



Nepal Earthquake (photo: Dinçşahin, Umut, GEA Conference 12.12. 2015).



Argentina Flooding (photo: <http://www.aljazeera.com/news/2015/08/argentina-floods-150812083646292.html>).

Message of the President Görün Arun

Disasters and Heritage

Looking back on 2015, many heritage structures in the World have suffered many disasters.

Although historic cities and landscapes, museums, monuments and archaeological sites are seriously affected by natural or man-made threats, globally heritage is usually not taken into account in statistics. Loss of such places as a result of earthquakes, floods, fire, armed conflicts and other hazards has become a major concern to heritage conservation society. In 2015, twenty earthquakes with magnitude ranging between 7.0-9.0 occurred in the world. Many heritage buildings were devastated in 25 April and 12 May 2015 earthquakes in Nepal.

Similarly many culturally important structures and landscapes for their users were demolished on 30 May in Japan, on 16 September in Chile and on 26 October in North Afghanistan and Pakistan.

Due to heavy continuous rainfall and heavy flood in river and resulting landslides places having social values for the community were affected during January Southeast Africa floods and East Malaysia floods, and during August Argentina floods in Buenos Aires Province.

Numbers of cultural heritage assets were damaged during February floods in Greece, June flood in Accra-Ghana and April floods in Dar-es Salaam and other regions of Tanzania. Downpours on 31 July in north-eastern Vietnam caused flooding

and toxic spills from several coal mine and power plant sites around the Ha Long Bay World Heritage Site. People were banned to visit heritage sites due to flooding after monsoon rains on September in Assam and on December in the north-east India.

Among the man-made disasters fires mainly due to negligence in taking proper measures, and armed conflicts made intentionally as a show of power may be counted. On January 14, the thatched roofs of the Royal Palaces of Abomey World Heritage complex in Benin were burned. On June 15, fire broken at the Basilique Saint Donatien in Nantes damaged properties in the Church.

And on August 20, the Palazzo del Lavoro designed by Pier Luigi Nervi, was threatened by fire after years of misuse and abandon. Heritage places are threatened by planned acts of terrorist operations in Iraq, Syria and Yemen. Intentional damage to the cultural heritage and the targeted destruction of Islamic and Christian religious sites, damage to the architectural remains in the ancient city of Palmyra, destruction of the Baalshamin Temple, the Temple of Bel, and tower tombs in the Valley of the Tombs and collapse of part of the walls of Aleppo's ancient citadel with bomb explosion are horrendous.

In Yemen, bombing of the World Heritage Site of the Old City of Sana'a and the old city of Sa'adah, and the Dhamar Museum; damage to the archaeological site of the pre-Islamic walled city of Baraqish; and destruction of the 1,200 year old mosque of Imam al-Hadi, in the city of Saada; or damage to the 10th century BC historic castle of Al-Cairo in Taiz worrying situations are evidenced.

March 19 terrorist attack at Bardo National Museum in Tunisia, June 10 suicide bomber attacks at Luxor and Pyramids in Egypt and De-

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September 29 gunmen attack at Naryn-Kala fortress, the world heritage site at Daghestan, Russian Federation were targeting tourists visiting the area.

Any natural or man-made damage to movable and immovable heritage and looting of the artefacts and antiques right after a disaster may harm the community and lead to irreparable loss to local social life.

After each event, to protect those who have been most harmed by such disasters, the destroyed heritage and the people living that trauma, rehabilitation and reconstruction process becomes necessary.

The reconstruction of living heritage site is a critical procedure that must be carried out identifying the priorities depending on how important they are to the daily lives of the people with great caution. It has to take into account that physical setting that people are accustomed to use continue to serve their functions so that they are part of the daily life. In order to avoid inappropriate interventions, reconstruction procedure must be based upon effective collaboration between professionals from many disciplines, cooperation of government authorities, stakeholders, implementing agencies, academic researchers, private or public enterprise, and the local residents.

The title of the Scientific Symposium that will be held during 2016 ICOMOS Annual Advisory committee Meeting on 15-21 October in Istanbul, Turkey is "Reconstructions: The Role of Rebuilding Monuments and Urban Landscapes".

Involvement of ISCARSAH members in this Symposium with their contributions will be very valuable.

May heritage prevail in 2016.



Pier Luigi Nervi. Turin, Palazzo del lavoro fire in August 2015

(http://torino.repubblica.it/cronaca/2015/08/20/news/brucia_palazzo_del_lavoro_fiamme_al_primo_piano_dell_edificio_abbandonato-121315743/).



Aleppo's ancient citadel walls (photo: <http://www.bbc.com/news/world-middle-east-33499609>).

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Editor: María Margarita Segarra Lagunes
Via Emanuele Filiberto, 190
00185 Roma (ITALY)

email: structurescommittee@gmail.com

The Old Courthouse reveals the Role of St Louis at the Forefront of Architectural Cast Iron in the United States

Stephen J. Kelley

FAIA, SE, FAPT, FUSICOMOS
Heritage Conservation Specialist
steve@kelleyaia-se.com

Dan M Worth

AIA, FAPT Senior Principal
Bahr Vermeer& Haecker Architects
(402) 475-4551
dworth@bvh.com

Al O'Bright

Technical Representative
National Park Service
(314)842-1047
al_o'bright@nps.gov

Introduction

At the request of the National Park Service (NPS), the authors developed an archival and physical examination report covering Special Issues for the Old Courthouse at Jefferson National Expansion Memorial (JEFF) in St. Louis, Missouri, USA. One of the identified special issues that were the focus of this study included an investigation of the use of structural cast and wrought iron and its specific application to the Old Courthouse.

The work included review of drawings, specifications, historic photographs, and other written and illustrative documentation about the history, construction, alterations, and repairs to the Old Courthouse. The authors built upon the extensive historical and archival research performed by others. Reference documents reviewed for this study are from the archival repositories at the NPS JEFF Archives in St. Louis; NPS Denver Service Center Technical Information Center; Missouri History Museum, St. Louis; and the St. Louis Mercantile Library, University of Missouri -St. Louis. Visual assessment was performed of selected metallic members which was facilitated by inspection openings. Metallurgical testing of materials samples was also performed on comparative structural members.

The Old St. Louis Courthouse is located in the heart of downtown St. Louis near the riverfront on a city block bordered by Fourth, Chestnut, Market, and Broadway (for-

merly Fifth) streets. It is on the site of a previous courthouse that was constructed in 1826-1833 and then replaced by the "Old" Courthouse in a phased construction period of 1839 to 1861. The Old Courthouse served as a center for western migration. St. Louis was a gateway to the west for settlers travelling along the Oregon and California trails. The city was a major outfitting point for many of these emigrants and a meeting point for many on the trails. In 1847, the first of the Dred Scott trials was held in the first level courtroom in the west wing,¹ and the Virginia Minor Case was held in the Old Courthouse in 1872 in which she sued the state for the right of women to vote in Missouri. The Courthouse grounds were used for political rallies and slave auctions as well as an area where troops gathered during the Mexican-American War and the Civil War.

The building has smooth stone and brick masonry walls and foundation, painted white, with entries on each primary facade. Formal colonnaded porticos are located at the east and west facades. These porticos are defined by monumental stairs leading from grade up to the first floor level, where massive paired entry doors provide access to the interior. Fluted Doric columns support the Classical pediment. The shallow pitched gable roofs intersect at the center of the building, where the multi-story dome rises.

Full scale use of cast and wrought iron was introduced into the construction of all construction by 1852. This sophisticated and utilitarian use of cast iron in particular is comparable to east coast structures of the era.

It is apparent that its location on the Mississippi River and the role in river commerce, along with the great fire of 1849, provided a catalyst for the use and development of cast iron in building construction that placed St. Louis on the forefront of architectural cast iron production in the United States. Of the wealth of architectural cast iron buildings that were constructed

following the fire, the majority of which were demolished circa 1940, the Old Courthouse remains among the earliest known examples of the use of this new technology in the United States.

Historical overview

Iron is the workhorse of metals due to its great strength, and was used extensively for building structure in this country during the nineteenth and early twentieth centuries. Because it oxidizes rapidly when exposed to the elements, iron is rarely used today for architectural ornament that is exposed to humidity. Wrought and cast irons are both ferrous metals but are different in composition, methods of fabrication, and physical characteristics.

In the United States, wrought iron was used for minor structural members such as lintels and decorative elements beginning in the eighteenth century, while cast iron was a major nineteenth-century building material of the Industrial Revolution.²

Pig iron, which contains approximately 4 percent carbon along with other impurities, is the initial source used in developing wrought iron, cast iron, and steel (Figure 1).³ Metallurgically, pig iron is identical to cast iron, but it is cast into unfinished bars (pigs) for shipping.⁴ The easy handling of pig iron allowed the smelting process to be freed from the founding (casting) process.⁵

Iron smelting operations needed to be located close to iron and coal sources. By the 1850s foundries that produced architectural cast iron were located in cities to provide ready access to waterways and railroads for shipping of raw materials and fabricated products.⁶

Definition and Manufacture**Wrought Iron**

As suggested by its name, wrought iron can be heated to a temperature at which it becomes soft and can be wrought (shaped by hammering) on a forge or rolled under great pressure. Wrought iron consists of iron with slag fibers entrained in a ferrite matrix.⁷ It is



FIGURE 1. Ingots of pig iron smelted near the mine were easily handled and transported to the foundry, where it could be cast or wrought. Source: <http://equatorline.indonetwork.co.id/2279287/pig-iron-iron-scrap-roll-coil.htm>, accessed November 2012.

almost pure iron with less than 1 percent carbon. Slag exists in wrought iron in a purely physical association rather than as an alloy, giving the wrought iron a characteristic laminated structure. Wrought iron has good tensile strength and can be shaped into many intricate forms because of its high elasticity.⁸

Wrought iron manufacture required machine forges, anvils, and hammers. The melting temperature of wrought iron, 1,534 degrees Celsius (2,793 degrees Fahrenheit), could not be achieved with machine forges of the time; however, the iron could be made hot enough to be worked. Iron manufacturers could also make the metal in wrought iron pure by controlling the temperatures in their furnaces. By the 1840s it was understood that wrought iron should be free of sulfur, which made the iron brittle at high temperatures ("hot short"); should not have excessive phosphorus, which made the iron brittle at room temperature ("cold short"); and should not contain excess or poorly distributed slag, which would reduce its ductility.⁹ It was also understood that phosphorus hardened otherwise pure iron more than any other alloying element. If the carbon content of the iron was less than 0.1 percent, it would remain ductile with the addition of phosphorus.¹⁰

Wrought iron provides strength in tension, making it appropriate for

tension members such as truss elements and flexural members such as beams and girders.

Cast Iron

Cast Iron is an iron-carbon alloy with a higher carbon content than wrought iron, usually averaging 3.0 to 3.7 percent, and varying amounts of silicon, sulfur, manganese, and phosphorus. Cast iron has enough carbon to lower its melting temperature so that it can be put into a molten state and cast into decorative or structural shapes.¹¹ However, cast iron is too hard and brittle to be shaped by hammering, rolling, or pressing.¹² Cast iron is very brittle and inelastic. It is strong in compression but weak in tension; therefore, it cannot effectively take bending stresses as a beam.¹³

Cast iron, with carbon content of 2 percent to 4 percent by volume, is highly fluid and can be cast into intricate shapes. The melting temperature of cast iron is approximately 1,150 degrees Celsius (2,102 degrees Fahrenheit). Such a temperature was easily attained in a small blast furnace.¹⁴ The previously described metallurgical understanding of wrought iron by the mid-nineteenth century is also applicable to cast iron.

Iron Industry Development for Building in the US

By the turn of the nineteenth century, blacksmiths were ubiquitous and working iron into horse shoes,

iron straps, tie rods, and nails for builders.¹⁵ Wrought-iron rods were universally used in the mid-nineteenth century in wood and iron trusses for buildings and bridges where the structural member was put in tension.¹⁶ By the 1840s some foundries had developed their technology to fabricate larger elements that could be used in building construction. The "bulb-tee," with a flat flange on the bottom and a convex bulb on the top, could be used either as a railroad rail or as a beam for buildings.¹⁷

Prior to 1850 there were small foundries scattered throughout the country producing cast iron items such as stoves, fireplace equipment, wash tubs, and cookware. Foundries at the time were located near the mines, as the items produced were easily transportable. In building construction, by the 1820s builders had adopted the British practice of using interior cast iron columns. By the early 1830s, cast iron columns were occasionally being adopted for shop fronts in American cities.¹⁸ Foundries that produced architectural cast iron sprang up in nearly every major American city of the nineteenth century, as shown by the city directories of the period.¹⁹ By the time iron ore was being profitably exploited and adequate transportation was becoming available in America, Europeans were already benefiting from the advantages of cast iron over wood and masonry in building construction.²⁰ American foundries producing architectural cast iron borrowed from British and French developments in this field, thus the advanced research and development in Europe were put to practical application in the United States.²¹

Despite these developments and the use of both wrought and cast iron in construction, the varying physical qualities between these materials were not fully understood in America until well into the 1870s. This is exemplified by the fact that many buildings were being constructed with cast iron beams (used in flexure) and wrought iron columns (used in compression), which was not the best use of these materials.²² Cast iron was used for both columns and beams through the first seven decades of the nineteenth century. In the 1860s wrought iron became competitive with cast iron and more widely produced as improved

industrialized processes for rolling were developed to meet the railroad demand.²³

Cast iron beams were capable of carrying light loads at shorter spans. Cast iron beam sections were unsymmetrical about their horizontal axis in profile, with the larger areas being in the tension zone at the bottom, revealing an understanding of the tension-carrying shortcomings of this material.²⁴ Larger areas for tension meant that the tensile force per area was less.

The Bessemer converter process, developed in England in 1857, was the first industrial process for the mass-production of steel from pig iron. Steel had physical properties that were superior to both wrought and cast iron, and, when it was introduced to the American market as an inexpensive alternative in the 1880s, cast and wrought iron quickly fell from favor for structural applications. By 1889 the United States was the largest fabricator of steel in the world.

Iron Industry Development in St Louis

The era of cast iron architecture in America has been defined by some architectural historians as lasting from approximately 1850 to 1880, although structural and decorative iron elements were used in the 1840s in Boston and New York, and, largely uncredited, in St. Louis.²⁵

Wrought iron, ironsmiths, and the foundries that fed the St. Louis architectural cast iron industry were located within the city and were an important factor in the swift recovery of the commercial district following the 1849 St. Louis fire. Established fur trading families turned their investments to iron mining acquisitions to support this need.

The largest source of iron ore for St. Louis was the Precambrian core area of the Ozark Uplift in Iron County located about 80 miles south of St. Louis, which began producing iron ore at the beginning of the nineteenth century (Figure 2). There were other iron mines and forges to the southwest of St. Louis in the Rolla area. In 1843 the American Iron Mountain Company near Pilot Knob was incorporated by the Missouri legislature. Ore was transported eastward to smelting furnaces in the Farmington area. Pig iron was then trans-



FIGURE 2. Iron ore mine in Pilot Knob, Missouri, circa 1919. Source: Iron County, Missouri Genealogical Society, photo courtesy of Marcine Lohman. <http://www.rootsweb.ancestry.com/~moicgs/photos1.html>, accessed November 2012.

