definitive service lives and are meant to be cyclically maintained and reapplied. Because of this, there is no literature which addresses methods to “fix” a protective coating after failure, other than to reapply it.

Aesthetic functions aside, coating failure can be defined as an undesired change in the coating’s physical or chemical properties which causes premature damage of the coating and substrate. Mill’s article states that

“A major reason for applying coatings to many different types of substrates is to protect the substrate from deterioration. Coatings on steel, when applied properly, have the ability to stop corrosion in hostile environments for a period of time. When coatings are applied to protect the substrate and the substrate sustains premature damage, a coating failure has occurred (Mills 1987).”

It is important to make the distinction that the damage caused must be premature to constitute a failure. Protective coatings have a limited service life.

A coating failure may originate from deficiencies in a coating’s formulation, interference in the coatings film formation by the atmosphere, use of incompatible materials, improper or inadequate surface preparation, and improper application of the coating. Furthermore, failures can result from
problems with the pigment (volume, composition), with the medium and
extender (too much, too little, contaminants, etc), as well as with the substrate
(improper preparation, surface contaminants).

Some molecules, including water, carbon dioxide, hydrogen sulfide, and sulfur
dioxide can migrate through a polymer film. The rate at which this occurs is
known as the vapor transmission coefficient. It is of particular interest in coatings
for corrosive metals, as permeable films can allow the formation of corrosion to
occur.

A study by R.M. Holsworth defines weathering as the cumulative effect of
outdoor exposure on a material’s properties and performance. It states that
weather can change the properties and performances of coatings through
the following chemical and physical reactions: volatilization or leaching of
plasticizers and solvents; chemical decomposition of plasticizers, pigments etc.;
breakage of main polymer chains in the coating vehicle; splitting off of side
groups along the main polymer chains; reactions among the new groups or
residues formed; reactions of reactive groups, such as residual double bonds
in the vehicle; oxidation of susceptible groups, catalyzed by driers and catalyst
residues; and stressing deformation of the coating due to dimensional change in
the substrate, swelling by water, or temperature changes (Holsworth 1982, 5).

Exposure to water can affect paints both chemically and physically. Chemically,
hydrolysis of the polymer can occur. This causes degradation of the paint film.
Physically, water may attack the pigment-polymer bond and result in chalking.
Humidity, its presence or absence, may causes expansion or shrinking of the
coating. The relative humidity influences the amount of condensation on a
coating’s surface. A film of condensation on the coating surface can result in materials in the coating being extracted and re-deposited on the surface. This affects not only the appearance of the coating but also the polymer life (Holsworth 1982, 5-7).

Besides the effects of weathering and aging on a paint film, surface contamination from various sources can prevent the proper adhesion of the coating to the substrate and undermine the longevity of such protective coatings. A study by W.C. Johnson entitled “Detrimental Materials at the Steel/Paint Interface,” outlines substances which may be found on the surface of mass produced metal for structural and architectural purposes at the time of application of protective coatings which can undermine adhesion and coating performance. Such materials are grouped into general categories: greases and oils, moisture, chemical contaminants, and iron oxide (Johnson 1984, 29).

The author asserts that because oxygen and gaseous water can penetrate many coating films, that they are often readily available to bond with sub-paint contaminants that were not properly removed from the surface of the metal during preparation for paint application.

Grease and oil at the interface of metal and coating can prevent the coating from properly adhering to the surface of the metal. Grease and oil may find its way to the surface of mass produced metal objects of construction in many ways including accidental splattering from other tools and machinery, purposeful lubrication of areas of the metal components for drilling or machining, deposition from nearby traffic, and may also be left on the surface of a metal even when cleaned if cleaning solvent is left to evaporate from the metal’s surface rather
than being wiped dry (Johnson 1984, 29-30).

Moisture accumulates on the surface of a metal when the temperature of the surface is below the dew point. Moisture may also be attracted to salts on the surface of the metal, such as ferric chloride or ferric sulfide, which may remain even after cleaning. The presence of moisture on the surface of the metal prevents proper adhesion of the paint and may also promote the formation of corrosion (Johnson 1984, 30-31).

Chemical contamination takes the form of deposited environmental salts, such as those deposited by pollution or snow removal efforts. Acid from acid rain is also considered a potential chemical contaminant. These residues can also be deposited by contaminated blasting media used in abrasive cleaning methods. The presence of these residual deposits undermines the effectiveness of the applied coatings by interfering with its adhesive and cohesive properties. For example, salts trapped beneath the surface of a coating can attract moisture by osmosis through the paint membrane and allow the completion of a galvanic cell and fuel a corrosive reaction (Holsworth 1982, 31-32).

Iron oxides in the form of mill scale, corrosion scale, or rust are also commonly found on the surface of architectural steel. Mill scales differ from corrosion in that they are primarily composed of wustite (FeO) which is only formed at temperatures above 570 degrees F. These types of scales tend to be compact and stable enough to form a protective, corrosion inhibiting coating on the underlying steel as long as they remain intact, as opposed to rust and corrosion

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1 Dew point: the temperature below which atmospheric moisture condenses in the form of liquid water droplets.
scale, which are active and hygroscopic and accelerate the corrosion reaction.

The presence of mill scale is less of an issue in terms of paint compatibility than that of rust or corrosion scale. Both rust and corrosion scale promote delamination and undermine the adhesion of the paint system to the metal surface. Mill scale as a paint substrate presents an additional problem. The flexing of most architectural metal components causes the formation of cracks through the wustite of the mill scale, which invites the formation of rust, which in turn attracts moisture to the area, eventually fueling a corrosion reaction which undercuts the layer of mill scale and, effectively, any paint system applied to it. The article recommends blasting to bright metal and carefully cleaning with appropriate solvents to remove contaminants, mill scale, and other detrimental materials from the surface of the metal to facilitate long lasting protection (Holsworth 1982; Burns, 1939).

In addition to breaks in a protective paint film caused by paint failure, defects in the metal substrate and in the over layers of the protective surface such as random pores and cracks, promote localized corrosion phenomena by exposing the vulnerable metal to the atmosphere.

As explained by Dan Parera’s “Stress Phenomena in Organic Coatings,” physical stresses can also affect the performance of a protective coating. Stresses occur during film formation, which usually results in a contraction of the polymer. Stresses are also inherent in the coating at all times as a result of adhesion: it is constrained from movement by its bond to the substrate. Because of this constraint, changes in temperature and relative humidity cause a great deal of stress in coatings. Increases in temperature will cause expansion of a coating,
while decreases will cause contraction. Similarly, high relative humidity can result in absorption of water molecules and expansion of some coatings, and low relative humidity will cause a contraction by a loss of such molecules.

Common responses to stress include cracking, delamination, and peeling. If the high stress develops in a coating and the coatings adhesive strength is greater than its cohesive strength, the damage will occur in the coating as cracking and fissuring, rather than at the coating interface as would happen if the cohesive strength was greater than the adhesive strength.

Breaches in the coating film from any of these causes can result in the formation of corrosion at the exposed site. Once started, the corrosion may then undercut the paint film, completely undermining its protective function.

Remedial Treatments of Finishes on Corroded Metal

A search of the conservation literature for sources addressing the conservation of finishes on steel or cast iron yielded few results. In all cases the metal substrate was different from that at San Sebastian—galvanized steel or copper rather than mild steel or cast iron. These kinds of publications focus on the remediation of the aesthetic changes imparted to such painted objects by the corrosion damage. Studies recount the approach to treatment as the mechanical removal of accumulated corrosion scale, consolidation of delaminated paint, and the replication of the painted design to infill lacunae. Methods referenced in such studies dealt with the problem of the potential for future corrosion exclusively by placing the object in a regulated, low humidity environment.
While there has been a great deal of study dedicated to the conservation of corroded architectural components of steel and iron, few studies have been identified which deal specifically with the problem of conserving original, decorative finishes on such surfaces. This is so because in most cases where painted building members are corroding, the paint coating is a sacrificial protective layer which is replicated as a means of conservation. Of the few published studies that have taken on the challenge of preserving fine paintings on corroded metal substrates (Ankersmit 2004; Marinas-Feliner 2001; Nagy 2007), the studies deal with panel paintings or other painted objects which can be placed in an environment in which it is possible to control temperature and humidity fluctuations and maintain them in a range in which the corrosion process can be halted by eliminating the possibility of the deposition of an electrolytic film on the metal surface from atmospheric water.

One case involved the deterioration of a work of art by Venezuelan artist Jesus Rafael Soto, Espaces Virtuels: Jaune et Blanc (1965) (Ankersmit, Timmermans, and

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ii In the literature search, the following repositories were consulted:

AATA Online: Abstracts of International Conservation Literature http://aata.getty.edu/nps/
American Architectural Manufacturing Association http://www.aamanet.org/
American Coatings Association http://www.paint.org
American Society of Civil Engineers http://www.asce.org/
American Society for Testing and Materials http://www.astm.org
ASM International http://www.asminternational.org/portal/site/www/
Association for Preservation Technology http://www.apti.org
Building Science Corporation http://www.buildingscience.com/index_html
Canadian Conservation Institute http://www.cci.icc.gc.ca
Conservation Information Network (BCIN) http://www.bcin.ca/
National Association for Surface Finishing http://www.nasf.org
Journal of the American Institute of Conservators http://cool.conservation-us.org/jaic/
JSTOR http://www.jstor.org
Proquest Dissertations and Theses Database http://www.proquest.com
Weerdenburg 2004). This piece is a conceptual painting composed of square iron rods (2 mm by 3 mm and 99 cm long) painted with PVA emulsion paint yellow on one side and white on the other, suspended by nylon threads in front of a white board covered in black painted lines. The overall effect is a vibrating optical illusion, which is the content and meaning of the piece. Because of inappropriate storage, the iron rods were corroding, depositing diffuse rust stains on the yellow areas and pitting on the white (Ankersmit, Timmermans and Weerdenburg 2004, 60).

After analysis by microscopy, SEM, and FTIR, it was found that the primer which was applied under both colors was cracking due either to movement of the thin flexible rod over time or deficient preparation and a loss of binding medium. It was decided to attempt to remove the rust stains and stabilize the pitting using a chelate. The panels were treated with a chelating agent to inactivate the corrosion process by forming bonds with the iron ions to prevent them from reacting with oxygen to form rust scale (Ankersmit, Timmermans and Weerdenburg 2004, 60). Several reagents were tested including ethylenediamine tetraacetic acid (EDTA), diethylenetriamine pentaacetic acid (DTPA), diammonium citrate (DAC); triammonium citrate (TAC), and phytic acid (PA). The test showed that the removal of iron ions using these reagents resulted in a large amount of paint disturbance except in the case of phytic acid. Treatment with PA did not significantly disturb the paint surface in this case, and transformed the brown rust spots on the art work into a white iron-phytate complex. In the case of Jaune et Blanc, this white complex was preferable to the visible rust (Ankersmit, Timmermans and Weerdenburg 2004, 60).
A paper entitled “Saving Judd’s Untitled 1964: Revival of a Galvanized Steel Single Stack Sculpture with Red Nitrocellulose Paint” by Eleonora Nagy and Karlis Adamsons was reviewed, and it showed some similarities to the problem at San Sebastian Basilica. In this case, a significant galvanized steel sculpture by Donald Judd was deteriorating due to corrosion of the zinc coating and, to some degree, the steel below it, causing the red Harley Davidson paint to flake off of the surface of the sculpture (Nagy and Karlis 2007, 248). Although the conservators postulated that the best way to prevent the loss of paint was to enclose the sculpture in a controlled environment, the owner of the piece wished the piece to be on public display unencumbered and so different treatment options were considered (Nagy and Karlis, 252).

In the end, the conservators chose to stabilize the painted areas by consolidating the flaking paint and infilling the lacunae with a paint system devised to replicate the original. Because the original paint system was composed of three layers (a grey primer, a layer of metallic flake, and a semi-transparent red top coat) which all moved in response to the environment and factors of deterioration to differing degrees, a consolidant with appropriate flexibility and good adhesion to metal was necessary (Nagy and Karlis, 253).

The paint was consolidated with a mixture of 4g Acryloid B67, 50ml isopropanol, 10ml xylene, and 1.28g Tinuvin 292. The conservators were unable to identify a solvent to remove the excess consolidate. Furthermore, the consolidate caused a slight lightening of the painted surface (Nagy and Karlis, 254-256). After consolidating the painted areas of the sculpture, the unpainted metal areas were treated. White accretions were mechanically removed, and small areas
of iron oxide corrosion which had caused some degree of staining were treated with 5% triammonium citrate, a chelating agent (Nagy and Karlis, 257). Although the treatment identified for this sculpture produced some undesired effects, the application of the consolidant mixture was largely successful as a method of stabilization of the paint system.

Another study focused on the conservation of original paint on baroque period iron bars from a cathedral. Laboratory testing of reversible acrylates centered on finding the most effective treatment for the rusted areas of the bars. The conservators in this case were unable to achieve sufficient penetration into the paint coated rust layers to consolidate and isolate the material from the corrosive environment with such materials. In this case, an irreversible solution was taken in the application of a coating of polyurethane. This served to consolidate the flaking layers and re-adhere the paint surface, but raises considerable questions about the possibility of future treatment (Scott and Eggert 2009, 235).

