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Tile Vaulting as an Alternative

David López López

Department d'Estructures de l'Edificació
Universitat Politècnica de Catalunya, Barcelona, Spain
e-mail: lopezlopezdavid@gmail.com

Marta Domènech Rodríguez

Departament de Projectes Arquitectònics
Universitat Politècnica de Catalunya, Barcelona, Spain
e-mail: marta.domenech@upc.edu

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Abstract

Hundreds of years support the effectiveness and efficiency of some traditional building techniques which solved architectural aspects of housing, as well as other tiypologies.

Tile vault origins might date back to Roman times, when they used this technique as permanent formwork for their vaults. However, tile vaulting, or "volta catalana", appeared in Spain as we know it today five centuries ago. It consists on the construction of vaulted structures of different geometries with bricks placed flat. The first layer is joined with plaster or quick setting mortar and serve as formwork for the next layer which is joined with mortar.

Several factors can justify building using this traditional technique, among others:

1. Within the context of the current crisis, it is increasingly essential to take the economy of building into account. The fact this construction does not need scaffolding makes its cost very low.

2. The versatility of this technique makes it possible to be used in both small and large spans, and to build floors and stairs of different geometries operating under compressive stress.

3. The stability of these structures depends on its geometry, which optimizes the amount of material used. These vaults can withstand housing common loads and cover the typical spans of this type.

4. The easiness of brick manufacturing and the possibility of purchasing it within a local trade ensures a sustainable technique that, in addition, after its collapse, doesn't mean a serious pollution.

5. Due to the material used, this technique has a considerable resistance to fire and is not susceptible to insect attack or decomposition, as wood may be.

The fact is that recovering this traditional technique means a smart choice, specially when the budget is limited or the resources reduced.

1 Origins and method of tile vault

"... tile vaults are an effective constructive invention because, with bricks and plaster or fast cement, a skilled mason can do in a few hours, a huge variety of resistant forms, without any other tool than drawer and palette .. . " [1]

Tile vaults -or "volta catalana"- are included within the masonry vaults, but are built with a particular technique: the bricks are arranged flat, to form a sheet or sheets, and is made without formwork. The first sheet is built with plaster, which hardens very fast and is used as formwork for the next sheet of bricks. The bricks are disposed closing successive rings or arches. While closing the arches, holding the bricks is achieved by the accession of fast-setting mortar with previous -already built- rings and arcs, or with the edge walls. [2]
The number of sheets of bricks may vary depending on the span and the acting loads. They can be a layer (about 5 cm thick, self-supporting, but it does not serve as framework), two layers (about 10 cm thick, the mo used) or more layers.

Although it was mainly in the nineteenth and twentieth centuries when the most spectacular and more quality examples were built, tile vaulting is known in the East of Spain and Southern France since the beginning of the fifteenth century, and some people see a credible precedent in the formwork used by the Romans in their buildings. [3] Until its decline about mid-twentieth century, tile vaulting was used regularly in homes in this area for stairs and floors.
With the Catalan modernism it reached its peak in terms of expressiveness, versatility and importance, with the works of, among others, the great Antoni Gaudí Cornet and Lluis Domenech i Montaner. No less important in the history of these vaults is the episode of this technique's exportation to the U.S. by Rafael Guastavino Moreno and his enormous success in these lands, where there are hundreds of examples, especially in the city of New York, extraordinary feats of engineering are achieved with spans up to 40 meters and where the tile vault is at the core of buildings of great significance.
In both the Catalan Modernism and the American episode, the "volta catalana" is used in major public and private buildings, but not abandoned at any time, even in this era, its routine use in housing construction.

2 Challenges of tile vaulting

2.1 Within the context of the current crisis, it is increasingly essential to take the economy of building into account. The fact that the construction of the "volta catalana" does not need scaffolding makes their cost very low.

The works constructed with "volta catalana" are sparking new enthusiasm and begin to be studied in academic circles. Since the sixties, this type of construction was abandoned and it is only now beginning to have the space and attention it deserves.
This recognition is due in part to the currently growing interest in low cost construction. And this certainly is: no need for formwork and it requires little material. The material used, the traditional brick, now it may also be made of sand, clay, "marés" stone –a mixture of sand and chalk-, or what best suits what the environment supplies.

