SCAFFOLDING TO STRUCTURE

CONSTRUCTION IN THIN-SHELL MASONRY

CAMBRIDGE, UK
October 23 - 30, 2010

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BLOCK TEACHING

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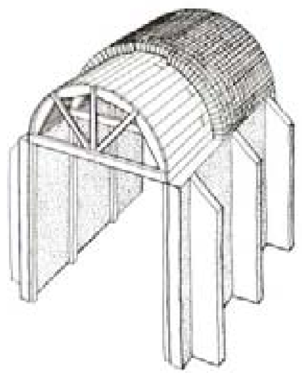

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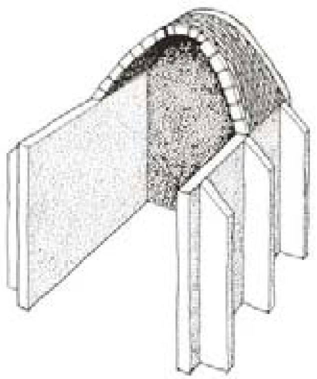

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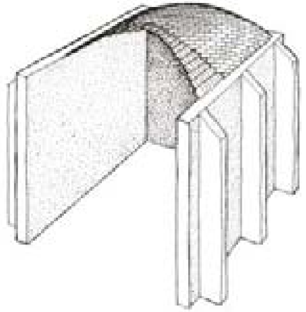


Thin-Tile Vaults
SPAIN

SCAFFOLDING TO STRUCTURE

CONSTRUCTION IN THIN-SHELL MASONRY

British fan vaulting, Catalan thin-tile vaulting, and Mexican 'leaning brick' vaulting: These three enduring methods of construction in thin-shell masonry – each with their associated structural theory and constructional praxis – represent the three primary methods of spanning space in unreinforced masonry.

Masonry experts from ETH Zurich (Dr. Philippe Block and Lara Davis), University of Cambridge (Michael Ramage and Dr. Matthew DeJong), and Universidad Nacional Autónoma de México (UNAM) (Alfonso Ramírez Ponce) led seminars in vault construction, in which structural principles were tested through hands-on practice with materials and methods. Based in Cambridge, UK, our excursions included locations closed to the public. On the roof of King's College Chapel, at Ely Cathedral, Peterborough Cathedral, and the Wren Library, the theoretical engineering themes were translated from "scaffolding to structure".

Prof. Dr. Philippe Block
Lara Davis

ETH

Collaboration with:
Prof. Michael Ramage
Prof. Dr. Matthew DeJong

UNIVERSITY OF CAMBRIDGE

Distinguished guest:
Prof. Alfonso Ramírez Ponce

UNAM

Photo by Demjan Haller

SCAFFOLDING TO STRUCTURE

CONSTRUCTION IN THIN-SHELL MASONRY

CAMBRIDGE, UK

SATURDAY OCTOBER 23	SUNDAY OCTOBER 24	MONDAY OCTOBER 25	TUESDAY OCTOBER 26	WEDNESDAY OCTOBER 27	THURSDAY OCTOBER 28	FRIDAY OCTOBER 29	SATURDAY OCTOBER 30
Arrival	Service at Kings College 10:30	Introduction 9:00 – 12:00	Bus Excursion Departure: 9:00 Peterborough Cathedral 10:30	Skills/materials Charette 9:00	Workshop: Mexican vaults & Tile vaults 9:00	Workshop cont... 9:00	Bus to London 7:00 Flight to Zürich 11:30
MEET: EasyJet Check-In 12:45 Flight to London 14:45 Bus to Cambridge 17:25	Exploring in Cambridge	Excursion: King's College Chapel	Ely Cathedral 2:30 Return 18:00	Excursion: Wren's library 14:30 Lecture A. Ramírez Ponce 17:00	Lecture Prof. P. Block 17:00	Wrap up	*Departure*
	Dinner in a college 19:00						

Cambridge. Eine Woche. Sieben Tage. Hundertachtundsechzig Stunden. Zehntausendachtzig Minuten. Sechshundertviertausendachthundert Sekunden. Ja so lange haben elf Männer und drei Frauen zusammen in einer Stadt wie im Film verbracht. Hat einer von euch Harry Potter auf seinem Besen vorbeifliegen sehen? Staunen, sich wundern, zweifeln, bewundern, glauben, nicht glauben. Dinge wie diese haben die ersten paar Tage unserer Reise geprägt. Kann es wirklich sein? Wie ist es möglich? Unter den Dächern einiger Kathedralen wurden unsere Horizonte erweitert. Faszinierende Konstruktionen, stimmungsvolle Gottesdienste, lehrreiche Gespräche. All dies war Teil unserer kleinen Reise.

– Isabelle Schulz

KING'S COLLEGE CHAPEL

The fan vaults at King's College are the largest in the world, spanning 12.66 meters, with an extraordinarily thin shell (between 10 and 15 centimeters). Completed by 1515, the Chapel at King's College was built in sporadic periods, with the credit of the fan vaulting to the master mason John Wastell. Each vaulting bay, compartmentalized by transverse arches, is composed of four quarter fans and a central spandrel panel with a boss. Since the bays are rectangular, the fans intersect at a transverse ridge. A longitudinal ridge runs the 88.5 meter length of the chapel. The Seminarweek group's visit included a Sunday morning service with choral music, closer inspections of the chapel, and exclusive structural and constructional tours under the roof, over the vaulting, along the entire length of the longitudinal ridge, and down the north and south eave walks on the chapel roof.

Inside of King's College Chapel, Cambridge
BY WILLIAM WORDSWORTH

Tax not the royal Saint with vain expense,
With ill-matched aims the Architect who planned—
Albeit labouring for a scanty band
Of white-robed Scholars only—this immense
And glorious Work of fine intelligence!
Give all thou canst; high Heaven rejects the lore
Of nicely-calculated less or more;
So deemed the man who fashioned for the sense
These lofty pillars, spread that branching roof
Self-poised, and scooped into ten thousand cells,
Where light and shade repose, where music dwells
Lingering—and wandering on as loth to die;
Like thoughts whose very sweetness yieldeth proof
That they were born for immortality.

One thing that seemed interesting to me during our time in such an old and well conserved city, is that most of all these old buildings, that were built hundreds of years ago, are still there and perfectly conserved. Of course there was restoration, but the structures, most of the time, didn't need any repair. I believe that one of the reasons for their capacity to endure comes from the shape of these structures. Even people that never studied something about them could easily, roughly understand how forces run in these amazing buildings. An element which is constantly repeated in most of the buildings is the arch. Most are english arches (pointed arches), but in some old Cathedrals and other old buildings you can also see Norman arches (which are our Roman ones, so called because this art of arches arrived in England with the Norman conquer after the Battle of Hastings in 1066). Of course there are other variations of them. The thing that amazed me, was that even though the master builders of these old times couldn't calculate the forces, they could imagine the right shape of structures to make forces elegantly flow through them, and maybe they understood these principles even better than we do today. Probably they tried and tried again until they found the right shape – the one that could hold for thousand of years against the forces of nature.

– Pablo Valsangiacomo

Photo by Raphael Fitz

Sonntagmorgen stehen wir alle (mehr oder weniger) ausgeschlafen auf, und machen uns auf den Weg zur Kings College Chapel, wo wir zum Gottesdienst erwartet werden. Sobald wir de Füsse über die Schwelle gesetzt haben, kommen wir uns vor wie im Film: ehrwürdige Gemäuer, dunkle Holzschnitzereien, Kerzenlicht, riesige ledergebundene Bibeln... Durch die Bunten Fenster des Kirchenschiffs tritt Dämmriges Licht in den Chor. Zusammen mit den Senior Members vom Kings College, kirchlichen Würdeträgern und Einheimischen dürfen wir das Ritual erleben. Vom Kirchenchor über den Gastprediger bis zum Schlussgebet ist alles dabei was dazugehört. Noch ahnen wir nicht, dass wir schon am nächsten Morgen auf dem Dach eben dieses eindrücklichen Sakralgebäudes stehen werden...

– Demjan Haller

Until now cathedrals and other middle-aged buildings to me were more like memorials of social injustice from a time when perverted competitions took place to build higher and more expensive. I was stunned though, that King's Collage Chapel made me think of a church of the Enlightment (Aufklärung) in which church music sounds like being written by Pink Floyd, and in which the priest's reading could be used as a contemporary commentary in a cultural magazine. It was a great experience to see King's College Chapel in action; to attend a service - without getting religious. Browsing through the reader I began to realize that Fan-Vaults define their own category of vaults and that the British master builders demonstrate a perfect equilibrium of thrust forces -even by filling up the vaults with heavy loads. I was thrilled.