A case study that was particularly relevant to San Sebastian Basilica addressed the examination and conservation treatment of a number of retablos from the University Art Gallery Retablo Collection of New Mexico State University were examined and conserved prior to a large traveling exhibition. In this study, three types of retablos were examined: those executed on tin-coated iron, on canvas, and on copper supports. The examples of the tin-coated iron retablos are the most relevant to this study. Although the iron supports in this case differ from the ferruginous supports present in San Sebastian Basilica, similarities exist in the behavior of paint on metal surfaces. Failures in the tin coating of the
retablos in the collection resulted in the corrosion of the iron substrate resulting in pronounced areas of rust staining and active corrosion causing delamination of the paint film in areas, which is similar to what appears to be happening in the Basilica (Marinas-Feliner 2001, 39).

The treatments of these paintings focused on removal of the built up corrosion product through the use of solvents as well as mechanical means on the painted front surfaces, and chemical conversion treatments on the corroded areas of the unpainted reverse surfaces. After cleaning and treatment, the panels were coated front and back with a protective layer of acrylic polymer resin Acryloid B72 and placed in an environment with a maintained RH of 30% or lower (Marinas-Feliner 2001, 40).

An additional applicable case study involved the conservation of high potassium content corrosive glass tesserae in the Last Judgment Mosaic of St. Vitus Cathedral, Prague, Czechoslovakia (Pique and Stulik 2004). Because the glass formed obscuring and damaging corrosion crusts in response to moisture and pollutants in the atmosphere, a method was needed to isolate the reactive glass from the air. A coating system was developed which incorporated the use of an amorphous oxide of silica (SiO2) applied to the surface of the tesserae through a sol-gel process. In this process, tetraethoxysilane (TEOS) is mixed with ethanol in the presence of water to cause a hydrolysis reaction, releasing oxygen, and causing the solution to increase in viscosity until it has “gelled.” Infrared radiation is then applied to cure the amorphous oxide into a crystalline phase. This process worked particularly well in the case of this glass mosaic, as the sol-gel formula actually forms bonds with the glass, creating a very durable protective coating.
The sol-gel coating was followed by a layer of a cross-linked fluoropolymer, and then a layer of non-cross-linked fluoropolymer. This system allowed there to be a very well bonded protective layer in contact with the corrosive glass surface to prevent contact with the atmosphere, as well as an outer sacrificial layer that could be cyclically removed and reapplied to protect the protective coating from weathering and degradation.

Conclusions

Previous work in the conservation of historic finishes on metal substrates centers on consolidation of the paint system and stabilization of corrosion through environmental control. Because it is not currently possible to control the interior climate of the Basilica to a degree sufficient to arrest corrosion, the majority of the traditional conservation literature on the subject has limited application to the approach to the preservation of the finishes in the Basilica.

Professional trade publications on the performance and properties of protective coating systems for large steel structures in industrial applications are a valuable resource for information on deterioration phenomena in such systems. The recommended treatments for failed systems involving blasting to bright metal and re-coating with improved systems are not relevant to San Sebastian Basilica. Such treatments are very effective at stopping the corrosion reaction, but would result in the loss of the valuable decorative quality of the finishes at San Sebastian Basilica.
4.0 | Investigation of Deterioration

4.1 Methodology

Investigating the type and causes of deterioration of the painted finishes at San Sebastian Basilica began with a detailed visual condition survey followed by materials analysis to determine composition and optical microscopy to examine the microstructure of the coating. Archival research helped to confirm the presence of original materials and shed light on original technique.

The purpose of the visual conditions survey and resultant condition maps was to identify patterns of deterioration manifesting on the walls of the Basilica. Since it was not possible to survey the conditions throughout the entire interior of the church, three survey areas were chosen based on their accessibility as well as for their representation of the painting types and accurate representation of the conditions present in the Basilica. Survey areas were chosen in the nave of the church, on the east and west walls, as well as in the choir loft, on the south wall. The different locations provide a sampling of possible micro-climates in the building and allows for comparisons to determine possible relationships between condition and location. Each area encompasses each painting type used in the decoration of the church; trompe l’oeil, faux marble, and faux jasper. The conditions observed on the painted surfaces were examined and noted. The conditions were assigned unique color IDs to denote one from another. Each of the survey areas was then studied in depth and the conditions found were recorded on field drawings overlaid on photographs of the survey area. By documenting and mapping the conditions occurring on the survey panels,
patterns in the deterioration can be recognized and studied. The information resulting from the condition maps illuminates the extent and severity of the deterioration and is helpful in understanding causes.

Sample collection was carried out after the completion of the survey of each area. The collection was primarily focused on obtaining representative samples of each condition manifest on the wall.

4.2 Description of Finish Types

![Diagram showing finish types in the interior of the Basilica, by location.](image)

<table>
<thead>
<tr>
<th>Finish Type</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faux Jasper</td>
<td>Section looking south, showing the choir loft and front door; section looking east; section looking north, showing the altar area; section looking west.</td>
</tr>
<tr>
<td>Faux Marble Ashlar</td>
<td></td>
</tr>
<tr>
<td>Trompe L'oeil</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.1 Diagram by the author showing the finish types in the interior of the Basilica, by location. (From left to right) Section looking south, showing the choir loft and front door; section looking east; section looking north, showing the altar area; section looking west.

Photo: Estan Cabigas, 2011; Drawing: Richard Tuason-Sanchez Bautista; Diagram by C. Leggio.

i Sampling was carried out by Christine Leggio in January of 2012. Samples were taken from the walls of the Basilica using a stainless steel scalpel. Samples were collected and stored in paper coin envelopes and glass vials. See Appendix B for sample schedule.
As discussed in chapter 2.3, there are several finish schemes decorating the interior of the Basilica. The simulated stone schemes cover the greatest surface area of the interior of the church. The marble ashlar scheme is present on the flat steel panels of the walls and ceiling of the church, in both the nave and choir loft. The jasper pattern covers every column, as well as the cast iron tracery around the windows and doors, the ribs of the ceiling vaults, as well as the ornamental cast iron friezes which extend along the upper part of the walls and surround the rose windows in at each end of the nave and transept.

The marble pattern is predominantly grey-green in color, with more saturated greens used on the ceiling and in the dome. The green is streaked with darker veins and brush strokes of reds and browns, and is touched with yellow and pale green highlights. The marble scheme is sectioned off into individual ashlar blocks.

Figure 4.2 The ceiling near the altar, showing painted ashlar blocks in the simulated marble finish. Note the missing piece of molding at the lower right of the image.
the joints of which are painted in a shade of dark grey.

The jasper pattern relies on red for its base color. The variegated reds are streaked with green and yellow veining and accents. The columns are sectioned into drums, with the joints painted in grey in a manner similar to the simulated mortar joints in the marble ashlar blocks. Where it is applied to the decorative cast iron friezes and tracery, the jasper pattern runs continuously over the ornament with no indication of mortar joints.

![Figure 4.3 Jasper scheme painted column showing evidence of deterioration at the seams. Note the painted mortar joints denoting the divisions between drums in the column.](Photo: Chester Ong, 2011)
The trompe l’oeil paintings are present in a few different schemes in different locations. The panels of the dome are decorated with full figures of saints and religious figures. Each figure stands on a decorative trompe l’oeil pedestal on a simply shaded background.

Supporting the dome are the triangular pendentives which are divided into three tear-drop shaped sections which together form a triangle whose base supports the dome and whose point meets the supporting column; this is bordered by rows of seven arched divisions on the free sides.

The twelve drop shaped sections of the pendentives are painted with figures of angels. The angels wear red, blue, or yellow robes, have white wings, and float on a yellow background. The arched paneled borders are painted with the faces of cherubs, all centered in light blue grounds; there are 56 in total.
There are twelve trompe l’oeil paintings adorning the walls of the nave on the lower level of the church. Six of these are full figures of saints in realistically painted trompe l’oeil scrolled niches. They are the Saints Augustine and Nicolas de Tolentino, to the right and left of the altar; Saints Monica and Rita of Cascia on the western wall; and the figures of two Augustinian Recollects who were martyred in Japan in the 17th century. These figures are approximately 25 feet in height by 4.5 feet in width.

Above the figures of Saint Augustine and Saint Nicolas, set in lancet arches, are paintings of the Recollect and Carmelite coats of arms. Both are painted in shades of golds, reds, and browns, on backgrounds of clouds and sky. In the arches above the niches of the other figures are paintings of the four evangelists, Matthew, Mark, Luke, and John.
Figure 4.6 A lancet-arched molded frame containing the painted image of Saint Matthew, the Evangelist.

Figure 4.7 The choir loft at the southern end of the church, above the main entryway.
The trompe l’oeil paintings in the choir loft are painted in a decorative border which forms an arch over the rose window centered in the south wall of the church. This arch spans the entire width of the choir loft and is divided into 17, roughly square panels, by raised frames painted in the jasper scheme. Each panel is painted with a multi-figure composition depicting scenes from purgatory. Above the arch, painted on the wall outside of the border is an image of the virgin and child hovering over the scene.

In addition to the figural trompe l’oeil, there are trompe l’oeil motifs simulating three dimensional medallions adorning the ceiling at the entrance of the church. Because the configuration of the choir loft was extended to fill the width of the entire church in 1894, this scheme is probably a later addition. It is painted in shades of blue and yellow, and is unlike any other trompe l’oeil in the Basilica in terms of color, subject, and style of painting.

Figure 4.8 Trompe l’oeil medallions in blue and yellow can be seen on the ceiling below the choir loft.
4.3 Survey Areas

Figure 4.9 Survey area NE, an Augustinian Martyr (left) located on the east wall in the nave of the Basilica, and survey area NW (right), located on the west wall.
Survey areas of equal size were chosen from the side walls of the nave on the ground floor. One panel from the east wall, which depicts a Recollect Martyr, and one from the west wall which depicts Saint Monica were chosen. The third survey area is located in the choir loft and is roughly half the size of the survey areas in the nave due to the size of the choir loft. This survey area includes three framed panels depicting scenes from purgatory.
Figural trompe l’oeil schemes, as well as an adjacent section of marble ashlar background and the jasper design of the adjacent columns, are represented in each of the nave survey areas. The location of each of the panels, as well as the inclusion of all painting types in each survey area allows the comparison of different micro-climates and conditions within the Basilica.

The trompe l’oeil images in the nave survey areas cover flat steel cladding plates situated between two engaged fluted steel columns. The whole of the each figural panel is composed of seven individual plates joined and bolted to an interior cross bracing and structural bracket system. The plates measure 47.5 inches in length by 52 inches in height. These seven make up the entire height of the wall below the cast iron frieze. The survey area is limited to the lower five of
Figure 4.12 Diagram by the author showing the location of the figural trompe l’oeil paintings within the Basilica. In this section looking east, figures of Recollect Martyrs can be seen on the side wall. The one on the right is survey area NE.

Figure 4.13 Diagram by the author showing the location of the figural trompe l’oeil paintings within the Basilica. In this section looking west, figures of Saints Rita and Monica can be seen on the side wall. Saint Monica, on the left, is survey area NW.
these panels and extends 22 inches beyond to include a portion of the simulated jasper column as well. In total, the survey area measures 20.5 inches in height and 8 inches in width.

The choir loft survey area is composed of three square panels which depict scenes from purgatory. The three panels are framed in jasper molding. The survey area extends to the right of the figural panels to include the adjacent area of marbled ashlar and a section of the jasper painted column as well. In total, the south east survey area measures 12 inches in height by 49 inches in width.
Survey area NE, an Augustinian Martyr, is located on the east wall of the Basilica, at the northern (altar) end of the nave. The painting depicts a Recollect Martyr standing in a simulated carved sculptural niche and clutching a bundle of palms, a symbol of martyrdom.

Survey area NW is located on the west wall of the Basilica at the northern (altar) end of the nave directly across from survey area NE. Survey area NW depicts Saint Monica in a simulated carved sculptural niche.

Survey area SW differs from survey areas NE and NW in location, environment, configuration, and painting technique. Survey area SW is located in the choir loft, which is exposed to higher temperatures and is poorly ventilated in comparison to the nave of the Basilica.

The configuration of the plates in survey area SW differ from those in NE and NW. Rather than a single, large figural painting executed upon flat cladding panels between engaged columns, area SW is a series of smaller paintings depicting multiple figures subjected to the fires of hell. Each plate is surrounded by a molding, which separates the individual scenes. These plates are stacked one above the other, and form an arch around a large rosette stained glass window which is the focal point of the choir loft. Survey area SW consists of the lower three panels on the west side of the south wall, as well as an adjacent area of marbled ashlar bordering the decorative arch, and a section of jasper column on the right side of the panels. See Appendix B for sample location charts and condition maps.
4.4 Scientific Analysis: Objectives and Methodology

The analysis of the samples collected during the condition survey served five specific purposes: 1) to illuminate the artist’s working methods and identify interventions; 2) to detect the presence of corrosion occurring beneath the paint layers; 3) to identify inter-layer separation; 4) to locate loss of cohesion within individual paint layers; 5) to examine the depth and extent of cracking and other conditions affecting all of the layers of paint.

Understanding the working methods of the artist is important to understanding the creation of the paintings. Surface preparation is a major factor in the protection of steel structures, and is also integral in the creation of fine paintings. Examining the paint layers closest to the steel substrate allowed the determination of the composition of the priming layers. Above the prime layers, the artist’s painting technique becomes apparent and the original design layers can be distinguished from any later intervention layers of varnish or over-paint.