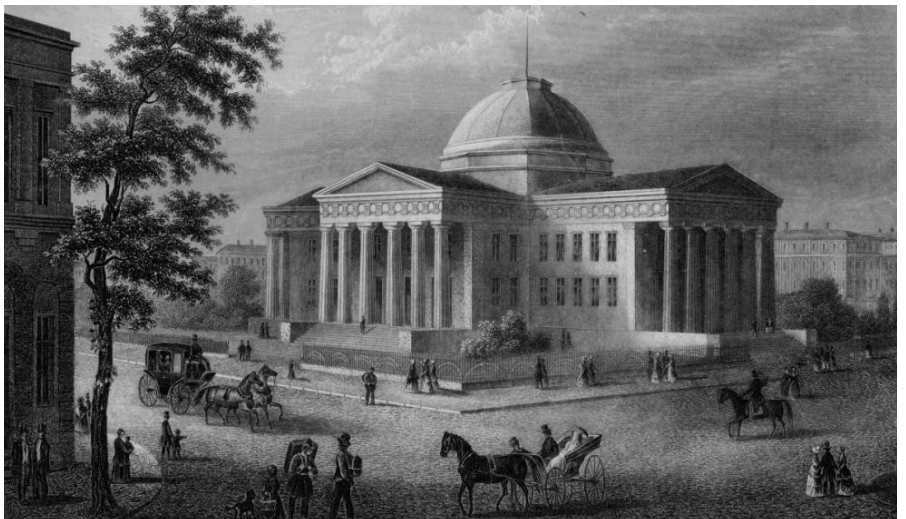


FIGURE 3. Artist rendering representing Henry Singleton's cruciform plan courthouse with the original concept for the dome and porticos at all four elevations. Source: Missouri History Museum collection.

ported to the Mississippi River for shipment. In 1855 the St. Louis and Iron Mountain Railroad Company's line was constructed with its terminus in Pilot Knob, Missouri, running directly into the heart of St. Louis.²⁶ The rail line had a terminal at Plum Street and the river, one block south of the current southern boundary of Jefferson National Expansion Memorial.

Construction of the old Courthouse

The first county courthouse to be constructed on this site in 1826-1828 was designed by St. Louis architects Laveille and Morton in the Federal style. In the decade following completion of the first court-

house, the population of St. Louis tripled. By 1838, the courthouse was considered inadequate to handle the required case load and in need of expansion. The city held a competition to solicit new designs for a larger courthouse to serve increased demands in 1839. Ultimately the design of Henry Singleton of a cruciform plan with a central rotunda, which incorporated the first courthouse as the east of its four wings was selected. The building was designed in the Greek Revival style (Figure 3). Work would begin on the west wing.

In 1840 the St. Louis foundry of Gaty, Coonce & Belzhooover was given a contract to fabricate six

"Greek Doric" cast iron columns for the southern entry to the Courthouse.²⁷ Fabrication of these columns proceeded in July 1842. In 1843 this contract was cancelled following an examination of the columns by an appointed commission of Meriwether Lewis Clark and John Martin.²⁸ It is not known whether the contract was annulled due to the poor quality of the cast iron or a change in the design at the Old Courthouse. However, documentation related to the contract reveals that architectural cast iron was available in St. Louis as early as 1840.

The West Wing

Construction began on the west wing and north and south transepts of the Old Courthouse in 1842. The second floor is believed to have been composed of wood framing though there is no conclusive archival data. In January of 1843 the contractor, John Foster, was asked to make structural changes to the second level of the west wing, which was noticeably settling, although the wing was not yet completed. Foster was directed to procure iron of the best quality for this work by connecting the second floor to the timber framing of the roof above according to a scheme of his own design.²⁹ The work was completed with a central dome and inclusion of the first courthouse by 1845 (Figure 4).

The St Louis Fire of 1849

On May 7, 1849, a fire began aboard the steamboat *White Cloud* while it was moored on the St. Louis levee at Cherry Street. The boat, engulfed in flame, broke free from its moorings, drifted downstream, and set twenty-two other steamboats ablaze. Whipped by unusual northwesterly winds, the fire jumped over the levee from the boats to the warehouses and stores along Wharf Street, burning its way inland to destroy 418 buildings situated in fifteen blocks of the riverfront district (Figure 5). Through the efforts of the St. Louis volunteer fire departments, the blaze was stopped before it consumed the Old Cathedral or the Old Courthouse.³⁰ The process of rebuilding the commercial heart of the city began immediately. Financed by insurance claim settlements, nearly all of the burned area was rebuilt within a calendar year. New construction reflected the latest build-



FIGURE 4. Southeast view of the courthouse in 1851, just before demolition of the previous courthouse and construction of the east wing. The first courthouse completed in 1828 is visible at right, with the south transept and west wing visible at left. Source: Half plate daguerreotype by Thomas Easterly taken in 1851. Missouri History Museum collection, reference n17030.



FIGURE 5. Artist's illustration from the east representing the Great Fire of 1849 in the commercial district of St. Louis. The dome of the Old Courthouse can be seen in the depiction. The Old Courthouse was not damaged during the fire. Source: Missouri History Museum collection.

ing trends and materials in America: cast iron, plate glass, shutters of iron, and roofs of sheet metal. Thus St. Louis after the fire became a crucible for development and use of architectural cast iron. Not only did architectural cast iron create aesthetically pleasing storefronts much to the taste of contemporary business owners, but it was also "fireproof" as mandated by the city to prevent a recurrence of the 1849 conflagration.³¹

The East Wing

The first Courthouse was demolished in 1851-1852 and in August of 1852, John T. Dowdall was awarded a contract to supply cast iron girders for a new east wing based on designs by architect Robert S. Mitchell. By 1853 their fabrication had been completed and by June, Dowdall was awarded a contract for the cast iron girders for a new south wing extension as well.³²

Dowdall had established the Washington Foundry, J. T. Dowdall Proprietors, at the corner of Second and Morgan Streets by 1852. He was the only permanent partner of the Washington Foundry, which advertised the manufacture of "steam engines and boilers; saw and grist mill machinery; tobacco, lard and oil press screws; lard kettles, building castings; wool carding machines, etc."³³ The Washington Foundry was closed and demolished in 1870.³⁴

The profile of a cast iron beam used on the first floor is shown in Figure 6. Levelness measurements and drill probes taken below the top flange indicate that the top flange is sloped (Figure 7). On December 10, 1853, McMurray & Pauley was awarded a contract for the wrought iron work at the east wing roof, and by the following March the roof was under construction.³⁵ The east wing was completed in 1856.

The South Wing

In 1853 construction of the south wing extension had begun. In May 1854, the firm of Dowdall Carr & Co. furnished the iron work for the south wing in accordance with their 1853 contract.³⁶ Little is known presently about the supplier of the wrought iron roof. The south wing was completed in 1856.

The profile of a cast iron beam used on the second floor is shown in Figure 8. The beam is similar in section to iron railroad tracks of the time. Levelness measurements taken below the top flange indicated that the top flange is not level however we could not determine whether the top flange is tapered or curved.

Rehabilitation of the West Wing

In May 1856 the roof of the west wing was found to be unsafe and was ordered to be rehabilitated and strengthened. The weight of the sagging floor had initially been sustained by heavy iron rods attached to the wooden roof trusses. Partition walls had been added from below to the second floor to the top of the foundation walls in 1855. The new roof was to be of wrought iron with cast iron fittings.³⁷ The west wing roof framing was to match that of the east wing. The work was performed by McMurray Winklemaier.³⁸ The second floor was most likely replaced at this time with the cast iron

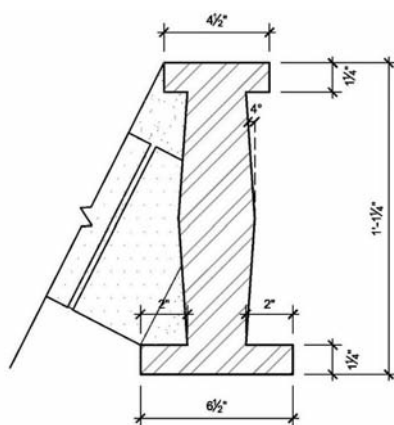


FIGURE 6. Sketch of the profile of a cast iron beam at the east wing - first floor. This beam was likely fabricated and installed by J. T. Dowdall circa 1852.

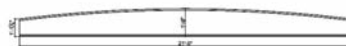


FIGURE 7. Sketch in elevation of a cast iron beam at the east wing - first floor.

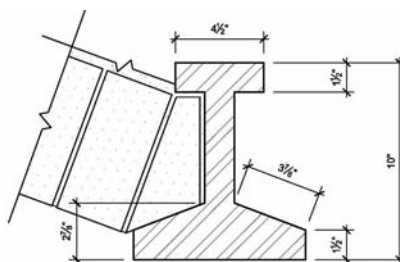


FIGURE 8. Sketch of the profile of a cast iron beam at the south wing - second floor. This beam was likely fabricated and installed by J. T. Dowdall circa 1853. The large triangular mass of iron at the bottom increases strength of this shape in tension as cast iron has low tensile strength.

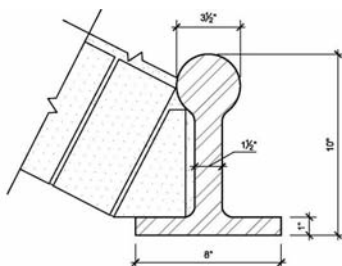


FIGURE 9. Sketch of the profile of a cast iron beam at the west wing - second floor. This beam was likely installed circa 1855 and the fabricator is not attributed. In addition, the custom-made brick that forms a spring point is depicted.

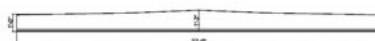


FIGURE 10. Sketch in elevation of the cast iron beam at the west wing - second floor.

beams but the manufacturer has not yet been identified.

The profile of a cast iron beam on the second floor is shown in Figure 9. The beam is similar in section to iron railroad tracks of the time. A speculative sketch of the beam in elevation is shown in Figure 10.

The North Wing

The construction of the north wing extension was begun in 1856. J. G. McPheeters, owner of the Excelsior Works at Clark Avenue and Eighth Avenue (established in

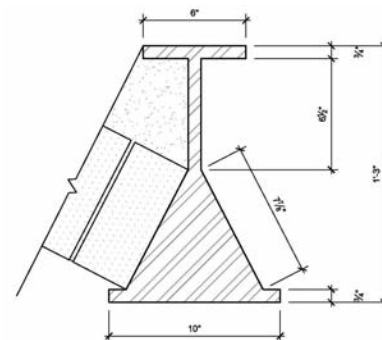


FIGURE 11. Sketch of the profile of a cast iron beam at the north wing - first floor. This beam was likely fabricated and installed by J. G. McPheeters circa 1858. The large triangular mass of iron at the bottom increases strength of this shape in tension, as cast iron has low tensile strength. It also forms a bearing surface for the spring point of the brick floor vault.

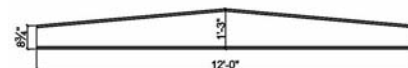


FIGURE 12. Sketch in elevation of cast iron beam at the north wing - first floor.

1840 and expanded in 1849), was awarded the contract for the north wing roof framing, which was to be composed of wrought iron with cast iron fittings at the rafters. The contract also included the ironwork for the stairs from the first to third floors in both the north and south wings, the columns within the north wing, and all cast and wrought iron work for the dome. In February 1858 McPheeters was also awarded a contract to cast, install, and furnish all the cast iron floor beams and girders required for the north wing.³⁹ The profile of a cast iron beam from the first floor is shown in Figure 11. A speculative sketch of the beam in elevation is shown in Figure 12. This sketch compares with cast iron beams that were depicted by architectural cast iron manufacturer

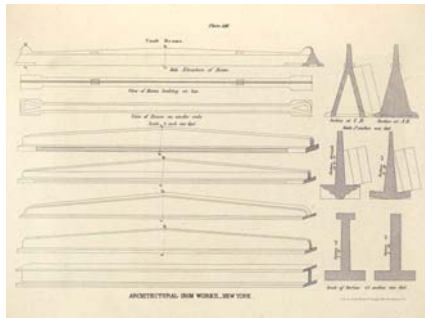


FIGURE 13. Plate LIII from the publication by Daniel Badger in 1865. These beams are similar to beam shapes used in the north wing of the Old Courthouse.

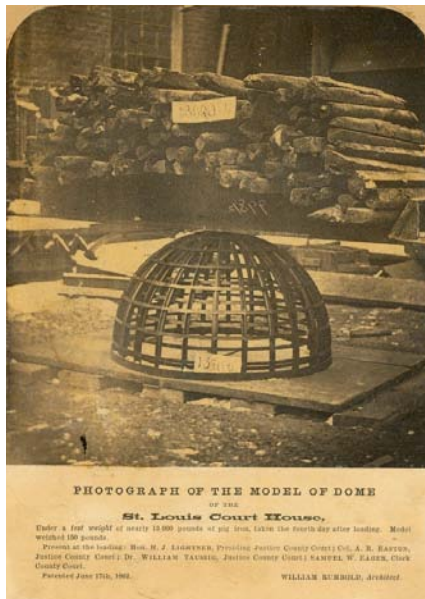


FIGURE 14. Controversy surrounded the Old Courthouse dome design by William Rumbold. Construction was delayed until confidence could be established regarding the strength of the dome structure. A test loading of a model of the dome during this period of uncertainty illustrates a prolonged loading that is many times beyond that which would have been required in construction. Source: Missouri History Museum collection.

Daniel D. Badger in his 1865 publication, *Illustrations of Iron Architecture made by the Architectural Iron Works of the City of New York* (Figure 13).

The Dome

The first dome of the Old Courthouse had been demolished in 1857 leaving the rotunda open to the elements. The new dome designed by County Architect T. D. P. Lanham included twenty-four decorative cast iron columns at the drum.⁴⁰ The hoisting of the twenty-four iron columns that would support the stone cornice of the dome commenced in June and the instal-

lation was completed by September 1858.⁴¹ Controversy over the stability of the dome as designed caused the work to be stopped so that the structural capacity of the dome could be evaluated (Figure 14) and the previously mentioned McPheeter contract was rescinded. After analysis it was determined that the dome would be composed of wrought iron rather than cast iron and would be constructed in accordance with the design of County Architect William Rumbold. McPheeter & Pauley was awarded the contract for the work, which

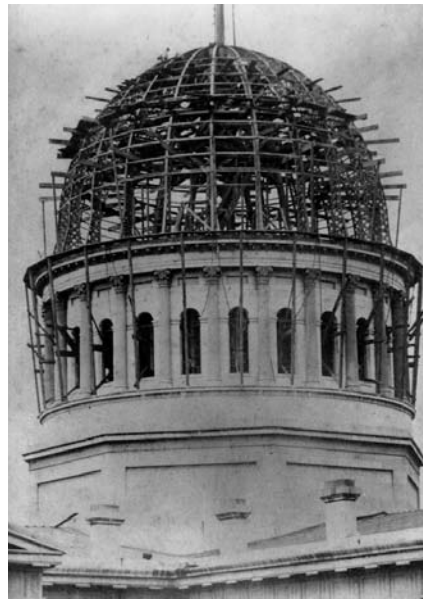


FIGURE 15. Photograph of the Rumbold-designed dome with twenty-four radially oriented wrought iron ribs set in place. The cast iron Corinthian columns below had been previously set for the Lanham-designed dome, which had been abandoned. Source: Missouri History Museum collection. Photograph by unknown photographer.



FIGURE 16. The dome ribs are lattice work, radially laid members constructed of structural T-shapes for the inner and outer flanges, with plates riveted to the stems of the T-sections and at the intersection of the plates. The 2x6 wood purlins are fastened to the outer T-section with metal joist hangers to provide a nailable surface for the wood plank sheathing below the sheet metal copper roofing.

was begun in 1860 (Figure 15).⁴² The wrought iron ribs of the outer dome were fabricated by the Phoenix Iron Company of Phoenixville, Pennsylvania, near Philadelphia as evidenced by the markings on the ribs. This seems to be the lone example of ironwork at the Old Courthouse that was fabricated outside of St. Louis.⁴³ The dome structure was completed in 1861. The dome ribs are radially laid members constructed of structural T-shapes for the inner and outer flanges (3 inches in depth with a 5-1/2 inch flange width) and



FIGURE 17. View of the dome ribs and radial straps. The straps are located only in the lower portion of the dome, where the outward thrust would be greatest.

