2022.05.31 Lecture Notes
Lecture 4 – Engineering & Material Innovations

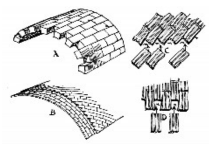
3:15

Guastavino benefitted from arriving in America at the start of a renaissance in architecture, inspired by the Beaux-Arts movement and fueled by the Industrialists new found wealth, as we saw in last week's lecture on Architectural innovations.

Today we will be focusing on his innovations in Engineering and Materials, that coincided with developments of modern materials: Portland cement, steel, concrete.

1885 Structural Clay Tile Vaults (Valencian) 

On **October 24, 1889**, as **Boston Public Library** was under construction, Guastavino delivered a lecture to **Society of the Arts at MIT** (published in 1892 as Essay on the Theory and History of Cohesive Construction: Applied Especially to the Timbrel Vault), constructing demonstration arches of **plaster tile method**:



ordinary boards cut to proper curve as centering, on which laid course of flat brick tiles (12"x6"x1"), joints in **Plaster of Paris** (fast setting). First course completed, centering removed and second course laid with **Portland cement** (high strength), breaking joints with the first course, as with the third course, completing the arch with 4" thickness (3 layers of 1" thin tile bricks, 2 layers 1/2" mortar).

Unlike traditional stone vaults, dry stacked without mortar, use gravity for stability, transferring the loads through center of stones lined as a path, Catalan cohesive tile construction **strength of mortar bonding making tiles act as single cohesive material**, like a **board** (bóveda **tabicada**), transferring loads downward at the end, eliminating lateral thrusts of stone vaults.

"The flat brick was used with the idea of decreasing the number of pieces, closing the space with the least possible joints; thus, to give more strength and cohesion to the arch, they placed four rows, one on top of the other, breaking the joints, constituting through this medium an arch without joints." Woven, not stacked.

Developed this understanding observing/emulating **grotto** in Spain (1871): "Within this great specimen of nature's architecture… the thought entered my mind while in this immense room… that all of this colossal space was covered by a single piece, forming a solid mass of walls, foundation and roof… all being made of particles set one over the other, as nature had lain them. This grotto is really a colossal specimen of cohesive construction."

In theory, if the weight (load) of the pieces (tiles) is small enough proportionately to the strength of adhesive (mortar) binding them together, then the system acts as a **cohesive monolithic whole**, as the natural grottos made of dust sized sediment deposited within drops of water seeping through fissures, eventually crystalizing into a solid.

Fig. 2. A surface (paper), unable to support its own weight, can sustain that and more if given a slight curvature (Salvadori & Heller, *Structure in Architecture*, Englewood Cliffs, N. J., 1963).

Timbrel term invented by Guastavino, derived from drum-like nature of thin vaults, that resulted from a curvature in tension, therefore resonated when struck.

Thin vaults, consisting of little more than a surface, derives rigidity not from massiveness or thickness but rather from geometric form, the type of curvature. The vaults survive because the **form** is correct and the correct form was built by Guastavino with empirical methods based on years of experience. To this day, none of Guastavino's vaults have failed in use.

Modern engineering has proven that increasing the slope (pitch) of a roof decreasing the lateral thrusting forces, which is why the profile of a vault (or dome) transitioning from a flat or low slope at the top to a vertical or high slope at the bottom is how the **loading is transferred from lateral to downward** into the supporting foundation below. However, one of the defining features of the Catalan tile vaulting is the **shallowness of the vault**, near horizontal and low sloped, which defies the structural logic of modern day engineering and mechanical physics.

Lamination of thin layers, transformed masonry arches and domes from individual stacked units to a single cohesive sheet acting more as a horizontal beam spanning across an opening, than a corbelling of stones that require vaulting vertically.

1889 Shallow Board Vaults (Catalan)

From **1889 MIT Lecture**: "In some cases the 'timbrel vaults' were used as a ceiling and floor, having two or three thicknesses of tiles, with plaster, and the haunches were filled with pottery; this pottery was levelled over with rubbish and mortar, finishing with flooring tiles."

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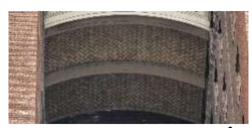
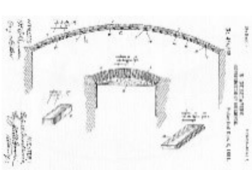
Doherty Hall (basement, bridge vaults; **Henry Hornbostel**; Pittsburgh; 1908-09)
Pittsburgh sloping hills requiring stepped footings – drawing during construction. Basement floor vaults, in addition to exterior bridge vault.

 +3 

William Penn Hotel (bridge vault; **Benno Janssen**; Pittsburgh; 1914-28)
Section cut overlaid on elevation drawing – showing vault supporting 16th floor. Steel beam frame supporting exterior bridge wall (and 17th floor) – vault only floor.