Examining the samples for the presence of corrosion beneath the first prime layer allows the determination of the extent of corrosion occurring on the surface of the steel, undercutting the paint layers. Inter-layer cohesion as well as cohesion throughout individual layers was important to establish in order to determine whether the cause of delamination are inherent in the material or occur as a result of the disruption of the metal surface. Examining the depth and extent of micro-cracking through the paint stratigraphy is important in determining the level of exposure of the steel substrate to the atmosphere.
CHAPTER FOUR

The embedded cross sections\(^{ii}\) were examined using a Nikon Alphaphot 2-YS2 microscope with reflected/quartz halogen illumination with fluorescence 400-446 wavelength range BV 1A filter. By examining embedded cross sections under visible reflected light and reflected UV light it was possible to determine aspects of the artist’s original painting technique, such as the sequence of paint application. Examination of cross sections also shed light on the depth of penetration of surface cracks and fissures and sometimes provided evidence of the migration of corrosion product through the paint film.

The study of cross sectional samples also made clear the presence of later applications of paint or other interventions such as the spot retouching of corroded areas with a commercial rust inhibiting paint or the later applications of clear water repellent or protective coatings, as were found on the NW and SW survey areas. By looking at paint properties such as pigment particle size and texture, as well as the presence of dirt layers between original and later layers, it was possible to identify alterations to the scheme, which were not always evident in the condition survey.\(^{iii}\)

Fourier-transform infrared spectroscopy\(^{iv}\) (FTIR) and gas chromatography/mass
spectrometry (GC-MS) were used to determine the composition of the original paint binders as well as later retouching. By identifying the binder, it is possible to confirm the presence of original materials and to identify standards for the material’s application, maintenance, and service life.

Scanning electron microscopy and energy-dispersive X-ray spectroscopy (SEM-EDS) determined the composition of the pigments in the paint as well as the presence of corrosion product and other contaminants within the paint stratigraphy. Identifying the composition of the materials present on the walls of the Basilica helps to understand the properties of the material and their behavior as they age.

Raman spectroscopy determined the specific corrosion products. The spectra were taken from different areas within each scraping. Spectra were collected with Omnic 8.0 software and analyzed in this program with various IRUG (Infrared and Raman Users Group) and commercial reference spectral libraries.

Samples containing oil, resin, varnish and wax compounds are composed, in part, of carboxylic acids or esters. To reduce the molecular weight and make the components more volatile, treatment of the samples with MethPrep II reagent converts carboxylic acids and esters to their methyl ester derivatives. Samples were transferred directly to a heavy-walled glass GC vial and then 100L of 1:2 MethPrep II reagent (Alltech) in benzene was added. The vials were warmed at 60°C for one hour in the heating block, removed from heat, and allowed to stand to cool.

Samples were analyzed using the Hewlett-Packard 6890 gas chromatogram equipped with 5973 mass selective detector (MSD) and 7683 automatic liquid injector. The Agilent Technologies MSD ChemStation control software was used with Winterthur RTLMPREP method with conditions as follows: inlet temperature was 300°C and transfer line temperature to the MSD (SCAN mode) was 300°C. A sample volume (splitless) of 1µL was injected onto a 30m×250µm×0.25µm film thickness HP-5MS column (5% phenyl methyl siloxane at a flow rate of 1.5mL/minute). The oven temperature was held at 50°C for two minutes, then programmed to increase at 10°C/minute to 325°C where it was held for 10.5 minutes for a total run time of 40 minutes.

The cross-sections were mounted to a carbon stub with double-sided carbon tape adhesive. Carbon paint was applied on the side and top surfaces of casting medium, without covering the cross-section itself, to prevent charging once in the SEM (scanning electron microscope). The sample was examined using the Topcon ABT-60 scanning electron microscope at an accelerating voltage of 20kV, stage height of 20mm, and sample tilt of 20°. The EDS (energy dispersive spectroscopy) data was analyzed with the Bruker X-flash detector and microanalysis Quantax model 200 with Esprit 1.8 software.

The corrosion sample found directly on the metal substrate of the building was analyzed with the Renishaw Invia Raman spectrometer (785nm diode laser) in conjunction with WiRE 2 software with extended scan
identification of the specific type of corrosion forming in the Basilica helps to confirm the composition of the metal components. Knowing the specific corrosion product will shed light on the specific corrosion reaction and its specific causes.

from 200-800cm⁻¹, 50X objective lens, exposure time of 30 seconds/scan for one accumulation, and 50% laser power.
5.0 Pathology

5.1 Building Deterioration

The deterioration at San Sebastian has manifested itself in many physical and chemical forms. Corrosion has caused losses of metal in the church, resulting in large holes in some of the steel cladding panels. In other areas, the build-up of expansive corrosion products between plates and at joints has caused corrosion jacking and displacement of some steel panels. This is in addition to the smaller scale surface corrosion, which is now causing paint loss but has not yet progressed to the point of forming holes in the metal panels.

Because the greatest threat from the corrosion is a loss of structural stability, the work of the SSBCDF has focused on recording and diagnostics to investigate the effect that the corrosion is having on the building’s structural framework. The foundation began a campaign of inspections using endoscopic cameras to study the interiors of the building’s internal column system for extensive damage. Although the building has been declared structurally stable for now, the survey of the interiors of the columns has revealed a layer of compact corrosion product covering the surfaces, as well as standing water at the base of the columns following rain storms. The implication is that the corrosion will continue to undermine the stability of all of the ferrous components of the building unless the sources of moisture are eliminated.

Iron corrosion, what is often termed “rust,” is a mixture of crystalline and amorphous forms of the oxides and hydroxides of iron. The specific chemical
composition of rust is dependent on the climatic conditions and the length of time for which it is exposed to the atmosphere. The chemical composition of steel corrosion products also tend to differ across the strata of corrosion crusts. The most common components of rust are magnetite (Fe3O4), lepidocrocite (gamma-FeO(OH)), and goethite (alpha-FeO(OH)). Magnetite is dense and lamellar in structure, and is often found closest to the surface of the metal within the rust deposit. Lepidocrocite and goethite are porous in structure and are found in the outer layers of the rust formation (Landolt 2007, p348).

The primary components of the corrosion of the steel cladding panels in the Basilica were determined by Raman spectroscopy to be lepidocrocite and goethite. It is likely that magnetite is also present, but was not represented in the sample analyzed. See Appendix A for full analytical results.

When produced at high temperatures, 150° C or higher, magnetite forms compact, protective layers. When formed by atmospheric corrosion, however, it does not form continuous films and does not lend any protective quality to the metal surface. Because it is a good conductor of electricity, this loose magnetite formation acts as a cathode for oxygen reduction and thus helps to facilitate the corrosion reaction.

Lepidocrocite and goethite are the predominant phases of the outer part of the rust layer, which forms on corroding steel surfaces. Goethite is more thermodynamically stable than lepidocrocite, however it forms slowly and it is common for lepidocrocite to be the primary formation (Landolt 2007, p349).

Lepidocrocite is often lamellar and acicular in structure and is yellow-orange
in color. It is commonly found in mild steel that is corroding, particularly in mildly saline environments classified as mixed marine, such as the environment in Manila. It is commonly found with goethite, which was found to be the secondary form of iron oxide present in the corrosion scale of the steel paneling of the Basilica.

The presence of a porous layer of corrosion product on the exterior of the metal surface accelerates environmental corrosion on the one hand, and slows it on the other. The porosity of the rust layer increases the exposed surface area and allows the adsorption of pollution and the condensation of water vapor within its pores. As a result, it increases the potential for a corrosion cell to form. Alternatively, the imperfect barrier formed by such corrosion products also
may slow the rate of corrosion by reducing the access of oxygen to the metal surface. Therefore, un-corroded, exposed steel corrodes at the highest rate. That rate diminishes somewhat as the layer of rust builds up at the metal surface. After an initial period of exposure (often lasting years), the corrosion rate levels out and the conversion of metal to corrosion product still increases linearly with time as the accelerating and inhibiting effects of the rust layer come to cancel each other out (Landolt 2007).

Once the corrosion products have begun to form at the surface of the metal, additional phenomena occur. Some forms of ferrous oxides become hydrated, meaning they contain moisture within their chemical structure, which accelerates the rate of corrosion. Additionally, porous corrosion products hold liquid water, thereby keeping it in contact with the metal surface and continuing the corrosion formation.

The proliferation of this corrosion reaction is affecting both the appearance and performance of the interior finishes at San Sebastian. Because the corrosion is occurring at the interface between the paint film and the metal substrate, significant disruption has occurred. This disruption has manifested itself in many forms in the Basilica. The following report on the condition survey findings describes these conditions in detail.

5.2 Condition Survey Findings

One hundred percent of the survey areas are affected by one type of deterioration or another. Level one micro-cracking, and level one pitting, for
example, affect roughly 90% of the areas surveyed.

The conditions fall into three different categories: 1) conditions related to the infiltration of liquid water to the surface of the walls, including staining and corrosion formation; 2) breaching of the paint film, taking the form of cracks, lacunae, and pits; corrosion formation at the paint/steel interface, manifesting as blistering and delamination; 3) and additive accumulations and encrustations such as retouching, repainting, and accumulated soiling. The extent and range of the conditions found are described by survey area below. See Appendix A for a full, illustrated glossary of conditions.

SW Survey Area – Choir Loft – Scenes of Purgatory

In general, deterioration of the figural trompe l’oeil paintings, the SW survey area, is moderate. Severity and impact of the conditions range from cosmetic to total loss of paint.

Here, a figural passage located in the choir loft presents less micro-cracking than elsewhere and minor pitting, possibly because the thicker paint application used for rendering the forms has more successfully protected the steel from corrosion than areas where the paint is thinner and more subject to cracking and associated breaches. As a case in point, the lesser pitting and cracking is prevalent on the thinner paint of the faux ashlar border and the jasper column.

A significant amount of soiling and accretions are present on all plates of the SW
CHAPTER FIVE

Figure 5.2 Painting from the choir loft survey area. Note the thick painting style and the large pits in the upper right hand corner.

Figure 5.3 The bottom most plate of the SW survey panel, located in the choir loft.
survey area. The panels are so soiled that it is difficult to discern the colors in situ. They are heavily soiled with an accumulation of cobwebs and dust. Soot is also probably present, as candles were used during the early history of the church. These paintings are also obscured by a whitish haze, in addition to a general darkening of the yellows, reds, and oranges used to create the flames of hell and the flesh tones of the figures in the composition. Tests indicate that hazy film may be related to the presence of zinc stearate, which most probably derives from a water repellant coating such as a micronized wax. Dust and debris attracted to the surface by electrostatic action contribute to the dull appearance.

The structure of all three panels and adjacent cladding are in good condition. There is no significant warping, displacement, or misalignment of plates 1 or 2, although plate 3 is missing a few bolts and bolt heads. A small area of corrosion jacking (roughly 10 centimeters in length) has caused warping of the plates in the marbled ashlar area to the right of the figural paintings.

NE Survey Area – East Wall of Nave – Figure of a Recollect Martyr

Survey Area NE is in good condition. The panel plates are sound. They have not been affected by warping from corrosion jacking, nor do they present corrosive deterioration, to the point of holes in the metal cladding. Neither are they significantly warped or displaced. Corrosion on the interior face of the panels has not progressed to the point of corrosion jacking nor changed the profile of any of the plates beyond a few millimeters of pitting cavities.

Pitting occurring approximately three inches apart, described as diffuse pitting,
appears on both the flat and fluted plates. It covers approximately 90% of the surface area of the NE survey zone. Localized pitting, referring to pitting at intervals a few millimeters to one inch apart, is also present and covers roughly 2% of the surface of the surveyed area.

Water seepage from between the flat plates corresponds to a large amount of white streaking running down the length of the panel. This streaking begins from the joints between the upper plates and runs down the entire length of the painting panel causing streaking on the lower plates. The white crusts deposited by the water, initially thought to be either solubilized zinc corrosion from the roofing material above or crystallized soluble salts. FTIR determined the presence of zinc stearate, although it is not clear if this substance was applied intentionally.

Figure 5.4 Trompe l’oeil painting from the NE survey area showing white streaking from water from leaks running down the wall surface.
as a water proofing agent.

Additionally, the paint and substrate are in poorer condition in the NE Survey Area than elsewhere. More evidence of paint cracking and loss, more exposed substrate, and associated corrosion formation appear in this area. Together with it is evidence of corrosion migration and associated lifting and flaking of the paint film. Fine cracking and crazing cover slightly more than 2% of the surface.

The deterioration of the paint film appears to be influenced by pigment. The black and yellow areas of the painting are cracking, flaking, and pitting to a higher degree than the white, brown, and grey areas, which appear to be more stable and better adhered to the substrate. Additionally, many small areas have been retouched, in most cases with one of several types of commercial rust inhibiting paint. Many of these retouched spots have flaked off since application, leaving a ring of rust-inhibiting paint surrounding an area of paint loss under which the metal has continued to corrode.

Deterioration of the trompe l’oeil panels is most severe at the center of the survey area, around the figure’s chest and hand. This area probably corresponds to the intersection of internal cross bracing, which may be collecting and holding water that has infiltrated the cavity wall. It also corresponds to a seam in the cladding panels where the transmission of moisture to the interior surface would be likely to occur.

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i  See Appendix A for full analytical results.

ii  According to documentation outlined by the parish in the 1992 publication “The Basilica of San Sebastian” by Salvatierra.

iii  Future examination of such exterior conditions is recommended.
Figure 5.5 Areas which have been retouched with rust inhibiting paint which has now corroded through.