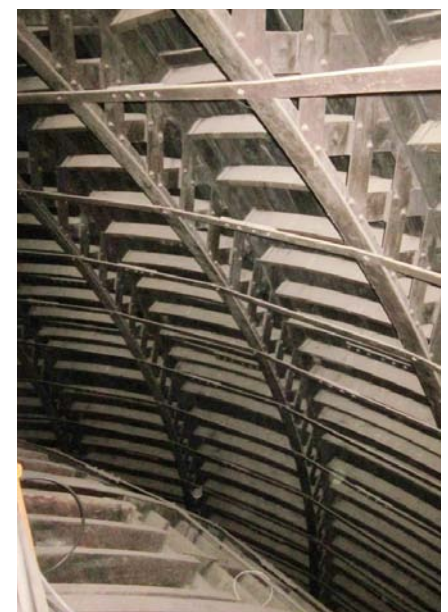


FIGURE 18. Cast iron x-bracing installed between the ribs near the top of the dome.

5 inch by 1/4 inch plates installed as a lattice and riveted to the stems of the T-sections and to each other where they intersect (Figure 16). The ribs are set on metalwork above the rotunda columns at the base of the dome and are affixed to a compression ring at the top of the dome just below the lantern. Circumferential straps approximately 2-1/2 inches wide by 1/4 inch thick are fastened to the inner flange of the ribs and are spaced at approximately 3 feet 8 inches on the ribs on the lower part of the dome (Figure 17). Cast iron x-bracing was installed between ribs near the top of the dome (Figure 18).

All of the major construction campaigns were completed with the topping of the dome (Figure 19). Presently all of the cast and wrought iron of the Old Courthouse described remains in place except for the roofs of the wings. The wrought iron trusses with cast iron fittings, wrought iron lattice beams and purlins in the wings were removed circa 1940 and replaced with a system of steel beams.

Laboratory Studies of the Cast Iron

The difference between wrought and cast iron components can, in most cases, be readily seen by the experienced eye. Cast iron can be fabricated in numerous utilitarian and decorative shapes that cannot be obtained by working iron. Cast iron beams also typically have cast lines.

Iron production at the time was an art as well as an evolving science, and it is noteworthy that the chemical composition of the cast iron samples fabricated in different factories over a period of time are comparable to one another.

It is significant that the cast iron samples from a two decade period and three to four different fabricators are chemically very similar to one another. This suggests that acceptable cast iron composition was well understood in the St. Louis community of cast iron fabricators. Iron content from the samples ranges from 93 percent to 94.5 percent and is within the typical range expected for cast iron of this era. **Carbon content** ranges from 3.34 percent to 4.90 percent, which is within the typical range.⁴⁴ **Sulfur content**, except for one sample which had 0.325 percent, ranges from 0.06 percent to 0.13



FIGURE 19. The southeast courtyard, 1866. This 1866 view of the southeast courtyard illustrates the southeast courtyard, including the fountain surrounded by a wrought iron fence, perimeter fence and wall, walk leading to the south wing areaway, and street trees set within the sidewalks edging the city streets. Source: JNEM Archive. "The view from the southeast in 1866, shortly after completion of the dome.

percent, which is at the high end of the typical range.⁴⁵ **Manganese content** ranges from 0.12 percent to 0.73 percent, which is well below the typical range.⁴⁶ **Phosphorus content** ranges from 0.200 percent to 0.543 percent, which is above the typical range.⁴⁷ **Silicon content**, an indication of slag content, ranges from 1.10 percent to 2.44 percent and is within the typical range.⁴⁸

Conclusion

Our research reveals that all of the cast and wrought iron that was used in the extant Old Courthouse, excluding portions of the dome, was smelted close to St. Louis and was fabricated within the limits of St. Louis' mid-nineteenth century commercial area and only blocks from the Old Courthouse. Furthermore, this research reveals that St. Louis was on the frontier of architectural cast iron development in the United States along with New York.

Full scale use of cast and wrought iron was introduced into the construction of all wings by 1852 and thereafter. This sophisticated and utilitarian use of cast iron in particular is comparable to East Coast structures of the era such as the Cooper Union building (1853-1859) (Figure 20) and the Harper and Brothers Building (1854, demolished) (Figure 21), both designed in part by James Bogardus and located in New York City.

It is apparent that its location on the Mississippi River and the role in river commerce, along with the great fire of 1849, provided a catalyst for the use and development of cast iron in building construction that placed St. Louis on the forefront of architectural cast iron production in the United States.

Of the wealth of architectural cast iron buildings that were constructed following the fire, the majority of which were demolished circa 1940 as part of the Jefferson National Expansion memorial that was realized in 1965, the Old Courthouse remains as one of the earliest known examples of the use of this new technology in the United States.

¹ "The Revised Dred Scott Case Collection," Washington University in St. Louis, www.digital.wustl.edu, accessed April 17, 2012, and October 28, 2012.

² Margot Gayle, David W. Look, and John G. Waite, *Metals in America's Historic Buildings: Uses and Preservation Treatments* (Washington: U.S. Department of the Interior, Heritage Conservation and Recreation Service, Technical Preservation Services Division, 1980), 42.

³ L. William Zahner, *Architectural Metals: A Guide to Selection, Specification, and Performance* (New York: Wiley, 1995), 186.

⁴ Antoinette J. Lee, "Cast Iron in American Architecture: A Synoptic View," *The Technology of Historic American Buildings: Studies of the Materials, Craft Processes, and Mechanization of Building Construction*, H. Ward Jandl, ed. (Washington, D.C.: Foundation for Preservation Technology, 1983), 99.

⁵ *Smelting* is producing metal from its ore. Smelting uses heat and a chemical reducing agent to decompose the ore and expel gasses and slag to leave a relatively pure metal behind. The reducing agent, typically charcoal or coal, when burned creates carbon monoxide, thus removing oxygen from the ore and leaving behind the elemental iron.

⁶ Lee, 99.

⁷ Slag, also known as cinder, is fused and vitrified matter separated during the reduction of a metal from its ore. In iron production the slag, rich in silicon, rises to the surface when the iron is molten and can be easily removed.

⁸ Zahner, 187.

⁹ Robert B. Gordon, *American Iron: 1607-1900* (Baltimore: Johns Hopkins University, 1996), 7.

¹⁰ *Ibid.*, 13.

¹¹ Daniel D. Badger, *Badger's Illustrated Catalogue of Cast-iron Architecture* (New York: Dover Publications, 1981), reprint, 5.

¹² Gayle, Look, and Waite, 130.

¹³ Zahner, 185.

¹⁴ Gordon, 10.

¹⁵ Margot Gayle and Carol Gayle, *Cast-iron Architecture in America: The Significance of James Bogardus* (New York, New York: W.W Norton Company, Inc., 1998), 34.

¹⁶ Gayle, Look, and Waite, 48.

¹⁷ Gayle and Gayle, 141.

¹⁸ Gayle and Gayle, 35.

¹⁹ Lee, 109.

²⁰ Ibid., 100, 101.

²¹ Cast iron for non-architectural purposes had been well developed in England, France, the Germanic states, and Sweden. Gayle and Gayle, 34.

²² Lee, 99.

²³ Lee, 99.

²⁴ J. Stanley Rabun, *Structural Analysis of Historic Buildings: Restoration, Preservation, and Adaptive Reuse Applications for Architects and Engineers* (New York, New York: Wiley, 2000), 317.

²⁵ Bryan, "Iron in St. Louis Architecture between 1800 and 1900"; Lee, 97–116; Betsy Hunter Bradley, *The Works: The Industrial Architecture of the United States*, (New York and Oxford: Oxford University Press, 1999), 3–53; Elaine B. Ulman, "The Eyes of the House," *Early American Life* August 1979, 42–45; Diane Welebit, "A Century of Pressed Glass," *Americana*, July/August 1983, 55–57; Gayle and Gayle; Charles E. Peterson, "Inventing the I-Beam, Part I : Richard Turner, Cooper Hewitt and Others," *Bulletin of the Association for Preservation Technology* 12, no. 4, 1980, 3–28; "Inventing the I-Beam, Part II: William Borrow at Trenton and John Griffen of Phoenixville," *Bulletin of the Association for Preservation Technology* 25, no. 3/4, 1993, 17–25.

²⁶ "Missouri Mines."

<http://www.miningartifacts.org/Missouri-Mines.html>, accessed November 2012.

²⁷ 1841 *St. Louis City Directory*, Gaty Coonce & Glasby, foundry and steam engine manufactory, located at 210 North First Street, 1840–1841.

²⁸ Clark was the son of William Clark and named after his father's fellow explorer, Meriwether Lewis. He was an architect, engineer, politician, and a general in the Confederate army during the Civil War.

²⁹ JEFF Archives, Records of St. Louis County Courts, Vol. III, page 285.

³⁰ Laura Wilson, "The Great Fire of St. Louis in 1849," research report, Jefferson National Expansion Memorial, September 1938, 1–35.

³¹ John Albury Bryan, "Iron in St. Louis Architecture, 1800–1900," National Park Service research report, Jefferson National Expansion Memorial, August 1961, 23–28; Wilson, 23–34; Betsy Hunter Bradley, *The Works: The Industrial Architecture of the United States* (New York and Oxford: Oxford University Press, 1999), 3–53.

³² JEFF Archives.

³³ Cara Jensen, *The History of 712 North 2nd Street, City Block 26, Laclede's Landing, St. Louis, Missouri* (St. Louis: Sherlock Homes, n.d.) 3, <http://www.sherlock-homes.us/712.pdf>, accessed November 2012, citing 1855 *Missouri Democrat Advertisement*.

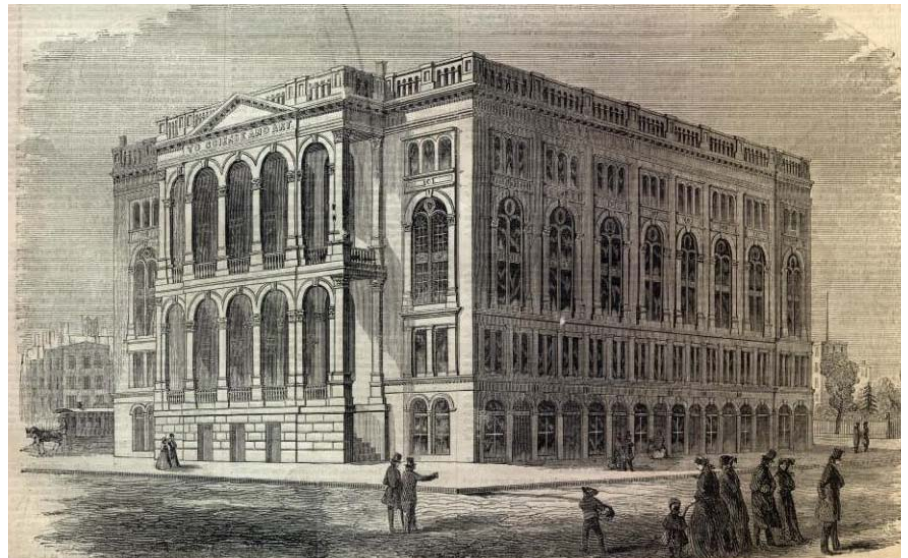


FIGURE 20. View of the Cooper Union building in New York City, which used cast iron construction developed by James Bogardus, as illustrated in the March 30, 1861, edition of Harper's Weekly.



FIGURE 21. Harper & Brothers Building, New York, NY, circa 1870. The building was demolished in 1925. Source: Albumen Print, Museum of the City of New York.

³⁴ Ibid., citing Sanborn Fire Insurance maps from 1872 and 1874; JEFF Archives, Mechanics' Institute of St. Louis Records, 1816–1894, RU 113.

³⁵ John D. McMurray, Iron Railing Manufacturer, was established by 1841 at 6 North 2nd Street. By 1860 the McMurray, Winklemaier Co. had relocated to Chestnut Street between Ninth and Tenth Streets. JEFF Archives.

³⁶ JEFF Archives.

³⁷ *Daily St. Louis Intelligencer*, July 3, 1856.

³⁸ Ibid., July 8, 1856.

³⁹ JEFF Archives. Contract between J. G. McPheeters and Thos. D. P. Lanham.

⁴⁰ *St. Louis Missouri Republican*, June 17, 1858.

⁴¹ Ibid., JEFF Archives, contract for four flights of stairs in the courthouse, September 25, 1857.

⁴² *St. Louis Democrat*, June 2, 1860.

⁴³ Fabrication markings of the Phoenix Iron Company were observed on the

wrought iron ribs of the outer dome during the investigation performed for this study.

⁴⁴ Carbon content lowers the melting point of the alloy, making the molten material conducive to casting.

⁴⁵ High sulfur contents will make alloy brittle at high temperatures.

⁴⁶ Manganese was typically added to cast iron to counter the effects of sulfur, and contributes to the strength and hardness of the iron. Like carbon, manganese also lowers the melting point of the alloy and increases its fluidity in the molten state.

⁴⁷ Phosphorus was important as an alloying agent and for hardening of the iron. Excessive phosphorus content, around 0.900 percent, makes iron brittle at room temperature.

⁴⁸ Slag inclusions are a result of the manufacturing process in irons made by rolling or forging rather than an intentionally added ingredient.

Impact of the 2016-02-05 earthquake on the Architectural Heritage of Tainan (Taiwan)

Pierre Smars - National Yunlin University of Science & Technology (Taiwan), April 2016

Introduction

February 5 2016, a ML 6.6 magnitude [2] (MW 6.4 [3]), earthquake hit Taiwan (figure 1) [4]. The epicentre (22.938°N 120.601°E) is estimated [3] to be located at 46 km NE of Kaohsiung, the second biggest city in Taiwan (2.8 million inhabitants) and at 40 km ESE from Tainan, the sixth biggest city in Taiwan (1.9 million inhabitants).

It left 116 dead (114 of them in the collapse of a 16th story building in Tainan) and 550 injured [5].

This short account specifically deals with the impact of the earthquake on the historical buildings of Tainan, the oldest city in the country, and the richest in terms of the number of listed Monuments (131) and Historical Architecture (48) [6].

In Tainan, the Modified Mercalli Intensity of the earthquake was estimated to 7 (very strong) [3].

Geographical and Geological Context

Taiwan is formed from the collision of the Eurasian Plate with the Philippine Sea Plate [7]. Earthquake are frequent.

September 20 1999, the Jiji earthquake (7.6 MW) caused 2400 deaths. Regularly, weaker earthquakes hit the country: in 2006 in Hanchuan (7.0 MW), in 2009 in Hualien (6.8 MW), in 2010 in Kaohsiung (6.7 ML), in 2013 in Nantou (6.2 MW), etc.