As it often happens in traditional work, all the ingenuity of this technique is the result of exercise simultaneously accurate and deep intuition, and the patient task of experimental verification.
What is practical and cheap is sometimes considered opposite to what is beautiful and ethical: on one side what should be, on the other side what it is, either for convenience or inertia of the practical issues. However, in this case, despite its low cost, tile vaulting does not give up the qualitative values.

The project by Pr. Peter Rich, Mr. Michael Hector Ramage, Prof. John Ochsendorf, Ms. Anne Fitchett and Mr. Mathew M. Hodge, academics from the MIT is an example of this advantage.

Figure2: Mapungubwe National Park Interpretive Centre

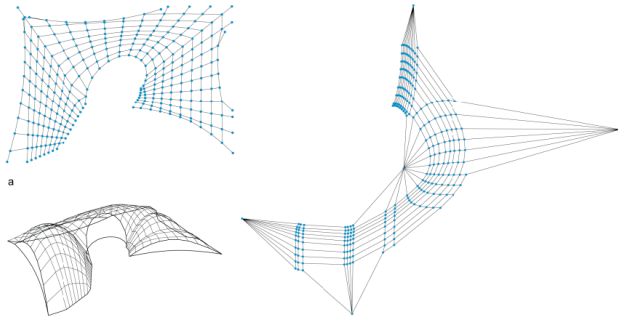
They built an Interpretation Centre for the Mapungubwe National Park in Ethiopia. The restrictions were about budget and construction time, but the use of steel was also limited and the use of local materials was requested to boost the economy by creating jobs. These limitations led to the use of the tile vaults to build the center.
It was built with earth bricks typical of the vernacular, a decision that led to cheapen the work 30% more than if it had been made with concrete [4]. Moreover, the use of local materials adds socio-economic benefits, as it generates employment in the area, an important factor in a developing country. Several unemployed South Africans were instructed to learn to build with this technique and with adobe to build vaults.
Thus, this technique has been rediscovered as a low-cost method and affordable for the majority of the world population.

2.2 The versatility of this technique makes it possible to be used in both small and large spans, and to build floors and stairs of different geometries operating under compressive stress.

The brick is the basis for the construction of tile vaults, giving construction multiple formal possibilities. Either large domes with big spans in a cathedral or small stairs in a little house can be built with this technique. According to Guastavino, tile vaults had to become more common constructions in the world. But that didn't happen. In 1962, they closed the office and the technique became obsolete with the advent of steel and concrete, which offered many more formal possibilities.
However, two examples tried to keep the technique a few years more:
The first, Eladio Dieste, who incorporated the steel to the construction of such vaults expanding greatly the formal possibilities. Also notable and relevant -and more faithful to the traditional technique of tile vaults- is the example of the art school in Cuba by the architects Ricardo Porro, Roberto Gottardi and Vittorio Garatti. A project that explored the formal possibilities of this building technique. It was an unfinished work, built between 1961 and 1965. The ambitious plan was for a national complex of art

schools. As modern construction materials were scarce but labor abundant, they decided to use tile vaulting.

Art School in Havana 1961-1965



The TNA form finding for freeform vault: a) diagram; b) the resulting compression-only thrust network in equilibrium with a given loading; and c) its corresponding reciprocal force diagram.

In 1965 construction was halted and the complex was abandoned until 1991, when John Loomis visited the schools and was surprised by the "magical realism of landscape and architecture." In the late 90's, he published a book that rehabilitated the Cuban revolutionary architecture (Revolution of forms. Cuba's Forgotten Art Schools). When Fidel Castro read it, he criticized the officials for allowing the art schools fall into such a state of neglect. In December 1999 the three architects were invited to return to Havana to finish the job. The work progresses; slow though.

Currently, several research groups explore the formal possibilities of this technique. A notable example is Lara Davis, Matthias Rippman and Philippe Block, from the group “Swiss BLOCK” in ETH Zurich University, where they explore traditional techniques combined with new software tools and CNC manufacturing, and new low-tech materials such as cardboard. The tile vaulting system allows them to build with little material and it does not need a strong formwork for construction. The group has designed a new software to combine the advantages of this traditional technique with a large formal variety. The "Rhinovault" enables the design of forms that work under compressive stresses using the minimum amount of material.