Figure 5.6 Trompe l’oeil painting from the NE survey area. Note the large losses and distressed paint around the figures hand in the center of the plate.
The paint of the jasper scheme on the adjacent column appears to be in better condition than the figural and ashlar schemes on the flat panels. On the fluted jasper columns, the paint is affected by minor cracking and pitting. Except for rare areas of loss exceeding one centimeter, these areas are well adhered.

NW Survey Area – West Wall of Nave – Figure of Saint Monica

A combination of oral accounts and scientific analysis revealed that Survey Area NW was coated with a clear, protective varnish.\textsuperscript{iv} Based on the presence of the dirt layer beneath the varnish layer, it is clear that this particular passage was coated sometime after its original execution, possibly as a test to consolidate and preserve the paintings. According to the building custodian, the coating may have been applied between 1990 and 1991, when the church altars were restored. FTIR determined that the coating contains a natural tree resin, most closely matching dammar varnish.\textsuperscript{v}

The flat steel cladding plates in this area are in considerably worse condition than those of Survey Area NE. In particular, there is a large lateral gap between plates 4 and 5 in which plate four is bowed out in the center, standing proud of plate 5 as much as 4 cm in the center. This gap has been filled with a silicone caulking compound in attempt to seal it; however, the caulking has failed

\textsuperscript{iv} No formal documentation of this treatment has been found, but an oral history from the building’s custodian indicates that the coating was applied at the same time the church’s altars were restored in 1990 and 1991.

\textsuperscript{v} The coating of sample NWb3 is characterized as a natural tree resin such as dammar with FTIR analysis. More specific identification of the natural resin could be achieved with GC-MS (gas chromatography – mass spectrometry) analysis. See Appendix A for full analytical report.
as the plate has continued to bow and pull away from the lower plate in the center. The sealant has also been applied to the joint between plate 4 and the engaged jasper column, as well as to the left two feet of the joint between plates 3 and 4.

The coating on the trompe l’oeil painting in this area is not found on other survey areas. It is clear and shiny in appearance, and trails of it running down the surface of the painting in some central areas are evident. The application of this coating seems to have been concentrated in the figural areas of the panel, with
the faux ashlar at the top and sides of the panel largely uncoated (ie: coated incidentally as it was applied to the more significant trompe l’oeil areas of the wall), and the jasper columns not coated at all. This coating was applied prior to the campaign of retouching with the commercial rust converter, as all instances of such spot painting are uncoated.

Deterioration associated with pigment in this survey area is consistent with that occurring on panel NE. However, on this panel the yellow areas appear to be in better condition than on the NE panel, possibly as a result of the protection of the coating.

Figure 5.8 Cross section of sample NEb3, showing the dammar varnish coating that is believed to have been applied in the early 1990’s.
Evaluation of Condition

In general, the finishes in the survey area are in fair to poor condition. Fine cracking and small breaches pervade much of the coating. The most detrimental conditions are those that will progress to paint loss, such as blistering, and delamination. Although these conditions do not seriously diminish their aesthetic appeal at this time, they jeopardize the stability of the steel substrate and, in turn, the paint itself. The most prevalent conditions on the survey areas are superficial pitting and cracking which have insidiously caused exposure of the substrate in many small areas. Otherwise, the paint which remains is well adhered to the steel.

The conditions affecting the largest area of the survey areas suggest that deterioration is caused by the atmospheric corrosion of the exposed steel substrate. The most prevalent condition, level one cracking, covers roughly 40% of the surface area of panel NE, 30% of panel NW, and 30% of panel SW. The next most prevalent condition in all locations is level 1 pitting, which affects roughly 40% of panels NE and NW, and 20% of panel SW.

Level two cracking, the progression of level one cracking to a more severe degree, affects roughly 4% of panel NE, 13% of panel NW, and 5% of panel SW. Level two pitting covers approximately 10% of panel NE, 8% of panel NW, and 18% of panel SW. Losses cover 5% of the surface area of panel NE, 0.5% of panel NW, and 1% of panel SW. Blistering affects 1% of panel NE, 0.5% of panel NW, and 3% of panel SW. One square foot is the equivalent of 0.5% of the area of panels NE and NW, and 1.4% of panel SW.
CHAPTER FIVE

Figure 5.9 Graphic showing the percentage of surface area affected by a particular condition for each survey area.
Figure 5.9 (continued) Graphic showing the percentage of surface area affected by a particular condition for each survey area.
Of the conditions affecting the paintings, blistering and related detachment and loss are most damaging. Those conditions indicating the existing or imminent loss of the finish, are most severe on the trompe l’oeil panels, particularly survey area NE, where both conditions are prevalent. Unfortunately, the most severely deteriorated areas of the painting are located centrally, near the figure’s face.

Of the survey areas, NE is the most severely deteriorated. In addition to being affected by micro-cracking and pitting over roughly 90% of its surface, it is affected by staining, losses, more severe pitting and cracking, darkening of the paint film by subsurface corrosive activity, as well as soiling and accretions. Losses account for roughly 5% of the survey area’s surface.

![Figure 5.10 Detail of survey panel NE.](image)

The NW survey area is in the best condition of the areas surveyed. While cracking
and pitting are roughly the same in study areas NE and NW, the NW area is more stable and presents less loss, blistering/delamination, and advanced pitting and cracking. This difference in condition may correspond to the presence of a layer of dammar varnish applied to the NW survey area in the 1990’s. This coating seems to have stabilized the paint to some degree. The paint in this area is better adhered, consolidated, and corrosion on the exposed metal less pronounced than that on the NE panel. The total percentage of losses on this panel compared to the NE panel is drastically less. It comprises roughly 0.5% of the surface, as opposed to 2% on panel NE. The protective role of the varnish will be further explored in Chapter 6.

Panel SW is affected by all of the same conditions, but shows less evidence of direct run off of water. Rather than patterns of streaking seen on panels NE and
NW, the SW panels present a white crust and heavy soiling. Salt strips tests of material from this area confirm that this crust contains chloride and nitrate salts.

5.3 Results of Sample Analysis

Figure 5.12 Interior of the domed cupola during a test mounting in Belgium in 1888. Note the white primer on the panels, as well as the numbering.

The sample stratigraphies confirm that the interior steel walls, trusses, and supports
were coated with one layer of red lead primer, vi followed by an additional layer of white lead primer, as indicated in the documentation. Coatings were applied at roughly the same time, each wet on wet (see Appendix B for full cross section documentation). A photograph of the interior of the dome, taken during the test mounting in Belgium in 1889 vii, shows the white ground on the numbered panels (Figure 5.12).

As expected, these coatings are composed of red and white lead by SEM. The red lead primer contains barium, a common filler. The white lead layer is essentially pure lead pigment. The binder of the white lead layer was determined by FTIR to be linseed oil. FTIR analysis of the red lead primer layer yielded no result for the composition of the binder, GC-MS results show that the organic components of the red primer detected the presence of a drying oil, which is probably linseed oil. Design layers were found to be mostly composed of zinc pigments. The organic components of the binder for the design layers detected with GC-MS indicate the presence of a drying oil vii.

Most samples taken from flat panels (as opposed to those taken from cast iron moldings) show the application of an additional white layer, in some cases with a dirt layer in between. This second, more recent white layer is bound in drying oil, probably linseed, and is pigmented with zinc white rather than lead.

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vi Confirmed by SEM, Optical Microscopy
vii The Spires of San Sebastian, Romanillos, 1993 p69
viii The drying components include azelaic acid dimethyl ester (with peak at retention time of 13.97 minutes), palmitic acid methyl ester (18.07 minutes), and stearic acid methyl ester (19.98 minutes). The large peak at 10.42 minutes is a MethPrep artifact. The small peak at 12.89 minutes is due to a phthalate which may suggest the presence of an alkyd paint. Additional GC-MS analyses of this paint layer would be necessary to confirm the presence of an alkyd paint. Because the cross sectional samples from this area showed no over paint, it would seem that this is an anomaly.
Figure 5.13 Cross section with cracking through the stratigraphy, with corrosion migration. Also note the layers of red and white lead primer, which are consistent across all samples.

Figure 5.14 Cross section with upwards crack, illustrating corrosion migration upward from the substrate. Also note the corrosion product pooled at the top of the stratigraphy.
suggesting that this second white layer was applied after assembly in Manila, in preparation for the decorative painting.

The design layers of the samples vary in color and stratigraphy and are bound with organic media. The stratigraphy shows that the layers of paint, including second generation of repainting, have good adhesion to one another, as well to the substrate. Roughly 90% of all samples taken show a layer of corrosion product adhered to the underside of the shop-applied layer of red lead primer. Samples taken from areas showing no signs of corrosion beneath the paint layer do not present evidence of loose corrosion product below the lead red primer, indicating that the paint in those areas are well adhered to the un-corroded substrate.

Additionally, many cross sections illustrate that brown and red staining appears in the upper, and in some cases, lower layers of the stratigraphy. SEM analysis indicating that these deposits are rich in iron suggests that they derive from corrosion. Apparently, they are being deposited on the surface from corrosion-rich run off in some cases. In other cases they appear to be migrating upward from the substrate.

Additionally, some samples were determined by FTIR to have a zinc stearate coating or deposited layer on the upper surface. It was present in both the white streaking deposits from samples from the panel on the east wall of the Nave (Panel NE), as well as in the second generation over-paint from samples taken from the choir loft panel (Panel SW).

Zinc stearate is a waxy metallic soap formed by a reaction of zinc to stearic acid.
Its presence on the NE panel was found in an area of white streaking. The white streaking was thought to be a result of run off from the galvanized roofing above percolating through the roofing and wall system and running down the panel and depositing zinc oxide. It is possible, but not likely that the zinc from the roof, or from the pigment in the upper layers of the paint, reacted with stearic acid in the environment to form the zinc stearate, as stearic acid is primarily sourced from animal tissues. However, zinc stearate is a common ingredient in water proofing coatings, and was also found in a design over-paint layer from the SW panels.

Because zinc stearate has water repellent properties, it is often used in water proofing coatings for industrial uses. It can also be a component of micro-
crystalline waxes used for the same purpose. It has also been shown that these waxy coatings tend to develop a whitish haze over time called “bloom” (Blankshaen 2000). Because there is some record of a coating of microcrystalline wax being applied to the surface of the interior finishes, it is possible that the source of the zinc stearate is a remedial water proofing coating that was applied sometime in the building’s history. This would account for the presence of zinc stearate detected in samples from the choir loft (SW) and east wall of the nave (NE), offers an answer to the cause of the haze on the SW paintings.

5.4 Interior and Exterior Environmental Conditions

According to the Philippine Atmospheric, Geophysical and Astronomical Services Administration, Manila is classified as a “Type 1” climate – meaning that it has two distinct seasons: wet and dry. It is dry from November to April and wet from May through October. The rainfall is heaviest in the months of April through December, with peak rainfall in August reaching 19 inches of average rain fall in that month. In the driest months of January through April, rain fall is as little as 2 cm on average.

The wettest period is from July through September, when it rains an average of 20 days per month. May and June and October and November trail close behind at between 10 and 19 rainy days per month. The dry months of January through April have an average of four rainy days per month. Average temperatures in Manila range from an average high of 94°F in April to an average low of 73°F in January and February. The relative humidity is lowest in March and April with an
CHAPTER FIVE

Figure 5.16 Chart showing the average annual weather statistics for Manila.

Figure 5.17 Graph showing the interior climate of the Basilica’s choir loft over the period of one year. The red line indicates the RH% above which corrosion will form.
Figure 5.18 Streaking from water runoff from leaks is visible above a window in the nave.

Figure 5.19 The interior of a column, water is visible at the bottom of the shaft.
average of 35%. It is highest in June-September, at 80% (PAGASA).

The San Sebastian Basilica Conservation and Development Foundation Data provided data on the interior environment of the Basilica. It was based on recordings of temperature, relative humidity, and dew point in three locations of the Basilica for one year from March 2010 to March 2011. HOBO data loggers recorded data in two hour intervals from positions in the choir loft and in the central nave.

The interior of the Basilica is regularly exposed to fluctuations of temperature and relative humidity. Although it is open to the elements by way of gaps between components of the roofing and wall panels, it is poorly ventilated, which encourages it to retain atmospheric water. Additional sources of moisture within the Basilica include rain water, which infiltrates the Basilica through openings in the joints of the galvanized iron roofing panels and collects at various points in the wall and column cavities. Some of this water seeps into the interior of the

Figure 5.20 Graph showing the interior climate of the Basilica over the period of one month (July through August, 2011).
church through gaps in the interior cladding plates and runs down the surface of the walls leaving characteristic white streaks and rust stains.

Temperature recordings from the monitoring period range from lows of 75°F to highs of 95°F. Relative humidity ranges annually from 31% to 95%. The relative humidity within the Basilica was logged at values above 70% for approximately 45% of the recording period. When the thermal coefficient of expansion for steel is calculated using the 20 degree temperature range found in the Basilica, it can be determined that the steel will expand roughly 0.02 inches for every ten linear feet of steel. This calculation is best made using measurements of surface temperature rather than using the ambient temperature of the building, because radiant thermal energy from the heat of the sun is almost certainly transmitted to the interior surface of the walls through the cross bracing and air within the cavity walls. It is likely that the expansion coefficient is greater than indicated by using the ambient temperature to make the calculation. In any case, if the movement caused by thermal expansion exceeds the coefficient of elasticity for the paint, it can cause cracking and fissures throughout it\textsuperscript{ix}. Because the oil paint has become brittle over its 120 year life, it is particularly susceptible to this type of cracking.