In 1964, the 6.3 M Baihe earthquake caused extensive damage in Tainan (see [8] for data and historical photos; [9]). Its epicentre

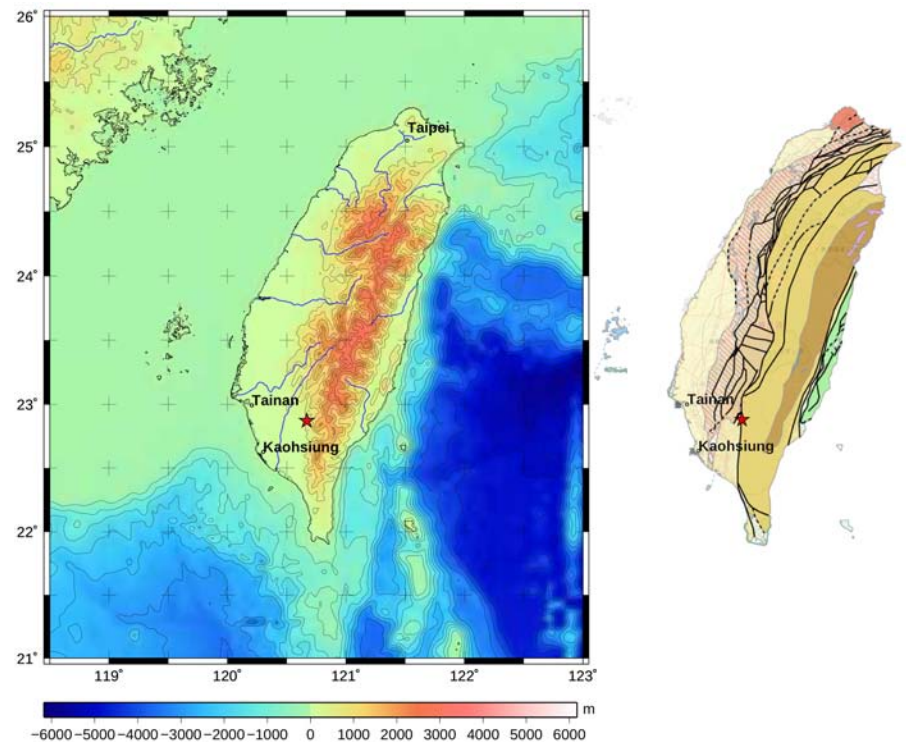


Figure 1: Taiwan. Star: earthquake epicentre. Left: topography (Data: NOAA ETOPO1 Global Relief Model; processed with GMT); Right: major faults and tectonic elements (Data: Central Geological Survey, MOEA [1]).

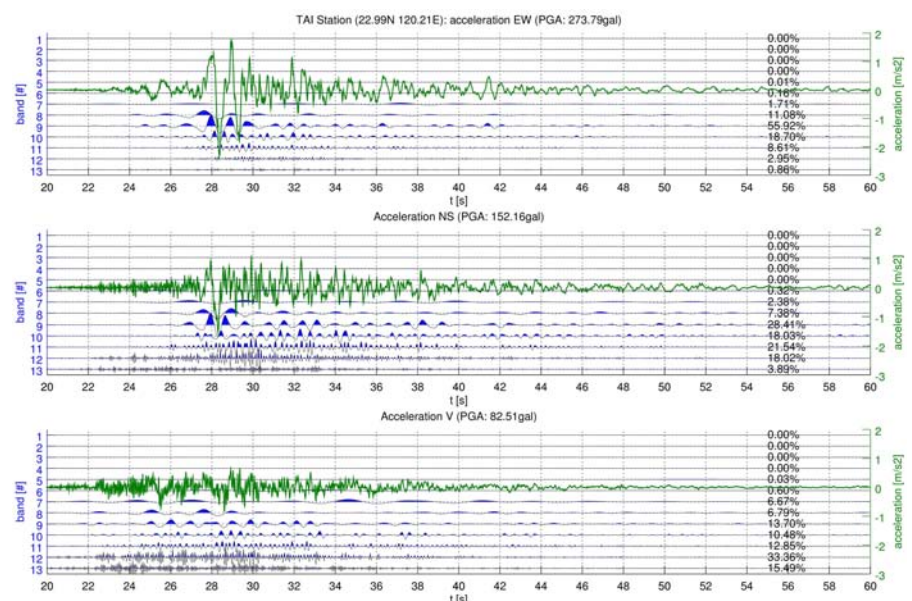


Figure 2: Accelerogram recorded at the TAI station (Data: Taiwan Rapid Earthquake Information Release System [15]; processed with GNU Octave).

was at 45 km from the city centre, about 29 km North of this year's earthquake.

The city of Tainan is located on the West coast of the island (where most of the population lives), in the



Figure 3: Listed buildings with structural concerns after 2016-02-05 earthquake in Tainan Municipality (Earthquake data: Tainan Municipal Administration of Cultural Heritage; Map data: 2016 ©Google).

Chianan plain (about 35 km wide and 60 km long) [1]. The plain is formed of a strata about 60 m thick of Holocene alluvium on top of 60 to 300 m thick strata of Miocene to Pleistocene sediments; consisting of poorly sorted alternating beds of sand, silt and clay [10]. In the Tainan area, the average shear-wave velocity of the upper 30 meters of soil profile (V_{s30}) is estimated to 230-250 m/s [11], the Peak-Ground Acceleration is estimated to 0.55g (for a 475 return period) [12]. UN OCHA Regional Office of Asia Pacific estimates to 20 the probability that an intensity 7 or higher hits Tainan in the following 50 years [13].

Earthquake Event

According to the United States Ge-

ological Survey [3], the earthquake: “occurred as the result of oblique thrust faulting at shallow-mid crustal depths (20 km). Focal mechanisms indicate rupture occurred on a fault oriented either northwest-southeast, and dipping shallowly to the northeast, or on a north-south striking structure dipping steeply to the west.”

The main earthquake was followed by seven aftershocks of maximum 4.9 [4]. The highest PGA (344 gal) was recorded in Caoling (Yunlin county), in an area of low population density. The TAI station of the Central Weather Bureau recorded the acceleration in the city centre (figure 2). The station is located at 41.3 km of the epicentre, the PGA was 23.835 %g and the PGV 29.400 cm/s [2, 4, 14].



Figure 4: Tie-Xian-Qiao Tungi Temple (Tiexian Village, 1692, Municipality level listing): damaged acroterion (Photo: Tainan Municipal Administration of Cultural Heritage).



Figure 5: Wind God Temple. Left: Drum Tower (Photo: <http://www.fingermedia.tw/>). Right: Collapsed Bell Tower. The furnace is also damaged. (Photo: Tainan Municipal Administration of Cultural Heritage).



Figure 6: Official God of War Temple (Photos: P. Smars, 2016).



Figure 7: Official God of War Temple. Far, on the right side: Fort Provintia (Chihkan Tower): undamaged by the earthquake (Photo: P. Smars, 2016).

Tainan Cultural Heritage

As stated above, Tainan is the richest city of Taiwan in terms of architectural heritage. It keeps built evidences of the main historical periods of the country, starting from 1623 when the Dutch East India Company (VOC) arrived in Taiwan looking for a base for their trade activities with China

and Japan (Fort Zeelandia in Anping District and Fort Provintia in the West Central District, both undamaged). It is also there that the Ming commander Koxinga landed in 1661 to fight (and eventually defeat) the Dutch. From the Ming and then Qing presence to the present day, numerous temples were built. Many buildings (ad-

ministrative building, train station, factories, etc) also witness the Japanese colonial period (1895-1945). Tainan remained the most important city of the island from 1623 to 1887 (when Taichung and soon after Taipei replaced it). Most of the historical buildings damaged in the earthquake are brick and stone masonry constructions with wooden roof structures.

Damages on the Cultural Heritage

The Tainan Municipal Administration of Cultural Heritage, responsible of the listed monuments of the municipality (i.e., the county and the city) [6], coordinated the actions following the earthquake. To assess the situation, the administration was helped by the experts (usually University professors), which are their permanent advisers for specific areas of the municipality. With the site managers of their area, the experts surveyed the damages and recommended actions. 43 historical buildings and monuments were damaged (list below; figure 3). Buildings were classified in two categories, whether they raised structural concerns (14 buildings) or not (29 buildings, figure 4). As far as I am aware, the effect of the earthquake on non-listed historical buildings was not yet assessed.

- Old Tainan Watercourse (Shan-shang village, 1912, National level listing)
- Sing-ji Temple (North District, 1647~1683, National level listing)
- Old Julius Mannich Merchant House (Anping District, 1875~1895, Municipality level listing)
- Huang's Residence (Houbi Village, 1923, Municipality level listing)



Figure 8: Courtyard of the Official God of War Temple (Photos: P. Smars, 2016).



Figure 9: Temple of Confucius. Left: Stele. Right: Hall of Great Achievement (Photos: P. Smars, 2016).

- Tainan Confucius Temple (West Central District, 1665, National Level listing)
- Official God of War Temple (West Central District, 1647~1683, National level listing)
- Grand Mazu Temple (West Central District, 1664, National level listing)
- Wind God Temple (West Central District, 1739, Municipality level listing)
- Chen Cheshing Residence (West Central District, 1719, Municipality level listing)
- Yanshui Octagonal Building (Zhongjing Village, 1847, Municipality Level listing)

pality Level listing)

- Shanhua Cing An Temple (Dongkuan Village, 1709, Municipality Level listing)
 - Lutaoyang Chiang Family Shrine (Lu-Tian Village, 1906, Historical Architecture level listing)
 - Fu Chenghuang Temple (West Central District, 1669, National Level listing)
 - Old Barrack of the Second Battalion of Japanese Infantry in Taiwan (East District, 1912, National level listing)
- Below, a few photographs illustrate the type of damages observed.

Only one construction collapsed: a stone tower belonging to the complex of the Wind God Temple, a temple founded in the 18 c. (and rebuilt in 1927 after the original temple was demolished for urbanistic reasons by order of the Japanese administration). Three stone constructions stood in front of the temple: a gate of three bays and two towers (a bell and a drum tower). The higher and slender gate did not suffer damages but the top heavy towers did. The bell tower collapsed (figure 5-right) and the drum tower, heavily damaged (figure 5-left), was dismantled a few days later. Both of them were not experiencing their first misfortune. The bell tower already collapsed in 1930, following the M 6.5 Xinying earthquake (Tainan municipality), was rebuilt in 1967 and displaced in 1995. And the drum tower collapsed in 1946, following the M 6.1 Xinhua earthquake (Tainan municipality) and was only rebuilt in 1995. Possibly the most common damage pattern observed in historical buildings is cracks appearing between structural elements imperfectly connected, especially stone elements (columns, slabs) and

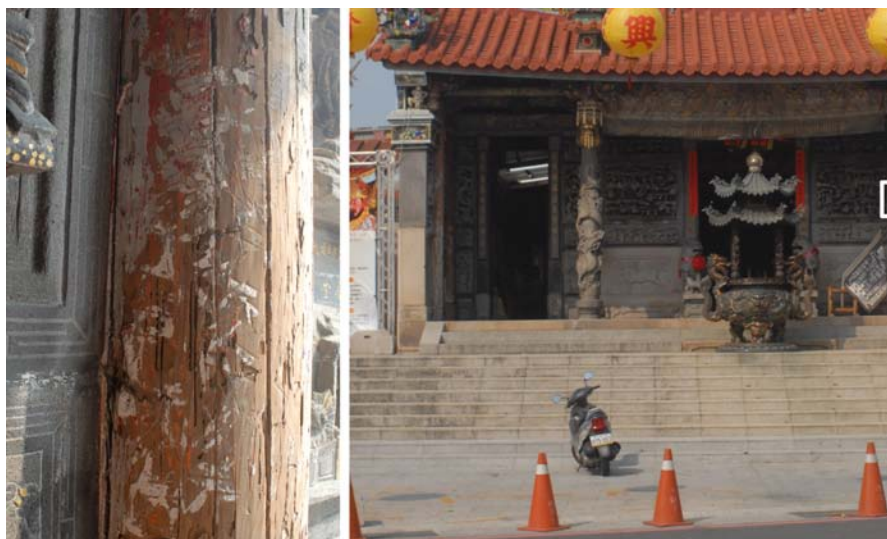


Figure 10: Sing-Ji Temple (Photos: P. Smars, 2016).



Figure 11: Temple of Confucius (Photos: P. Smars, 2016).

Acknowledgement

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Figure 11: Grand Mazu Temple (Photos: P. Smars, 2016).

walls. In the Official God of War Temple significant displacements of columns were observed, in the entrance (figure 6) and inside the temple complex. Provisional strengthening structures were installed there, in the courtyard (figure 8) and on the outside wall of the temple (figure 7). Cracks in between structural elements are also observed in the Singi Temple (figure 10) and in the Confucius Temple (figures 9-left).

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Restauración de la iglesia de San Bernardino en Urbino (Italia)

Stefano Gizzi

Ministero per i Beni e le Attività Culturali e il Turismo, Italia



El conjunto de San Bernardino de Urbino.

1. Introducción

La iglesia de San Bernardino de Urbino, uno de los ejemplos más perfectos y célebres del Renacimiento italiano, fue realizada como Mausoleo de los Duques de Montefeltro de Urbino¹, por voluntad del Duque Federico, sobre los restos preexistentes de la iglesia de San Donato y del convento de los frailes franciscanos conventuales². Situada en una extraordinaria posición paisajística, dominante la ciudad de Urbino por un lado y las colinas y la campiña por el otro, integrada

en un contexto arbóreo y agrícola de gran belleza, su historia ha cautivado desde siempre a los historiadores de la arquitectura, sobre todo por la atribución, aún incierta, que oscila entre dos personajes de primer orden del Renacimiento italiano: Donato Bramante³ y Francesco di Giorgio Martini⁴.

2. Diferentes hipótesis sobre los autores y sobre el proyecto del edificio

La iglesia se presenta como un organismo de planta central, con

dos brazos casi iguales, formados por una nave longitudinal y un transepto que se concluye con dos ábsides que sobresalen hacia el exterior. El ábside original semicircular, correspondiente a la nave principal, fue sustituido en época imprecisada con una terminación rectangular. Sus restos fueron estudiados y documentados en los años Treinta del siglo XX⁵. Externamente, como ya había observado el historiador de la arquitectura alemán Heinrich Strack a finales del siglo XIX, su configuración corresponde perfectamente a la distribución interior, de acuerdo a una concepción típica de la arquitectura renacentista⁶.

Dejando a un lado las hipótesis, hoy superadas, de Carlo Promis, que atribuía el edificio a Baccio Pontelli⁷, y de Cornelio Budinich, de inicios del siglo XX, que identificaba al autor con Pippo d'Antonio Fiorentino⁸ (arquitecto de la corte de Urbino mencionado por Giovanni Santi, padre de Raffaello Sanzio), de acuerdo a la interpretación de Arnaldo Bruschi⁹ – el mayor especialista de Bramante –, es verosímil que el proyecto haya sido preparado entre 1472 y 1482, pero que en 1491 la nueva iglesia no estuviese todavía acabada.

En efecto, algunos documentos certifican que ésta estaba prevista antes de 1482 – fecha de la muerte de Federico, «que había decidido que se rehiciera la iglesia de San Donato, donde había designado ser sepultado»¹⁰ – y que fue terminada después de 1491, cuando aparece citada por primera vez en un testamento. El área para edificar el nuevo edificio (a un lado de San Donato) era, como se ha dicho, de propiedad del Duque Federico, cuya voluntad «era la de ser inhumado en esa iglesia, junto al Conde Guido»¹¹. De hecho, a su muerte, «fue llevado su cuerpo a San Donato, conforme a su testamento»¹².