2.3 The stability of these structures depends on its geometry, which optimizes the amount of material used. These vaults can withstand housing common loads and cover the typical spans of this type.

In order to understand the tile vaulting structural behavior, we should know that tile vaults are masonry structures, with the structural features that that entails:

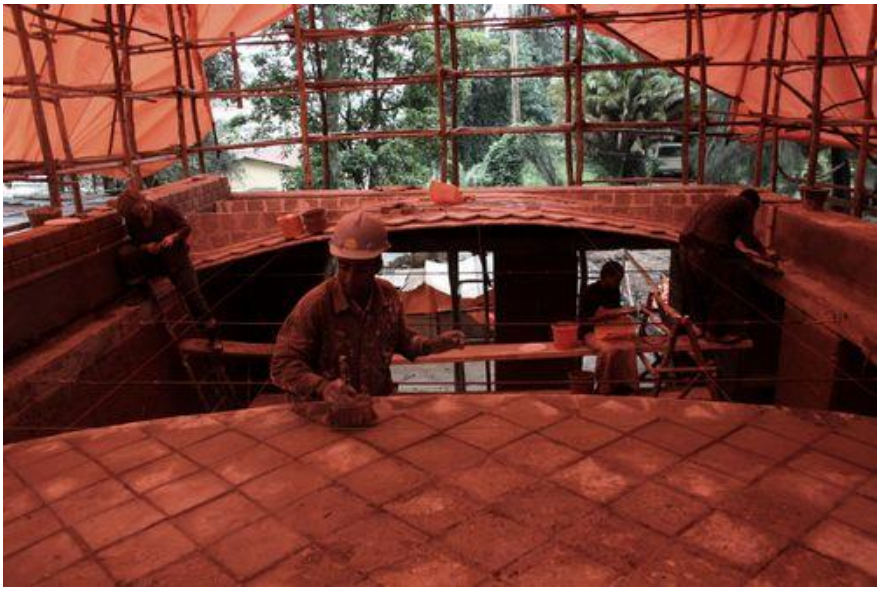
- Its tension strength is minimal, and could be considered void.
- The compressive stresses achieved in these structures are generally much lower than the endurance limit of the material, therefore resistant analysis is unnecessary.
- There is no elastic deformation in them, but there are movements.
- The condition of equilibrium is, therefore, what becomes important for the stability of the structure. A tile structure will be stable provided it is in balance.

Graphical analysis of these structures, although not the only valid one, is usually the most appropriate and straightforward in most cases.
Throughout history there have been various opinions as to the structural behavior of such vaults. The statements set forth above were not -nor are today- shared by the entire set of professional scholars.
In the late nineteenth century Guastavino himself -exporter of this technique to the U.S.- or the Comte d'Espie –who spread it in France- in the eighteenth century, attributed bending and tension capacity to these vaults, and talked about "cohesive" or "monolithic" structures. Such an assertion could be dangerous since it was accompanied by the denial of the thrusts on the basis of the vaults. Fortunately there was usually not a direct translation from their writings or theories to their built works, because experience told builders -and the Guastavino's were great builders- that tension rings, little partitions or filling material had to be used to absorb possible tension stresses as well as sufficiently heavy walls were needed to support horizontal thrusts.
It is possible that those who so thought had not read -or had not believed- Fray Lorenzo de San Nicolas when he stated in the seventeenth century that the lightness of tile vaults reduces the horizontal thrusts compared with other masonry structures -but there are thrusts-.[2]
Analyzing the above, we can deduce certain advantages:
- They are calculated like the rest of masonry structures, which can be a simple graphical analysis.
- It does not need walls as thick as other masonry structures since the thrusts are lower due to low weight.
- Since the resistance is usually not a problem and its stability depends on the equilibrium, its bearing capacity is usually more than enough for the common loads in housing, as demonstrated empirically with numerous load tests. (It should be emphasized again the importance of little partitions or filling material to withstand tension stresses resulting from possible asymmetric or mobile loads).