– Lucas Treyer

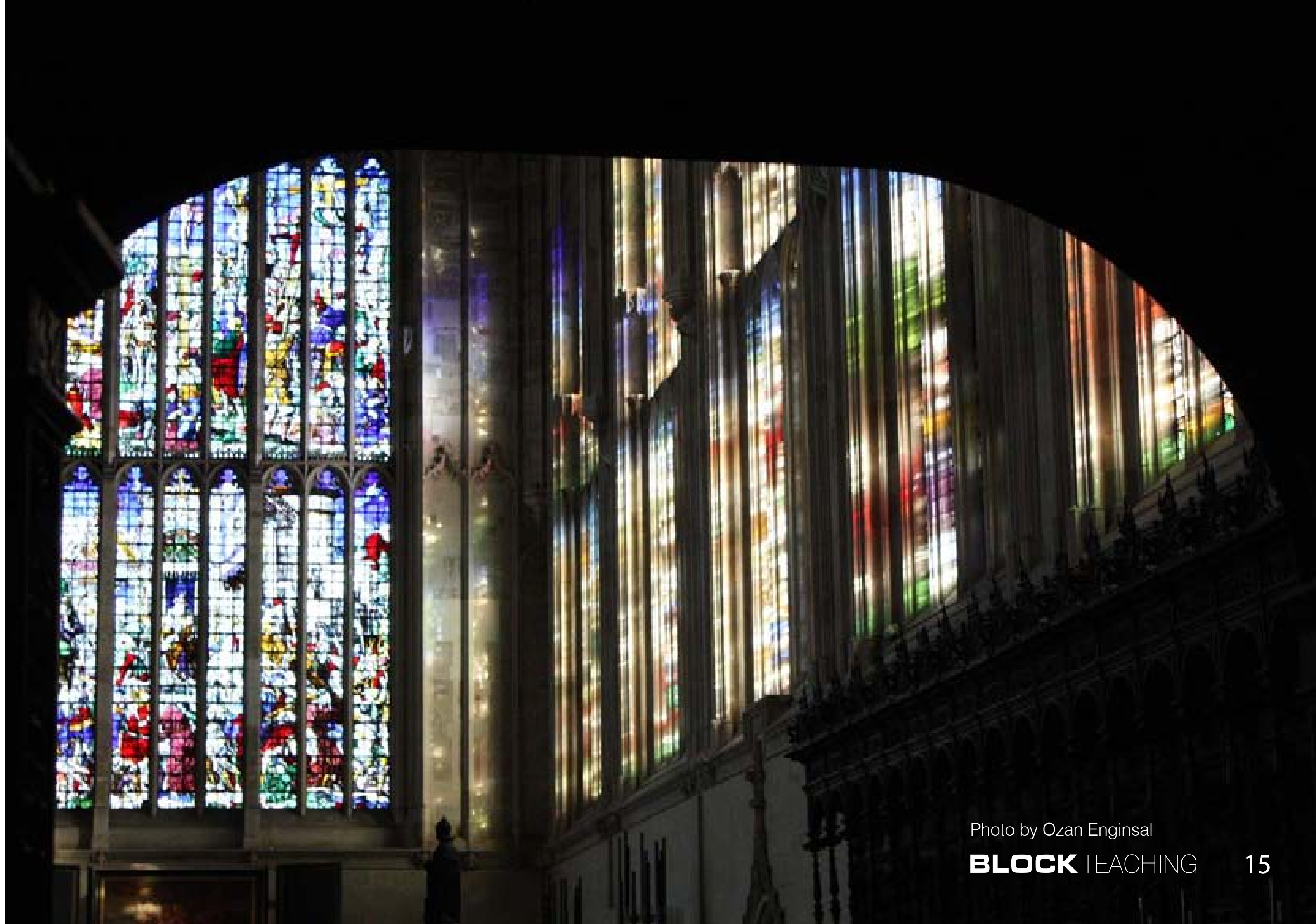
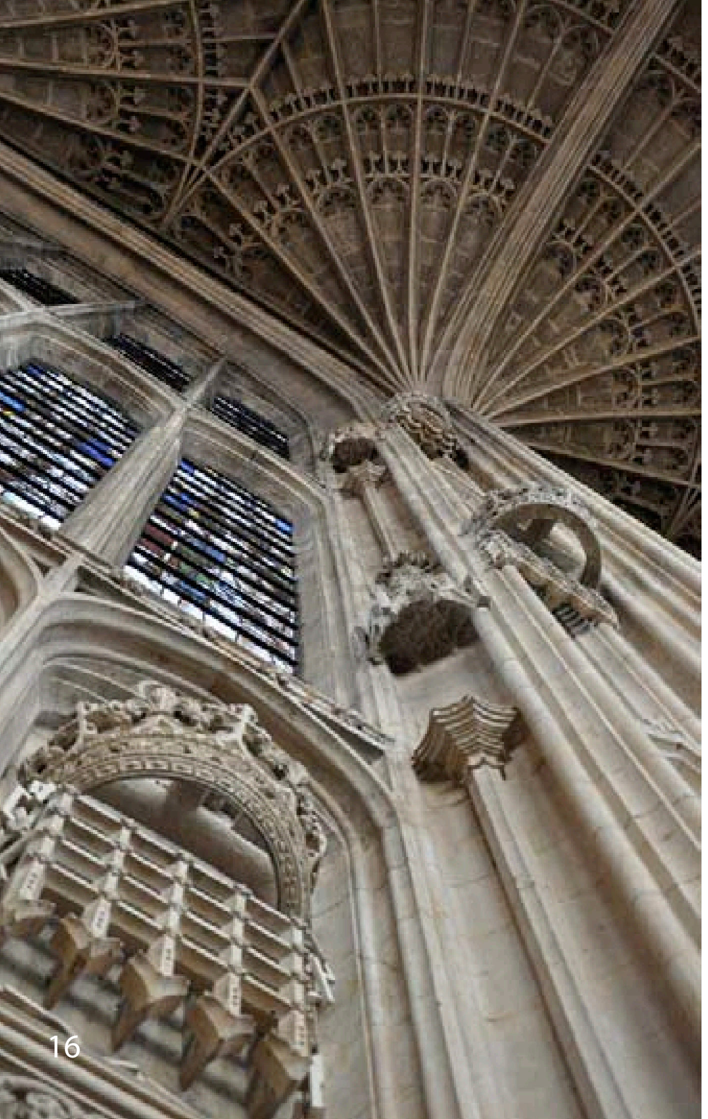
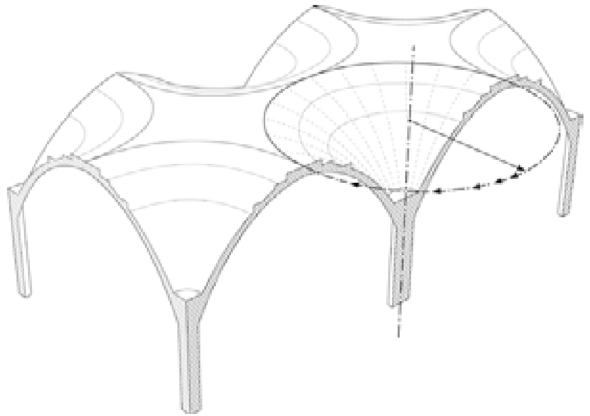
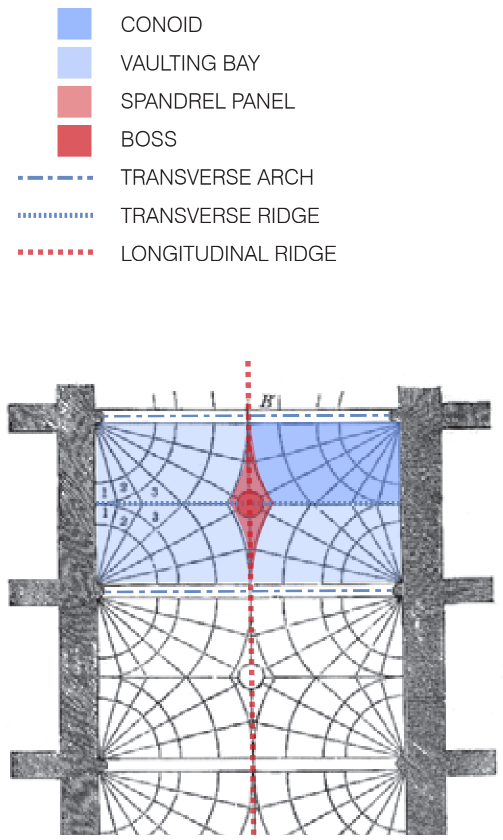


Photo by Ozan Enginsal



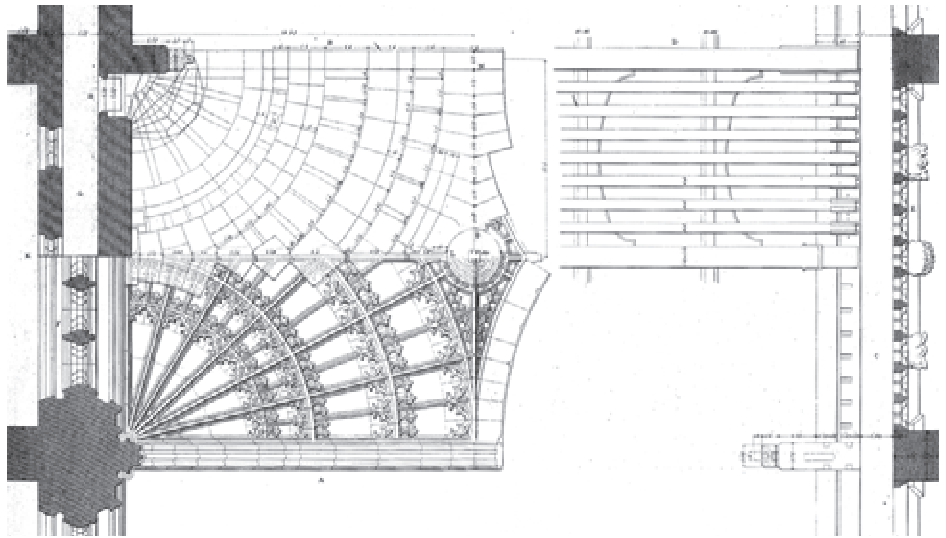


The “conoid” of a fan vault is a geometry of revolution, in which each radial section and rib geometry is equal. The vaults at King’s are an exception to this rule, however, since two of the primary ribs of each conoid are of a slightly different curvature to accommodate for the modified curvature of the transverse arches spanning the chapel. Though this is not visible to the eye, it is apparent from the masons’ marks on the upper surface of the stones that these voussoirs (or stone masonry units) had unique cutting patterns (see p.54). Along the circular courses of the conoid with greatest ornamental detail is “jointed masonry”; the ribs and relief are carved directly from solid voussoirs. In all other locations, the ribs are “rebated”, or set back on the upper side to receive the thin panels of the vaulting conoids. In fan vaulting, the ribs are always perpendicular to the vaulted surface, because the regular conical curvature is an easy reference geometry; in comparison, the ribs of quadripartite vaults are perpendicular to the ground plane and must be vertically projected to a complex surface.



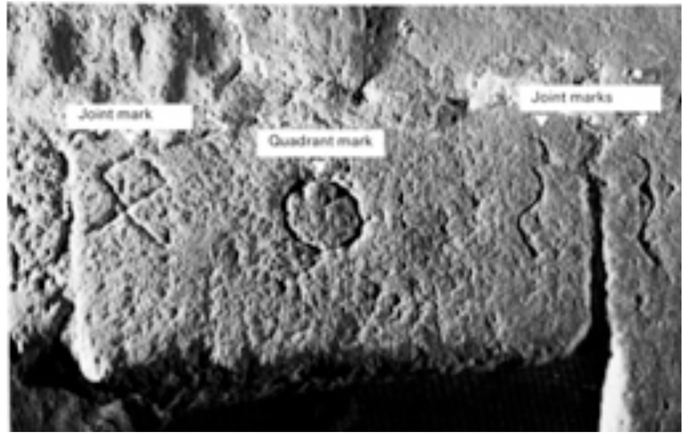
After a sight-seeing tour on Sunday, the first days we concentrated on developing knowledge of how brick vaults were applied, especially in medieval churches. King's College Chapel (1446), Peterborough Cathedral (1118) and Ely Cathedral (1083) were amazing examples of such very efficient and „sexy"-looking structures. The roof construction at King's College Chapel impressed me most with its only 10 centimetre thickness in some parts. Whitout the high reputation of all our tourguides, the walk on that awesome structure wouldn't have been possible.

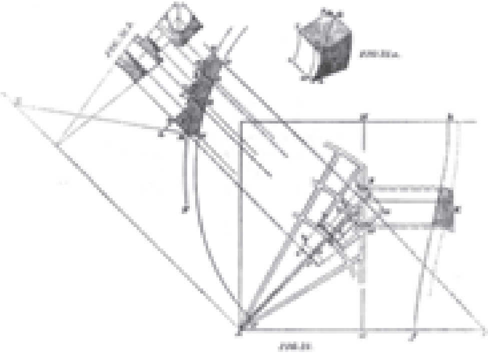
– Jonas Hodel

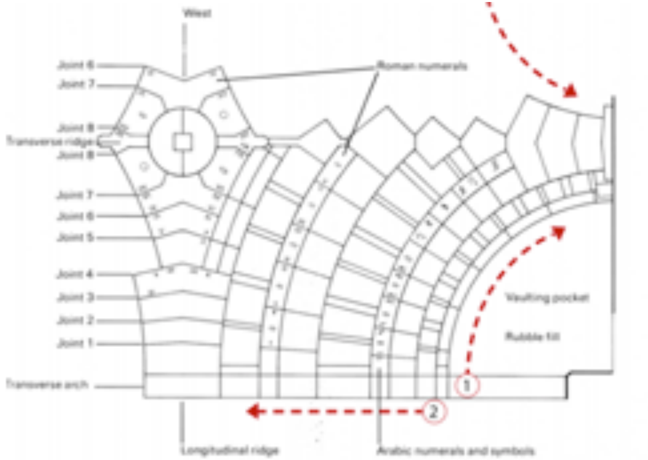


To the left, the heavy voussoirs of the transverse ridge may be seen between two fan conoids, along with the flat, "working surfaces" of the stones (the registration surface which would have been face-down on the masonry workshop bench while the voussoir was being carved. Also visible is the surface of the fill for each conoid, which transmits the high horizontal thrust of the vaulting and add a heavy self-weight to push the thrust lines down in the buttresses. Over each transverse ridge and arch is a roof truss, to which steel tension ties were added in Elizabethan time. These ties are now thought not to be necessary, according to Dr. Cam Middleton. Note the structural system supporting each of these truss types: the trusses installed over the transverse arches are supported with sizable masonry columns, which carry the pinnacles and push the thrust vertically down through the center of the fan. These are in turn supported by a buttress on the exterior facade. The trusses installed over the transverse ridges, however, are supported by a relieving arch, which carries the load of the vault and roof truss along the wall, over the large, traceried chapel windows, to the primary fan supports. There is evidence on site that the set of roof trusses over the transverse ridges were thought, prior to the installation of the tension ties, to thrust excessively over the chapel windows. In one location, a cable crank is still in place, indicating that tension was induced into the trusses before they were tied back with steel ties. This may account for the regular holes punched through the relieving arches across from each mid-bay window, the purpose for which is unknown.