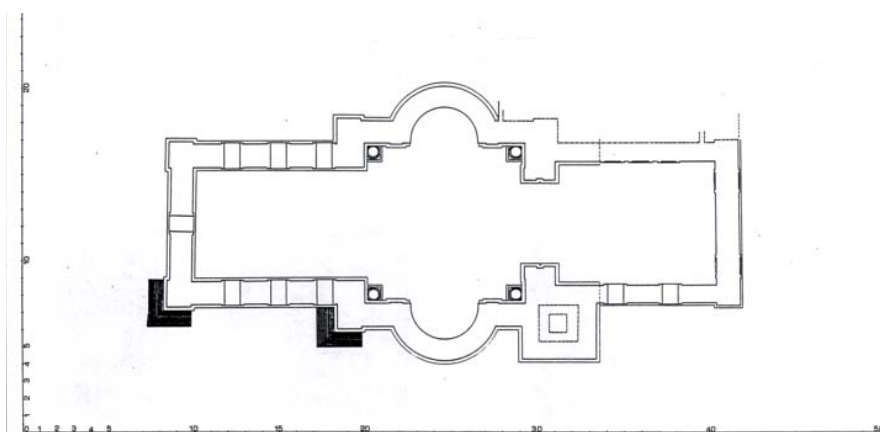
Sobre el autor del proyecto de la iglesia, la tradición local tiende a



Vista del conjunto de San Bernardino desde la ciudad de Urbino (Foto S. Gizzi, 2012).



Exterior de la iglesia a principios del siglo XX.



Planta de la iglesia de San Bernardino de Urbino.

«todo esto es, naturalmente, hipótesis, basada en comparaciones de conjunto y de detalles», por ejemplo de las «ventanas geminadas, con dintel y una columnilla al centro, en forma de puntal», parecidas a las «de Santa María de las Gracias en Milán»¹⁹; sin embargo, aclara, «no creo que en el estado actual del conocimiento se pueda decir algo más»²⁰. Quien se inclinaba enérgicamente a favor de Bramante era el abogado e historiador de Urbino Francesco Canuti²¹, quien a mediados de los años Cincuenta del siglo XX llevó a cabo numerosas investigaciones, muy influenciadas por la mentalidad de la época y por los estudios de Roberto Papini sobre Francesco di Giorgio, publicados a finales de la década de los Cuarenta. En la opinión de Pasquale Rotondi, Superintendente de Urbino a partir de 1939, la iglesia en 1482 no existía o estaba en construcción, pero fue terminada antes de 1498²². Por su parte, el historiador y archivista de Urbino, Monseñor Franco Negroni, pensaba a un inicio posterior a la muerte de Federico y el mismo Bruschi, en la segunda edición de su *Bramante*²³, ya consideraba incierta la atribución a Bramante. Sin embargo, de nuevo en forma dudosa, en uno de sus últimos textos, Bruschi afirmaba: «la iglesia fue construida (1482-95 ca.) después de su muerte [del Duque Federico], bajo la supervisión de Ottaviano Ubaldini y por obra de Francesco di Giorgio. Un dibujo de este último²⁴ puede identificarse con un proyecto para la iglesia. Otro dibujo, contenido en el mismo código, tal vez copiado de un original de Martini, muestra el interior en perspectiva. Ambos dibujos, publicados y estudiados por Howard Burns, conciernen una fase del proyecto que podría haberse iniciado antes de la muerte del Duque y antes de la partida de Bramante hacia Lombardía»²⁵. Pero veamos los puntos en los que las hipótesis de Canuti – que lo atribuye a Bramante – son discutibles: Francesco di Giorgio Martini (1439-1501) llega a Urbino en 1475, cuando se distancia del pintor Neroccio en Siena, o bien en 1476, visto que

atribuirlo a Donato Bramante. Entre los historiadores de la Región de las Marcas, Michele Angelo Dolci, en la segunda mitad del siglo XVIII, daba por cierta la paternidad del arquitecto urbinato: «Iglesia de los Padres menores reformados franciscanos. Fuera de la ciudad. [...] La iglesia fue diseñada por el célebre Bramante y por ello merece una observación especial, tanto por la construcción y solidez de la fábrica, como por la magnificencia y esbeltez del presbiterio»¹³. Esta afirmación es retomada por el abad Andrea Lazzari a principios del siglo XIX: «la iglesia fue diseñada por nuestro famoso arquitecto Bramante»¹⁴. En la opinión de Arnaldo Bruschi, es posible que Bramante hubiese preparado, antes de partir hacia Milán, un

proyecto posteriormente reelaborado y ejecutado por Francesco di Giorgio Martini y, de acuerdo a una hipótesis de Corrado Maltese¹⁵, que la solución de éste último hubiera sido discutida por ambos arquitectos en Milán en un posible encuentro hacia 1491¹⁶. Entre los autores más acreditados que consideran la iglesia como proyecto de Bramante, nos limitaremos solamente a citar a los más conocidos. Entre los principales se encuentran Adolfo Venturi – sólo en una primera fase¹⁷, ya que posteriormente la atribuirá a Francesco di Giorgio Martini¹⁸ – y Gustavo Giovannoni que, por afinidades estilísticas y constructivas con otros organismos bramantescos, la da como posible obra del arquitecto de Fermignano, aunque, escribe,

en la primavera de 1477 firma ya para Federico de Montefeltro documentos notariales para la construcción del revellín de Costacciaro, que habría de realizarse conforme a su diseño. Debe recordarse que Bramante (1444-1514) parte hacia Lombardía en 1476-1477, pues en 1477 está ya documentado en Bergamo, en donde realiza una serie de pinturas murales en el Palacio del Podestà²⁶. Por lo tanto ha ya dejado Urbino y tiene treinta y dos o treinta y tres años. No sabemos si haya regresado a Urbino desde Bergamo o desde Milán, aunque estudios recientes sobre su familia²⁷ confirman que el arquitecto volvió a aparecer en sus lugares de origen para ocuparse de sus propiedades inmobiliarias. Un legado efectuado en 1473 a favor del «Convento de San Donato» no confirma que la nueva iglesia estuviese ya en construcción, sobre todo porque en el cuerpo del convento podría fácilmente identificarse un núcleo más antiguo, que podría haber sido precisamente el objeto de la donación; por otra parte Canuti afirma que la tardía denominación de San Bernardino «no prueba que la iglesia de San Bernardino no hubiese sido edificada antes de 1482»²⁸; pero la doble negación no puede constituir una prueba de que la nueva iglesia fuese erigida antes de 1482; y, en todo caso, antes de 1477, año de la partida de Bramante.

Se cuenta con la noticia de un Capítulo general que se llevó a cabo en Urbino en 1475, cuando se reunieron en la ciudad los Provinciales de la orden, en el cual, un no precisado arquitecto «*hunc locum magnifice satis ac pro tanti Principis splendore omnibus satis numeris absolvit*»²⁹; ello sin embargo no constituye una prueba fehaciente, ya que podría al contrario haber urgido la edificación de la nueva iglesia. Algunos documentos de 1476 «*pro fabrica*» de la nueva iglesia parecen sufragar esta hipótesis y todavía en 1483 un documento análogo cita San Donato y no San Bernardino³⁰.

En el volumen *De origine seraphicae religionis...*, Francesco Gonzaga³¹ – franciscano y obispo – narra de Federico «*ac fratis pijs votis satisfactorius inchoa-*



El conjunto de San Bernardino en la tela de Girolamo Caldieri (primera mitad del siglo XVII).



Interior de la iglesia en los años Treinta del siglo XX (publicada en L. Serra, *op. cit.*).



Detalle de la Madonna Cowper de Rafael, en cuyo fondo se distingue una iglesia parecida a San Bernardino.

*tum hunc locum magnifice fatis*³², usando el tiempo futuro, y por lo tanto mencionando que la iglesia y la nueva parte del convento habrían de ser construidas.

Ninguna mención a Francesco di Giorgio (ni a Bramante) como autor de San Bernardino hace el especialista Enrico Rocchi en su amplio discurso, pronunciado en Siena en 1900 sobre la actividad de Martini³³. A favor de la atribución a este último, como autor del proyecto, se pueden considerar los siguientes elementos: un dibujo descubierto por Howard Burns en la Biblioteca Laurenziana de Florencia³⁴, en un fascículo de bosquejos procedentes de Urbino claramente copiados de Francesco di Giorgio, que representan un estado de elaboración cercano pero no idéntico a cuanto realizado, y por ello considerados estudios anteriores de proyecto³⁵. Otro elemento es el hecho que la iglesia de San Bernardino tenga caracteres (basamento, «*ricinti*» – como los definía el mismo Francesco di Giorgio –, y una relación entre paramentos y partes esculpidas) muy parecidos a los de la iglesia de Santa María de las Gracias al Calcinaio en C

ortona, obra cierta de Martini, con cúpula posterior de Pietro di Domenico di Norbo (1509), que se apoya sobre un tambor realizado, como toda la iglesia, a partir del diseño de Martini y sobre todo con una concepción de conjunto que bien se coloca en la arquitectura de Francesco di Giorgio y de sus estudios sobre la antigüedad. Y, finalmente, el testimonio de Giovanni Santi (padre de Raffaello) que ofrece, entre 1484 y 1494, una cronología de la fábrica en su volumen dedicado al Duque Federico³⁶.

En conclusión, dejando a un lado las consideraciones estilísticas de Canuti, que evidentemente no era un experto en los años de formación de Francesco di Giorgio, ni podía conocer los documentos descubiertos posteriormente a su texto, puede quedar la duda que la iglesia de San Bernardino haya sido comenzada antes de la muerte del Duque Federico – aunque parece imposible colocar su inicio antes de 1476 – y, si así fuese, atribuirle sin pruebas a Bramante, que ciertamente participa de esa cultura figurativa, como por otra parte, toma también parte Francesco di Giorgio. Uno de los mayores historiadores de la arquitectura italianos, Leonardo Benevolo, se inclina, con cautela, hacia Martini: «faltan documentos sobre el autor y sobre la época de construcción. La arquitectura parecería referirse a Francesco di Giorgio y la edificación a los últimos años del *Quattrocento*»³⁷.

Algunos autores sostienen que un dibujo de Bramante, el célebre *Templo en ruinas* – conocido a través del grabado de Bernardo Prevedari – realizado en 1481 y hoy conservado en el British Museum, sea una referencia personal de una de sus soluciones para San Bernardino o bien de la iglesia de San Bernardino ya terminada por Francesco di Giorgio Martini.

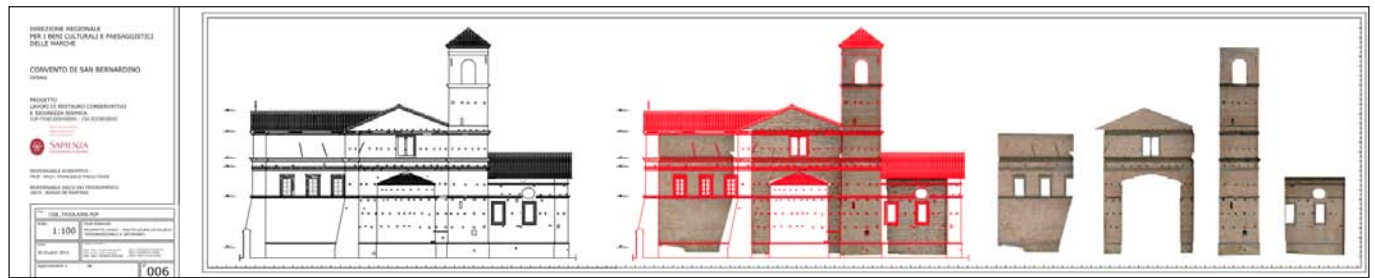
De cualquier manera, se notan algunas analogías con la solución arquitectónica de la capilla del Perdón del Palacio Ducal de Urbino (realizada antes de 1480, probablemente alrededor de 1476³⁸) tal vez por el mismo Bramante o por Baccio Pontelli³⁹, aunque últimamente algunos especialistas tienden a atribuirle

también a Martini⁴⁰.

La excepcionalidad de la iglesia fue reconocida casi inmediatamente. Rafael Sanzio conocía y apreciaba la solución arquitectónica y los detalles decorativos de San Bernardino. La representa (con ligeras variaciones) en el fondo de algunas de sus pinturas, como el de la pequeña *Madonna Cowper* (1504-1505) o en los estudios arquitectónicos presentes en el verso de uno de los bocetos preparatorios de la *Virgen del Jilguero*⁴¹, en donde, en la parte alta a la derecha, muestra un fragmento de planta de iglesia con coro y transepto con ábsides y columnas en las esquinas de grandes dimensiones y, en el margen inferior del folio, el mismo transepto repetido y ligado a una nave central, referibles a San Bernardino. El mismo Rafael vuelve a proponer el modelo del portal de San Bernardino en las escuderías Chigi en Roma, proyectadas entre 1512 y 1513 y hoy desaparecidas. De 1495 a 1503 el párroco de San Donato en Urbino es un tío de Rafael, don Bartolomé de Sante. ¿Habría ido Rafael desde Roma a visitar a su tío a Urbino y podría haber visto la nueva iglesia ya terminada?

3. Materiales constituyentes y fenómenos de deterioro: problema de restauración y consolidación

A continuación se examinan los materiales constitutivos de la iglesia y los problemas relacionados con su acentuado deterioro. Los paramentos exteriores son de ladrillo aparente, formados por elementos no homogéneos con diferente grado de alteración, dispuestos en hiladas horizontales, con juntas de mortero de diferentes espesores, a menudo faltante o que ha sido manipulado. En la fachada, las cornisas son en bloques de piedra arenisca, empotrados en el muro, así como los elementos que constituyen el tímpano, las ventanas y la columnilla central de la ventana superior. Son en piedra caliza compacta blanca los elementos del portal de acceso a la iglesia, es decir las dos columnas con basas y capiteles, el arco y el dintel. Las ventanas son especialmente elegantes en su simplicidad. Así las describió



Levantamiento e interpretación diagnóstica efectuados por el Departamento de Diseño, Historia y Restauración de la Facultad de Arquitectura de Roma "La Sapienza".

Egidio Calzini, historiador de Urbino (que había mantenido una extensa correspondencia con Camillo Boito) en 1897: «Otro carácter típico de Bramante lo encontramos en las graciosas ventanas rectangulares con jambas cuyas partes simples y con poco relieve están en perfecta armonía con la columna de en medio, también muy simple»⁴². Para llevar a cabo la investigación histórica y los análisis diagnósticos preliminares a la intervención, la Superintendencia de Monumentos de las Marcas, por iniciativa de quien escribe, proyectista y director de las obras⁴³, firmó un convenio con el Departamento de Historia, Dibujo y Restauración Arquitectónica de la Universidad de Roma "La Sapienza"⁴⁴, y para las obras de restauración, recientemente terminadas, contó con la asesoría del Instituto Superior de Conservación y Restauración del Ministerio de Bienes y Actividades Culturales, que proporcionó una valiosa orientación⁴⁵. Ya los terremotos de 1695 y especialmente el de 1703 (devas-

tador en gran parte del centro de Italia, sobre todo en el Abruzzo) habían causado daños significativos en la iglesia y en el convento: «En 1704 fueron reparadas las tumbas de los Duques, dañadas por el terremoto. Se rehizo entonces el remate del campanario que, aunque deteriorado, por un milagro no cayó sobre la iglesia. La cúspide fue reconstruida en travertino del Monte Nerone»⁴⁶. Hoy en día se conservan todavía los contrafuertes de mampostería, no empotrados, sin duda posteriores a la construcción original de la iglesia y colocados como elementos de consolidación, quizá provisional, muy probablemente en siglo XVIII (éstos ya habían sido notados por Serra en 1932: «hubo que proceder con la realización de contrafuertes para apuntalarla»⁴⁷), aunque los ladrillos, por tamaño y disposición, son similares a los del resto de la iglesia, siendo probablemente reutilizados. Por otra parte, observando una pintura del siglo XVII⁴⁸, en la que se representa

en el fondo la iglesia de San Bernardino con la cúspide de la torre del campanario y cuatro pequeñas torres en las esquinas⁴⁹, se nota que el contrafuerte no está presente. Como el lienzo es de la primera mitad del siglo XVII, ello confirmaría la hipótesis que los mencionados refuerzos sean posteriores, probablemente del siglo XVIII y, según algunas conjeturas, incluso posteriores al terremoto de 1781.