2.4 The easiness of brick manufacturing and the possibility of purchasing it within a local trade ensures a sustainable technique that, in addition, after its collapse, doesn't mean a serious pollution to the environment, which may occur using other kind of materials.

In this article "Tile Vaulting as an alternative" we want to retrieve this medieval technique that allowed to build structures that today no architect would dare to do without steel. The technique, as we have seen, is cheap, fast, durable and environmentally friendly. Since a few years tile vaulting is reappearing in various sectors: in search of low-cost, formal exploration and sustainable construction.
In this section we show two projects: Crossway Passive House of Richard Hawkes in England and the Sustainable Urban Dwelling Unit (SUDU) in Ethiopia, a joint project between ETH Zurich and the Ethiopian Institute of Architecture, Building Construction and City Development (EiABC).
The Crossway is one of the first buildings officially certified as a liability in the UK. The building explores the use of solar energy to generate all its electricity and thermal energy, and construction techniques with minimal environmental impact: tile vaults, light wood and a land settlement.
SUDU in Addis Ababa is less spectacular, but it shows us how to build the metropolis without using concrete, steel or wood. It is a sustainable and ecological building, made with a combination of tile vaults and compressed earth blocks.

The SUDU combines techniques of the past from different continents, giving rise to a new approach to low-tech construction adapted to local resources: stabilized cement and compressed earth block (CEB) as materials. The project aims to eliminate dependence on imported and high-energetic-consumption materials such as steel and concrete. It also excludes the use of wood, because wood is scarce in the country also.



The Sustainable Urban Dwelling Unit (SUDU) under construction

One of the most challenging current problems in Africa (and throughout the developing world) is the tremendous lack of housing for the urban poor. In Ethiopia, this is reflected in informal housing all over the country, reaching perhaps 80% of the built areas of the capital, Addis Ababa.
The most common construction method is the construction with eucalyptus wood and mud, an economically and environmentally sustainable, but the problem is that no more than one store can be built and this creates kilometric cities where a balance between movement in the city and access to resources is difficult.
The government is promoting the construction of large concrete dwellings. However, that is not a model of economic and environmentally sustainable development; it does not offer an alternative low-cost housing and does not prevent the number of people who are forced to live homeless grow day after day.
The technique used in the SUDU, inspired by traditional methods and using materials available locally, provides jobs, introduces new techniques and encourages self-sufficiency.

2.5 Due to the material used, this technique has a considerable resistance to fire and is not susceptible to insect attack or decomposition, as wood may be.

The construction technique of tile vaulting has historically been considered very effective against fire or insect attack. The church Santa Maria del Mar in Barcelona, burned for 11 days due to the bombing of the Civil War and remained standing. When Guastavino went to America after the Great Fire of Chicago

in 1871, his company was a great success called "Guastavino Fireproof Construction Company". Floors, ceilings, arches and stairways were also provided with sound isolation and were resistant to flooding, moisture and pests such as rats and cockroaches.
Today, reinforced concrete, steel, or even certain types of wood can also provide these guarantees, but it must be remembered that some of the treatments to get these benefits are really expensive.

3 Conclusions

Tile vaulting is a traditional building technique from the western Mediterranean abandoned as a usual construction system, but able to be retrieved both in housing and in other typologies considering its qualities such as its low cost, formal versatility, load bearing capacity, sustainability and resistance to fire and insect attack.

If this paper defends the possibility of recovering a construction technique is because previously it has disappeared for some reason. The disappearance of a building tradition is logical to be caused by an improvement of construction techniques, its economy or its ease of implementation, among other reasons. Therefore, this paper does not seek an uncritical return to the past nor a simplistic and systematic rejection of concrete and steel. It only tries to present a construction technique that had a long history thanks to its many benefits and whose disappearance -probably inevitable- in a place with a particular context does not mean it is not valid for other locations with different contexts. It is perhaps not the most versatile system for every dwelling construction, but we wanted to show briefly its advantages because it can be a choice between the different techniques in certain circumstances, that is to say, an alternative.

We claim the possibility of its recovery -mainly but not exclusively- on projects for housing construction in poverty contexts where this solution can give a response which is quick, quality, sustainable and with local materials to reduce the cost.

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