Air pollution, a major health concern in Manila, is a potential source of contaminants. The types of contaminants commonly found in polluted urban air (sulfur, chlorine, salts, metals) that hasten the corrosion reaction of steel are probably present in some quantity on the surfaces of the Basilica. A very fine layer of deposited lead was detected by SEM on a layer of zinc paint in the choir.

\textsuperscript{ix} Future research should consider the specific elastic properties of paint films at more than 100 years old.
loft of the Basilica that had been exposed to the environment. Because the x-ray lines for lead and sulfur overlap (at about 2.3kV) it was not possible to distinguish between the two with the SEM-EDS data. The presence of lead was confirmed by additional lead peaks at 10.5kV, but there is no such confirmation in the case of sulfur. Therefore it is not known at this time if sulfur contamination is playing a role in the acceleration of the corrosion.

The nature of air pollution and its impact on the church and paintings is another subject requiring additional research.
0.6 Conclusions

6.1 Diagnosis

The most prevalent condition, the formation of corrosion product on the substrate, has been facilitated by several conditions. Cracking, pitting and losses exposing the substrate, offer paths for moisture to travel to the iron substrate and promote the corrosion reaction. The corrosion reaction in turn exacerbates the cracking and pitting of the surface, leading to losses at the most severe stage. Furthermore, because the corrosion products are also expansive, the corrosion below the paint causes dimensional change to the profile of the support and spalls the paint film and corrosion products from the surface as it progresses.

Given that all of the paint layers observed in the cross sections are well adhered to one another, as well as to the substrate where not undercut by corrosion, and do not exhibit interlayer cracking or separation, it is believed that the defects in the paint layers are a result of the advanced age and the resulting corrosion rather than from improper formulation of the paints themselves. The formation of loose corrosion products at the coating/substrate interface has produced a weak boundary layer where cohesion cannot be sustained. As thermal expansion and contraction occur and corrosion formation continues, paint and substrate delaminate and are lost.

The initial cause of these coating defects is probably a combination of factors.
Figure 6.1 Sample from an area of marble ashlar finish which is cracking but well adhered (NEc6). Note the absence of corrosion product adhered to the underside of the sample.

Figure 6.2 Sample from the background of the trompe l’oeil niche, exhibiting level 2 cracking. Note the layers of corrosion beneath the primer.
Stress, adhesion, and porosity all affect the performance of coatings (Smyrl 1987). Stress is inherent in all coatings. When strained, they compromise both adhesion and cohesion. Stresses build up almost immediately upon application as a result of the drying or curing process. A coating will tend to contract during film formation, causing tensile stress to develop in the coating as a result of that contraction being constrained by adhesion to the substrate. One means of release of these tensile stresses is the formation of cracks, micro fissures, and delamination (Parera 1987).

Porosity, adhesion, and stress response are the three most important factors affecting the performance of protective coatings. (Smyrl 1987)

Reduction in adhesion and cohesion, crucial properties contributing to durability, can be caused by stresses within a coating. Stress can form as a result of adhesion to the substrate.
Micro-fissures are evident over almost all of the paint surfaces in the Basilica. They probably result from a combination of factors, including inherent stresses, thermal stresses from the expansion of the metal panels, and the brittleness and loss of elasticity of the paint film from age.

Some stresses that affect coatings are inherent, such as those induced by the curing or drying stage of the paint, and those that are associated with adhesion to the metal substrate. Environmental fluctuations also stress polymeric coating systems. In particular high relative humidity causes dimensional changes while high temperature creates compressive stresses. Because the thermal expansion coefficients of the paint coating and the steel substrate are different, thermal stresses develop in the coating when it is exposed to heating and cooling cycles, such as the day and night cycles that occur in the Basilica. If the adhesive strength of the coating exceeds its cohesive strength, damage will tend to occur in the coating body, resulting in cracking and fissuring, rather than at the interface between the coating and substrate. These cracks and fissures provide a pathway for ions and electrolytes, which initiate a corrosion reaction at the surface of the steel. This is consistent with the conditions affecting San Sebastian Basilica. A network of fine cracks covers nearly every painted surface, and as the cycle progresses the cracks show signs of rust formation until gradually the condition advances to delamination and finally loss.
Additionally, moisture, high RH, temperature fluctuations, and the presence of pollutants influence corrosion (Smyrl 1987), especially when the RH reaches the "critical humidity" at 65%, the threshold at which atmospheric corrosion will occur (Hicks and Crewdson 1987). A data logger in the choir loft had documented that the RH there has been above 70% for 45% of the year.

The presence of pollutants in the city of Manila certainly accelerates the rate of corrosion. Sulphur dioxide, nitrite, nitrate, hydrogen sulfide, chloride and certain salts are particularly reactive, with chlorides being known to enhance pitting corrosion (Smyrl 1987). Contaminants can reach the substrate via pathways in stress cracks, however, sulphur dioxide molecules, as well as molecules of water, carbon dioxide, and hydrogen sulfide can migrate through polymer coatings (Mills 1987).

The presence of impurities on the surface of the substrate before coating can

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iii  Precipitation, ambient and dew-point temperatures, atmospheric pollutants, wind direction and wind velocity, and solar radiation are factors in corrosion occurrence. Moisture, RH, temperature, and pollutants such as sulfur dioxide and chlorides are important variables (Smyrl 1987).

iv  It is generally accepted that atmospheric corrosion cannot occur at RH levels below 65%, however surface contaminants such as pollution and salt can cause the metal to corrode at much lower RH levels (Landolt 2007).

v  The presence of air pollutants such as sulfur dioxide, nitrite, nitrate, hydrogen sulfide, chloride, and some kinds of salts accelerate the corrosion reaction. Chlorine gas or chlorides also enhances atmospheric corrosion. Chloride ions usually enhance pitting corrosion (Smyrl 1987).

vi  Small molecules such as water and carbon dioxide, hydrogen sulfide, and sulfur dioxide gasses have the potential to migrate through a polymer film. This increases the possibility of corrosion (Mills 1987).
also promote corrosion formation by interfering with proper adhesion. Some common adsorbed contaminants include water vapor molecules, oxygen and other gasses, as well as oils and surfactants from the manufacturing process (Mills 1987). Additionally, it is possible that the steel panels were not adequately prepared before the application of the priming coats after manufacture, which would undermine adhesion from the very beginning. The penetration of water, oxygen, and ions through the paint can cause a loss of adhesion as well (Hicks and Crewdson 1987).

The various coating breaches have allowed the formation of corrosion below the paint in San Sebastian Basilica. The hydroscopic nature of the corrosion product, as well as the high RH in the interior of the church and abundant sources of water from leaks, has accelerated the corrosion process (Mills 1987).

Extensive evidence of widespread micro-cracking through the layers of paint confirms that the surface of the metal is exposed in these discrete locations on all painting schemes (marble, jasper, figural) and on all substrates (steel, cast iron). These cracks were probably the result of dissimilar coefficients of expansion between the metal and the coating, with thermal expansion and contraction cycling (day and night as well as warm-cool season) of the metal components causing stresses in the coating.

Apparently detachment of paint is a result of the formation of corrosion below the paint, which produces loose corrosion product. The corrosion product, in

vii Corrosion beneath the paint is a common occurrence when contaminants remain on the steel interface at the time of coating application (Mills 1987).
turn, functions as a weak boundary layer; ie: its cohesive strength is less than the adhesive strength of the coating, and splits in response to competing stresses in the metal and the coating (Mills 1987). The presence of the corrosion product and the exposure to moisture then causes rust staining, and promotes the continued corrosion reaction by drawing more moisture to the metal surface as a result of its hydroscopic nature. Delamination is caused by corrosion, and at the same time is responsible for enhanced corrosion as well (Hicks and Crewdson 1987).

Minor conditions advance (cracking, pitting, and losses) to more severe ones. Micro-cracks become wider. Small pits develop into wider and deeper ones. Level 1 micro cracking is often coincident with pitting. This insipient deterioration at the level of the substrate eventually lead to paint loss, as corrosion creeps beneath the coating film, exerting physical pressure between the substrate and paint, and causing it to rupture.

Anomalous conditions found on the NW survey area may offer insight into treatment approaches as well as providing a possible datum point for the rate of corrosion. As confirmed by analysis, this passage is believed to have been varnished with dammar varnish in the early 1990’s. Unlike the other survey areas, which were not varnished, it demonstrates markedly better conditions. Far fewer losses and less severe pitting and cracking occur, when compared to the

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viii Failures associated with delamination of a coating from its substrate often taken to be ‘adhesion’ failures when in fact they are often a breakage through a weak boundary layer near the interface (Mills 1987).
NE survey area, although it too exhibits level one pitting and corrosion across roughly 90% of its surface area. What is interesting is the fact that micro-cracking (level one) has not advanced to the wider more serious cracking (level two).

The performance of the painting in this varnished survey area may have bearing on future interventions. Although the role of other variables warrants examination, it is possible that the varnish effectively arrested corrosion by sealing the painting from the environment.

If the varnish was indeed applied in 1990-91 and if this survey area accurately represents the response to coating of varnish, it provides a possible datum point of 1990-91 when the level of pitting was less than it is now. Images of the interior of the Basilica taken some time in the mid-20th century (c 1960) suggest that the finishes were in markedly better condition than they are today. While it is not possible to see fine details such as pitting and cracking in these images, it is clear that large scale damage to the paintings, such as staining, losses, or major pitting or discolored areas, is not present at that time, supporting the theory that the damage has become progressively more severe. Considering self-perpetuating nature of the failure of anticorrosive coatings, it is logical for this to be the case.

6.2 Summary and Conclusions

The deterioration of the paintings at San Sebastian Basilica is almost entirely caused by the interaction of water with the ferrous materials of which the church is constructed. Rainwater from leaks, high and fluctuating relative humidity and
associated condensation have converged to create the ideal environment for corrosion and damage to the painted surfaces. With breaches in the paint offering paths for corrosion, a cycle of deterioration is set in place: the metal substrate is exposed; corrosion attacks the exposed metal; moisture, attracted to the corrosion product facilitates more corrosion, which disturbs the paint and causes more loss, and the cycle continues. Although insidious, the pattern of deterioration is well established. Judging from conditions in the survey areas, extensive pitting, cracking, and loss of paint reveal early stages of deterioration and loss that will advance exponentially with time. Based on the comparison of the painting which was coated with varnish as recently as 20 years ago, to those which were not coated, the rate of deterioration is increasing with time. Without intervention to deter the environmental conditions and seal the exposed metal surfaces, the paintings will continue to deteriorate until they are entirely lost.

Corrosion of the steel and iron substrates directly impacts the preservation of the paintings at San Sebastian Basilica, however insidious it may be at this time. To predict the longevity of the paintings is to predict the rate of deterioration of the substrate, and the building itself.

As long as the potential for atmospheric corrosion and continued paint stresses exist in the interior climate of the Basilica, the finishes will continue to deteriorate.

Although it is not possible to entirely arrest deterioration at this time, it is possible to slow it down. The role of an impervious coating in retarding corrosion, such as seen in the NE survey area, where dammar varnish was applied, warrants further study.
7.0 | Recommendations

7.1 Treatment

The use of a clear coating, such as the dammar varnish applied to the NW survey area in the 1990’s, presents a possibility for slowing corrosion and paint deterioration. Further research and testing to determine the viability of this type of intervention are at the center of recommendations for additional research.

Slowing deterioration of painting on metal in an exposed environment has scarcely been addressed. Neither the field of conservation nor industry has produced information applicable to treating the conditions of the paintings at San Sebastian. After all, retaining a damaged finish coat on corroded steel while successfully arresting the corrosion reaction in an unregulated, highly humid environment presents an impossible, long term challenge. The acceptance of loss at a reduced rate becomes the more realistic goal.

Experimental testing is needed to identify the appropriate conservation materials and approaches to slow deterioration, while understanding that long term preservation may not be viable.

Building on the example of dammar varnish applied to the paintings, it is promising that a coating system may slow the rate of deterioration. Care would have to be taken to find a coating that would adhere to the substrate, consolidate the paint, be sufficiently reversible, and not susceptible to the
moisture in the atmosphere itself.

Potential protective coatings for the interior of the Basilica must be completely transparent, hydrophobic, and impervious to vapor transmission. It must be sufficiently adhesive to cling to the paint and corrosion product, and should be soluble so as to facilitate future retreatment.

Some coatings that warrant further research include varnishes with similar properties to natural resin varnishes, such as dammar, but with a higher glass transition temperature and greater color stability. Because the dammar coating applied to the NW area has proven somewhat effective, accelerated weathering tests could help to predict its long term behavior, and ac impedance tests\textsuperscript{ii} can be used to gauge the varnish’s effectiveness as an electrochemical barrier. The results could then be compared to appropriate synthetic coatings and coating systems.

Another potential coating that deserves further research is a product called Never Wet, a super-hydrophobic coating, developed by Ross Nanotechnologies, LLC. This coating was initially developed as an anti-corrosion coating and was soon adapted for use on fabrics as well. The coating is based on ultrahigh molecular weight polyethylene. The surface of this material raises the contact angle of water droplets to nearly 180\textdegree causing the droplets to take the form of

\textsuperscript{i} Additional interior and exterior environmental monitoring is needed to determine the specific role of air pollution in the deterioration of the steel and finishes.