Después de este sismo se registran también diversos desperfectos: «un daño no indiferente se produjo en la iglesia y convento, tanto que la primera estuvo sin poder oficiar durante casi todo un año; sirviendo para las funciones sagradas la iglesia llamada de San Donato [...]. El nuevo Guardián [...] presentó una súplica a esta Ill.ma Comunidad para que concediera alguna ayuda pecuniaria y solicitó la asignación de 25 escudos. [...] Se supo que el Papa Pío VI [...] había repartido entre los lugares más dañados [...] la suma de doce mil escudos romanos y,



Fachada sureste con contrafuertes (Foto S. Gizzi, 2012).



Detalle de los contrafuertes en mampostería (Foto S. Gizzi, 2012).



Torre campanaria con cornisas originales y de restauración (Foto S. Gizzi, 2012).



Tambor con evidente deterioro de las cornisas en piedra arenisca.



Una cornisa de reintegración con la fecha grabada: 1933 (Foto S. Gizzi, 2015).



Deterioro de las cornisas del frente noroeste (Foto S. Gizzi, 2015).



Deterioro de las cornisas del frente noroeste. Nótese las partes reintegradas con piedra arenisca (Foto S. Gizzi, 2012).

después de haber asignado a la Ciudad Arquidiócesis de Urbino la cantidad de mil escudos, [...] benigneamente fue beneficiada con el favor de cincuenta escudos [...]. El día 8 de abril del año siguiente 1872, el mismo Guardián [...] dio inicio a la restauración de la Iglesia [...] y en el curso de cinco semanas dio fin a la obra»⁵⁰.

A finales del siglo XIX se llevaron a cabo otras restauraciones, como nos informa la *Relación* de Giuseppe Sacconi, entonces Director Regional para la Conservación de los Monumentos de las Marcas y Umbría⁵¹: «Este templo importantísimo para el arte y la historia desde hace mucho tiempo se encuentra en estado de deterioro, tanto que requiere reparaciones rápidas y eficaces. Para ello, la Oficina elaboró una estimación con fecha 21 de agosto de 1898 por la suma de 2,000 liras. [...] Las obras consisten en la reconstrucción del techo y de las cornisas exteriores».

En 1932, escribe Serra: «El estado de conservación es mediocre. Los marcos y las cornisas se han renovado en gran parte debido a las heladas. Fue restaurada, devolviéndole en lo posible su severa majestad original, en 1927-1929»⁵². En este caso, parecería que la reintegración de las cornisas, más que por razones de conservación, se haya debido a factores estéticos, enfocados al «retorno» a una supuesta antigua gloria.

Al año siguiente, el Municipio de Urbino, en una carta enviada a la Superintendencia el 8 de junio de 1933, señalaba que «en el alzado lateral de la iglesia de San Bernardino, que mira hacia el norte, se derrumbó una parte de la cornisa del tímpano por casi cuatro metros, y la caída de los materiales ha dañado la cornisa horizontal subyacente del mismo tímpano y también del techo que cubre el espacio semicircular, en el que está colocado un altar lateral» (firmado el Podestá).

Un cuarto de siglo más tarde, el 1 de julio de 1959, el Superintendente Vittorio Mesturino informa al Ministerio que «la Superintendencia ya desde algún tiempo se está ocupando del insigne monumento, en especial

para la conservación de los perfiles de piedra arenisca que el tiempo está deteriorando. Por lo tanto, prepara un presupuesto por un importe de 1.000.000 de liras para la renovación de algunas secciones de cornisas, arquitrabes, frisos etc., y para obtener un modelo para la re- hechura completa de todas las cornisas, frisos, dinteles». Y en la estimación de los costes, preparada por el prof. Belli y re- frendada por el Superintendente Mesturino, en la partida 2 se preveía el suministro, fabricación e instalación de cornisas en piedra arenisca gris [...] de acuerdo con los diseños que serán proporcionados por la Dirección de Obras»⁵³.

La iglesia y el convento, además de haber sufrido daños por la guerra, también fueron utilizados como refugio bélico: «todo el edificio por la larga permanencia de las tropas alemanas, aliadas y de muchas personas desplazadas necesita con urgencia ser limpiado y encalado»⁵⁴.

En 1959, el Superintendente, en un comunicado al Sacro Guardián del Convento (12 de noviembre 1959), señala que ha incluido en el programa decenal una serie de intervenciones en San Bernardino, que incluyen «la restitución de las cornisas en piedra arenisca en sustitución las viejas piezas desgastadas por el tiempo». De esta manera, la idea era proceder a través de la sustitución de elementos y no a través de la consolidación de los existentes.

Similares a los de la iglesia son los problemas relativos a la degradación de los arquitrabes del claustro⁵⁵, también en piedra arenisca; con el tiempo, algunos de ellos han sido reemplazados con una serie de elementos de hormigón armado, que hoy muestran plenamente su avanzada decadencia.

En la intervención actual, efectuada a partir de 2012, la columnilla en piedra arenisca de la ventana principal de la fachada de la iglesia – fisurada por una errada restauración precedente en la que se utilizó un núcleo de hierro – se ha consolidado de acuerdo al siguiente *iter*: pre-consolidación de las lagunas lenticulares través de microinyecciones de resina acrílica; desmontaje y montaje de las

piezas desprendidas con un sellador especial; inserción de micropernos en acero inoxidable con rosca antes del desmontaje y de la eliminación de los refuerzos inadecuados (realizados anteriormente con un simple alambre); corte y remoción del capitel; eliminación de elementos en hierro oxidado del fuste de la columna; protección del fuste con policloruro de vinil durante el desmontaje; montaje del basamento; consolidación por aspersión hasta rechazo de silicato de etilo; preparación de un soporte adecuado al sucesivo montaje de la columna; reposicionamiento de la base e inserción de una barra de acero inoxidable con rosca en lugar del hierro oxidado; montaje del capitel con mortero a base de cal, polvo de piedra arenisca gris y puzolana adicionada con filamentos de fibra de vidrio⁵⁶. Las restauraciones anteriores pueden identificarse – no sin cierta dificultad – comparando los diversos tipos de materiales; en la fachada se notan, en efecto, morteros diferentes de los originales, aplicados a través del tiempo para efectuar reparaciones y reintegraciones. Son, en especial, de dos tipos: *mortero rosado o de color cemento* aplicado para sellar lagunas de diferentes tamaños, como la cúspide del tímpano o el paramento del tambor de la cúpula; *mortero de cemento*, aplicado como una espesa lechada sobre



Monitoreo del frente principal (Foto S. Gizzi, 2013).

elementos de piedra muy deteriorados, que ya no conservan las líneas de su perfil original. También se observan otras inserciones de restauraciones anteriores: pernos y fajillas de metal para la columnilla de la ventana del orden superior y elementos de piedra, en el dintel de la portada, en la ventana del primer orden y en el resalte por debajo de la cornisa del segundo orden. La presencia de elementos de sustitución ha afectado los paramentos de todo el monumento; en las cornisas en piedra arenisca, constituidas por bloques casi completamente destruidos – de tono oscuro, con



Detalle de las cornisas originales y de sustitución en el frente noroeste (Foto S. Gizzi, 2013).



Deterioro de la piedra arenisca en el Palacio Papal de Camerino (Foto S. Gizzi, 2012).

depósitos negros y pátinas biológicas, carentes de definición formal – destacan bloques de color más claro, con talla neta, mucho más dura con molduras continuas y regulares con una superficie lisa.

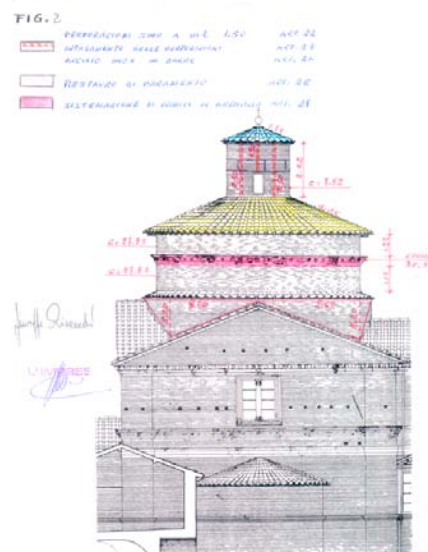
En especial, en el lado lateral, intercalados con los de reciente integración, se pueden ver otros bloques que se caracterizan por fenómenos de exfoliación y muy marcada erosión: su diferente grado de alteración, intermedio entre la completa destrucción de los elementos de la fachada y los más recientes, prácticamente intactos, sugeriría una reposición parcial repetida en el tiempo. Difíciles de fechar son algunas reintegraciones, tales como las constituidas por fragmentos de ladrillo insertados en los residuos de los elementos de piedra arenisca o introducidas a lo largo de las líneas de empotramiento de los bloques de piedra arenisca en los muros o incluso en los cortes del paramento a los lados de las columnillas del portal de acceso.

Como se ha dicho, los problemas más significativos se producen por la degradación progresiva de los elementos constructivos. Entre ellos, la corrosión piedra arenisca es uno de los más intensos en la zona de las Marcas y de la Umbría y son numerosos los casos en los que se manifiesta: de Camerino, a Fano, hasta Città di Castello, Castiglione del Lago y Gubbio. En la iglesia de Urbino se trató de resolver la erosión a través de numerosos intentos, no del todo exitosos, a lo largo del siglo pasado. Algunos importantes historiadores del arte contemporáneo, como Corrado Maltese y Howard Burns, señalaron en su momento



Deterioro y reintegraciones de la piedra arenisca de la iglesia de Santa María de las Gracias al Calcinato en Cortona (Foto S. Gizzi, 2012).

el deterioro de las molduras. El primero hizo hincapié en que «si la intemperie no hubiese corroído de esta manera esas cornisas exteriores, la similitud con las cornisas típicas de Francesco



Proyecto de consolidación de los años Noventa del siglo XX, efectuado con resinas sintéticas.



Efectos negativos de la consolidación efectuada con resinas sintéticas en los años Noventa del siglo XX (Foto F. Lanari, 2013).

di Giorgio sería sin lugar a dudas muy fuerte»⁵⁷; el segundo observó cómo «las cornisas de piedra arenisca» son de «una piedra que al aire libre se deteriora considerablemente y, hoy en día, de hecho, se está desmoronando o ha sido sustituida por reformas reciente»⁵⁸. Ciertamente, en las partidas de diversas estimaciones elaboradas entre los años Treinta y los años Noventa del siglo XX, casi siempre se menciona «el suministro de cornisas de arenisca (piedra serena) de cualquier espesor y altura»⁵⁹. E incluso en las estimaciones de los canteros se subraya que «por razones estáticas que requiere la renovación de los

bloques, que deben ser reemplazados con superficie lisa, visto que no quedan restos de la ornamentación y de los relieves», sugiriendo, como solución, «la renovación de las reintegraciones en las bases de las columnas y del dintel»⁶⁰.

Sólo en algunos de estos bloques de reintegración se ha anotado la fecha de la restauración. En una cornisa en piedra arenisca del tímpano se lee la fecha de una de esas sustituciones: 1933. En la fachada principal y en las laterales se perciben numerosos fenómenos de deterioro tanto de los materiales pétreos como del ladrillo. En el portal, tan admirado y citado por Rafael Sanzio,



Claustro del convento de San Bernardino (Foto S. Gizzi, 2013).



Tipos de ladrillo y deterioro de los capiteles en el claustro del Convento (Foto S. Gizzi, 2013).



Urbino, Convento de Santa Clara de Francesco di Giorgio Martini (Foto S. Gizzi, 1972).



Tipos de los ladrillos y deterioro de los capiteles en el claustro del Convento de San Bernardino (Foto S. Gizzi, 2013).



Detalle del deterioro del capitel en piedra arenisca en el claustro (Foto S. Gizzi, 2013).



Ladrillos con restos de revocos policromados y esgrafiados (Foto S. Gizzi, 2015).



Pruebas de consolidación de los ladrillos y test de tratamiento del mortero (Foto S. Gizzi, 2015).

gregadas requieren una mano de obra altamente cualificada y productos de compleja aplicación (silicato de etilo, nanosílices; microemulsiones acrílicas; morteros hidráulicos con granulometrías muy finas para las inyecciones), con operaciones delicadas y laboriosas, que demandan un control muy preciso para minimizar la incertidumbre sobre el resultado final y en el corto o mediano plazo (eficacia; inercia química, ausencia de cambios de color).

Existe además un problema considerable en lo relativo al suministro del material de reintegración: varias canteras de piedra arenisca presentes en Urbino – ahora casi todas abandonadas o agotadas –, eran tan ricas que fomentaron una extracción muy intensa durante el Renacimiento, tanto en Umbría como en las Marcas, al grado que el hijo de Federico, Guidobaldo, para evitar que faltase material útil para la construcción del Palacio Ducal de Urbino, promulgó una ordenanza con la que limitaba la comercialización de la piedra, que podía llevarse a cabo sólo después de obtener una licencia ducal⁶².

Para la arenisca, la solución actual es o bien la consolidación de lo que quedaba de la materia original, casi completamente informe, o bien la sustitución con material nuevo, con un aspecto más duro, como se ha hecho en otras iglesias (por ejemplo, Santa María delle Grazie al Calcinai, en Cortona, del mismo Francesco di Giorgio Martini, que presenta los mismos problemas de desintegración gradual de la piedra arenisca). La tendencia

en piedra caliza blanca, se advierte la presencia de una colonización generalizada de líquenes, pero el estado de conservación es bueno, sin excesivos fenómenos de disgregación, a excepción de pequeñas zonas de dintel, donde son muy evidentes algunos desprendimientos.

Acerca de los materiales y elementos de piedra, en el interior de la iglesia se conservan las huellas que el compás y el cincel dejaron impresas sobre las caras superiores de los capiteles del orden interno; tales huellas fueron descubiertas después de haber removido una ligera capa

de encalado. Estos capiteles son similares a algunos prototipos proto-renacentistas que se conservan en el Museo Nacional Romano⁶¹.

En la fachada, todos los elementos en piedra arenisca (a excepción de algunos segmentos de las cornisas de evidente sustitución) se encuentran en condiciones de avanzada destrucción. Fragmentos residuales de las líneas arquitectónicas sólo pueden apreciarse en las partes terminales de las cornisas del frontón. Como es bien sabido, a nivel general, los tratamientos de restauración habituales para la consolidación de areniscas dis-



Detalle de la prueba elegida (Foto S. Gizzi, 2015).

es, en general, la de conservar lo más posible la materia original: en otras consolidaciones llevadas a cabo por el Instituto Central de la Restauración, por ejemplo, en Lecce, en la iglesia de Santa Croce, con otro tipo de piedra (la

llamada piedra leccese), se evitaban las sustituciones de material y se procedió con la imbibición de productos químicos, con un resultado que, sin embargo, ya no es satisfactorio a distancia de poco más de una

década. En el caso concreto, se observó que algunas zonas del paramento son sede de colonización de líquenes, mientras que otros aparecen completamente exentos. Existen numerosas lagunas e interrupciones: los ladrillos aparentes, dispuestos en hiladas horizontales – con juntas de mortero faltantes, desintegradas o alteradas –, presentan discontinuidades en las proximidades de los elementos de piedra. Los ladrillos se diferencian por color, tamaño e integridad y presentan varias formas de alteración con diferentes niveles de gravedad; muchos parecen ser elementos reemplazados. Las operaciones últimamente realizadas (no especialmente complejas y con diferentes niveles de problemáticas) consistieron en la desinfección, la eliminación de los depósitos y de piezas sueltas, la reconstrucción puntual de las juntas faltantes y la consolidación de los ladrillos en estado de pulverización. En las cornisas horizontales fueron, en el pasado, colocados ladrillos con pendiente adecuada, unidos para formar una superficie adecuada para la eliminación del agua de lluvia. Pero hoy en día estos elementos de protección están incompletos, por faltar muchos de los elementos constituyentes. La oportuna reparación de la continuidad y de la funcionalidad de esas superficies, en la restauración en curso, se ha llevado a cabo reintegrando las partes faltantes y los huecos con morteros tradicionales con elevada cualidad hidráulica. Los problemas que plantea el monumento en su conjunto son de gran importancia y estimularon muchas reflexiones; en la perspectiva de una intervención general, el primero está relacionado con la dimensión de los paramentos, con la extensión de los elementos a ser tratados y a su accesibilidad en ausencia de andamios. A esto se conecta un segundo tema, el de la elaboración de metodologías aplicables ampliamente, realizadas fácilmente por trabajadores no especializados. Un tercer aspecto está relacionado con la historia de la conservación, para entender mejor – además de la incidencia de los factores



Estado de deterioro de la columnilla de la ventana bifora del frente principal antes de la intervención (Foto S. Gizzi, 2014).