Each voussoir is carved with three separate inscriptions, masons' marks including both Roman and Arabic numerals to indicate the vaulting quadrant and the relative position of the voussoirs. These position markers provide information for adjacent voussoirs, and thus give us significant clues regarding the basic sequencing of the fan vaulting. We may extrapolate that, similar to the development of quadripartite vaults, the transverse arch was used for constructional registration: radial courses of the four quarter fans were simultaneously laid, beginning at the transverse arch, working inwards towards the transverse ridge. Each of these radial courses, which alternate between carved voussoirs and rebated rib and panel systems, would then be 'closed' with a heavy voussoir at the transverse ridge. When the radial courses and the transverse ridge had been laid, the central spandrel panel – composed of a compression ring of voussoirs and a heavy boss – were dropped into position to close the vault and to provide the weight to equilibrate the fan vault conoids.





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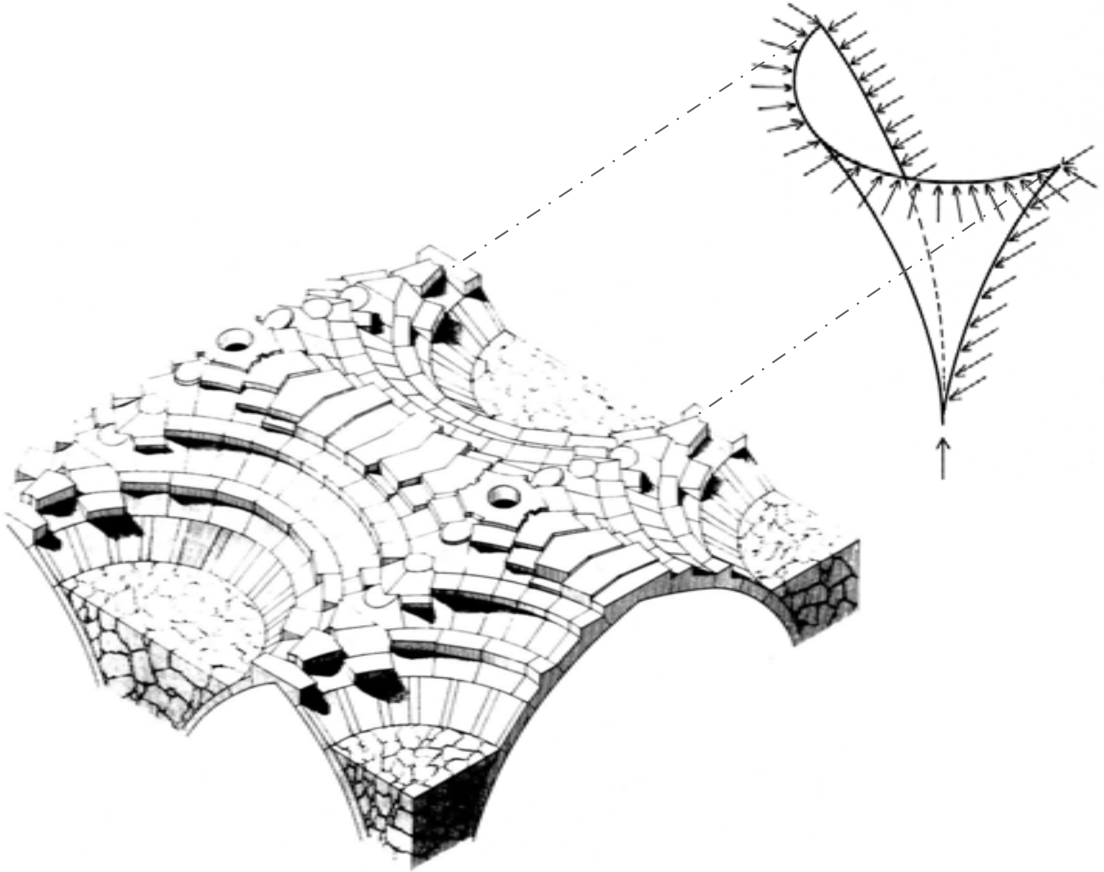
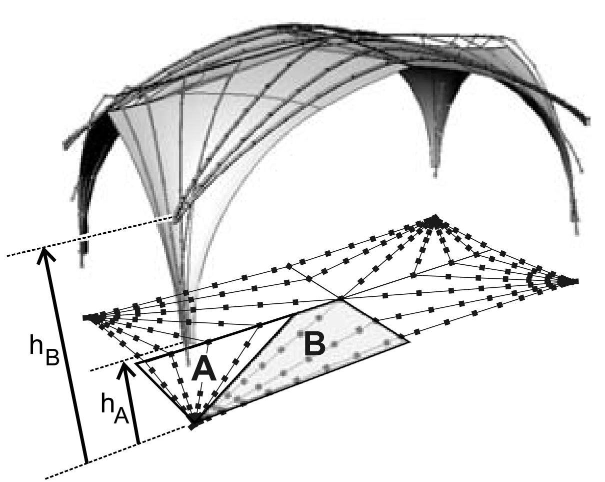
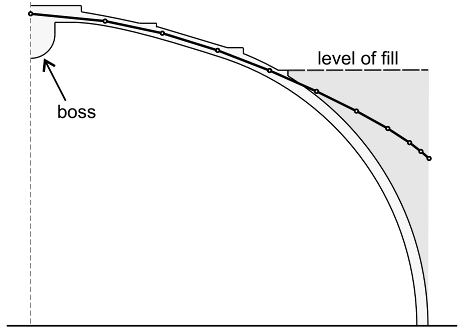
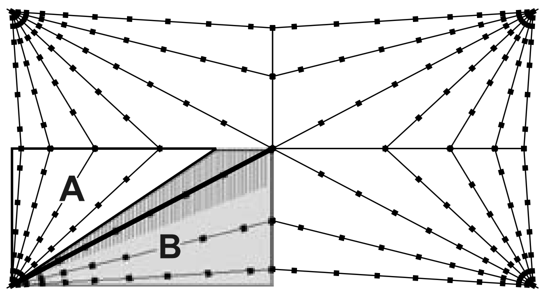
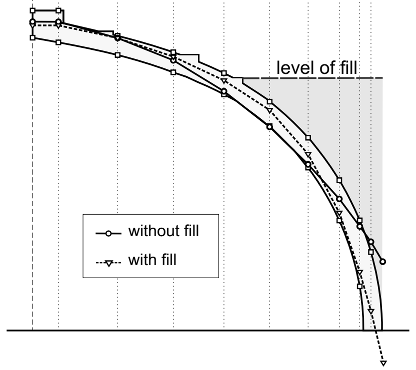










The transverse ridge, which marks the intersection of two conoids, exhibits very pronounced voussoirs on the extrados (or upper side of the vault). According to the novel analysis in the PhD dissertation of Prof. Block, the added weight of the transverse ridges is critical to maintaining the equilibrium of the vault system, insuring that the thrust of the fan conoids stays within the depth of the fill. The added weight of the fill additionally alters the thrust lines as they travel through the fan vault.

A careful inspection of the extrados provides a wealth of information about masonry preparation in the workshop and assembly on site. To the left, the unique spandrel panel voussoirs provide a compression ring, into which the boss is dropped.

Alternately referred to as a ‘swallow tail’ or ‘bow-tie’, this custom wooden pin (right) would have been dipped in wax and then inserted into a carved hole to join two halves of a voussoir, which had cracked during carving. Once the voussoir is inserted into position in the vault, the compressive forces in the structural vaulted surface seal the crack. The adjacent, bored hole is speculated to be a Lewis hole for lifting voussoirs into place. There are several such exposed holes visible in the vaulting, allowing one to appreciated the thinness of the vaulting panels. This particular one provides a view from above the vaulting into the organ pipes and Chaplain’s seating.

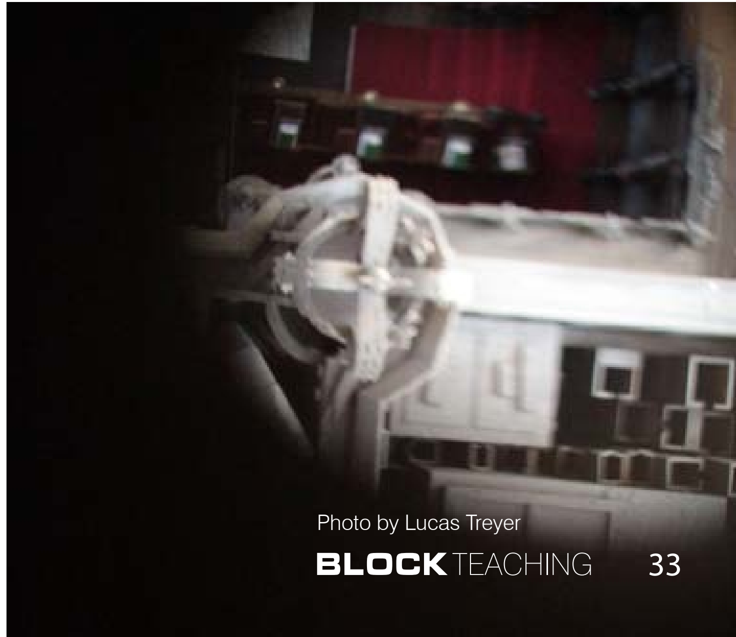
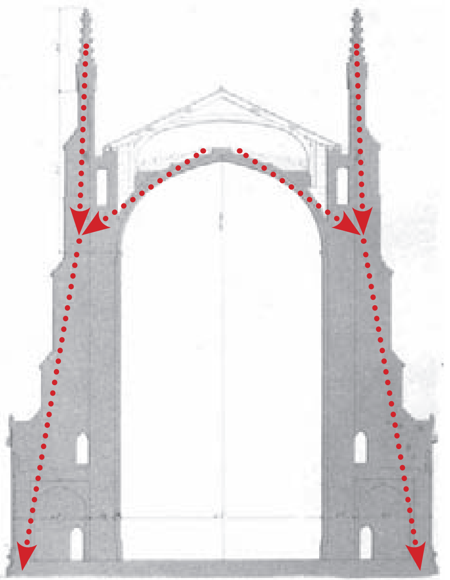
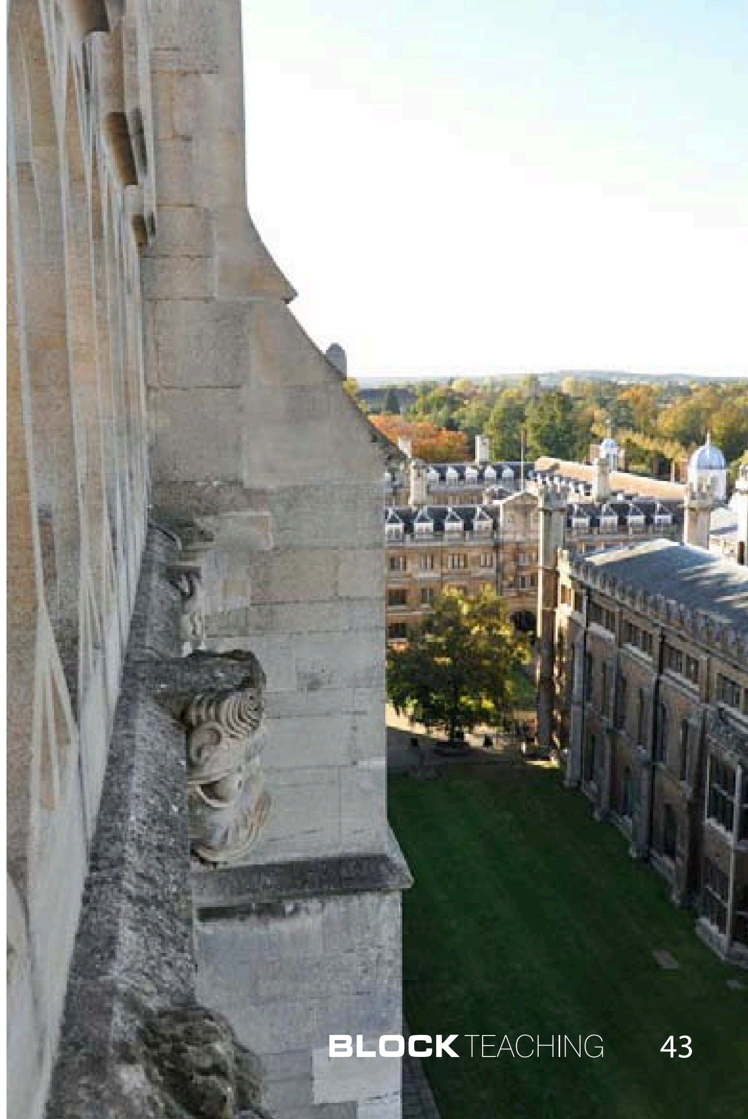


Photo by Lucas Treyer

The long explorative tradition has worn a footpath into the Weldon stone along the ridgeline, and is inscribed upon the walls at the far ends of the vaulting. The chapel has long been a favorite haunt of students, but access to the vaulting and roof is much more controlled in recent years; only fellows of the college and their guests are granted access. Dr. Cam Middleton, a Senior Fellow at King's College who served as our guide, raised his voice suddenly in warning as students clambered after him onto the vaulting – before chuckling and explaining the tradition of first-visit hazing which he received as a young student. With such thin panels and a 12.6 meter span, these fan vaults are proportionately thinner than an eggshell in thickness to "span" ratio, and only held in compression. The vaulting indeed easily transmits the vibration of average-weight footsteps, and it is reasonably easy to unsettle a person by jumping.

