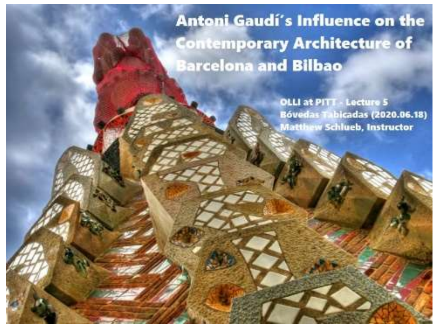
2020.06.18 Lecture Notes 10am

Lecture 5 – Bóvedas Tabicadas (Vaults Walls)

Preset: Baker Hall Staircase Videos



Welcome back to **Antoni Gaudí's Influence on the Contemporary Architecture of Barcelona and Bilbao**.

Housekeeping Items for New Students:

Questions > **Raise Hand** & **Chat questions to Erin (co-host)**.

5 to 10 minute break & 10 to 15 minutes at end for **Q&A**

POLL: #14 What is Gaudi most know for? mosaics, forms, craftmanship

Today's lecture, combines all three – one of his greatest achievements.

Bóvedas Tabicadas 1x (construction photos)

"We call thin brick vaults (Bóvedas Tabicadas) those that are made by bricks placed **one against the other in a flat way following the curve**, so that its curve is like a **thin wall (tabique 'partition'**). Depending on the place of the vaults in the building, they can be **made of double or single bricks, …sometimes three**, never more, as if they were thin walls placed one over the other, the one that is on top has to have its **joints over the brick underneath (woven)**." – Friar Lorenzon de San Nicolas (Madrid, 1633-1664).

1x (stone & tile vault diagrams)

Thin ceramic tiles, roughly **6 x 12 x 1 inches**, which are laid flat in multiple layers. This method was **considered to be revolutionary in the 14th century**, when it was first described as being a lightweight and inexpensive method of construction compared to traditional stone vaulting.

Originating in Valencia, Spain in by Moorish builders (Jofre Chapel of Santo Domingo Monastery by master mason Juan Franch, 1382), as inexpensive way to **infill the webs of stone-ribbed vaults**. Quickly spread to become common throughout the Mediterranean region.

4x (duomo & stairs between)

Brunelleschi's Florence Duomo (1418) **without formwork or buttressing**.
By using brick in a **herringbone pattern**, technique unknown to Florentine masons at the time, discovered by Brunelleschi – a watch maker.

[The thin bricks are laid flat, with their narrow edges in contact, the total thickness of the vault is less than conventional masonry, and therefore the self-weight and corresponding horizontal thrust values are reduced. In the traditional tile vault, the tiles are joined with plaster of Paris, which sets quickly enough that the interior of the vault does not require any support from below during construction. By contrast, a traditional stone arch must be supported on wooden centering, or formwork, and will only support its own weight once the keystone is in place. By building out from a wall in successive arcs, tile vaulting can be constructed with minimal to no formwork.]

2x (Guastavino atop arch & vualts)

Leitmotif (recurrent theme): **Architectural Synthesis**:
The **strength is in maximizing the bond area**, the **wide flat side adhered to the layer beneath/above**, making **staggered joints act as a single continuous piece** without seams, **as a board without the lateral thrusts** caused by the spreading of individual pieces in compression, but a **single horizontal board plank/partition in purely vertical load**. Forces were nearly reduced to the loads carried, because the **thin vaults were significantly less weight**.

Lime used in 14th century, Ecole des Beaux Arts introduced gypsum (hardens quickly) as Plaster of Paris, Guastavino used English calcium (greater strength) in Portland Cement.

1x (St.Paul Stair)

October 17, 1961 **George R. Collins**, professor of the history of art and architecture at Columbia University, rediscovered Guastavino tile. As he sat in the back of the university's St. Paul's Chapel (1907) . . .his eyes wandered to the **ornate herringbone of tiles of the domed ceiling**. The **curves and colors reminded him of the work of the Catalan architect Antoni Gaudi** (1852-1926). As he studied the ceiling, he suddenly realized that it used the same vaulting technology that Gaudi had deployed in many of his famous works in Barcelona.