Desmontaje del capitel de la columnilla de la ventana bifora del frente principal (Foto Gamma s.r.l. Fano, 2015).



Detalle de la fisura de la columna (Foto Gamma s.r.l. Fano, 2015).

y las grietas de muros, que se manifiestan sobre todo en la fachada principal, con respecto a las demás paredes. Es un problema que apareció ya a finales del siglo XIX, como señalaban los eruditos locales (véase Calzini «desde hace algunos años el abultamiento o hundimiento de la tierra [...] ha comenzado a desprender la parte frontal del templo, y las rendijas se amplían sin interrupción. ¿No sería un crimen, por descuido o por otra cosa, dejar que muera la más justa y más genial obra juvenil de Bramante?»⁶³).

Pero los problemas más graves se deben a las imbibiciones recientes, de los años Noventa, realizadas con resinas sintéticas que han alterado por completo, en pocos años, desde el punto de vista cromático y material, la piedra.

Las lesiones estructurales también conciernen otros elementos, como por ejemplo las lápidas sepulcrales (la tumba estaba en *cornu epistulae*, o sea en el lado derecho del altar): así también la del Duque Guidantonio de Montefeltro – padre de Duque Federico – (representados con el hábito franciscano y con una espada y el signo de la caballería en el lado derecho) en la antigua iglesia de San Donato, fracturada y en fuerte estado de degradación. La intervención debe ser incluida en un programa más amplio de revisión general que incluya también la pavimentación.

La restauración actual estuvo dirigida a una consolidación general de las mamposterías y de las decoraciones, para una mejor apreciación y conservación del monumento.

Notas

¹ Urbino, ciudad de la Región de las Marcas, fue Ducado de la familia Montefeltro y su época de esplendor se coloca en la segunda mitad del siglo XV, en tiempos del Duque Federico, cuando numerosos artistas fueron llamados a trabajar en la corte: Piero della Francesca, Luciano Laurana, Francesco di Giorgio Martini. Fue cuna de Bramante (que nació en una pequeña localidad cercana llamada Fermignano) y de Rafael Sanzio.

² A partir de una idea inicial de ubicarlo en el interior del Palacio Ducal.

climáticos – las causas y la dinámica de una degradación tan pronunciada. Un nuevo elemento de complejidad está ligado a la existencia de piezas ya tratadas durante las restauraciones recientes, con características estéticas y de rendimiento distintos de los materiales pre-existentes. Existe, además, un tema muy interesante e intrigante de tipo histórico, que consiste en la identificación y colocación temporal de un paramento de ladrillo simulado con el revoco (¿Es original? ¿Es del siglo XVIII? ¿Fue

propuesto por Valadier, que trabajó también en la catedral de Urbino? ¿Se remonta al siglo XIX?), presente en varias zonas de la fachada resguardadas por los aleros, que fue realizado con una capa de mortero muy ligero, aplicado con técnica pictórica no demasiado refinada y que muestra esgrafiados horizontales que imitan las juntas de ladrillo. Desde el punto de vista estructural, dentro del edificio se han instalado algunas espías para evaluar y monitorear los acentuados fenómenos de desplome



Fases de la restauración de la columna (Foto Gamma s.r.l. Fano, 2015).

³ Arquitecto urbinato (Fermignano 1444-Roma 1514). Entre sus obras principales se cuenta el proyecto para la reconstrucción de la Basílica de San Pedro, el templete de San Pedro in Montorio, el claustro de Santa María de la Paz, todas en Roma.

⁴ Arquitecto e ingeniero militar (Siena 1439-Fighille 1501), conocido por sus fortificaciones y castillos situados en Italia central y por varios proyectos llevados a cabo en el Palazzo Ducale de Urbino, en el de Gubbio y por muchas iglesias, como la de Santa María de las Gracias al Calcinato en Cortona (Toscana).

⁵ Las excavaciones fueron dirigidas por el ingeniero Enrico Cardelli, por iniciativa de Luigi Serra. Cfr. L. Serra, *Nota sulla chiesa di San Bernardino a Urbino*, en "Rassegna Marchigiana", enero-febrero 1932.

⁶ H. Strack, *Central- und Kup-*

pelkirchen der Renaissance in Italien, Ernst & Korn, Berlin 1882, I-II.

⁷ C. Promis, *Vita di Francesco di Giorgio Martini architetto senese del secolo XV. Aggiuntovi il catalogo de' codici*, Tipografia Chirio e Mina, Torino 1841, p. 23: «De Federico [de Montefeltro] son también la iglesia y el claustro de' Zoccolanti, en las inmediaciones de Urbino, por tradición atribuidas a Baccio Pontelli».

⁸ C. Budinich, *Il Palazzo Ducale d'Urbino. Studio storico-artistico illustrato da nuovi documenti*, Stabilimento Tipo-Litografico Emilio Sambo, Trieste 1904, p. 126.

⁹ A. Bruschi, *Bramante Architetto*, Laterza, Roma-Bari 1969, pp. 732-739, espec. p. 734.

¹⁰ V. da Bisticci, *Vite di uomini illustri del secolo XV, rivedute sui manoscritti da Lodovico Frati*, Romagnoli Dall'Acqua, Bologna 1892.

¹¹ *Ibidem*.

¹² *Ibidem*.

¹³ M. A. Dolci, *Notizie delle pitture che si trovano nelle chiese e nei palazzi di Urbino*, ms., Bologna 1775, edición a cura di L. Serra, Tip. G. Federici, Pesaro 1933, pp. 310-311. y, en la p. 317: en «la iglesia de los Zoccolanti fuera de la ciudad, el presbiterio es diseño de Bramante».

¹⁴ A. Lazzari, *De' vescovi d'Urbino con alcuni aneddoti concernenti il dominio temporale de' conti e duchi*, presso Giovanni Guerrini, Urbino 1806.

¹⁵ C. Maltese, *Opere e soggiorni urbinati di Francesco di Giorgio*, en P. Rotondi (ed.), *Studi artistici urbinati*, Istituto d'Arte per il Libro in Urbino, Urbino 1949, vol. I, pp. 59-83.

¹⁶ C. Maltese, *Opere e soggiorni urbinati...*, cit.. En efecto, Maltese supone que «Francesco di Giorgio va a Milán en 1490, encuentra casi ciertamente a Bramante, visita a Leonardo, a quien regala una copia de su Tratado. ¿No podría en esa breve estancia haber tenido lugar un intercambio entre Bramante y Francesco di Giorgio?» C. Maltese, *op. cit.*, p. 81. En la opinión de Arnaldo Bruschi «Maltese [...] pospone [...] exageradamente, la construcción a 1490-91, después del viaje a Milán de Francesco di Giorgio»: cfr. A. Bruschi, *Bramante*, ed. Universale Laterza, Roma-Bari 1977, nota 21, pp. 735-736. La hipótesis de un encuentro en Milán entre Bramante y Francesco di Giorgio para discutir sobre San Bernardino es retomada explícitamente por F. Mazzini, en su *Guida di Urbino*, Eretna, Vicenza 1959, pp. 264-265.

¹⁷ A. Venturi, *Il luogo di nascita di Bramante e i suoi esordi*, en "L'Arte. Rivista di storia dell'arte medievale e moderna", n. 21, 1918, pp. 210-219, espec. pp. 218-219: «todos los detalles de la construcción se encontrarán en obras posteriores ciertas del arquitecto de Urbino».



La columna después de la restauración (Foto Gamma s.r.l. Fano, 2015).



Espías para monitorear las fisuras en el interior de la iglesia (Foto Gamma s.r.l. Fano, 2015).

¹⁸ A. Venturi, *Storia dell'arte italiana*, VIII, *L'architettura del Quattrocento*, I, Hoepli, Milano 1923, pp. 779-787, espec. pp. 779-782: «Otra obra, en la capital de los Montefeltro, se debe a Francesco di Giorgio: la discutida iglesia de San Bernardino, que no ofrece suficientes analogías con edificios conocidos de Bramante, el presunto arquitecto [...]. Las bellas cornisas extendidas y las ovas con relieve muy pronunciado, casi separados, como en un efecto pictórico; las ventanas rectangulares, con tímpano muy saliente, tan altas que alcanzan, como en la iglesia de Cortona, las cornisas del entablamento, siendo profundas y parecidas a tabernáculos luminosos, con una puerta rica y esbelta, con el arco enmarcado por columnas apoyadas en un pedestal y por el alto y liso tronco del entablamento, preferido para coronar puertas y ventanas por



Lápida funeraria del Duque Guidantonio de Montefeltro, existente en la antigua iglesia de San Donato colindante con San Bernardino, afectada por los asentamientos estructurales del edificio (Foto Stefano Gizzi, 2012).

Francesco di Giorgio, los granos perlados de los ornatos que adornan los frisos, las volutas invertidas que se enganchan como articulaciones metálicas a los vértices del ábaco, orientan claramente hacia el Maestro de Siena, arquitecto de la bella iglesia, sepulcro de los Duques de Urbino».

¹⁹ G. Giovannoni, *Commenti e recensioni. S. Bernardino di Urbino*, en "Belle Arti", año I, n. 2, noviembre-diciembre 1946, pp. 121-122, espec. p. 121

²⁰ *Ibidem*, p. 121.

²¹ F. Canuti, *Chi fu l'architetto di S. Bernardino d'Urbino*, en *Lo storico convegno di Castel della Pieve*, Urbino, STEU, Urbino, 1952, pp. 31-41.

²² P. Rotondi, *Quando fu costruita la chiesa di San Bernardino in Urbino?*, en "Belle Arti", n. 1, 1947, pp. 191-202.

²³ A. Bruschi, *Bramante, op. cit.*

²⁴ Firenze, Biblioteca Laurenziana, Codice Ashburnham 1828, App., ff 63v-64r.

²⁵ A. Bruschi, *L'architettura religiosa del Rinascimento in Italia da Brunelleschi a Michelangelo*, in H. Milion - V. Magnano Lampugnani, *Rinascimento da Brunelleschi a Michelangelo. La rappresentazione dell'architettura*, Bompiani, Milano 1994, pp. 123-181, espec. p. 151.

²⁶ O. H. Förster, *Bramante*, A. Schroll, Wien-München 1956.

²⁷ A. Falcioni, *La famiglia Bramante. Fonti archivistiche urbinati*, Deputazione di Storia Patria per le Marche, Ancona 2014.

²⁸ F. Canuti, *Chi fu l'architetto di S. Bernardino d'Urbino...*, *op. cit.*

²⁹ Trad. «Llevó a cabo este lugar en modo bastante magnífico y, a gloria de semejante Príncipe, lo completó suficientemente en todos sus detalles».

³⁰ A. Festa, *La chiesa e il convento di San Bernardino in Urbino*, en "Quaderni dell'Istituto di Storia dell'Architettura", n.s., 41, 2003, pp. 17-38.

³¹ F. Francisci Gonzagae, *De origine seraphicae religionis franciscanae, eiusque prograssibus, de regularis observantiae institutione, forma, administratione ac legibus, admirabilique eius propagazione*, Typographia Dominici Basae, Romae 1587), p. 213. Dedicado a Sixto V, en el párrafo De Conventu S. Bernardini Urbini Conv. LII.

³² Trad. «Que habría de dar satisfacción a los píos deseos expresados por su hermano, llevando a cabo magníficamente este lugar ya iniciado».

³³ E. Rocchi, *L'opera e i tempi di Francesco di Giorgio Martini*, Conferencia 31 marzo 1900, Commissione Senese di Storia Patria nella R. Accademia dei Rozzi, en "Buletto senese di Storia Patria", a. 7., fasc. 2., Tip. E Lit. Sordomuti di L. Lazzeri, Siena 1900.

³⁴ Firenze, Biblioteca Laurenziana, codice Ashburnham 1828.

³⁵ M. Tafuri, *Ricerca del Rinascimento. Principi, città, architetti*, Einaudi, Torino 1992, nota 20 en la p. 219.

³⁶ G. Santi, *La vita e le gesta di Federico di Montefeltro duca d'Urbino. Poema in terza rima*, Codice Vat. Ottob. Lat. 1305, edición a cargo de L. Michelini Tocci, Biblioteca Apostolica Vaticana, Istituto Salesiano Pio XI, Città del Vaticano 1985, I, pp. 1-96.

³⁷ L. Benevolo - P. Boninsegna, *Urbino*, Laterza, Roma-Bari 1986, pie de foto de la fig. 95 en la p. 116.

³⁸ A. Bruschi, *Bramante architetto...*, *cit.*, pp. 730-731.

³⁹ F. P. Fiore, *Il Palazzo Ducale di Urbino*, en F. P. Fiore - M. Tafuri (ed.), *Francesco di Giorgio architetto*, Electa, Milano 1993, pp. 164-179, espec. p. 169.

⁴⁰ G. De Zoppi, *La cappella del Perdono e il tempio delle Muse nel Palazzo Ducale di Urbino. Analisi e proposta d'attribuzione a Francesco di Giorgio Martini*, en "Annali di architettura", n. 16, 2004, pp. 9-24.

⁴¹ Oxford, Ashmolean Museum, f. 517 v.

⁴² E. Calzini, *Urbino e i suoi monumenti*, Licinio Cappelli Editore Libraio, Rocca San Casciano 1897, p. 102.

⁴³ Soprintendente per i Beni Architettonici e Paesaggistici delle Marche, entre 2012 y 2015. Responsable Unico del Procedimiento arq. Biagio De Martinis, colaboración del arq. Paolo Mazzoli.

⁴⁴ Responsable científico Francesco Paolo Fiore, grupo formado por Flavia Cantatore, Carlo Inglese, Leonardo Baglioni, Francesco Borgogni, Elisabetta Giorgi, Marco Di Giovanni.

⁴⁵ G. M. Fazio, *Relazione per conto dell'Istituto Superiore per la Conservazione ed il Restauro del 28/1/2014, a seguito del sopralluogo del*

15/11/2013, prot. ISCR 530 del 28/1/2014.

⁴⁶ B. Ligi, *Le chiese di Urbino*, STEU, Urbino 1937.

⁴⁷ L. Serra (a cura di), *Catalogo delle cose d'arte e di antichità d'Italia. Urbino*, La Libreria dello Stato, Roma 1932, p. 104.

⁴⁸ Que en el texto del siglo XIX de Egidio Calzini se atribuía a Antonio Viviani «el sordo de Urbino».

⁴⁹ Más recientemente atribuida por Manfredo Tafuri a Girolamo Cialdieri, conservada en el Museo Albani en Urbino *Madonna y niño con los santos Gregorio y Antonio abad*.