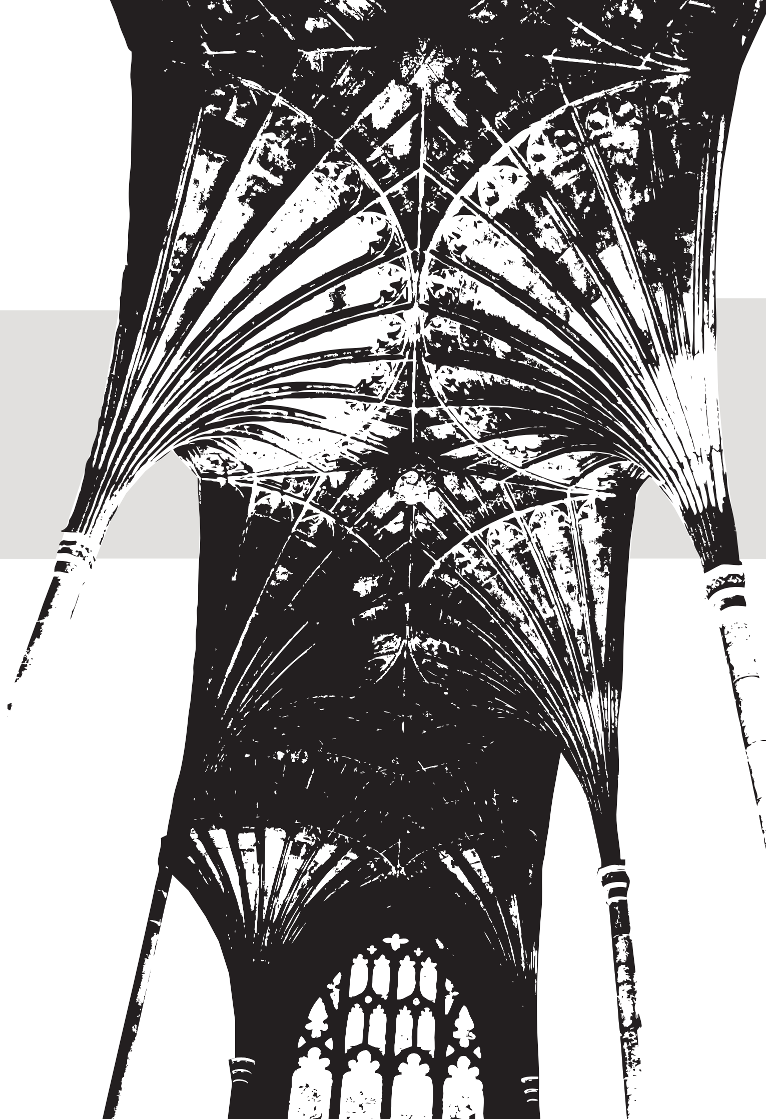


Masonry towers and pinnacles typically play a critical role in structural masonry systems, a feature which is demonstrated in the distinctive profile of King's College Chapel. The weight of these substantial elements is necessary to redirect the thrust of the long-span and extremely horizontal vaulting. The resultant must lie within the cross-sectional thickness of the Chapel buttresses for the structure to remain in compression and stable.



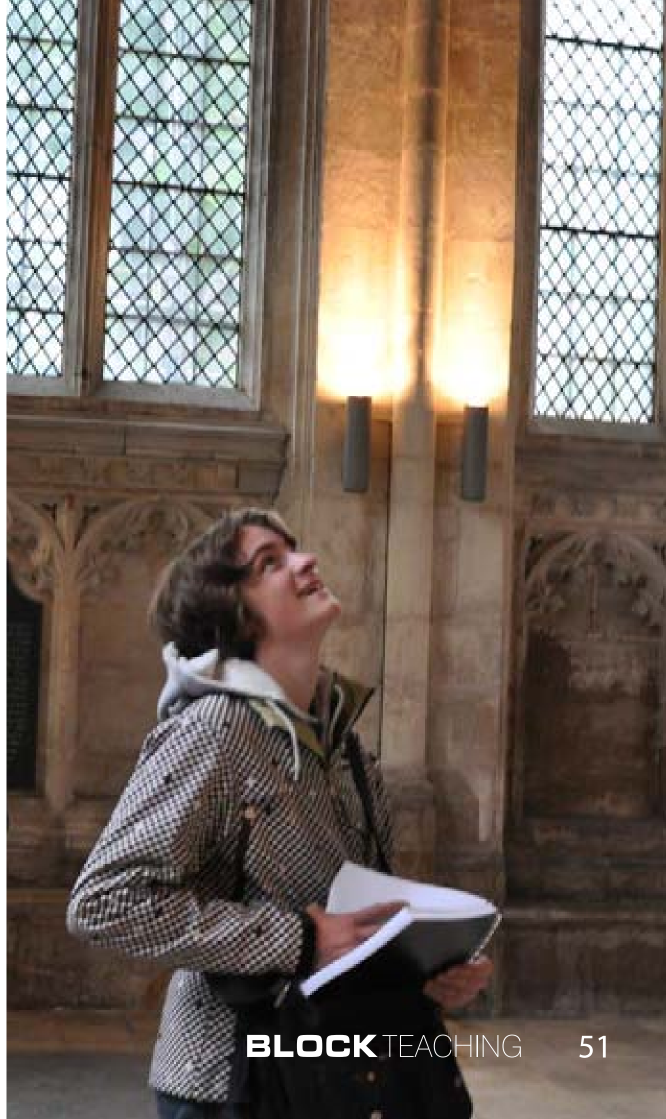
PETERBOROUGH CATHEDRAL

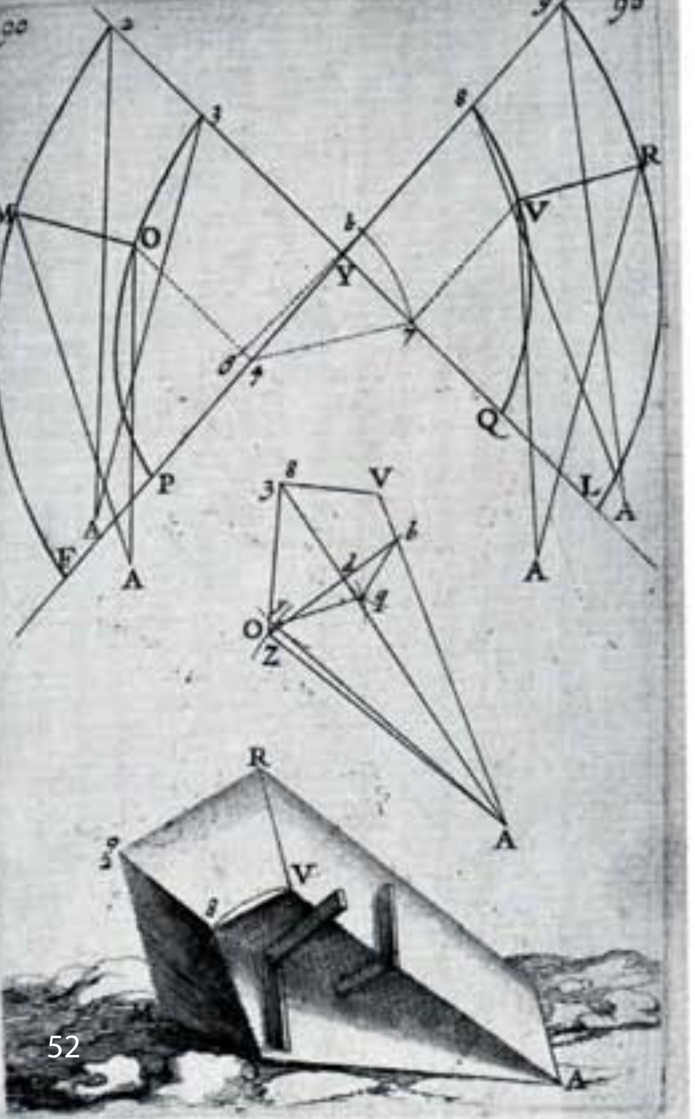
According to Robin Evans, Peterborough Cathedral exhibits the culminating moment in the development of the fan vault. Indeed, the formal complexity of the retrochoir fan vaulting is impressive, including two 270-degree fan conoids wrapping around corners, and conoids which extend straight up through the spandrel panels. The fan vaulting at Peterborough and King's College Chapel were arguably built by the same master mason, John Wastell (c.1460 –1515). However, unlike King's College, there are no transverse ribs employed in the construction of Peterborough, a detail which contributes to an aesthetic of seamless, conic undulation.



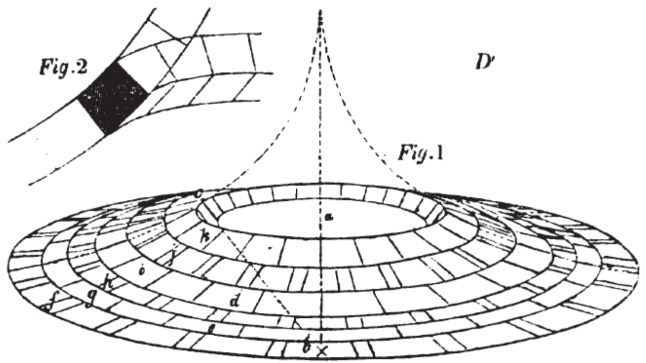
At the end of this tree covered avenue we reached a large open square with an unassumig gothic gate. It was well integrated in the surrounding row of houses which framed the square. That gate or what it was hiding seemed to be our destination. And when we went through the gate it bared its secret to us. A still wet green spread in front of us and behind it three gigantic pointed arch porches of which the one in the middle was more narrow than the other two and with something like an entryhouse in it. I was standing there a few moments not able to do anything but being astonished and staring at this grand facade. Since that moment I was lucky that the weather was so dark; it made the appearance of the Peterborough Cathedral even more powerful. When I entered the cathedral I was surprised again by the dimension of the three-story Romanesque central nave with its gorgeous painted roof, even if one could have await its hugeness after seeing the main front. At that time I guess most of us had been wide awake; this impressive building did its best. But it had even more going for it. Not in its bigness but in details and craftsmanship. By advancing to the crossing of the middle nave and the transept it opened to us the amazing view into the tower - and to the beautiful choir with its wooden and colored fan-vaults. In the choir there was a marmoreal altar and its surrounded by the so called new building, a fan-vault-pass, one story high. Walking through that pass made me feel like dandering through a stoney palm alley. A walk of magnificent forms and details. Outside it wasn't less spectacular, but much more archaic. All the forces who formed the building over those hundred of years, were visible, the walls were leaning outwards to the graveyard where the bishops are resting in peace.

