ABSTRACT
The advent of the skeletal frame structural system and the use of terra cotta to clad skyscraper facades in the late 19th century, introduced a new set challenges caused by the differential movement and volumetric changes between the structural frame and the expansive clay cladding materials to the building industry. While the distress caused by the differential movement in masonry-clad skyscrapers, including cracking, crushing and displacement, has been a long known issue, preservation professionals have addressed this issue using different methods. Several key lessons have been learned from the various approaches over the last 40 years. One common repair approach to relieve accumulated stresses is known as strain relief. In the mid-1970s, this method was used at the Woolworth Building in New York City, which is an early and widely published, example of the strain relief technique described below.

Strain relief in masonry-clad skyscrapers, usually begins with a series of tests that are used to measure compressive stresses, which exist in the cladding portion of the facade. These tests involve adhering carbon-filament strain gages to the cladding surface and then releasing the in-situ stress by saw cutting around the gaged facade area. The strain value is measured before and after saw cutting and the in-situ residual facade stress is computed by multiplying the modulus of elasticity (or assumed modulus based on historical data) of the facade material by the measured strain change. Once the approximate stresses are determined from the strain testing, the design professional may suggest cutting horizontal relief joints into the facade at regular intervals to alleviate some of the locked in compressive stresses. This process has been used with varying degrees of success on terra cotta clad facades with both steel and reinforced concrete frame buildings. The varied results are likely a reflection of the dissimilarities in the terra cotta material properties, restraints, unanticipated stress concentrations and general behavior structure, which are unique to each building in general and specific to facade areas.

This presentation will generally explore the process of strain relief, what has been learned from the early strain relief theories used at the Woolworth Building in 1976, and how these “lessons learned” have been implemented by the authors on various terra cotta building facades throughout the country. This presentation, by means of specific case studies highlighting terra cotta clad skyscrapers, will also illustrate how one aspect of the preservation practice in facade repair and restoration, such as strain relief, while seemingly formulaic and scientific oftentimes produces significantly varied results.

OBJECTIVES
Describe the general process of strain relief and what has been learned from the early strain relief theories used at the Woolworth Building in 1976. * Discuss how the “lessons learned” from the Woolworth building have been implemented by the authors on various terra cotta building facades throughout the county. * Utilizing specific case studies highlighting terra cotta clad skyscrapers, discuss
how strain relief, while seemingly formulaic and scientific oftentimes produces significantly varied results.

**CS05b: Stone Cladding Restoration of the National Gallery of Art's East Building: Investigation and Preliminary Design Phase**
Speaker: Kirk Mettam PE, Robert Silman Associates, Washington, DC USA

**ABSTRACT**
The East Building of the National Gallery of Art opened to the public in 1978. Designed by architect I. M. Pei, the building has won numerous awards and in 1991 was voted one of the top ten buildings in the United States by the College of Fellows of the American Institute of Architects. Located on the National Mall, at the foot of the U.S. Capitol, the building’s geometry is derived from its urban context, and is clad in marble to match adjacent buildings. The East Building was designed and built according to the highest standards of the late 1970s. After three decades of thermal cycling, however, displacement occurred in the stone cladding because of systemic structural distress of the anchors that support the marble panels.

Beginning in 2010, some 16,200 Tennessee pink marble panels were removed and re-installed with new supports. Each three-inch-thick panel weighs approximately 450 pounds and typically measures five feet wide by two feet high. When the repair project is complete in spring 2014, the East Building and its landscaping will be restored to its original appearance. The East Building remains open to the public during this re-cladding process. This federally-funded repair and restoration project is the largest single construction contract the Gallery has undertaken since the building was built.

This session will review the investigation process from initial observations through final conclusions and preliminary design approach and will describe the challenges that this unique set of circumstances created for the design team.

Marble panels are individually anchored to the building’s exterior concrete and brick masonry substrate wall. An air cavity separates the substrate and its marble cladding. The 1/8-inch wide joints between panels are a notable feature unique to the building and were originally filled with a hypalon-coated, neoprene gasket.

Initial survey suggested evidence of material degradation in the anchorage system. Site investigations included visual survey, lift assisted panel removals, in-situ-testing, hands-on surveys, and monitoring for movement, moisture and temperature fluctuations. The uninterrupted planes of marble and the exacting tolerances achieved in the original construction made it difficult to identify failures. Significant efforts were involved in the tracking of panel displacements over time, in order to try to predict the rate of failure. Engineering investigations were performed in parallel with the field work, and included structural analyses of cladding-frame interactions, hygrothermal analyses of the wall section and energy modeling of the whole building to understand the envelope’s role in energy performance. Ultimately, it was determined that a combination of physical mechanisms was causing stress in the anchorage system and progressive panel movement. As a result, joint widths were becoming highly compressed and contributing to the degradation of the neoprene gaskets.

Concurrent with the investigation, the design team considered a range of alternative solutions to retain
the original stone panels while solving the anchorage problem to restore the façade to the original I.M. Pei design.