In **May of 1962**, Collins **traveled to Pittsburgh to give a lecture**, and he was astonished to find that **thirty of the most significant buildings in the city** contained Guastavino vaulting. (Allgh.Co.Court., William Penn, Heinz Chapel…)

1x (stair without center)

Rafael Guastavino Sr. (1842-1908) was educated as both an architect and an engineer at the **school of "masters of works"** in Barcelona in the **1860s**, by the same professors who would later teach the Catalan master Antoni Gaudi. Catalan constructional methods to create **shell vaulting and stairs of cohesive tiles** hand-assembled in strong mortar. A structural system of interlocking tiles, legendary in Spain for its **ability to support tremendous loads with a remarkably small amount of material**.

3x (loaded arch & stairs)

Empirical design, loading test spans (100K# on 12ft.span in 1901).

His last major work before immigrating to the United States in 1881 was the **La Massa Theater in Vilassar de Dalt**, with a **56-foot span built of unreinforced** masonry **only 4 inches thick**. This astonishing thinness is possible because of the **double-curvature of the masonry shell**, which allows for compressive load paths to be **transferred to the supports in multiple directions**.

1x (Boston Library)

Eventually he got his break when he was contracted by the leading firm of McKim Mead and White to build structural tile vaulting throughout the **Boston Public Library** in 1889. Trustees **demanding fireproof building**, after Chicago Fire of 1871 and Boston Fire of 1872.

[The Guastavino Company worked repeatedly with many architectural firms, the most notable being **McKim, Mead, and White**; Bertram Goodhue; Charles Haight; Cass Gilbert; Warren and Wetmore; and Henry Hornbostel. "Of all the architects who used the Guastavino Company, **Hornbostel's work is the most varied in the purely structural sense**." Pittsburgh-based architects included Thomas Hannah; Alden & Harlow; Stanley L. Roush; E. B. Lee; A. F. Link; Benno Janssen and his partners Franklin Abbott and William Cocken; and Ingham & Boyd. E. P. Mellon was born and educated in Pittsburgh before moving to New York in his mid-30s.]

[Three Pittsburgh buildings with Guastavino tile are known to have been demolished: as noted earlier, the Phipps Natatorium; the Central YWCA 1909 [59 Chatham Street]; and the R. B. Mellon residence, 1908-11, 6500 Fifth Avenue and Beechwood Boulevard (now Pittsburgh Garden Center and Mellon Park).]

Between 1889 and 1962, the firm installed structural masonry vaults in more than **1,000 major buildings across the country**, more than **100 projects under construction simultaneously**.

Exposed brick, Guastavino considered "vaults **covered in lath and plaster to be papier-mache**, lacking the permeance and visual impact of tile."

1x (spiral stair)

Rafael Guastavino, Jr. (1872-1950) continued the firm after his father's death in 1908. Guastavino Jr. supervised the construction of a church dome in 1895, only 23 years old. The 70-foot span tapers in thickness from 6 inches at the support to only **4 inches at the crown of the dome**, and the span-to-thickness ratio of roughly 200 is **twice as thin as an eggshell by proportion**. Built in less than two months and was self-supporting throughout construction, with minimal formwork to guide the geometry. Because tensile hoop forces would appear in the lower region of the spherical shell – below about 52 degrees as predicted by membrane theory – Guastavino provided a tensile band of steel to resist the outward thrust at the intersection of the buttressing barrel vaults and the dome. Structural shells would not be constructed in thin shell concrete until decades later, superior to the later reinforced concrete shells because of the absence of formwork as well as the minimal reinforcing steel. Hundreds of Guastavino domes have functioned as safe structures for more than a century, and **none have ever failed in service**.

3x (section & interiors) 10:20

Baker Hall Staircase (CMU), Rafael Guastavino, Jr. (1914)

Guastavino spiral vaulted staircases represent an additional category of structural achievement. The main staircase of Baker Hall at Carnegie Mellon University is a masterpiece of Guastavino construction, with a **4-inch thick shell of masonry spiraling in three dimensions**. The load-bearing masonry structure is made only of **brittle ceramic tiles and does not contain reinforcing steel**. The stair is constrained by a cylindrical brick structure, which resists the outward thrust of the vaulted staircase. Though calculating the ultimate load capacity of such a structure is extremely difficult even today, the Guastavino Company conducted many **successful load tests**, and the survival of the stair for the last century is proof of its adequate load capacity. 1x (patent section)