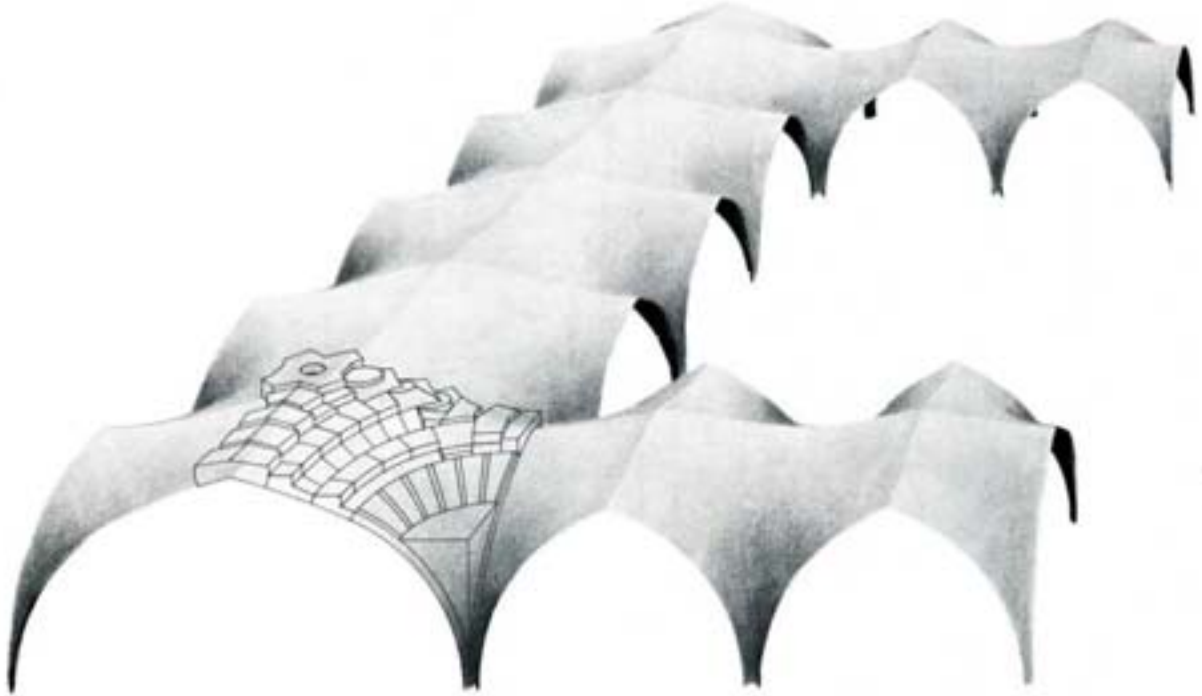
– Raphael Fitz





Stereotomy (or “stone cutting”) was the operational technique of the medieval mason, the method of drawing by which a vault geometry was “cut up” into individual voussoirs, to be later carved and installed in sequence by masons. The greatest constructional efficiency of the fan vault is that it is a surface of revolution; the geometry of the fan conoid is generated by rotating about a vertical axis with no change in curvature (as opposed to the typical quadripartite vault). In this respect, the fan vault was an ingenious innovation towards the reduction of labor – and thus expense – in vault construction, because its stereometric variation was dramatically simplified. Thus, the evident ‘seamlessness’ of Peterborough is somewhat deceiving; while it is formally more expressive, it has actually equal, if not reduced, stereometric complexity than that of King’s College. It is still only the boundary condition and intersections between each individual fan bay that required more complex stereometrical operations.





Kicking off the week with some educational sightseeing was incredibly inspiring – to personally see the fan vault systems of renowned English sanctuaries, particularly King's College Chapel and the 270 degree conics of Peterborough Cathedral, was initially overwhelming because of the sheer scale of construction. As was made clear over the course of the week, the statics of the structures are actually quite logical; however, the fact that such intricate complexities were based off of scale-models and a healthy dose of intuition still amazes me.

Reflecting back on our week in Cambridge, what struck me most was the inherent simplicity of these seemingly complex masonry designs, where beauty arises from well-made pieces serving their intended structural role.

– Lindsay Blair Howe

Left: Peterborough Cathedral crossing
Right: Ely Cathedral crossing

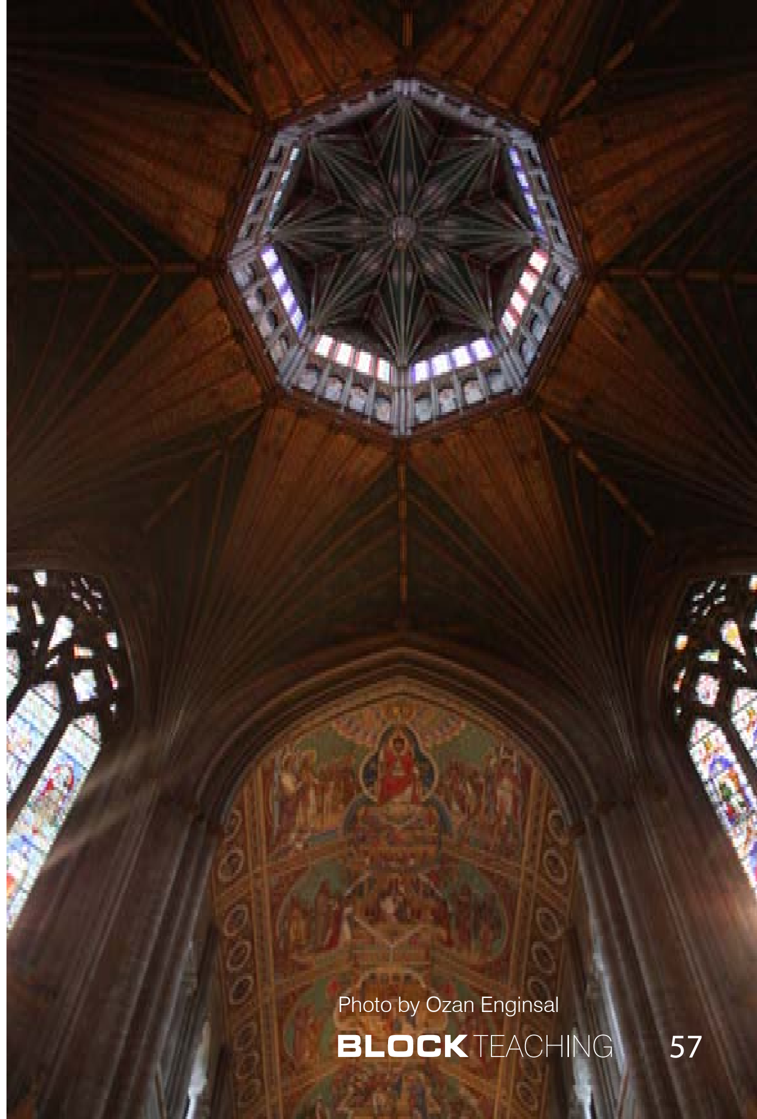


Photo by Ozan Enginsal

ELY CATHEDRAL

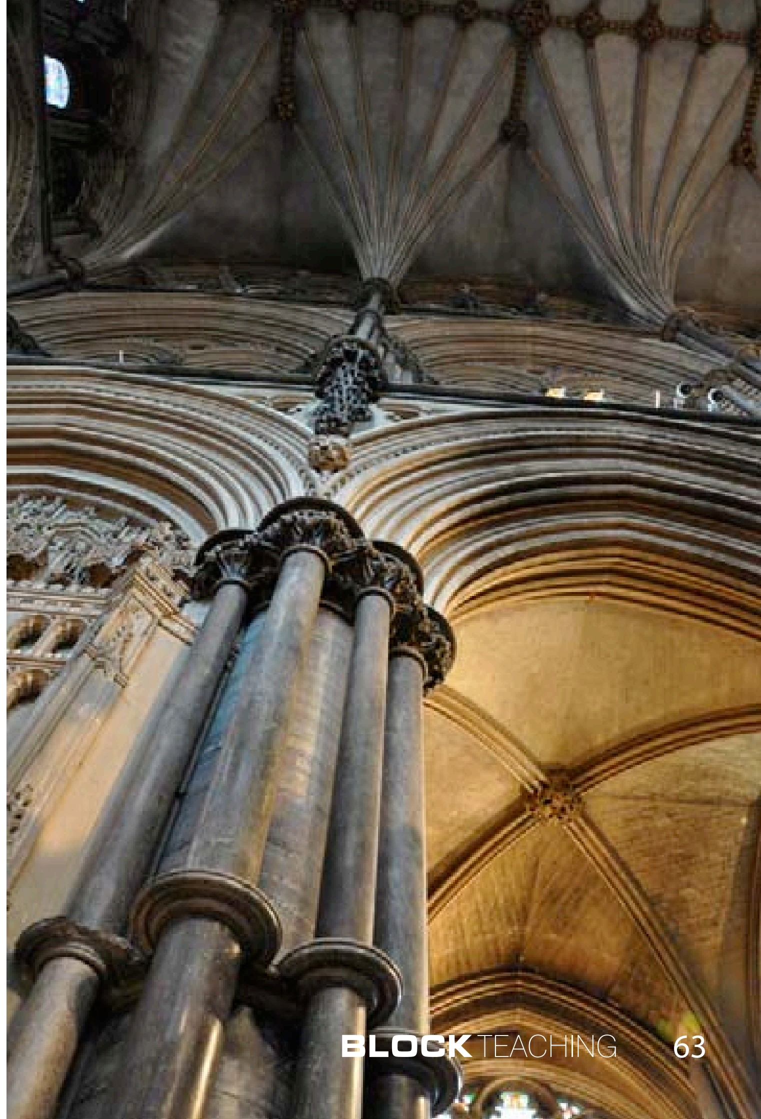
Ely Cathedral, built between 1083 and 1375, includes Norman, early Gothic and late Gothic features. Ely offers several vaulted treasures, including the small, fan vaulted Bishop Alcock chantry chapel, the Lady Chapel net vaulting with elaborate tracery, and the Octagon 'Lantern Tower'. This timber Octagon structure – 23 m wide and 52 m high – was re-built after a catastrophic collapse of the main transept tower in 1322. The history of the tower collapse at Ely demonstrates some of the tremendous complications of ground settlement in the stability of historic cathedrals. The construction of the Lady Chapel disturbed the water table significantly enough to cause the comprehensive differential settlements of the foundations throughout the cathedral, which precipitated the collapse. Evidence of serious ground settlement is still apparent in the deformation of arches in the West tower.

On the day we visited Ely Cathedral we had the only typical English weather of the whole week we stayed in Cambridge. This was rather fitting since it gave the building a mysterious touch. The huge object loomed over us when we got off the bus, after having slept the whole ride. It was an impressive sight for all of us, although the others probably viewed the structure with more understanding of it than I. Little did we know we would be spending the next 3 hours in this church, learning many details about its history and construction.

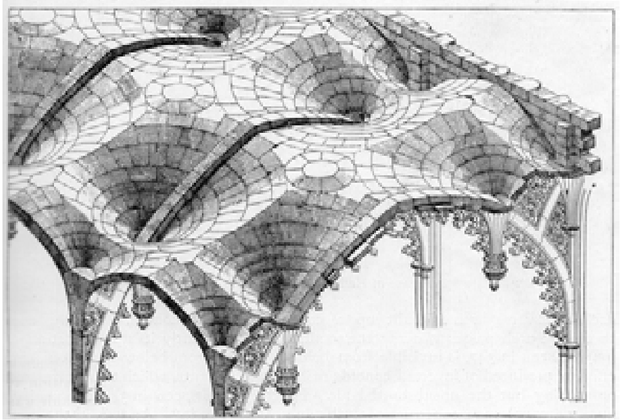
Introducing herself our guide stated: "I'm very old and I'm afraid my eyesight is leaving me, so correct me if I point out something wrong." This was definitely true. Our guide was a small (and visibly very old) woman, who thought it was important to pass on (every last piece of) information on Ely Cathedral. She had a great typical English accent and also a cane to emphasize her gestures.