\textsuperscript{ii} AC impedance tests measure the resistance that a circuit presents to the passage of a current when a voltage is applied. It is used to determine the protective power of coatings on metal.
a near perfect sphere and shoot off the treated surface. Experimentation to
determine the effect of atmospheric vapors, as well as durability is needed (Ross
Nanotechnology 2011). If the corrosion were to continue to occur through water
vapor transmission, the coating may have some viability in conjunction with
another, impermeable, coating.

A silica oxide coating such as the sol-gel formulation used in the conservation
of the Last Judgment Mosaic of Saint Vitus Cathedral, Prague could also be a
viable candidate for testing (Pique and Stulik 2004). Because it has shown signs
of success in the long term prevention of the corrosion of the glass tesserae of
the mosaic, it is possible that a similar formulation would also be able to isolate
the exposed steel in San Sebastian Basilica from the atmosphere. In the case of
the Mosaic, the silica oxide coating was just one component in a multi-layered
system designed with a built-in sacrificial layer to facilitate maintenance of the
treatment. The approach of layering coatings with complimentary properties to
build up a protective barrier is one that should be examined closely.

A poly-acrylic acid cross polymer based coating called Avalure 315 polyacrylate
was developed as a water repellent coating for painted bricks. Because it forms
polar and ionic bonds with metal oxides and metalsiii, it is worth further research.
Because this product permits vapor transmission (a desirable quality for a coating
for masonry) it is not likely to arrest the corrosion from atmospheric causes unless
used in conjunction with a non-permeable outer coating. Because it has the

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iii Lecture by Richard Wolbers, University of Pennsylvania, November 30, 2011.
potential to form bonds with the exposed metal and corrosion product, it may function well as a consolidant and could serve as the first layer in a multi-layered coating system.

It is likely that the conservation treatment would need to be a multi-step process. The walls should be cleaned of dirt and dust, loose and flaking paint consolidated, and bare corroded metal treated with the appropriate chemical stabilizing treatment before a protective coating is applied.

To determine the effectiveness of a consolidation-stabilization-coating treatment, it will be necessary to perform accelerated weathering tests on samples of the Basilica, or failing that, on appropriately pre-weathered facsimiles. By coating painted, corroding steel panels with a protective film and subjecting them to temperature fluctuations, high humidity, and condensation, it will be possible to determine the efficacy of a protective system. In situ tests should then be performed to confirm the appropriateness of the treatment in the particular case of the Basilica. Locating samples in the Basilica and allowing them to age in that environment over a well-considered period of time would yield the most accurate results. Continued monitoring of the environment is also recommended, as is periodic inspection of the paintings for changes in condition.

7.2 Conclusions

Future research focused on slowing deterioration of the paintings is the
logical next step from this primarily diagnostic research. The determination
of a comprehensive plan for the conservation of the interior finishes of San
Sebastian Basilica is a complex task. Because the deterioration is so pervasive
and corrosion, by nature, is so persistent it is likely that it will not be possible to
preserve the paintings in perpetuity. However, the undertaking is justifiable given
the significance of the site and the lack of formal studies on the subject.

Research and development of a manageable treatment program and
preservation approach will be a great asset to the survival of the Basilica. Like the
response of the building’s originators to the earthquakes which plagued previous
iterations of the church, the approach to its conservation must be innovative as
well as practical.
Bibliography


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APPENDIX | A

Condition Survey Information
Appendix A.1 | Condition Glossary
ACCRETIONS - accumulated matter obstructing the surface of the painting.

ALLIGATORING - separation of the paint body forming islands and gaps which leave the primer layer exposed.

BLISTERING - lifting and tenting of the paint from subsurface corrosion formation. The instances of blistering found in the Basilica have cracked and are progressing to loss.
Cracking - Level 1 - fine micro-cracking of the paint film.

Cracking - Level 2 - advanced cracking of the paint film. Corrosion is precipitated through the cracks.

Loss - a break in the paint film, causing exposure of the substrate in an area greater than 1 cm in diameter.
Lost Bolts - distinguished between missing bolts (green) and missing bolt heads (orange).

Over-paint - spot retouching of corroded area with daubs of single colored rust inhibiting paint.

Pitting - Level 1 - Pin-point spots of corrosion (>1 mm in diameter). Can be localized or diffuse.
Pitting - Level 2 - Spots of corrosion (<1 mm but > 1 cm in diameter). Can be localized or diffuse.

Streaking - Rust - oxide rich depositions on the surface of the paint, from rain water leaks running down the wall and forming orange-brown rust stains.

Streaking - White - white depositions on the surface of the paintings from rain water running down the wall.
Darkening - darkening of the painting surface as a result of subsurface activity.

White Crusts - white efflorescence forming on the surface of the paintings.
Appendix A.2 | Condition Mapping
Condition Survey
Trompe L’oeil Panel of an Augustinian Martyr

Survey Panel:

- Cracking (1)
- Cracking (2)
- Pitting (1)
- Pitting (2)
- Darkening
- Alligatoring
- Accretions
- Crusts (white)
- Blistering
- Streaking (white)
- Streaking (rust)
- Over-paint
- Loss
- Lost Bolts
- Lost Bolt-heads
- Caulk
- Plate Joint
- Abrasion
Condition Survey
Trompe Loeil Panel of an Augustinian Martyr

Survey Panel:
Plate A

Accretions
Cracking (1)
Overpaint
Streaking (rust)

Alligatoring
Cracking (2)
Pitting (1)
Loss

Blistering
Crusts (white)
Pitting (2)
Missing Bolts

Caulk
Darkening
Streaking (white)
Missing Bolthead
Condition Survey
Trompe L’oeil Panel of an Augustinian Martyr

Survey Panel:

Accretions
Cracking (1)
Cracking (2)
Crusts (white)
Caulk

Alligatoring
Cracking (2)
Crusts (white)
Darkening

Blistering
Cracks

Overpaint
Pitting (1)
Pitting (2)
Streaking (white)

Loss
Missing Bolts
Missing Boltheads
Streaking (rust)
Condition Survey
Trompe L'oeil Panel of an Augustinian Martyr

Survey Panel: NE
Plate C

Accretions  Cracking (1)  Overpaint  Streaking (rust)
Alligating  Cracking (2)  Pitting (1)  Loss
Blistering  Crusts (white)  Pitting (2)  Missing Bolts
Caulk  Darkening  Streaking (white)  Missing Bolthead
Condition Survey
Trompe Loeil Panel of an Augustinian Martyr

Survey Panel:

Plate D

Meters

Accretions  Cracking (1)  Overpaint  Streaking (rust)
Alligating  Cracking (2)  Pitting (1)  Loss
Blistering  Crusts (white)  Pitting (2)  Missing Bolts
Caulk  Darkening  Streaking (white)  Missing Bolthead
Condition Survey
Trompe L’œil Panel of an Augustinian Martyr

Survey Panel:
Plate
E

Meters

Accretions
Cracking (1)
Overpaint
Streaking (rust)
Alligatoring
Cracking (2)
Pitting (1)
Loss
Blistering
Crusts (white)
Pitting (2)
Missing Bolts
Caulk
Darkening
Streaking (white)
Missing Bolthead
Condition Survey
Trompe L’oeil Panel of Saint Monica

Survey Panel: NW

- Cracking (1)
- Cracking (2)
- Pitting (1)
- Pitting (2)
- Darkening
- Alligatoring
- Accretions
- Crusts (white)
- Blistering
- Streaking (white)
- Streaking (rust)
- Over-paint
- Loss
- Lost Bolts
- Lost Bolt-heads
- Caulk
- Plate Joint
- Abrasion
Condition Survey
Trompe L'oeil Panel of Saint Monica

Survey Panel:

Accretions  Cracking (1)  Overpaint  Streaking (rust)
Alligatoring  Cracking (2)  Pitting (1)  Loss
Blistering  Crusts (white)  Pitting (2)  Missing Bolts
Caulk  Darkening  Streaking (white)  Missing Boltheads
Condition Survey
Trompe L’oeil Panel of Saint Monica

Survey Panel:

Accretions  Cracking (1)  Overpaint  Streaking (rust)
Alligatoring  Cracking (2)  Pitting (1)  Loss
Blistering  Crusts (white)  Pitting (2)  Missing Bolts
Caulk  Darkening  Streaking (white)  Missing Bolthead
# Condition Survey

**Trompe L'oeil Panel of Saint Monica**

<table>
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<th>Condition Type</th>
<th>Description</th>
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<td>Caulk</td>
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<td>Cracking (1)</td>
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<td>Cracking (2)</td>
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<td>Overpaint</td>
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<td>Pitting (1)</td>
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<td>Pitting (2)</td>
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<td>Missing Bolts</td>
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<td>Missing Boltheads</td>
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**Survey Panel:**

**Plate:** C

---

**Image:** Trompe L'oeil Panel of Saint Monica with condition survey markings.
Condition Survey
Trompe L'oeil Panel of Saint Monica

Survey Panel:

Plate

Accretions
Alligatoring
Blistering
Caulk

Cracking (1)
Cracking (2)
Crusts (white)
Darkening

Overpaint
Pitting (1)
Pitting (2)
Streaking (white)

Streaking (rust)
Loss
Missing Bolts
Missing Bolthead
Condition Survey
Trompe L’oeil Panel of Saint Monica

Survey Panel: NW
Plate E

Accretions
Alligatoring
Blistering
Caulk

Cracking (1)
Cracking (2)
Crusts (white)
Darkening

Overpaint
Pitting (1)
Pitting (2)
Streaking (white)

Streaking (rust)
Loss
Missing Bolts
Missing Boltheads
Condition Survey
Scenes from Purgatory

Survey Panel: SW

Cracking (1)
Cracking (2)
Loss
Pitting (1)
Lost Bolts
Pitting (2)
Lost Bolt-heads
Darkening
Caulk
Alligatoring
Plate Joint
Accretions
Abraision
Crusts (white)

Blistering

Streaking (white)

Streaking (rust)

Over-paint
Condition Survey
Scenes of Purgatory

Survey Panel:
SW
Plate A

Meters
0 1 2

- Accretions
- Alligating
- Blistering
- Caulk
- Cracking (1)
- Cracking (2)
- Crusts (white)
- Darkening
- Overpaint
- Pitting (1)
- Pitting (2)
- Streaking (white)
- Streaking (rust)
- Loss
- Missing Bolts
- Missing Bolthead
Condition Survey
Scenes of Purgatory

Accretions
Cracking (1)
Overpaint
Streaking (rust)

Alligatoring
Cracking (2)
Pitting (1)
Loss

Blistering
Crusts (white)
Pitting (2)
Missing Bolts

Caulk
Darkening
Streaking (white)
Missing Boltheads
Condition Survey
Scenes of Purgatory

Accretions
Alligating
Blistering
Caulk

Cracking (1)
Cracking (2)
Darkening
Crusts (white)

Overpaint
Pitting (1)
Pitting (2)
Streaking (white)

Streaking (rust)
Loss
Missing Bolts
Missing Boltheads
APPENDIX | B

Sampling and Analysis
Appendix B.1 | Sample Schedule and Location
<table>
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<tr>
<th>Sample ID</th>
<th>Sample Description</th>
<th>Condition</th>
<th>Substrate</th>
<th>Type</th>
<th>Date Sampled</th>
<th>Sampled By</th>
<th>Test Method</th>
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<td>Black robes</td>
<td>Alligatoring</td>
<td>Steel</td>
<td>paint film</td>
<td>25-Jan-12</td>
<td>Christine Leggio</td>
<td>UV/PLM</td>
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<td>NEa2</td>
<td>brown ground, niche background</td>
<td>Subsurface darkening</td>
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<td>UV/PLM</td>
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<td>white, or blanched, with level 2 cracking</td>
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<td>UV/PLM</td>
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<td>level 2 cracking, blanching (?)</td>
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<td>UV/PLM</td>
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<td>25-Jan-12</td>
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<td>25-Jan-12</td>
<td>Christine Leggio</td>
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<td>UV/PLM</td>
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<td>joint compound overpaint</td>
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<td>Steel</td>
<td>paint film</td>
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<td>Column, Jasper scheme</td>
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<td>Christine Leggio</td>
<td>UV/PLM</td>
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<td>NWd3</td>
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<td>paint film</td>
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<td>SWa2</td>
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<td>black accretions, lifted and cracked</td>
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<td>tented, lifted, cracked</td>
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<td>Subsurface darkening activity</td>
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158
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<th>UV/PLM</th>
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<td>SWc7</td>
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<td>27-Jan-12</td>
<td>Christine Leggio</td>
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<td>SWc8</td>
<td>soiled flame, next to popped bolt</td>
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Sample Location
Trompe L’oeil Panel of an Augustinian Martyr

Survey Panel:

NE
Sample Location
Trompe L’oeil Panel of an Augustinian Martyr

Survey Panel: NE
Sample Location
Trompe L’œil Panel of Saint Monica

Survey Panel: NW
Sample Location
Trompe L’œil Panel of Saint Monica

Survey Panel:

NW
Sample Location
Scenes from Purgatory

Survey Panel:
SW
Sample Location
Scenes from Purgatory

Survey Panel: SW
Appendix B.2 | Cross Sections and Instrumental Analysis
**APPENDIX**