1890 Interlocking Flange Tiles

Boston Public Library (interlocking flanged tile vaults; **Charles McKim**; Boston, Massachusetts; 1889-1895)

1891 interlocking patent + 1895 beveled edge patent for level tiles at floor

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Interior Finish, no longer structural supporting floors or roof

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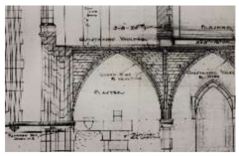
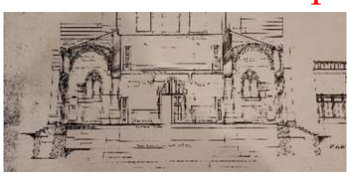
Calvary Episcopal Church (crypt vaults; **Ralph Adams Cram**; Pittsburgh; **1906**)

Gaustavino's first ribbed vaults in Pgh.

Written material specifications – mortar, Guastavino tiles, fireproofing.

Fireproofing under Gallery – Guastavino ribs – carved stone corner support

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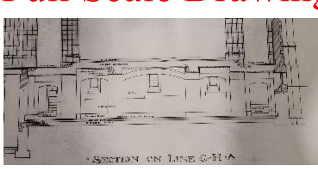
Full Scale Drawings for stone work in field, metal, Guastavino rib profile & tiles, ...

 +3 

Floor vaults in basement of unfinished tiles, tile ribs, layered based on loading.

Varied decorative finishes – showing off versatility, much like in Boston Library.

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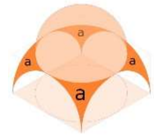
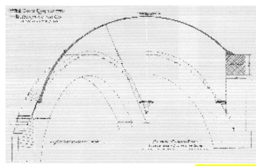
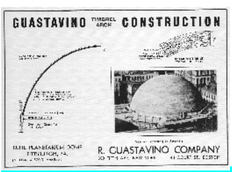
1893 Central Dome with Adjacent Pendentive Vaults  

Central Congregational Church from 1893 Chicago World Fair lecture; (Providence, Rhode Island, architects **John Carrere & Thomas Hastings**)

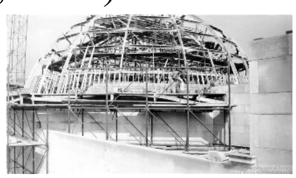
St. Boniface Roman Catholic Church (**A.F. Link**; Pittsburgh; 1926)

1895 Thin Span Domes 

Cathedral of St. John the Divine (132 feet span; **Rafael Guastavino Jr.**; Morningside Heights, New York; 1909)

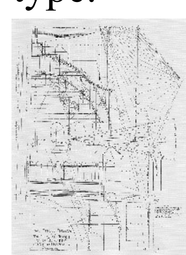
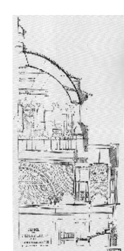


Buhl Planetarium (65 ft. dia. dome, thin shell dome; **Charles T. Ingham & William Boyd Jr.**; Pittsburgh; **1938**) **Oct.21 – Nov. 18 (4 weeks)**

  +2 

Steel frame exterior dome, Guastavino tile interior dome, now suspended metal skin

Zeiss II Planetarium projector with 106 lenses, producing 9,000 images of stars, the oldest operating projector in the world, moved to Carnegie Science Center in 1994. (Zeiss Optical Works, in Jena, Germany). Also, 35 ft. Foucault pendulum and 10 inch Siderostat type refractor telescope, second largest of this type.

1899 Double Dome (Exterior Weather & Interior Decoration)

St. Paul's Chapel (double flying dome; **Isaac Newton Phelps Stokes**; Columbia University, New York; **1907**) 1905 design, 1906 graphic statics

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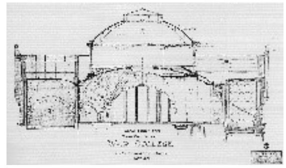
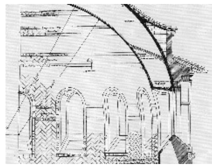
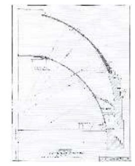


1905 Double Stacked Domes

Army War College (stacked domes; **Charles McKim**; Washington D.C.; 1905)



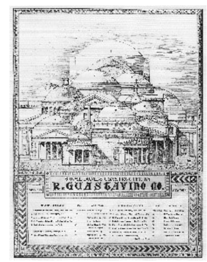


1909 Flying Buttresses

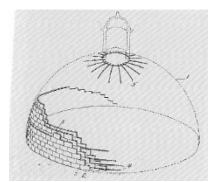
St. Paul's Chapel (**1907**)