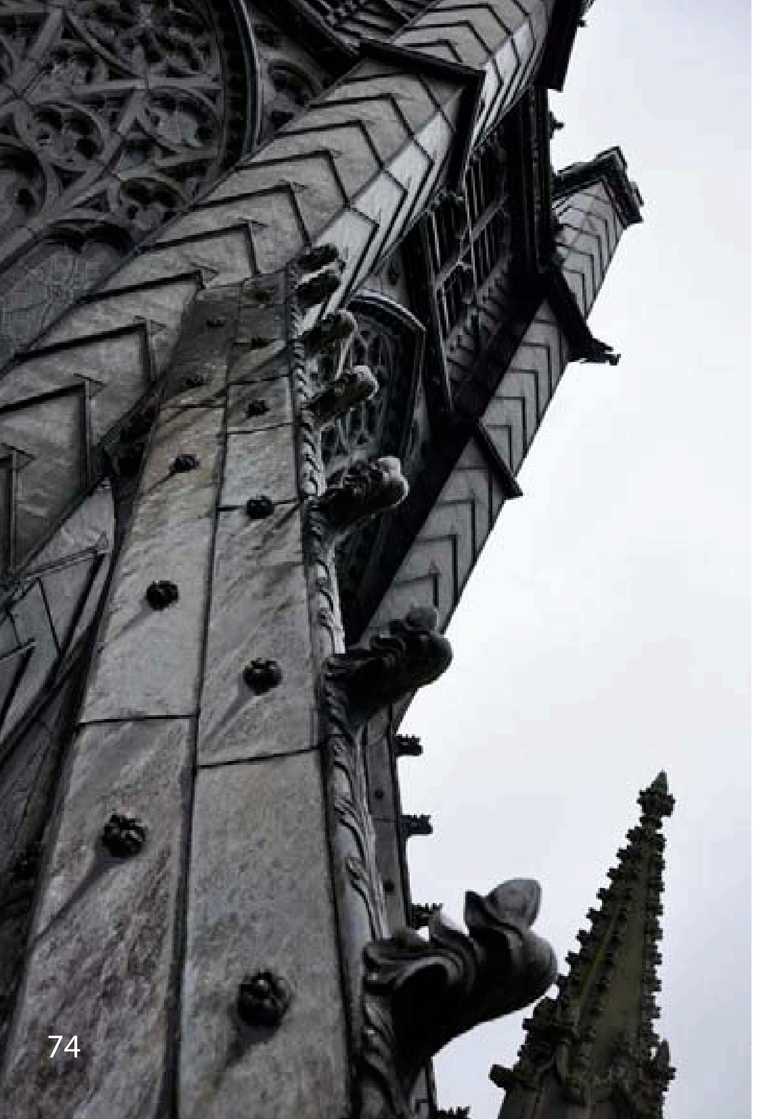
After 2.5 hours of tour we finally got the chance to get on top of the church and climb the octagon tower. This was very refreshing, not only due to the wind and rain outside, but also because of the amazing wood tower. Getting up there was fun enough already. The door and corridors of the tower staircases where about 1.50m x 0.4m. Watching people exit onto the roof was hilarious. After taking all the necessary photos we were able to return to our warming bus, left with an impression of the different corners of Ely Cathedral.

– Emmanuel Hofmann



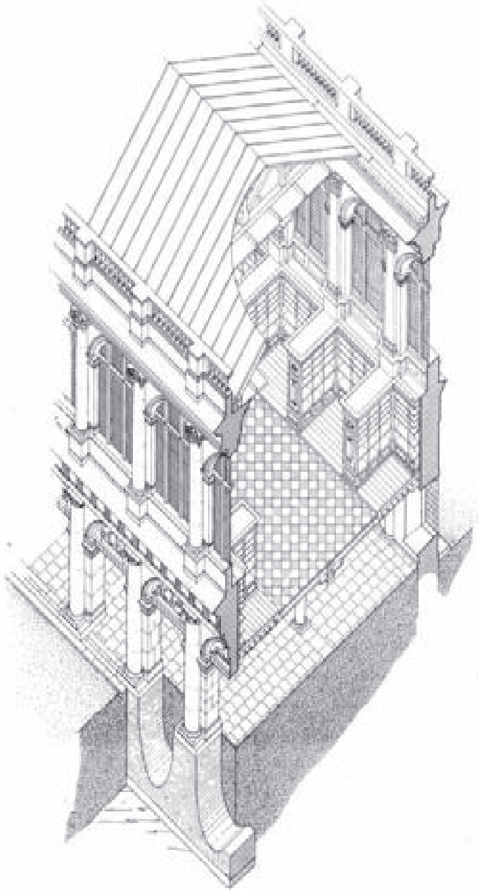
One of the hidden assets of Ely Cathedral is the tiny fan vault of Bishop Alcock's Chantry Chapel, square in proportions and exquisitely worked. Its dropped boss is similar to the stylistic approach later implemented at the Henry VII Chapel at Westminster Abbey in London. Indeed, there is certainly a chance that this little fan vault could have been used as a prototype; it is among the earliest precedents of pendant fan vaults. Scaled models were also frequently used by medieval masons to test experimental methods at practical and affordable scales. The scaled model provides a reasonably accurate test for the behavior of its full-scale counterpart, because it is the geometry of a vault, and not allowable stresses, which confers stability and equilibrium – making the structural behavior of masonry structures independent of scale. This is why small-scale experimental models could be developed profitably in chapels and porches, while allowing masons to test their more daring structures.

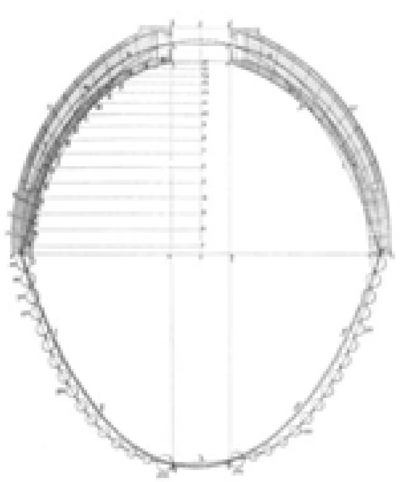




WREN LIBRARY

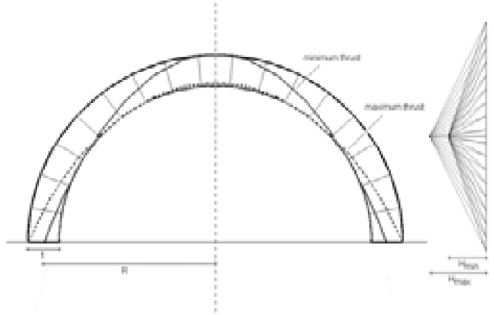
The Wren Library, at Trinity College, Cambridge, is among the first buildings in which Hooke's "Second Law" was put to use. Completed by Sir Christopher Wren in 1695, the library, which rests on ground with a very high water table alongside the Cam River, needed careful planning to prevent the foundations from settling. Wren's solution employed a substructure of deep, inverted, funicular arches spanning between foundation columns. While point-loading from individual foundation columns would have undoubtedly antagonized settlement of the building, inverted arches were known to evenly distribute the load of columns over a greater area, improving the conditions of poor soil-bearing capacity while increasing lateral stability from the arching action between columns. There are, however, no surviving original drawings of the inverted arches, and they were only discovered by chance during renovations in the 1970's.





"As hangs the flexible line,
so but inverted will stand the rigid arch."

– Robert Hooke, 1675



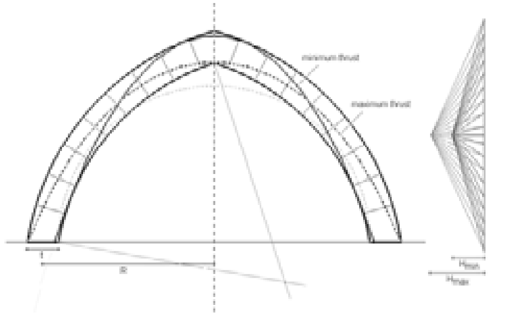


 Photo by Raphael Fitz

VAULTING WORKSHOP

The purpose of the test vaults was to give students an experience with materials and techniques, which would allow their knowledge of structural concepts to be employed as design tools in the development of structural forms. The students engaged in the construction of a 'leaning brick' (Mexican style) vault with unfired clay bricks, two single-curved, timbrel (or Catalan) vaults, and an entire courtyard full of their own experimental constructions. The contrast of these methods, further juxtaposed with analysis of built fan vault structures in the region, allowed students to conceptualize the flow of forces in each of the three primary typologies of spanning space. They developed not only a knowledge of equilibrium in built structures, but also an understanding of static and dynamic loading, stability during construction, and failure mechanisms. The students' loading-to-failure of their own designs gave them direct feedback of their structural design assumptions. They also actively participated in on-going research, building two thin-tile vaults, which were later tested with dynamic loading for seismic performance.

Aside from the thrill of clambering around cathedral rooftops, the practical part of the seminar was also inspiring. My initial contact with thin-tile masonry and the work of the Block Research group began this past summer, in conjunction with the ETH Sustainability Summer School Program in Addis Ababa, Ethiopia. As part of an experimental Sustainable Urban Dwelling Unit (SUDU) construction project supporting the use of low-energy processes and local materials, the flat Catalan vaulting system was to be used for the flooring and roof systems (thus avoiding timber use or requiring metal reinforcement). When first presented with some of the facts – for example, how little framework was required, and the strength of the extremely simple fast-setting plaster mixture – it seemed, frankly, too good to be true. How could it be that this technology wasn't more widespread? After having experienced the process in Ethiopia, and more in-depth in Cambridge, I see several benefits and several questions regarding this construction methodology. The historical precedents of the Catalan vault alone speak for its functionality, beauty, and durability. The ecological benefits of the tiles are also numerous: on-site production is possible, imported materials can be starkly reduced or even eliminated, and once the desired material composition is achieved, the bricks can be rapidly and simply reproduced. Therein, however, lie the primary difficulties associated with this method of construction: considerable time and experimentation is required in order to ensure that the tiles can bear necessary loads, and a certain level of competency and training are necessary to build successfully. It was only through touching the materials myself and having several hours (days, rather) of plaster-mixing and brick-placing failure that I began to develop an instinct for the trickier aspects of this sort of vault building. Because of the "sustainable" nature of the thin-tile vaults, I see great potential for their use particularly in places like Africa, where labor is affordable and readily available, and more relaxed construction schedules can permit the time for proper testing of local material compositions. In such locations, the matter of training and continued presence seem to be the most pressing issue. Concerns regarding climactic conditions come into play in other regions of the world; thin-tile vaulting seems to be impractical in locations with torrential rain, or intense wind or snow loading. It would be extremely interesting to learn more about waterproofing the tiles themselves, which could perhaps lessen this difficulty, or what other related design solutions can be developed in conjunction with the technology available today.