### NEa1  Black robes  Alligating

<table>
<thead>
<tr>
<th>Date Sampled: January 2012</th>
<th>Sampled by: Christine Leggio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microscope: Olympus CX3/Nikon YS2-7</td>
<td>Magnification:</td>
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<tr>
<td>Illumination: vis. spectrum: reflected halogen quartz</td>
<td>Illumination: UV: Mercury arc lamp BV1a</td>
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<td>Date Analyzed: February 2012</td>
<td>Analyzed by: Christine Leggio</td>
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### NEa2  Background  Darkening

<table>
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<td>Microscope: Olympus CX3/Nikon YS2-7</td>
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<tr>
<td>Illumination: vis. spectrum: reflected halogen quartz</td>
<td>Illumination: UV: Mercury arc lamp BV1a</td>
</tr>
<tr>
<td>Date Analyzed: February 2012</td>
<td>Analyzed by: Christine Leggio</td>
</tr>
</tbody>
</table>
Date Sampled: January 2012  
Sampled by: Christine Leggio

Microscope: Olympus CX3/Nikon YS2-7  
Magnification: b1: 40x | b2: 100x

Illumination: vis. spectrum: reflected halogen quartz  
Illumination: UV: Mercury arc lamp BV1a

Date Analyzed: February 2012  
Analyzed by: Christine Leggio

**NEb1**  
Black robes  
Delamination

**NEb2**  
Black robes  
Alligatoring
APPENDIX

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<tr>
<th>NEb3</th>
<th>Niche</th>
<th>Cracking</th>
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<thead>
<tr>
<th>NEb5</th>
<th>Black robes</th>
<th>Alligating</th>
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<td><img src="image4" alt="NEb5 sample" /></td>
<td><img src="image5" alt="NEb5 sample" /></td>
<td><img src="image6" alt="NEb5 sample" /></td>
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Date Sampled: January 2012  
Sampled by: Christine Leggio  
Microscope: Olympus CX3/Nikon YS2-7  
Magnification: 100x  
Illumination: vis. spectrum: reflected halogen quartz  
Illumination: UV: Mercury arc lamp BV1a  
Date Analyzed: February 2012  
Analyzed by: Christine Leggio
APPENDIX

Date Sampled: January 2012  
Sampled by: Christine Leggio

Microscope: Olympus CX3/Nikon YS2-7  
Magnification: b6: 100x | b7: 40x

Illumination: vis. spectrum: reflected halogen quartz  
Illumination: UV: Mercury arc lamp BV1a

Date Analyzed: February 2012  
Analyzed by: Christine Leggio

**NEb6**  
Column Capital  
Over-paint

**NEb7**  
Column Capital  
Over-paint
Date Sampled: January 2012  
Sampled by: Christine Leggio

Microscope: Olympus CX3/Nikon YS2-7  
Magnification: 100c

Illumination: vis. spectrum: reflected halogen quartz  
Illumination: UV: Mercury arc lamp BV1a

Date Analyzed: February 2012  
Analyzed by: Christine Leggio

**NEb8**  Highlight  Over-paint

**NEb9**  Background  Over-paint
Date Sampled: January 2012  
Sampled by: Christine Leggio  
Microscope: Olympus CX3/Nikon YS2-7  
Magnification: 40x  
Illumination: vis. spectrum: reflected halogen quartz  
Illumination: UV: Mercury arc lamp BV1a  
Date Analyzed: February 2012  
Analyzed by: Christine Leggio

**NEb10 Background White Streak**

**NEb11 Background Cracking 2**
Date Sampled: January 2012  Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7  Magnification: 100x
Illumination: vis. spectrum: reflected halogen quartz  Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012  Analyzed by: Christine Leggio
Date Sampled: January 2012  
Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7  
Magnification: 100x
Illumination: vis. spectrum: reflected halogen quartz  
Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012  
Analyzed by: Christine Leggio

**NEc1**  
Background  
Cracking and Pitting

**NEc2**  
Yellow detail  
Pitting 2
Date Sampled: January 2012  Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7  Magnification: 40x
Illumination: vis. spectrum: reflected halogen quartz  Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012  Analyzed by: Christine Leggio

**NEc5**  
*Background  Cracking, rust stain*

**NEc6**  
*Marble Ashlar  Pitting 1*
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<tr>
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**NEc8**

![Image of NEc8 sample]

**NEc9**

![Image of NEc9 sample]
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**NEc11** yellow highlight  pitting 2

**NEc12** yellow highlight  pitting 2
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NEc13  *trompe l'oeil highlight  sound*
APPENDIX

Date Sampled: January 2012  |  Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7  |  Magnification: 40x
Illumination: vis. spectrum: reflected halogen quartz  |  Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012  |  Analyzed by: Christine Leggio

**NEd1**  
**Background**  
**Pitting**

**NEd2**  
**Trompe l'oeil detail**  
**Corroded**
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<td>Olympus CX3/Nikon YS2-7</td>
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<td><strong>Date Analyzed:</strong></td>
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<tr>
<td><strong>Analyzed by:</strong></td>
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**NEd3**  
*trompe l’oeil detail*  
*sound, near loss*

**NEd4**  
*marble ashlar*  
*cracking*
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<td><strong>Ashlar</strong></td>
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**Date Sampled:** January 2012  
**Sampled by:** Christine Leggio  
**Microscope:** Olympus CX3/Nikon YS2-7  
**Magnification:** 40x  
**Illumination:** vis. spectrum: reflected halogen quartz  
**Illumination:** UV: Mercury arc lamp BV1a  
**Date Analyzed:** February 2012  
**Analyzed by:** Christine Leggio
Date Sampled: January 2012  |  Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7  |  Magnification: 40x
Illumination: vis. spectrum: reflected halogen quartz  |  Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012  |  Analyzed by: Christine Leggio

**NEe1**  
*ashlar*  
*retouched*

**NEe2**  
*trompe l’oeil*  
*cracking/pitting*
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<td>Olympus CX3/Nikon YS2-7</td>
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<td>vis. spectrum: reflected</td>
<td>UV: Mercury arc lamp BV1a</td>
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<td></td>
<td>halogen quartz</td>
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<td><strong>Date Analyzed</strong></td>
<td>February 2012</td>
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<tr>
<td><strong>Analyzed by</strong></td>
<td>Christine Leggio</td>
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**NWb1**  
*black robes  alligatoring*

**NWb2**  
*ashlar  cracking, some over-paint*
Date Sampled: January 2012  Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7  Magnification: 100x
Illumination: vis. spectrum: reflected halogen quartz
Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012  Analyzed by: Christine Leggio

**NWb3**  alligatored  coated

**NWb7**  Jasper scheme  retouched
APPENDIX

NWc1  Jasper  Pitting and cracking

NWc2  Ashlar  Pitting
Date Sampled: January 2012  |  Sampled by: Christine Leggio
---|---
Microscope: Olympus CX3/Nikon YS2-7  |  Magnification: 100x
Illumination: vis. spectrum: reflected halogen quartz  |  Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012  |  Analyzed by: Christine Leggio

NWc4 Jasper Pitting and cracing
NWd1 yellow highlight coated

NWd2 Ashlar Pitting and cracking
Date Sampled: January 2012  |  Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7  |  Magnification: 100x
Illumination: vis. spectrum: reflected halogen quartz  |  Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012  |  Analyzed by: Christine Leggio

NWd5  Ashlar  cracking - not coated
Date Sampled: January 2012  |  Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7 | Magnification: a1: 100x | a2: 40c
Illumination: vis. spectrum: reflected halogen quartz | Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012 | Analyzed by: Christine Leggio

**SWa1**  
*figure*  
darkened, edge of loss

**SWa2**  
*flame background*  
accretion
### SWa3

**background**

**stable**

### SWa4

**background**

**blistered, cracked**

---

<table>
<thead>
<tr>
<th>Date Sampled: January 2012</th>
<th>Sampled by: Christine Leggio</th>
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<td>Date Analyzed: February 2012</td>
<td>Analyzed by: Christine Leggio</td>
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SWa6

Date Sampled: January 2012
Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7
Magnification: 40x
Illumination: vis. spectrum: reflected halogen quartz

SWa7

Date Analyzed: February 2012
Analyzed by: Christine Leggio
Illumination: UV: Mercury arc lamp BV1a

SWa6

Figure
Cracked

SWa7

Ashlar
Pitting 1 cracking 2
Date Sampled: January 2012  |  Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7 |  Magnification: 40x
Illumination: vis. spectrum: reflected halogen quartz |  Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012 |  Analyzed by: Christine Leggio

**SWa8**  red flame  cracked
<p>| | | | |</p>
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<td>February 2012</td>
<td>Analyzed by: Christine Leggio</td>
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**SWb1**  
flame  blistering, pitting and cracking 1 & 2

**SWb2**  
flame  stable
**SWb3**

- **Color:** yellow
- **Condition:** cracked/lifted

**SWb4**

- **Color:** flames
- **Condition:** white crusts

---

<table>
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<td>Illumination: UV: Mercury arc lamp BV1a</td>
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<tr>
<td>Date Analyzed: February 2012</td>
<td>Analyzed by: Christine Leggio</td>
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**SWb5**

*background*  
*black accretions*

---

**SWb6**

*background*  
*darkening*
Date Sampled: January 2012  
Sampled by: Christine Leggio

Microscope: Olympus CX3/Nikon YS2-7  
Magnification: b7: 40x | b8: 100x

Illumination: vis. spectrum: reflected halogen quartz

Illumination: UV: Mercury arc lamp BV1a

Date Analyzed: February 2012  
Analyzed by: Christine Leggio

**SWb7**  
background  
darkening

**SWb8**  
background  
blister, pitting 1 cracking 2
<table>
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**SWb11 ashlar cracked**

**SWb12 ashlar cracking 2**
**APPENDIX**

Date Sampled: January 2012  
Sampled by: Christine Leggio

Microscope: Olympus CX3/Nikon YS2-7  
Magnification: 40x

Illumination: vis. spectrum: reflected halogen quartz  
Illumination: UV: Mercury arc lamp BV1a

Date Analyzed: February 2012  
Analyzed by: Christine Leggio

<table>
<thead>
<tr>
<th>SWc1</th>
<th>background</th>
<th>over-paint</th>
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<table>
<thead>
<tr>
<th>SWc3</th>
<th>figure</th>
<th>stable</th>
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Date Sampled: January 2012
Sampled by: Christine Leggio
Microscope: Olympus CX3/Nikon YS2-7
Magnification: 40x
Illumination: vis. spectrum: reflected halogen quartz
Illumination: UV: Mercury arc lamp BV1a
Date Analyzed: February 2012
Analyzed by: Christine Leggio

**SWc4** background cracking

**SWc5** background stable
Date Sampled: January 2012  
Sampled by: Christine Leggio

Microscope: Olympus CX3/Nikon YS2-7
Magnification: 40x

Illumination: vis. spectrum: reflected halogen quartz

Illumination: UV: Mercury arc lamp BV1a

Date Analyzed: February 2012  
Analyzed by: Christine Leggio

**SWc9**  
*background*  
*pitting 2*

**SWc12**  
*ashlar*  
*lifted/cracked*
NEd3

FTIR - White Prime Layer
NEd3

FTIR - Red Prime Layer
NEd3

GC-MS - Red Prime Layer
NEd3  GC-MS - Brown Design Layer
NEb10

FTIR - White Streaking Material
NEb10  SEM_EDS - White Streaking Material
NEb10  SEM_EDS - White Streaking Material
NEc11  SEM-EDS - White Streaking Material
NEc11  SEM-EDS - White Streaking Material
NEc12  SEM-EDS - Trompe L’oeil - corroded substrate
NEc12 SEM-EDS - Trompe L’oeil - corroded substrate
NWb3

FTIR - 1990’s Varnish
SWa7 SEM-EDS
SWa7

SEM-EDS
APPENDIX B

SWb6

SEM-EDS
SWb6

SEM-EDS

![SEM-EDS images of SWb6 sample](image1)

![SEM-EDS images of SWb6 sample](image2)
SWc9

FTIR - Red design layer
SWc9

FTIR - Yellow design layer
Goethite

Raman -- Corrosion Product -- Steel Cladding
Lepidocrocite  Raman -- Corrosion Product -- Steel Cladding
If the information in this report is to be incorporated in total or in part in a publication, even as a minor contribution, the manuscript must first be submitted to the Director of the Conservation Division, Winterthur Museum and Country Estate for approval because the data as stated may not be appropriate for its proposed use. Scientific Research and Analysis Laboratory Staff must be notified prior to any and all publications and presentations of this data.

**EXPERIMENTAL**

**FTIR**
Samples were analyzed by FTIR (Fourier-transform infrared) microspectroscopy, an instrumental technique that permits the general classification of natural organic materials (such as waxes, proteins, oils, polysaccharides, and resins) and the more specific identification of synthetic resins, inorganic pigments, and natural minerals. Sample material was acquired with a stainless steel scalpel and the aid of a stereomicroscope and then placed directly on a diamond cell. The material was rolled flat on the cell with a steel micro-roller to decrease thickness and increase transparency. The sample was analyzed using the Thermo Scientific Nicolet 6700 FT-IR with Nicolet Continuum FT-IR microscope (transmission mode); data was acquired for 128 scans from 4000 to 650 cm\(^{-1}\) at a spectral resolution of 4 cm\(^{-1}\). Multiple scrapings of the sample were taken from the bulk material and multiple spectra were taken from different areas within each scraping. Spectra were collected with Omnic 8.0 software and analyzed in this program with various IRUG (Infrared and Raman Users Group) and commercial reference spectral libraries.