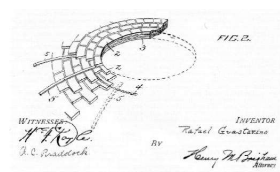
National Museum of Natural History (double flying dome; **Charles McKim**; Washington D.C.; 1909)

1910: Advertised Company's success with poster of domes, after completing



1. **St. John Divine** dome in **1909** (132 ft. span)
2. **National Museum (D.C.,** 80 ft. span**)**
10. **St. Paul's Chapel (Columbia, NY,** 52 ft. span**)**
11. **Rodef Shalom (Pgh.,** 90 ft. span**)**
12. **Univ. of Virginia, Thom. Jefferson Rotunda** (70 ft. span)





1932 Steel Reinforced Rib Arches and Vaults

Reinforced Dome Patent (**1910**)

As steel and reinforced concrete began to cut into commissions: reinforced vaults

+9 (2 videos)

Baker Hall (serpentine stair vaults w/o rebar; **Henry Hornbostel**; Pgh.; **1914**)

Steel frame roof structure – tile vault floors, cantilevering stairs, tile risers, …

Iron fascia on exterior side of stair stringer, visible through window

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BREAK

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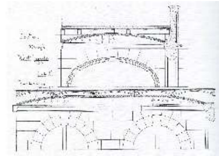


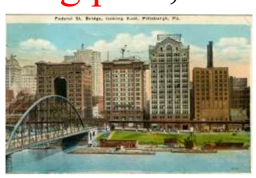
1894 Exterior Weatherproofing:

In **1889**, **George Washington Vanderbilt II** commissioned **Richard Morris Hunt** to create largest private home in America, set on an 8K acre property designed by **Frederick Law Olmstead** (NY Central Park & 1893 Chicago World's Fairground).

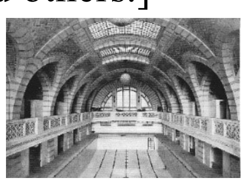
By **1894**, Guastavino began work on vaulting for the house, the form of vaults and patterns of the tile not specified, these design decisions left up to Guastavino. , which included outdoor loggias, where tiles provided a weatherproof exterior finish.

1894 Indoor Swimming Pools:

With Guastavino earning Hunt's trust and respect, he convinced him to expand the vaults on the **Biltmore Estate** to include corridors surrounding a glass roofed winter garden and an indoor swimming pool, also requiring moisture protection.



From 1875 to 1910, industrial Pittsburgh reached its apogee, both in its factories and the huge institutional buildings created from its new wealth. The spending by the robber barons of their vast wealth created new governmental and commercial architecture featuring both medieval styles and the Beaux-Arts, [the style of choice for Carnegie's partners **Henry Phipps**, **Henry Oliver**, and **Henry Clay Frick** for the skyscrapers they commissioned from New York City's **George B. Post** and Chicago's **Daniel H. Burnham** and others.]



Phipps Natatorium (1908)

In **1907**, **Grosvenor Atterbury** designed **The Pittsburgh or Phipps Natatorium**, a commercial (rather than charitable) public bathhouse, on Duquesne Way near the Sixth Street Bridge. For a quarter, could get a tub bath under Guastavino's vaults, in Pittsburgh's first monumental swimming pool.

4pm

Pgh. Athlectic Assoc (1910)

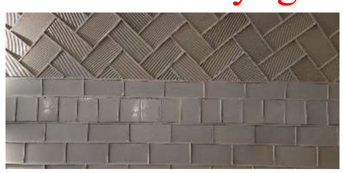
In **1910**, **Janssen & Abbott** was commissioned to design a similar indoor swimming pool for the **Pittsburgh Athletic Association** in Oakland.

Mellon Res. Pool (1917)

Andrew Mellon, a member of the Association, then hired Guastavino to create a vault enclosing a new pool addition to his private residence he acquired in **1917** (currently part of Chatham’s campus).

1894 Off-White Reflective Tiles (daylighting interiors)

The **Biltmore Estate** also featured off-white tiles on the vaults of the vestibules, brightening the interiors with natural daylight.



Mellon Res. Pool (1917)

Same off-white tiles used to draw light into Mellon’s indoor pool.

1900 Standardized Tile (tile factory: 1”x6”x12”)

By the turn of the century, Guastavino and his son were working with many leading architects (**Richard Morris Hunt**, **Cass Gilbert**, **Bertram Goodhue**, and **Ralph Adams Cram)**. As number of projects expanded, became difficult to obtain sufficient structural tiles on schedule, and **William Blodgett**, the company’s financial accountant, encouraged the Guastavinos to set up a suburban manufacturing plant in his home town of **Woburn, Massachusetts**. Just after 1900, the plant was operational and over time would develop the wide variety of kilned structural, decorative, and acoustical tiles and pressed acoustical blocks that made the Company's vaulting so distinct from anything in Europe.