– Lindsay Blair Howe

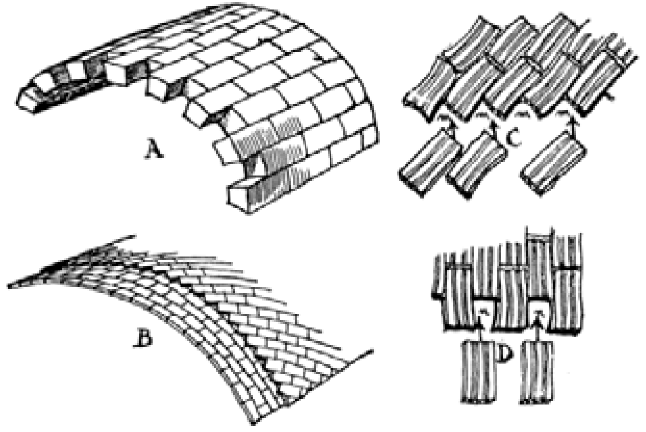

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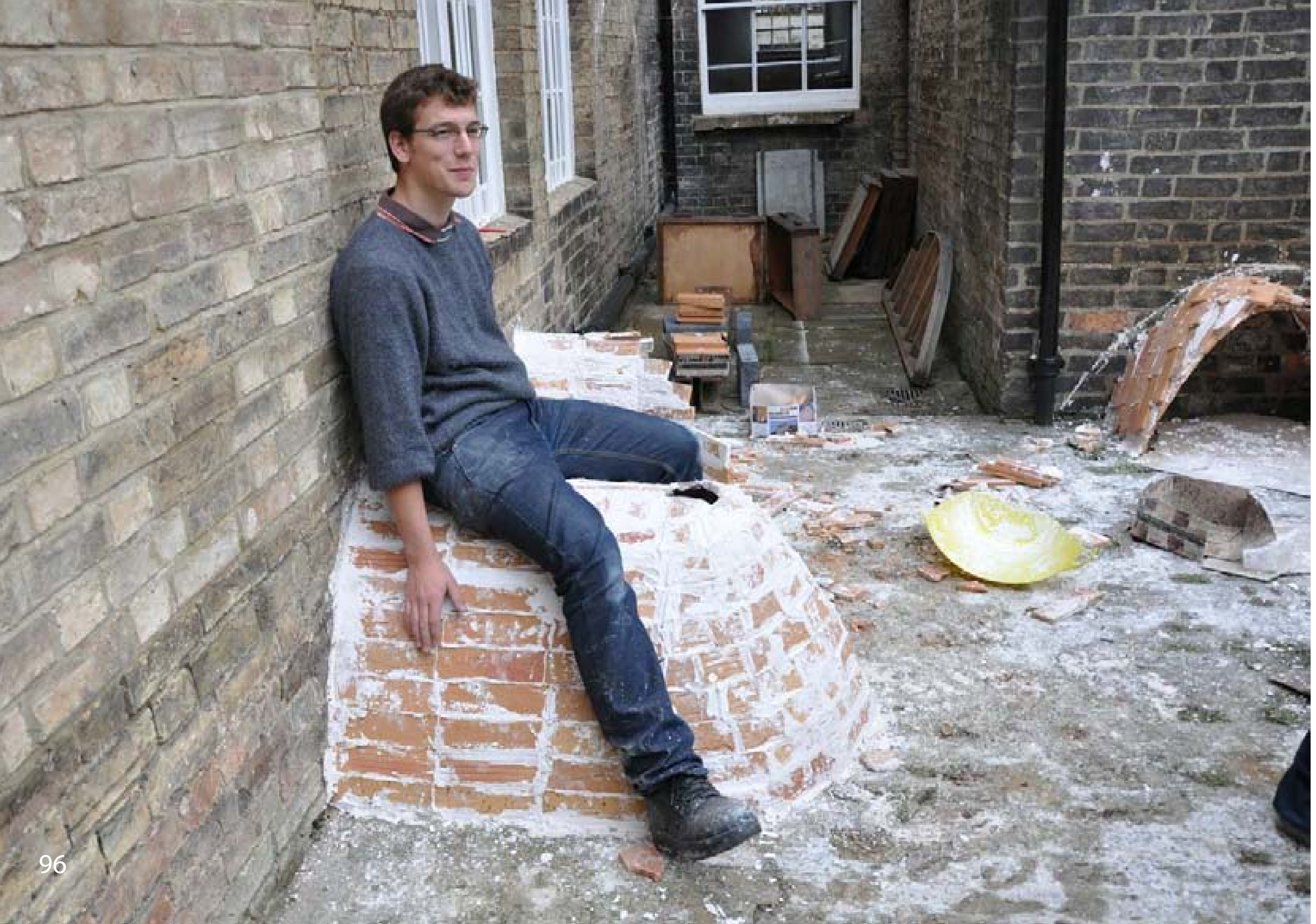
Photo by Demjan Haller



I would like to mention especially the workshop of the vaults. At last, we could ourselves build vaults that Philippe Block illustrated in his lecture slides, and not just always dream of it. The first time I got to substantiate. That was a real fun! This workshop inspired me to apply for an internship at the site. Stone by stone walls require precision. This appeals to me very much.

– Samuel Fent

The second part of the week, together we tried to implement our current achieved experience into praxis. In the backyard of a engineering department we constructed some little funicular structures out of small bricks. Also a mexican vault was built, supervised by Prof. Alfonso Ramîrez Ponce, a man who has a lot of experience with these sustainable constructions. And also a very precise vault was erected which will be used for some seismic tests. It was great to get dirty while working with plaster and cement and, due to the rainless weather, the mood was surpassingly good.

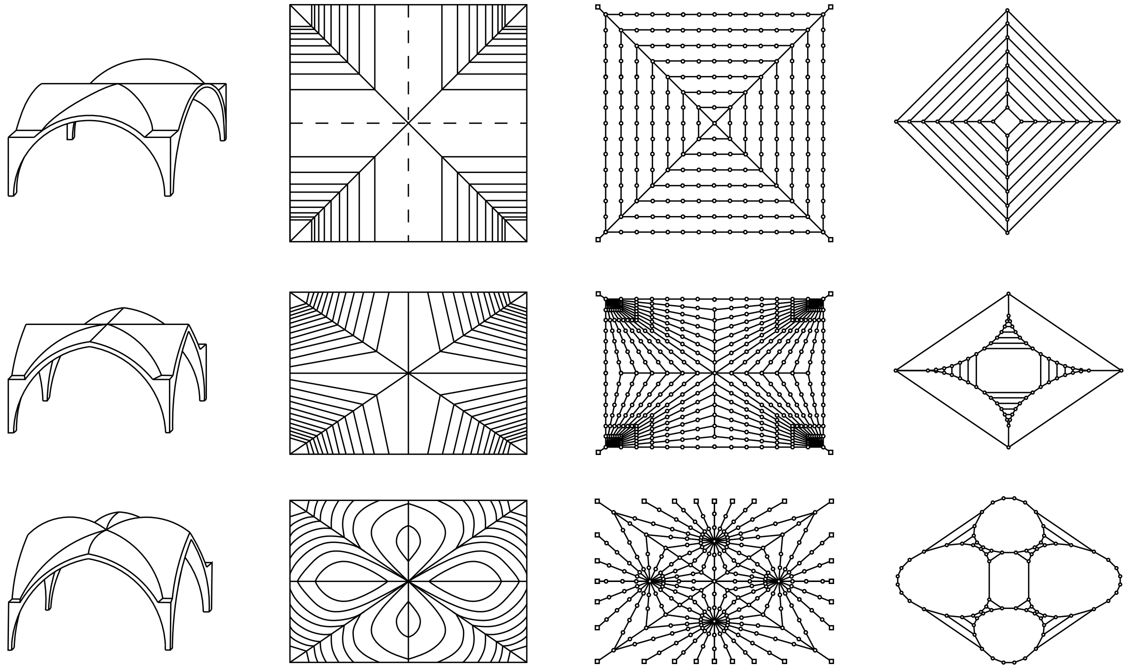
An observation which intensely impressed me was the appearance of the brick walls in general. Even if the buildings in Cambridge are much older than the plastered houses in my region, they look more interesting. The technical carefulness and the archaic aura of these brick houses convinced me. If you connect the brick-walls with such unusual funicular vaults the impression will be amazing. Such combinations can be very sustainable and much more efficient than the cubic shapes of the common buildings. I wonder which solutions will be explored with regard to seismic and thermal questions.

– Jonas Hodel

I could actually write only about the acoustics in Kings Chapel that made the choir and the organ sound so fabulous or about our exclusive trip to its roof; about the three-quarter-cone-vaults at Peterborough Cathedral or just about the beauty of Lady Chapel at Ely Cathedral. I could also write only about our guide at Ely Cathedral who didn't refuse our special request and shared her broad knowledge with us, or about the students of Cambridge University who not only showed us around and make us feel home but also informed us about the delicious, free coffee and tee at the cafeteria in Cambridge University that helped us recover… In other words we have seen wonderful structures; we have met special people that I could write about but I didn't. On the contrary, I have written an unfinished story.

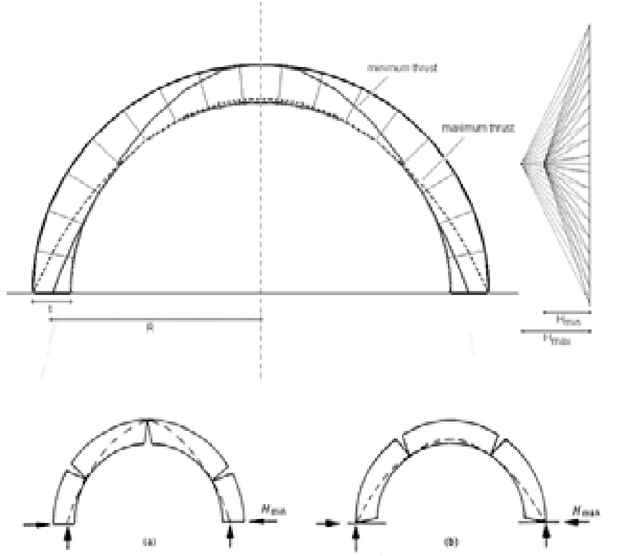
After visiting some of the important historical examples of Fan Vaulting and after a brief theoretical introduction, we were free to experiment with thin tiles at the courtyard of Architecture Department in Cambridge. There were three groups. The first group was building two thin-tile-vaults (one with and one without geotextile) for earthquake-tests. The second group was building the first Mexican vault in Europe. The third group, in which I took part, was assigned with the most serious task among all: We had to fill this courtyard with thin-tile-vaults. As a result of our work, a vault-festival emerged in this tiny courtyard. We built domes, asymmetrical and decentralized vaults. Each of them managed to carry the weight of its builder. *[continued pg. 110]*

– Ozan Enginsal



Nach dem anhören der inspirierenden Vorlesungen unser Dozenten aus Mexico, Amerika, England und Belgien; sowie den vielen spannenden Bauten die wir in und um Cambridge in den vergangenen Tagen besichtigen durften stecken wir voller Tatendrang. Im Hinterhof des Architekturdepartements der Universität Cambridge dürfen wir unserer Kreativität freien lauf lassen mit Gips, Mörtel, Zement, Backsteinen und Ziegelplättchen geht's an die Arbeit. Fachmännisch unterstützt von erfahrenen Gewölbebauern fühlen wir uns schon bald ziemlich vertraut mit dem Material und beginnen unsere eigenen Ideen umzusetzen.

– Demjan Haller



Photos by Demjan Haller

I have to confess, I was a bit skeptical at first –

There I was now, standing in the backyard of the architecture and engineering building of Cambridge observing Prof. Michael Ramage how he was constructing and building the first thin tiled masonry arch as an example. I was quite astonished when I saw how easy the construction was. The mortar, a pure and very viscous plaster, made it easy to stick the tiles together. Motivated from the easy construction, the three of us started to build our own vault. After some starting problems, the gypsum hardens really really fast), our structure grew pretty fast and after 2 hours we were the proud builders of a catenary vault.

Seeing this arch, we longed for more. Although Jonas concentrated on his own solo project the two others of us wanted to build a bigger, longer and more beautiful vault. With our new experiences of the first arch, Raphael and I started to construct the formwork for the vault; without the formwork the structure would have failed during the construction. We started to stick one tile after another and so, the first layer was finished very quickly. But we had the ambition to stand on our structure, though a second layer had to be built. As seen in the lectures, we turned the tiles of the second layer 45 degrees to avoid the overlapping of the joints. After some hesitant endurance testing we decided to build another layer for stiffening reasons. During the second day we finally finished our vault and the great moment of testing had come. Tentatively we ventured to stand on our structure and fortunately for us it passed the test. To our astonishment the vault was way more stable than we thought.

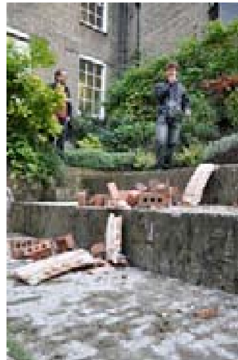
All in all it was a great experience to practice with this kind of construction. We have learned a lot about the behaviour of this structure and the construction phase. And of course it was a lot fun to actually build a structure and not only to design and calculate it.

– Michael Beerli

Two of my colleagues have managed to build a perfect "anticatenary", a three-layer thin-tile-vault. It was only 20 cm wide and 6 cm thick, spanned over 1,2 m and rose 1 meter. There was a height difference of 80 cm between its two-ends whereas the lower-end was thickened with a thin rib construction, which was recommended by Professor Block.