**SEM-EDS**
The cross-sections were mounted to a carbon stub with double-sided carbon tape adhesive. Carbon paint was applied on the side and top surfaces of casting medium, without covering the cross-section itself, to prevent charging once in the SEM (scanning electron microscope). The sample was examined using the Topcon ABT-60 scanning electron microscope at an accelerating voltage of 20 kV, stage height of 20 mm, and sample tilt of 20°. The EDS (energy dispersive spectroscopy) data was analyzed with the Bruker X-flash detector and microanalysis Quantax model 200 with Esprit 1.8 software.

**GC-MS**
Samples containing oil, resin, varnish and wax compounds are composed, in part, of carboxylic acids or esters. To reduce the molecular weight and make the components more volatile,
treatment of the samples with MethPrep II reagent converts carboxylic acids and esters to their methyl ester derivatives. Samples were transferred directly to a heavy-walled glass GC vial and then 100µL of 1:2 MethPrep II reagent (Alltech) in benzene was added. The vials were warmed at 60°C for one hour in the heating block, removed from heat, and allowed to stand to cool.

Samples were analyzed using the Hewlett-Packard 6890 gas chromatogram equipped with 5973 mass selective detector (MSD) and 7683 automatic liquid injector. The Agilent Technologies MSD ChemStation control software was used with Winterthur RtlMprep method with conditions as follows: inlet temperature was 300°C and transfer line temperature to the MSD (SCAN mode) was 300°C. A sample volume (splitless) of 1µL was injected onto a 30m×250µm×0.25µm film thickness HP-5MS column (5% phenyl methyl siloxane at a flow rate of 1.5mL/minute). The oven temperature was held at 50°C for two minutes, then programmed to increase at 10°C/minute to 325°C where it was held for 10.5 minutes for a total run time of 40 minutes.
EXPERIMENTAL

Raman spectroscopy

The corrosion sample found directly on the metal substrate of the building was analyzed with the Renishaw Invia Raman spectrometer (785nm diode laser) in conjunction with WiRE 2 software with extended scan from 200-800cm⁻¹, 50X objective lens, exposure time of 30 seconds/scan for one accumulation, and 50% laser power.

DISCUSSION OF RESULTS

FTIR analysis of the bright orange primer in sample NEd3 detected the presence of barium sulfate and a drier in an oil medium. The drier is likely lead-based, as suggested by the FTIR reference spectrum provided (Soligen lead drier) and elemental analysis with SEM-EDS. Both lead and barium are detected in the bright orange primer layer.

The white ground layer above the bright orange primer for sample NEd3 is composed of lead white in a drying oil (a reference spectrum for lead white in linseed oil is provided for comparison). The peak at approximately 1530cm⁻¹ is due carbonyl stretch of an organic acid salt, either in the form of an intentional drier added to the paint or due to reaction of the oil medium with the lead white pigment over time.

The coating of sample NWb3 is characterized as a natural tree resin such as dammar with FTIR analysis. More specific identification of the natural resin could be achieved with GC-MS (gas chromatography – mass spectrometry) analysis.

The FTIR spectra from both the white streaking material of sample NEb10 and the top red paint layer of sample SWc9 are very similar and detect the presence of zinc stearate, barium sulfate.
and gypsum. The zinc stearate may have been applied as a waterproofing coating to the decorative finishes. Water that has run down over the surface of the wall may have given the coating a hazy appearance as well as has carried barium sulfate and gypsum from above. The white streaking material either could not be cleanly separated from the top red paint for analysis or else that this coating material was absorbed into the red paint layer below.

FTIR analysis of the yellow paint layer of sample SWc9 indicates the presence of barium sulfate. The organic material detected in this paint layer could not be fully characterized but may be a metal salt (i.e. a metal drier).

Raman analysis of the bulk corrosion product identified the presence of lepidocrocite (γ-FeO(OH)), with peaks at 248, 375 and 524\,\text{cm}^{-1} and goethite (α-FeO(OH)), with a small peak at 343/346\,\text{cm}^{-1}. 
INDEX

A
Academia de Dibujo y Pintura 16, 40
Accretions 94, 137, 143, 149, 155
accumulations 96
ac impedance tests 130
Acryloid B67 68
Acryloid B72 70
adhesion 55, 58, 62, 63, 64, 68, 111, 122, 124, 125
Alligating 94, 107, 137, 149, 155
Antonio Sanchez 38
Archbishop 26
Arica, Chile 49, 50
atmospheric corrosion 91, 105
Augustinian Martyr 80, 85, 143
Augustinian Recollect 12, 24, 77 See Recollect
Australia 48
Avalure 315 polyacrylate 131

B
barium 110
Baroque 51
Belgium 13, 30, 31
bell tower 34, 36, 37
blistering 94, 96, 105, 108, 109, 137, 143, 149, 155
Brussels 30
Bulgarian Church of Saint Stephen 51

C
Calumpang 25, 26
carbon dioxide 61, 124
Carmelite 26, 42, 44, 77
cast iron 30, 31, 34, 35, 41, 42, 47, 48, 74, 75, 82
Cebu 22, 23, 24
chelate 67, 69
chloride 123, 124
Church of San Marco 49
cladding 19, 31, 34, 35, 41, 42, 82, 85, 90, 91, 98, 100, 102, 116
coating system 70
cohesion 86
cohesive strength 123, 125
condensation 61, 62
condition survey 72, 84, 86, 87
contaminants 55, 61, 62, 64
convent 24, 25, 26
corrosion 19, 20, 55, 56, 57, 58, 60, 61, 63, 64, 65, 66, 67, 68, 69, 70, 71, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 98, 100, 105, 109, 111, 112, 113, 118, 119, 120, 121, 123, 124, 125, 126, 127, 128
corrugated iron 48, 49
Costa Rica 50
Cracking 94, 106, 138, 143, 149, 155
cross bracing 34, 35, 82, 100, 118
cupola 17, 18, 36, 37, 42

d
Damian Domingo y Gabor 15
dammar 102, 104, 109, 129, 130
decoration 13, 16, 18
delamination 122, 123, 125
deterioration 19, 20, 21, 55, 60, 66, 68, 71, 72, 73, 75
dew point 116
diammonium citrate (DAC) 67
diethylenetriamine pentaacetic acid (DTPA) 67
Donald Judd 68
Doña Maria Enríquez de Céspedes 25
Don Bernardino de Castillo Maldonado y Rivera 25
Don Genaro Palacios 29, 30
drying oils 42, 57, 111

E
earthquake 13, 27, 28, 29, 33, 35
Effel, Gustav 49
energy-dispersive X-ray spectroscopy 88
environmental control 71
Espaces Virtuels: Jaune et Blanc 66
Espíritu, Manuel 38
ethylenediamine tetraacetic acid (EDTA) 67
Eulogio García 18, 39
expedition 22, 23

F
faux ashlar 46, 96, 104
faux finishes 19
faux jasper 72
faux marble 72
faux stone 18, 40, 42
Felix Martinez 16, 38, 46
ferric chloride 63
ferric sulfide 63
ferrous oxides 93
Fort Santiago 24, 25
Fourier-transform infrared spectroscopy 87

G

galvanized iron 33, 47
gas chromatography/mass spectrometry 87
goethite 91, 92
gothic 13, 30, 36, 39, 44
gothic revival 13, 30, 36
Grecia 50
Gustave Eiffel 49

H

Humidity 61
hydrogen sulfide 61, 123, 124
hydroscopic 124, 125
hydroxides 90

I

interior finishes 20, 21
Intramuros 15, 24, 25, 26, 28
iron 13, 14, 47, 48, 49, 50, 56, 58, 63
Iron Church 48
iron oxide 57, 58, 62, 69
iron-phytate 67
ironwork 31, 33
Islas de San Lázaro 22

J

Jamaica 48, 49
jasper 16, 41, 42, 46, 72, 74, 75, 79, 82, 84, 85, 125
Jaune et Blanc 66, 67
Jesus Rafael Soto 66

L

lacunae 96
lancet arch 37, 42
Las Islas Filipinas 23
Last Judgment Mosaic of Saint Vitus Cathedral 10, 131
lead 109, 110, 111, 112, 119, 120
lead pigment 110
lepidocrocite 91, 92
Linseed oil 57
Lorenzo Guerrero 38
Lorenzo Rocha 14, 16, 17, 18, 38, 40
Luzon 23

M

Magellan 16, 22, 24
magnetite 91
Maintenance 52
Manila 12, 13, 14, 15, 24, 26, 27, 28, 29, 30, 31, 33, 35, 36, 38, 39, 49
Manila Cathedral 26, 28, 29
marble 16, 41, 42, 53, 72, 74, 75, 82, 84, 125
marble ashlar 41, 42, 53, 74, 75, 82, 84
marbling 40, 53
Martinez, Manuel 38
masonry 12
metal soap 57
Methodology 72, 86
micro-cracking 86, 93, 94
micro-fissures 122
micronized wax 98
Miguel López de Legazpi 24
moisture 130
molave 27
molding 46
Msgr. Juan Vélez 26
Msgr. Miguel García Serrano 26

N

New Zealand 48
Nicolas de Tolentino 42, 77
nipa 27
nitrate 123, 124
nitrite 123, 124

O

optical microscopy 72
organic binder 111
Over-paint 94
oxides 90, 93
oxygen 124

P
paint 42, 52, 86, 87, 88
Parades, Clemente 38
Pasig 34
pendentives 18, 42, 43, 76, 77
Philippine Atmospheric, Geophysical and Astronomical Services Administration, 114
Philippine Islands 22
phytic acid (PA) 67
pitting 93, 95, 96, 99, 100, 102, 105, 106, 108, 109, 121, 123, 124, 125, 126, 127, 139, 140, 143, 149, 155
pollution 92, 119, 120
polymer 61, 62, 64, 70
porosity 122
Prague 131
pre-colonial 23
prefabricated 12, 31, 39, 49, 51
presbeterio 27
preservation 20, 21
primer 57, 67, 68, 94, 109, 110, 111
protective coating 57, 60, 64, 70, 71
Public Works 13, 29
Quakes 29. See earthquakes
R
rainfall 114, 116
Raman spectroscopy 88, 91
Real Sociedad Económica 15
Recollect 12, 24, 26, 27, 30, 43, 44, 77, 81, 83, 84, 85
red lead 57, 58, 109, 110, 111
relative humidity 116, 118
repainting 46, 52, 53, 54, 96, 111
restoration 52, 54
retablo 39
retouching 46, 54, 87, 88, 94, 96, 104
Rita of Cascia 43, 44, 77
Rocha 14, 16, 17, 18, 38, 39, 40
Royal Infantry Battalion 25
rust 54, 87, 90, 91, 92, 93, 100, 101, 104, 118, 143, 149, 155
Ruy López de Villalobos 23
Saint Monica 43, 44, 77, 149
Saint Nicolas 38, 42, 43, 44
Saint Nicolas de Tolentino 42
Saint Peter’s Basilica 37
Saint Rita of Cascia 43, 44
Saint Sebastian 25
salts 123, 124
San Augustin Church 28
Sangley Uprising 26
San Nicolas Church 25, 27
San Sebastian 12, 13, 16, 17, 18, 19, 20, 21, 22, 24, 25, 27, 28, 31, 32, 34, 35, 38, 47, 49, 50, 51, 52
San Sebastian Basilica Conservation and Development Foundation 20
San Sebastian Church 13, 25, 28
Scanning electron microscopy 88
silica oxide 131
Simon Fortic 38
simulated stone 74
Societe Anonyme d’Enterprises de Travaux Publics 30
soiling 96, 108, 109
Spain 16, 22, 23, 24
Spanish Colonial 18, 23
Spanish colonization 22, 24
stained glass 37, 40, 48
stearic acid 111, 113
steel 13, 14, 19, 30, 31, 34, 35, 42, 51, 52, 54, 55, 56, 57, 58, 59, 60, 63, 65, 66, 68, 71, 73, 74, 82, 86, 87, 90, 91, 92, 93, 96, 102, 105, 109, 118, 119, 129, 130, 131, 132
Steel 30, 31, 47
stone 14, 16, 17, 18, 26, 27, 28, 40, 42, 51, 54
Stone 25
stratigraphy 86, 88, 111, 112, 113
substrate 59, 60, 61, 62, 64, 65, 70
sulfur 119, 120
sulfur dioxide 61, 123
T
Tampinco, Isabelo 38
Tannic acid 58
temperature 88, 116, 118
termites 29, 30
tetraethoxysilane (TEOS) 70
thermal coefficient of expansion 118
tindalo 27
tin tabernacles 48
Tinuvin 292 68
triammonium citrate 67, 69
triammonium citrate (TAC) 67
trompe l’oeil 14, 16, 19, 39, 40, 42, 44, 46, 54, 72, 76, 77, 79, 82, 83, 84, 96, 100, 103, 108
Trompe l’oeil 14, 17

U
ultrahigh molecular weight polyethylene 130
United Kingdom 47, 48

V
vapor transmission 61, 130, 131
varnish 86, 88, 102, 104, 109, 129, 130
Vienna 51
Virgen del Carmen 26, 29, 38, 42

W
water 57, 58, 61, 62, 63, 65, 66, 70, 87, 90, 92, 93, 96, 98, 99, 100, 109, 113, 114, 116, 117, 118
weak boundary layer 121, 125
white lead 57, 59
William Burkitt 31
wrought iron 19, 48
wustite 63, 64

Z
zinc 57, 58, 68
zinc corrosion 100
zinc oxide 113
zinc pigments 111
zinc stearate 98, 100, 113, 114