OBJECTIVES
Explain the original design intent for the East Building stone cladding system and how it accommodated thermal movement. * Describe what the architects and engineers of the National Gallery observed on the building façade that led them to begin this investigation and design process. * Explain techniques used in a forensic investigation for a modern cladding system. * Understand the unique conditions that required removal and re-installation of the existing marble cladding to restore performance and maintain the original appearance of the East Building.

CS05c: Preserving the Cavity (Wall)
Speaker: James Dossett, The Facade Group, Philadelphia, PA USA

ABSTRACT
Widespread use of the brick cavity wall in the United States began in the 1930s and 40s, and since then it has become one of the most common types of construction for all types of urban buildings ranging from low rise residential to high rise commercial and institutional. Although often associated with inexpensive and "ordinary" buildings, there are many brick cavity wall buildings that have achieved historic significance. The sheer number of these building means protection practitioners we will be called upon more and more in the next decades to assess and repair brick cavity wall construction. Fast and inexpensive are highly desirable attributes of buildings but these qualities do not always produce long-lasting buildings. The goals of retention, protection, and continued use of buildings with cavity wall construction require that we find a way to extend the life of these walls. Appropriate repairs require an understanding of how the brick cavity wall is intended to function, as well as how all the parts of the system work together or - as in some cases - against each other.

This paper begins with an overview history of the brick cavity wall from its beginnings in the UK as a solution to damp buildings, to its development in the US both as a means of providing a weather resistant wall and as a way to meet the demands for inexpensive and fast construction during WWII and during the postwar building period. The overview includes a comparison to other masonry construction method including bearing masonry and masonry-clad steel frame structures. Next the author explores different types of brick cavity walls to identify common features that influence how the wall performs and also common features that often fail.

Emphasis is given to how the face brick, mortar, flashing, ties, backup and structural support interact, and how the wall works with other features such as windows doors and roofs. This information is applied to guidelines for assessing brick cavity wall systems: visual inspections, non-destructive testing, and destructive probes. Lastly, designing repairs. The paper does not attempt to present full case studies. The author will explore different repair strategies and compare them according to criteria such as: retention of existing masonry, preventing further deterioration, constructability, and cost. This section of the paper will also look at whether it is practical to improve the performance of brick masonry walls through the introduction of insulation, air barriers or water repellent coatings.

OBJECTIVES
will understand the history of cavity wall construction technology: what problems did the cavity wall attempt to address when it was developed in the late 19th century; how did the technology develop
differently in the US vs. the UK. * will be able to compare the cavity wall to other types of wall construction. * will know how cavity walls fail and understand some of the challenges that face practitioners repairing cavity walls

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**CS05ds: The Guaranty Building: The Restoration of a Terra Cotta Landmark**
Student: Jon Sargent, Savannah College of Art and Design, Savannah, GA USA

**ABSTRACT**
Louis Sullivan’s Guaranty Building in Buffalo, New York stands as a premier example of early skyscraper architecture, a precedent for the steel structures that would mold America’s skylines. The building is best known, however, for its elaborate ornamentation; an intricate terra cotta system covering two faces of the building’s thirteen stories. The ornate botanical motifs symbolize the pinnacle of Louis Sullivan’s artistic expression and an important influence for future legendary architects such as Frank Lloyd Wright.

At the time of the building’s completion in 1896, terra cotta was rapidly growing in popularity as a lightweight and supposedly “fire-proof” material that allowed for adaptability of shape and ornamental plasticity. However, the intricacies of the material’s structural application and attachment to the modern building frame had yet to be perfected. As such, the Guaranty Building represents a transitional period in American architectural history, having drawn partially upon masonry precedents for the attachment of its terra cotta tiles. Designated as a National Historic Landmark in 1975, the Guaranty Building faced the possibility of demolition just two years later. However, thanks to three restoration projects over the past 35 years, the building has proven to be a durable and lasting symbol for the city of Buffalo, brought back to life by architects, engineers and craftsmen dedicated to upholding responsible conservation techniques.

The full restoration of the Guaranty Building serves as a valuable case study in the treatment of terra cotta due to the wide variety of challenges encountered and addressed. Dealing with issues such as water infiltration, selective replacement of tiles, color matching, and patching of joints, the restoration teams maintained careful consideration for the authenticity of the structure. Through the process, the teams also helped to unlock some of the secrets to the success of Sullivan’s design. Historic anchoring systems used to secure the terra cotta tiles in place were restored and replicated, while efforts were made to protect the unglazed surface of the tiles; an architectural oddity when compared to the terra cotta structures of later years.

This presentation will examine the 1980, 2002, and 2007 restorations of the Guaranty Building, and provide a context for how these projects addressed common issues and trends in the overall field of terra cotta preservation. In the process, it will focus on particular elements of Sullivan’s design that have contributed to the longevity of this ornamental landmark.

**OBJECTIVES**
Place the construction of the Guaranty Building in a greater historical context of architectural terra cotta use in the United States. * Describe common threats to historic terra cotta and the specific conservation and preservation techniques used to address them in the case of the Guaranty Building. * Justify the longevity of the Guaranty Building’s terra cotta facade based on design factors like the use of a more traditional anchoring system that drew on masonry precedents.