Although we all have repeatedly seen dozens of people standing at the top of a single-layer shell in every structural-design-lecture, we just couldn't count on that, so we decided to start by loading it with brick units. Once there weren't any more bricks left to place, three of us stood on it. The results were obviously good but I had some mixed feelings about that. What was next? What would that mean if it could carry a much higher weight? Was that all about building a vault? At that moment Professor Block came up with the idea that we should try loading it again with brick units, after removing that additional rib construction at the lower-end, so we could see the difference. After we have placed same amount of bricks, it didn't hold more than two seconds. Those 3 bricks that we have removed made all this difference. That was the moment that I have learned something pretty simple, something that is written in every article about vaults, something that Professor Block told us every lecture, it was just something you can't really understand until you experience it, namely the fact that these are extreme structures that won't forgive any mistakes, and that makes these structures so beautiful. I came back to Zurich hoping to build more vaults and hoping that this is an unfinished story.

– Ozan Enginsal

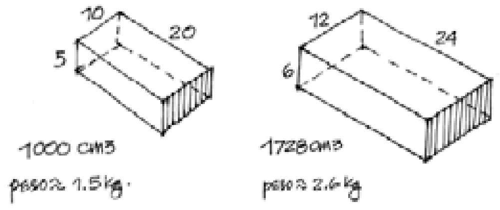


Building a mexican-style vault requires a lot of experience, good working conditions and good materials. Otherwise it can get quite dangerous. We did it exactly the other way around. The students got a crash-course in vault-building (mexican-style) and we used unfired bricks that were twice as heavy as standard Mexican bricks and that were sucking water like a desert sand. The conditions were favorable at least (for England) because it didn't rain. It's good that it didn't, because otherwise the bricks would have melted. At least they could be sculpted with ease with a precise trowel cut.

It took us the whole first day to actually get going with the mortar and brick-laying technique. Actually, the mortar premix that we used didn't stick at all. The bricks were sucking the water out of the mortar, turning it virtually to sand. So they kept falling on our heads (ha ha, not true, we kept dodging them). After the first day we weren't so optimistic that we were actually going to be able to build anything. Plus, any sign of rain would melt our efforts as well as problems away (no vault, no problems).

The next day we decided to make our own mortar mix. The Plaster of Paris we used the day before proved to be quite promising, but we couldn't build the whole vault using just that, so we made a cocktail-mortar made from the lousy premix mortar, added cement to make it harder, and topped it off with some plaster to shorten the binding time. It worked like a charm, especially when we wet the bricks before so they didn't suck too much water out of the mixture. After the initial mis-attempts with geometry (the strong foundations make a strong house) the construction of the vault proceeded forward with a striking speed, with only the occasional brick attempting to get closer to the center of the Earth. Our master-mason Prof. Alfonso called us The Dreammakers. With only one day more, we would actually have been able to build "our dream". But we all agreed that, with the work we did, one didn't have to employ such an imagination to envision it finished.

– Luka Piskorec



The hands-on part on Thursday and Friday was perfect to get an insight into building with bricks. There is probably no better exercise than building your own vaults. Suddenly I understood what it takes to keep a construction site running, what effort is needed to build cathedrals and what a sportive team spirit it takes to achieve an ambition together.

– Lucas Treyer

Photos by Michael Ramage

SEMINARWOCHE STUDENTS:

Lukas Treyer
Pablo Valsangiacomo
Ozan Enginsal
Luka Piškorec
Samuel Fent
Michael Beerli
Gregor Piontek
Emmanuel Hofmann
Isabelle Schulz
Maja Zeller
Demjan Haller
Lindsay Howe
Raphael Fitz
Mallory Taub
Jonas Hodel

Everything began with the lecture of Philippe Block about the Mapungubwe Interpretation Centre. That building thrilled me like no architectural masterpiece that I have seen this year in other lectures, because it had something beyond aesthetics – namely the way it was built. Being just introduced to this innovative, sustainable architecture, to this beautiful structure built from hand-made soil bricks, I asked Professor Block immediately after the lecture: When are we going to build one of those vaults?

– Ozan Enginsal

SEMINARWOCHE LECTURES

The Departments of Architecture and Engineering present:

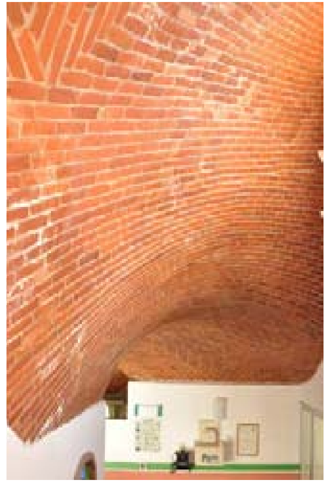
Prof. Alfonso Ramirez Ponce:

generous support from

SRE

Thursday, October 27
5:00 pm

Department of Engineering
Lecture Room 6, 1st Floor



Alfonso Ramírez Ponce is a Mexican architect who has explored for many years and in depth several low-cost and sustainable construction techniques through the use of regional materials such as clay brick, in projects built throughout Latin America. He currently lectures in the "Autonoma University of Mexico" (UNAM), and has been an invited professor in Argentina, Bolivia, Colombia, Cuba, Dominican Republic, Venezuela, Panama, Uruguay, Singapore, Italy, and Spain. He is the author and co-author of more than 200 articles and several books on Architecture.

His research and several of his projects have won diverse awards, including the "Armando Mestre Medal" in Cuba, and also the first prize i the "Competition for the Technology Transfer for Popular habitat" organized by CYTED. He is also a member of the "Academia Nacional de Arquitectura", and the "National System of Art and Culture Creators" of México.

The Departments of Architecture and Engineering present:

Exploiting Structural Indeterminacy:

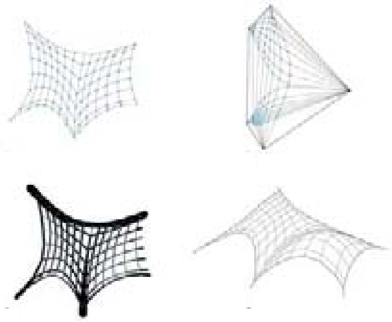
Free-form unreinforced stone shells

Dr. Philippe Block

Assistant Professor in Building Structure
Swiss Federal institute of Technology (ETH) Zurich
Institute of Technology in Architecture, Department of Architecture
Associated faculty of the Department of Civil, Environmental and Geomatic Engineering

Founding Partner | Structural Engineer
Ochsendorf DeJong & Block, LLC, Structural Engineering Consultants

Thursday, October 28
5:00 pm
Department of Engineering
Lecture Room 4, Ground Floor



This lecture will present a new computational form-finding method for exploring three-dimensional equilibrium shapes, inspired by the understanding of the old master builders. Through the use of intuitive graphical diagrams, the designer gains control over the exploration of form, which blurs the boundaries between funicular (compression-only) and free-form design. Several projects will demonstrate the power of this innovative method applied to the safety assessment of historic vaults with complex geometries in unreinforced masonry and to design explorations of funicular shapes, which range from unique signature vaults in cut stone to sustainable construction solutions for developing countries.

Philippe Block is a structural engineer and architect and is Assistant Professor of Structural Engineering at the ETH-Zurich in Switzerland, where he directs a research group in masonry structures and new structural design and fabrication approaches (see http://block.arch.ethz.ch/). He studied architecture and structural engineering at the Free University in Brussels and earned his PhD from MIT in 2009, where he developed a revolutionary computational method for masonry vault assessment and design. For his PhD research, he was awarded the Hangai Prize from the International Association of Shell and Spatial Structures. As partner at Ochsendorf DeJong & Block, LLC, he applies his research into practice in the analysis of vaulted historic masonry with complex geometries and the design and engineering of compression structures pushing innovation in unreinforced masonry.

PROF. JACQUES **HEYMAN**

WORKSHOP FACULTY

Prof. Dr. Philippe Block
ETH Zurich, D-ARCH

Philippe Block is a structural engineer and architect and is Assistant Professor of Structural Engineering at the ETH Zurich in Switzerland, where he directs a research group in masonry structures and new structural design and fabrication approaches (see http://block.arch.ethz.ch/). He studied architecture and structural engineering at the Free University in Brussels and earned his PhD from MIT in 2009, where he developed a revolutionary computational method for masonry vault assessment and design. For his PhD research, he was awarded the Hangai Prize from the International Association of Shell and Spatial Structures. As founding partner of Ochsendorf DeJong & Block, LLC, he applies his research into practice in the analysis of vaulted historic masonry with complex geometries and the design and engineering of compression structures pushing innovation in unreinforced masonry.

Lara K. Davis
ETH Zurich, D-ARCH

Lara Davis holds an MArch from MIT, a BFA from the NYSCC School of Art & Design, has pursued research at the Institute for Lightweight Structures and Conceptual Design (ILEK), and is currently a doctoral research assistant for the BLOCK Research Group. She received the Marvin E. Goody Prize for her master's thesis, "The 4-Dimensional Masonry Construction", which investigated limit states of unit hinging and modification in single-layer tile vaults. She has served as construction manager for the MIT Masonry Research Group, and has designed and built work in exhibitions at the MoMA, MIT Museum, and The Cooper-Hewitt National Design Museum. She has worked extensively in the field as a mason, foreman and project manager for structural and non-structural masonry projects, and recently led workshops on timbrel vault construction in Addis Ababa, Ethiopia, supervising the construction of the SUDU vault for the Urban Laboratory ETHiopia Summer School.

Prof. Michael Ramage
University of Cambridge (UK), Dept. of Architecture

Michael Ramage has a degree in architecture from The Massachusetts Institute of Technology and currently teaches structural engineering in the Architecture Department at Cambridge University in England. Prior to studying architecture, he had a Fulbright Fellowship to Turkey to study geology and archaeology. He is one of the designers of the masonry vaulting for the Mapungubwe Interpretive Centre in South Africa which won the World Building of the Year award in 2009 and the David Alsop Sustainability Prize from the Institution of Structural Engineers. He also designed the domes for the Pines Calyx, the first Guastavino-style vault to rise in the United Kingdom, and the 20-meter span vault for Crossway, one of Europe's lowest-energy houses. His most recent work includes The Bowls Project, a contemporary architecture and music installation at the Yerba Buena Centre for the Arts in San Francisco, and The Earth Pavilion in London, designed for HRH The Prince Charles as part of The Earth Awards 2010.

Prof. Dr. Matthew DeJong
University of Cambridge (UK), Dept. of Engineering

Matthew DeJong is a structural engineer and Lecturer (Assistant Professor) in Engineering at the University of Cambridge, specializing in structural engineering and structural dynamics (see http://www-civ.eng.cam.ac.uk/struct/mjd). He studied civil engineering at the University of California-Davis and has worked for a structural engineering design consultancy in California. He earned his PhD from MIT in 2009, where he focused on numerical modeling of masonry structures under earthquake loading. In 2007-2008, he was a Fulbright Scholar at TU Delft in the Netherlands and in 2009 he won the international Graduate Student Paper Competition from the Earthquake Engineering Research Institute (EERI) and the international Edoardo Benvenuto Prize from Italy for his research in mechanics and architecture. DeJong is also one of the founding partners of Ochsendorf DeJong & Block, LLC.

Prof. Alfonso Ramírez Ponce
Universidad Nacional Autónoma de México (UNAM)

Alfonso Ramírez Ponce is a Mexican architect who has explored for many years and in depth several low-cost and sustainable construction techniques through the use of regional materials such as clay brick, in projects built through out Latin America. He currently lectures in the "Autonoma University of Mexico" (UNAM), and has been an invited professor Argentina, Bolivia, Colombia, Cuba, Dominican Republic, Venezuela, Panama, Uruguay, Singapore, Italy and Spain. He is the author and co-author of more than 200 articles and several books on Architecture. His research and several of his projects have won diverse awards, including the "Armando Mestre Medal" in Cuba, and also the first prize in the "Competition for the Technology Transfer for Popular habitat" organized by CYTED. He is also a member of the "Academia Nacional de Arquitectura", and the "National System of Art and Culture Creators" of México.

IMAGE CREDITS