⁵⁰ Archivo del Convento de San Bernardino en Urbino, *Cronaca*, cc. 69, 70, 71, citada en la tesis de licenciatura de J. Montanari, *La chiesa di San Bernardino in Urbino*, director de tesis Marcello Fagiolo, co-director Amedeo Belluzzi, a.a. 1989-1990, Università degli Studi di Firenze, Facoltà di Architettura, Dipartimento di Storia dell'Architettura e Restauro delle Strutture Architettoniche, all. n. 23.

⁵¹ G. Sacconi, *Relazione dell'Ufficio Regionale per la Conservazione dei Monumenti delle Marche e dell'Umbria 1891-1892-1900-1901*, Tipografia Guerriero Guerra, Perugia 1901, pp. 321-322, espec. p. 322.

⁵² L. Serra (ed.), *Catalogo delle cose d'arte e di antichità d'Italia. Urbino*, *cit.*, p. 104.

⁵³ Archivo de la Soprintendenza delle Marche, *Perizia di spesa San Bernardino di Urbino*, 1959.

⁵⁴ *Lettera dei Conventuali Padre Nazareno Ruffini (Superiore) e di P. Francesco Angeletti (Sostituto) al Soprintendente*, fechada Urbino 29 de julio 1947.

⁵⁵ Análogo al Convento de Santa Clara de Urbino, obra cierta de Francesco di Giorgio.

⁵⁶ Restauración llevada a cabo por la empresa Gamma s.r.l. de Fano, de Giovanna Macchi.

⁵⁷ C. Maltese, *Opere e soggiorni urbinati di Francesco di Giorgio*, *cit.*, p. 79.

⁵⁸ H. Burns, *San Bernardino a Urbino*, en F. P. Fiore - M. Tafuri (ed.), *Francesco di Giorgio architetto*, *cit.*, pp. 230-243, espec. p. 230.

⁵⁹ Por ejemplo en la *Perizia di spesa per il restauro dei danni da guerra e consolidamento della chiesa di San Bernardino a Urbino*, con un importe de 1.000.000 de liras, del 14 de enero 1954, capítulo 3.

⁶⁰ *Ibidem*.

⁶¹ C. Martini, *scheda* en A. Giuliano, *Museo Nazionale Romano. Le Sculture*, Roma 1978.

⁶² *Carta al Podestà de Fossombrone* del 22 del septiembre 1568, conservada en los Registros delle Riformanze del Archivo Histórico Municipal de Fossombrone.

⁶³ E. Calzini, *Urbino e i suoi monumenti*, *cit.*, p. 110.

African House: Use of Synthetic Rope for Structural Intervention

Melrose Plantation, Louisiana, USA

S. Patrick Sparks, PE

Sparks Engineering, Inc., San Antonio, Texas USA

The “African House” was built c. 1820 on the Melrose Plantation, which was founded by Louis Metoyer, a free person of color. The unusually proportioned roof suspended over modest walls (Figure 1) has captured the imaginations of artists and architects for generations. Its original purpose is unknown, as are the names of its builders. In the early 20th century the African House was used for storage, but for the past few decades, the building has been interpreted primarily in reference to life on the Cane River and to the life and works of American folk artist Clementine Hunter, who lived on the plantation and whose important murals are protected and displayed in the upper story. For more information on Clementine Hunter and Melrose Plantation, see

<http://www.melroseplantation.org/blog/>



Figure 1 The African House as it appeared in 1940 after a restoration campaign (Historic American Building Survey, Library of Congress) (left), and in 2008 with temporary supports at the roof corners (right).

The lower story of the building is constructed of low-fired clay brick in lime mortar. The upper-story walls are constructed of squared cypress timbers with interlocking dovetail ends in the traditional Creole style. As identified by timber-framing expert Rudy Christian, the timber in the African House was produced by the method known as ‘mixed conversion’, meaning the logs were squared with axes first, then sawn by hand lengthwise. Sustained efforts in recent years have stabilized the soft-brick lower walls, and the timber walls of the second level have remained in good condition.

It was actually the perceived similarity of the roof shape to indigenous houses in Africa that prompted a visiting artist in the mid-20th century to assign the nickname “African House”.

In fact, the wide overhanging roof structure is in many ways characteristic of the regional French Creole style of construction, with the rather startling exception that it has no columns on the perimeter. In lieu of columns, inclined struts made of cypress poles laterally brace the roof edge against the building core. Documentary evidence suggests that this lack of columns was purposeful (Figure 2).

In early 2015 a conservation plan for the building was developed by the author through a process of review, assessment, and collaboration with the Association for the Preservation of Historic Natchitoches, the U.S. National Park Service, and historic timber framing experts.

Structure

Clearly, the roof framing represented the main structural challenge. Over the years after its 1940 restoration, the roof framing had deformed badly, and by 2008 during our initial assessment tempo-



Figure 2 Documentary evidence for the lack of columns at the roof edge: Left, as remembered by artist Clementine Hunter, and right, as seen in the earliest known photos.

rary supports had been added, as shown in Figure 1. The 2015 detailed inspection showed that the roof had failed structurally: rupture of the first common rafters at each of the building corners and of the 'flying' eave plates. Despite the appearance of considerable decay, after the investigation we concluded that many of the original timbers were still sound.

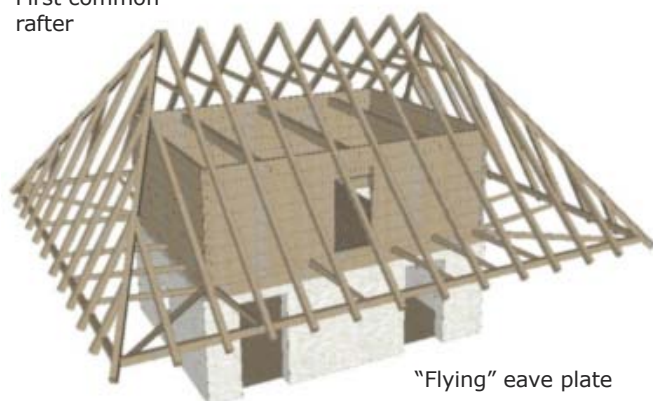
The failure was intuitively seen as being due to decay and to the intrinsic limitations of the column-less design. But we also found that the pole struts that support the eaves had slipped or fallen in the past, and also that the first common rafters had slid down approximately eight inches from their original bearing position on the timber walls, exposing the original iron spikes that had anchored them. Calculations using a three-dimensional computer model confirmed the general behavior (Figure 3) and verified that the pole struts that support the eaves are particularly critical, as is the connectivity at the various other timber joints. So long as the struts remain in place the roof structure is capable of supporting its dead weight. Historically, however, the struts, like the other frame members, were fastened in no other way than a few iron nails at each end. Minor wind loads were sufficient to dislodge the struts. Loss, or even slippage, of one strut would be enough to overload the rafter and eave plate. Similarly, slippage of one or more rafters from its bearing could induce overload elsewhere. It was also clear from the analysis that under full design loads, the other primary areas of structural deficiency remained: in the high bending stress in the first common rafters and in the inadequate stiffness of the eave plates.

Of course, a simple and important improvement was to add positive mechanical connections at all joints, to provide resistance to tensile and shear forces. This would assure that the pole struts would stay in place, even during wind storms. Strengthening of the various joint connections was done with small diameter stainless steel rods and specialty timber screws, and these were largely hidden.

Due to their structural damage, the decision was made to replace the eave plates and the first common rafters with hand-hewn and hand-sawn cypress timber. As a first alternative for strengthening these timber elements, we considered using embedded stainless steel flitches, but that level of intervention was deemed excessive. The idea was floated of adding cables or stays from the eaves to the second story timber walls to provide a suspension effect. Initial calculations showed, counter-intuitively, that a single suspension stay from each corner actually caused an increase in stress in the adjacent, perpendicular eave plate. But adding two stays at each corner, as shown in Figure 4, cut the stress in half.

Still, even with the stays at each corner supporting the eave plates, the permanent stress in the first common rafters was too high for long-term performance. And in the event of damage to other members, these rafters would need to have excess capacity. It seemed, then that tensile-only strengthening of the rafters, also using cables could be a simple solution.

First common
rafter



"Flying" eave plate

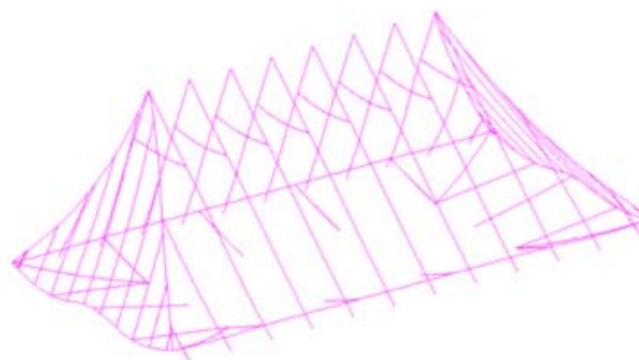


Figure 3 Rendering of the African House framing, left, and deflected shape under dead load, right (deflections magnified).

Ropes for Strengthening

Initially, stainless steel cable was identified as the material of choice. Calculations showed that a 7mm stainless steel aircraft cable would meet the requirements of the rafter strengthening. However, the minimum allowable radius of bends ($\sim 150\text{mm}$) would not be possible to achieve. Looking for options, we considered high-strength synthetic ropes, as are now used in sailing and other industries. Among

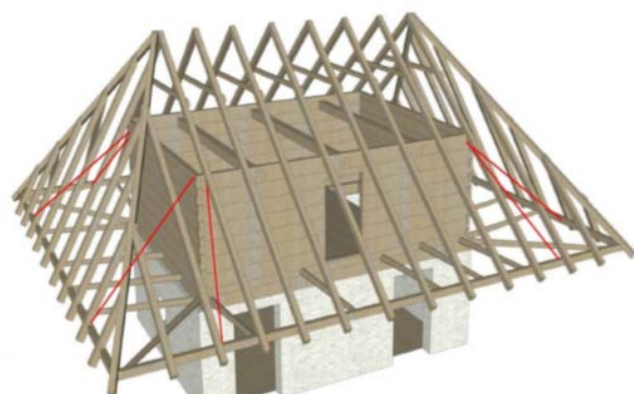
the strongest of these advanced rope materials are Vectran™ and Dyneema®.

The table below gives comparative strengths of these two synthetics against stainless steel cable, all for a 6mm diameter.

Dyneema® is made from ultra-high molecular weight polyethylene and is the world's strongest fiber. It is used extensively in the shipping industry for mooring and anchor lines, for example.

It has extremely good abrasion resistance, does not absorb water, and has a specific gravity of 0.97. Unfortunately, Dyneema® will creep under sustained load, making it a poor choice for this project.

Vectran™ is a liquid crystal aromatic polyester somewhat similar to the aramid ropes. It tolerates bends, exhibits good knot holding properties, has excellent chemical resistance and low moisture absorption. Resistance to ultra-violet radiation is achieved by coating the Vectran™ fibers



Stay cables: 6mm
Vectran™ braided
rope

Figure 4 Stay cables added at the building corners to alleviate stress in roof framing, deflected shape under dead load, right (deflections magnified).

	305 Stainless Steel Cable	Vectran V12	Heat-Set Dyneema
Breaking strength Mpa	33.8	51.7	85.5
Other Limitation	Bend radius	UV & abrasion*	Creep
* improved by manufacturer treatments; also, not exposed in this application			

Moreover, Vectran™ has no measurable creep when loaded with up to 50% of the breaking load, even at elevated temperatures (Beers & Ramirez 1990). A 12-strand, single-braid rope by New England Ropes would have sufficient strength for the project in 6mm diameter, with no practical limitation on bend radius (Petrina et al., 1995).

This is the rope that was finally chosen for the project.

Figure 5 shows how the common rafters were reinforced with the 6mm Vectran™ rope.

Figure 5 shows the rope installed, captured in a groove along the top of the rafter, and anchored with stainless steel bolts. Only the bolt head is visible to the public.

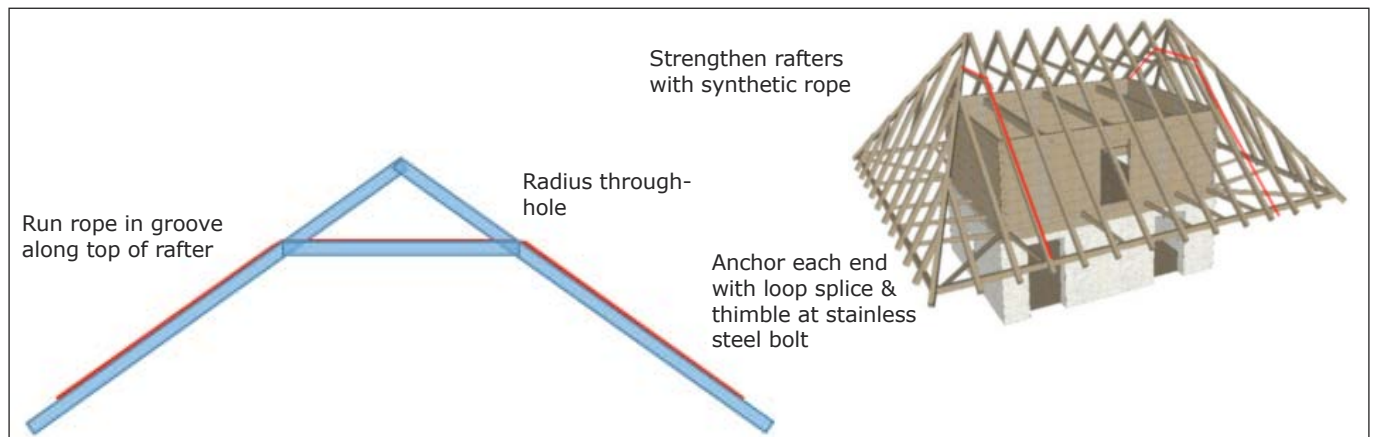


Figure 5 Scheme for improving flexural strength of the first common rafters by adding high-strength rope along the top edge.

Splicing and End Terminations

Typically, the high-strength synthetic ropes are terminated in the field with some variation of the eye-splice (*usually long-bury or locked*), which can achieve 95% or more of the rope strength. Mechanical end-fittings are expensive specialty shop-fabrications and are not available for many of the higher performing rope fibers. Even if available, they require pre-planning for exact lengths and allowance for manufacturing time. The rope manufacturers generally provide splicing guidance (e.g. New England Ropes Splicing Guide: www.neropes.com/Resources/84906_NEROPE.pdf). In the African House ropes, Brummel (locked and buried) eye-splices were used with stainless steel thimbles. It is recommended to set the rope after making up the end terminations by a brief period of tensioning prior to installation. Also, making up the rope a bit short of the anchor points will assure that the rope will accept load during service. As a reference point, applied strain at installation was targeted at about 0.40% to achieve 15% of breaking stress.

Conclusion

The structural conservation of the unusual roof system of the African House was made possible through careful investigation, analysis, and especially by multidisciplinary collaboration. Though initially perplexing, the challenge of strengthening the roof framing was met by a simple solution of selectively adding tensile elements. A state-of-the-art synthetic fiber rope, Vectran, was found to be a good choice because of its high strength, flexibility, and absence of creep. With the roof now permanently stabilized, this fascinating structure can continue to protect the valuable paintings of Clementine Hunter, and live on as a unique model of Creole building traditions.

Acknowledgements

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Figure 6 Synthetic rope used for flexural strengthening of the first common rafters. A stainless steel bolt anchors the end-loop, and the rope is recessed in a small channel along the top of the timber (photo by Sarah Marie Jackson).