4:05

In Guastavino's 1889 MIT lecture, he noted "France and England, like other nations of the north, have not bricks of the dimensions and conditions for cohesive form, they have bricks of a small top and bottom surface, that is 4 x 8 inches, when generally the type for the bricks for the cohesive system are the Assyrian bricks or the bricks of the Orientals, the dimensions of which were about 12 to 14 inches long, 6 to 8 inches wide and 1 to 2 inches thick."  

With their own manufacturing plant, Guastavino could standardize the size and quality of the thin tile bricks, most importantly produce the quantity needed.
By **1903**, making over 200K tiles per year, in a converted old wooden church.
In **1906**, **Guastavino Jr.** designed a new building, '**La Ceramica**', an ornamental brick building made specifically as a factory, opening in **1907**.

Pgh. Athlectic Assoc (1910)
Mellon Res. Pool (1917)
Examples of these standardized, structural clay tiles.

1892 Sound Absorbing Floor (patent):
However, the hard, smooth surface of glazed tiles, also reflected sound and created noisy spaces, especially interiors. The geometric, semi-hemispherical form of the vault coupled with the thin, light shell, the vault acts like a drum or diaphragm. This means that sounds generated both below and above the vault can be amplified.

Guastavino Jr. showed an interest in acoustics and tried to develop a floor system of tile vaulting to absorb the sounds transferring between apartments stacked atop. His first attempt to quiet transmission and reverberation of sound was the addition of a second tiled surface suspended from the vault using tile transverse rib arches that were also constructed using the Guastavino method.
Guastavino received a patent for this design in **1891**. The result, however, was less than satisfactory as the sound was simply transferred through the transverse ribs. Additionally, the sound that was not transferred through the transverse ribs could bounce between the two surfaces extending the time for noise decay.

1913 Ceramic Rumford Acoustic Tiles (patent with Sabine)
It was not until a request to the Guastavino Fireproof Company by the architectural firm of **Cram, Goodhue, and Ferguson** that **Guastavino Jr.** was introduced to **Wallace C. Sabine**, professor of Physics at Harvard, who was asked to measure the sound absorption coefficient for a standard Guastavino tile.

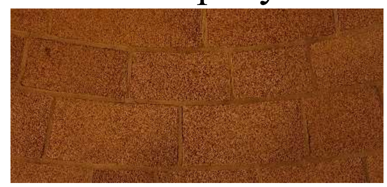
They devised an acoustically effective tile for vault and wall surfaces. Patented the **Rumford Tile** (**1914**; 1,119,543), a kilned tile that absorbed sounds by virtue of spongelike air chambers produced from clay that had been mixed with small particles of organic peat that burned out of the tile made of clay and feldspar. The inclusion of voids a major acoustical improvement over previous tiles, performed extremely well in the acoustic frequency range between 500 and 2000 Hz, ideal for musical ecclesiastical applications. **St. Thomas Cathedral in New York** first major project employing Rumford tile. (Riverside Church, NY, pictured)

The downside to the Rumford tile was the amount of material required to produce the tile, and an inability to control warping, color, density, and uniform sound absorption properties.

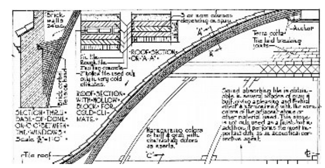
1916 Acoustic Akoustolith Tiles (patent with Sabine)
They then devised a molded, pre-cast concrete tile containing minute pumice particles that would not "pack" but left small air spaces, insuring uniform aggregate size, able to be mass produced with consistent color and sound absorption properties; 60% effective in absorbing sounds (in three octaves above middle C). Patented in 1916 (1,197,956), called **Akoustolith**, exceeded the sound absorption of the Rumford tile and extended the peak application range to 4000 Hz, used in much of the later work like the nave of **St. John the Divine**.

In the mid-1920s an Akoustolith plaster was developed and patented (1,563,846).

The Mellon family contributed heavily to Oakland's architectural monuments, employing the Akoustolith acoustical tiles.
[Mellons' architect **Benno Janssen**; used more aluminum in this building—for window frames, window grilles, doors, and stair rails—than had been used before in the United States, showcasing the Mellon’s ALCOA (Aluminum Company of America)].



Cathedral of Learning (1936)
In cloisters, in stairs (monastery)



1938 Hollow Thermal Tile Dome (71.5 ft. span)
Develop tiles with air space, to reduce internal heat loss in colder climates.
Buhl Planetarium (1938) (91ft. dia. dome)
Ingham & Boyd Architects, largest of the five planetaria in the United States.