Rafael Guastavino Jr. calculated the forces in his vaulted structures using **compressive equilibrium solutions defined by graphic statics**, and he often **shaped the structures to respond to the flow of forces**, **placing masonry where the resulting thrust lines acted**. The goal of the calculation is to demonstrate safe equilibrium solutions under all possible load cases, and to **ensure that the resulting thrust lines do not exit the masonry**. The stresses in traditional masonry structures are quite low, and the safety of such structures is typically **governed by stability and not by strength**. 8x (stair details)

By contrast, it is very difficult to demonstrate the safety of thin masonry shells using finite element methods, which seek to minimize the strain energy by invoking assumptions about the material behavior. Such elastic solutions predict substantial tensile stresses in traditional masonry and are highly sensitive to small movements of the supports. The calculation methods used by the Guastavino Company are similar to those used by the leading concrete engineer **Robert Maillart** and the great shell builder **Felix Candela**: they are based primarily on static equilibrium and not on the vain search for exact stress distributions in a hyperstatic structure. While assessing the safety of Guastavino structures remains a challenge today, new methods of equilibrium calculations can help today's engineers to discover load paths that these masonry shells have effortlessly found for more than a century.

2m (detail & sound effects)

Attempts to prove the safety of existing structures can also lead to the discovery of new structural forms that have not yet been invented. The **minimization of reinforcing steel and the use of local materials** can inspire engineers to design and build new masonry vaults in the future.

5x (BRG Model Study) 10:35

Venice Biennale (15th Architecture Exhibition, 2016)
Block Research Group (ETH Zurich), form designed by Zaha Hadid
Dry stack, without any mortar, keeping load path within contours of form.

2x (interior)

Colonia Güell Crypt, Gaudí (1908-14)
Monumental model of the Sagrada Familia.
Created the naves single space **without using buttresses**, flying buttresses or supporting walls. This was possible thanks to a combination of **leaning pillars** and **catenary arches** which also result in the **hyperbolic paraboloid shape of the perimeter walls**.

1x (holy water receptacle)

Vaulting inverted from concave to convex, **sagging between supporting elements, accentuating the visual weight of gravity**.

2x (exterior convex vaults)

Manifesto (public declaration): **Bóvedas Tabicadas: architectural synthesis, assembly of parts working together as one.**
Utilized the Catalan Bóvedas Tabicadas acting as **a singluar member exerting the same vertical load, wether traditionally concave or inverted convex AND pairing the convex curvature in opposition to the concave, with the inherent structural stability** of a sea shell.

3x (details)

Not Catalan tiles, but broken mosaics: **"The original is precisely that which returns with new means to the simplicity of first solutions"** Gaudi, 1892.

1x (St.Andrew X)

most **vulnerable center of span marked with St. Andrew's Cross** as reassurance from patron saint of the church.

2x (freestanding branches)

Incline pillars branching out to support the drooping tree canopies, foreshadowing the columns of Sagrada Familia, calculated with weighted threads of Estereostatic.

10:45

(10 MINUTE BREAK)

10:55

6x (fish) 10:55

El Peix (The Fish) Barcelona, Gehry (1992 Olympics)
Intertwining **gilded stainless steel strips** supported by a metal structure.
Interplay between the rays of the sun and skin creates the **impression of scales**, depending on the intensity of the light
First use of CAD to design a complex structure with compounded curves.

3x (exterior)

Guggenheim Museum in Bilbao, Gehry (1997)
Constructed on time and budget.
The 'organization of the artist' is a method used by architect Frank Gehry that places the artist in control of the design throughout a building construction and deliberately eliminates the influence of politicians and business people on design, particularly relevant to organizations that place innovation and innovators at the core of their business model.

4x (steel structure)

Detailed and realistic cost estimate before proceeding.
Computer visualizations produced by Rick Smith employing **Dassault Systemes' CATIA V3 software (precursor to BIM, 7 years later)**.
Collaborated closely with the individual building trades to control costs during construction.

3x (titanium scales)

Titanium plates, arranged in scales (fish), on a galvanized steel structure. Its lamination process is delicate and has to be done in places with high energy sources, that's why the **laminated parts were made in Pittsburgh**, the rolling allowed to obtain **titanium plates only 0.4mm thick**, which is much thinner than if we had to use steel plates. Moreover, titanium is about **half the weight of steel**, indeed, the museum's titanium coating represents only 60 tons. The pieces were designed to resist the bad weather, that is why a **quilted rather than undulated** shape was privileged, to resist the wind, and to avoid vibrations during storms.

