Michael H. Ramage
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Building a Catalan vault

Catalan vaulting is a masonry technique perfected in Catalonia, Spain which relies on fast-setting mortar for construction and structural form for strength. The origins of the technique are obscure, but likely come from the varied cultures of the Mediterranean.[1] The technique was brought to the United States in the 1880s by Raphael Guastavino, and perfected as a monumental construction method used in hundreds of buildings throughout America. Among many well-know examples are the Boston Public Library, The hall of Ellis Island, Grand Central Terminal, and the Dome of St John The Divine in New York City.

Although the technique died out in the United States, it remains in use in Spain today. One of its hallmarks is that it does not require formwork for spanning large open spaces. The final form of the vaults is pleasing to the eye, as best said by the Uruguayan engineer Eladio Dieste:

> "The resistant virtues of the structures that we seek depend on their form; it is through their form that they are stable, not because of the awkward accumulation of material. There is nothing more noble and elegant from and intellectual viewpoint that this: to resist through form."[2]

The Catalan system is effective at covering large areas gracefully and economically. It was used in Cuba just after the revolution to build a vast complex of art schools, at a time when labor was plentiful but materials were scarce. The Cubans learned the technique from a Spanish mason who had worked with Antonio Gaudi, and built an entire manufacturing system for the tiles and mortar[3].

There is nothing written recently in English on the process of building a Catalan vault, although the method is well-known in Spain and Italy. This paper attempts to describe the technique, which I learned both through conversations with Prof. John Ochsendorf of MIT and through trial and error. Using materials commonly available, I constructed a groin vault of 4' 9" span in the course of a weekend.

Design

I designed the vault in Rhino 3D modeling software. This was particularly useful because it allowed me to calculate the area covered by bricks (and thus the quantity I needed to purchase) and it gave me dimensions for the groins, which are not built in the Catalan technique, and thus needed formwork. Each groin is a parabola, the structural form for a

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[1] Collins, George R. "The Transfer of Thin Masonry Vaulting from Spain to America." *American Society of Architectural Historians Journal 1968* Oct., v. 27, n. 3, p. 176-201.

[2] Dieste , Eladio. La Estructura Ceramica. Bogotá: Escala, 1987.

[3] Loomis, John A. *Revolution of Forms Cuba's forgotten art schools.* New York : Princeton Architectural Press, 1999.

uniform load. The central vault is determined from the curves of the groins, and controlled during construction by wooden battens cut to length, again derived from the digital model.

Materials

As is the Catalan tradition, I laid the first course of tile using Plaster of Paris, which can be mixed in small batches to set in about 10 seconds. This is the key to the system: a fast-setting mortar on two edges of a tile allows it to hold itself after being tapped into place. No formwork is needed.

Contrary to the Catalan tradition, I used "thin brick" for tiles; traditional masonry uses significantly larger and softer terracotta tiles. Thin brick is the dimension of a brick face (7 $^{5}/_{8}$" x 2 ¼") but only a ½ " thick. It is typically used as facing on wood or concrete structure. I laid it horizontally like a tile, and it worked well. Its main drawback is its small size, which requires a lot of units to cover an area. Typical estimates of coverage are 7 bricks to the square foot, but because the plaster mortar joints are significantly thinner than typical mortar joints, I needed 8 bricks to cover a square foot.

Once the first course is laid, it serves as formwork for a second course that is laid in weatherproof Portland cement mortar. Instant setting is no longer a concern. Two or three courses allow structures of great span: the dome of St. John the Divine is 33 meters. The vault I constructed is only one course due to the constraints of time, materials, and the need to remove it post-construction.

I used Boston Pavers for the piers. The piers are not inclined to carry the structural load, but would be in an ideal system, or else properly restrained to carry the thrust of the vault.

Construction Method

The Plaster of Paris is mixed in small batches and applied to one tile at a time. Generally I mixed only enough for one tile, but sometimes I could do two. The technique I eventually settled on (after discussions with John) was to fill a large baking pan with plaster powder. I would then pour 2-3 tablespoons of water (measured by eye) into the corner, and mix in plaster with a flat mason's trowel until I got a toothpaste consistency. This I would then apply to one long and one short edge of the tile, and tap the tile into place, hold it for 5 seconds, and let go. I repeated this until I had used up all the power, usually an hour or so, sometimes discarding the junk that set up in the pan. Plaster which is set or setting has a powerful effect on getting newly mixed plaster to set – this can be used to an advantage as one strives to get a thick, fast-setting mixture, but it can also spoil the mixture. I found that an aluminum "lasagna pan" worked well as the container, since it was pliable enough to make small reservoirs for mixing the plaster, and it was easy to bend to get old plaster out.

Before buttering the bricks with mortar I soaked them in water. I found that the mortar adhered best to damp bricks, neither too wet nor too dry. To facilitate this I soaked all the bricks, then laid them out along the vault to dry off as I worked on each section. On a cooler day it might have been sufficient to dampen the tile edges with a sponge.

I used a lot of mortar on each brick, which squeezed out of the joints as I tapped them in to place. Tapping the bricks with the back of the trowel makes the mortar flow into openings and assures a tight connection.

The Groins
The groins are build on centering, and two layers thick. The curvature is accommodated by laying the first course on its long edge, then staggering the second layer as it works around the curve. The groins are supported on simple masonry piers.

The Vault
The shape of the vault is guided by two wooden battens cut to the length of the crossing. I laid the tile starting in a corner, where there is a connection on two sides. The tiles are canted upward to the shape of the eventual structure – one must rely on the eye and experience for this part. On area of the vault I constructed is a bit flat where I got off the true shape. I proceeded around the square, laying an entire row of tiles before turning the corner. On distinct difference in my method from many – again due to time and size constraints, I built the vault from above (very close to the ground), whereas a vault of this size would typically be built from below.

Acknowledgements
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Project Accounting

Materials:
468 "thin brick", typically used for brick facing (7 5/8" x 2 ¼" x ½")
Used for the vault
80 Brick pavers, (7 5/8" x 2 ¼" x 3 5/8")
Used for the supporting piers
100 lbs Plaster of Paris
Used for the mortar

Time:		
	Design and construction of formwork for groins	~8 hours
	Construction of piers and groins	~11 hours
	Construction of central vault	~14 hours

Cost:		
	Thin brick:	$135.72
	Pavers:	donated by Spaulding Brick
	Plaster:	$40

Tools:
Flat trowel (2)
Mason's hammer
Buckets
Sponges
Large aluminum tray