[Basque Sanitary Headquarters (Bilbao), Juan Carlos Coll Barreu (2004)
New glass facade greatly improves the carbon signature of the building and meets the strict demands of heritage planning.
A double façade is used to solve all of these Zoning rules, dramatically improving thermal performance as well as acoustic, fire and safety requirements.]

7x (interior structure)

Sagrada Familia Schools, Gaudí (1909)

Irregular undulating **hyperbolic paraboloid roof and walls, by simplest means**: **straight rafters and central beam**, with concave and convex bóvedas tabicadas brickwork spanning between.

"The original is precisely that which returns with new means to the simplicity of first solutions" Gaudi, 1892.

2x (exterior roof)

Parti Pris (organizing concept): **Undulating Form, balance of concavity with convexity, to arrive at static equilibrium**.

Irregular, asymmetric, curvilinear, Undulating, oscillating, linear segments, structural rigidity, resilience in adhesion, organic form described by geometry.

4x (exterior & interior)

Santa Caterina Market (Barcelona), Enric Miralles and Benedetta Tagliabue – EMBT (1997-2005) Market place, social housing, public space and parking. Supporting the demolition as the only way to "solve" the things is another mistake. On the contrary. The key is using and using again. It is like thinking and rethinking things. Architecture is just a way of thinking about reality.

Mosaic tiled designed by artist Toni Comella, displays vivid colors and figures that is a **metaphor of an immense sea colored by the memory of fruits and vegetables**. Influenced by Josep Maria Jujol.

6x (exterior)

Bodegas Ysios Winery (La Guardia), Calatrava (1998-2001)

Sinusoidal shape in both plan and elevation.

Roof volume creating a kinetic effect in contrast to the calm background of the vineyard. The roof, composed of a series of **laminated wooden beams, supported on the staggered sinusoidal cornice of the lateral walls**, is treated as a continuation of the facades. 3x (interior)

Calatrava adopted the strategy of giving a volumetric treatment to the roof and walls — physical limits of the landscape outside and the winery within — so that continuity between the two spaces is achieved through the 'static movement' of the enclosures.

Camino de la Hoya, s/n 01300 Guardia, Álava, Spain.

11:15

6x (pinnacles)

1914:
Righthand assistant Francisco Berenguer dies.
Sagrada Familia in debt, exploring termination, Gaudí sells family farm at Riudoms to reduce deficit and dedicates himself solely to Sagrada Familia:
Designs Passion Façade (1917), Hyperboloid Windows (1918),
Forest Columns/Canopy Vaults and Glory Façade (1922),
Nativity Bell Tower Pinnacles (1923-1925).
Dies (June 10, 1926)

POLL: #15 Favorite Lecture?

1. Trencadís Mosaic of Güell Stables' rooftop ventilators & Park Güell benches
2. Colades de Guix (Plaster Casts) of Sagrada Familia Nativity Façade sculptures
3. Inclined tensiles of the Estereostàtic Model for the Colònia Güell Church
4. Forma Deforma weighted metaphors of Casa Batlló and Casa Milà
5. Bóvedas Tabicadas synthesis of Colonia Güell Crypt & Sagrada Familia Schools

11:15

Q&A

11:30

Guastavino's Pittsburgh buildings:

Allegheny County Courthouse
Allegheny General Hospital
Bell Telephone Company
B'Nai Israel Synagogue
Buhl Planetarium (Children's Museum)
Calvary Episcopal Church
Baker Hall (CMU) 1914
Hamerschlag Hall (CMU)
Porter Hall (CMU)
Doherty Hall (CMU)
County Office Building
East Liberty Presbyterian Church
First Baptist Church of Pittsburgh
Holy Rosary Church
Mellon Residence
Pittsburgh Athletic Association
Pittsburgh City-County Building
Post Office and Courthouse
Rodef Shalom Synagogue
Shadyside Presbyterian Church
St. Boniface Roman Catholic Church
U.S. Bureau of Mines
Cathedral of Learning (Univ.Pitt)
Stephan Foster Memorial (Univ.Pitt)
Heinz Memorial Chapel (Univ.Pitt)
Western theological Seminary
William Penn Hotel

["When masons build a wall, they place two plumb uprights and string a line between them horizontally. If one of the uprights goes **out of plumb**, which happens much more often than you may think, the masons, believing that they are building a **flat wall**, are in fact making a **paraboloid**. We have gone directly and deliberately to this form and seeing its **beauty** and the **possibilities that it offers**, we have also **used it for the vaults**."]