Interview with Manuel Fortea Luna

MAFALDA BATISTA PACHECO
CHAM Centro de Humanidades
NOVA FCSH

JOÃO VIEIRA CALDAS
CiTUA Centro para a Inovação em Território, Urbanismo e Arquitetura
ULisboa IST

Manuel Fortea Luna is an architect and holds a Doctorate in Art History from the Universidade de Coimbra (2002) and a Doctorate in Graphic Engineering, Geometry, and Projects from the Universidad de Extremadura (2013). He served as the Dean of the College of Architects of Extremadura from 2003 to 2005 and is a specialist in vaulted structures. He is passionate about the recovery and teaching of traditional vault construction techniques in the Iberian Peninsula, focusing on their contemporary significance.

Manuel Fortea Luna has coordinated various workshops and courses on vaults in Spain and Portugal. He is the author of several books and articles on vaults, particularly timbrel vaults in the Extremadura region of Spain. His most notable works include the book *Bóvedas Extremeñas. Proceso constructivo y análisis estructural de bóvedas de arista* (Colegio Oficial de Arquitectos de Extremadura, 1998) and articles such as *Análisis comparativo en base a la sostenibilidad ambiental entre bóvedas de albañilería y estructuras de hormigón* (2012), *Bóvedas tabicadas. Tradición y oportunidad* (2015), *Bóvedas tabicadas: ¿Artesanía o punto de partida?* (2019), *La bóveda de escalera tabicada* (2020), *Método, gestión y tutela* (2023), and *The vault of Room H-100 at the site of Casas del Turuñuelo (Guareña, Badajoz, Spain). Hypotheses and interpretations based on archaeological evidence* (2024).

Between May 2022 and December 2023, Manuel Fortea Luna played a significant role as a scientific consultant for the project Vaulted South – Vernacular Houses in the South of Portugal. He organised a technical visit on vaulted constructions for the project members in Zafra, Spain, in June 2023.

ORCID: 0000-0002-1091-6325
https://orcid.org/0000-0002-1091-6325

ORCID: 0000-0001-9277-932X
https://orcid.org/0000-0001-9277-932X

Manuel Fortea Luna was interviewed by Mafalda Batista Pacheco and João Vieira Caldas during the forum Vaulted South – Vernacular Construction Knowledge and Brick Vaults, held at the Colégio Almada Negreiros, FCSH NOVA University, Lisbon, on November 16-18, 2023. During this event, he delivered a lecture entitled 'Vaults: A Historical Technique with a Future' at the headquarters of the Ordem dos Arquitectos, also in Lisbon. [Fig. 1]

Fig. 1 Manuel Fortea Luna during the forum Vaulted South – Vernacular Construction Knowledge and Brick Vaults, held at the Colégio Almada Negreiros, FCSH NOVA University, Lisbon, on November 17, 2023. Soure: Mafalda Batista Pacheco, 2023.

RHA: For decades, you have been researching vault construction systems, primarily the brick vaults in Extremadura, Spain, and also in Portugal, near the border. You were also a consultant for the Vaulted South project, which aimed to explore the current vaulted houses in Alentejo and Algarve, Portugal. What is unique about these vaults?

Manuel Fortea Luna: In the south-east of Portugal, there is a very particular kind of vault, a brick vault, constructed without centering. This type of vault is also found in parts of western Spain. Culture, technique, and knowledge, in general, do not align with administrative borders; they flow through the territory and are limited by other conditions.
These vaults are constructed with bricks, a masonry technique with its own rules and characteristics. The other construction technique for vaults is stonework, which has different features. Masonry vaults require two main elements: bricks and the mortar to bind them. Bricks are found in all places where the art of ceramics is mastered. The mortar traditionally used is lime mortar.
Brick is one of the oldest construction materials known. At its most rudimentary, manufacture consists of simply kneaded clay, dried in the sun and baked in kilns stacked with fuel. One of the earliest places where we find brick is in the paving and vault construction of the tombs of the 3rd Ur dynasty, in Ancient Mesopotamia.
The brick vaults in Spain and Portugal are constructed without centering, meaning without any auxiliary structure during their execution. This gives them both an advantage and a disadvantage. The advantage is that dispensing with the centering lowers costs. The disadvantage is the vaults must be stable at every moment of their construction; that is, they must be stable in all situations during the process. This presents a challenge for their builders. [Fig. 2]

RHA: Portuguese houses with vaults in the south were first made public in the book *Arquitectura Popular em Portugal* (Portuguese Popular Architecture, 1961), published by the National Union of Architects as a result of an inquiry into Portuguese rural architecture. That book led to further studies on vaults. In Spain, a decade later, compilations also appeared, such as *Arquitectura Popular Española* (Spanish Popular Architecture) by Carlos Flores (1973) and *Itinerarios de Arqui-*

Fig. 2 Technical visit of the Vaulted South Project team with Manuel Fortea Luna in Zafra, Spain. Source: Mafalda Batista Pacheco, 2023.

tectura Popular Española (Itineraries of Spanish Popular Architecture) by Luis Feduchi (1974-1984), among others. Were these a turning point in Spain?

MFL: In Spain, some authors had already noticed these unique vaults. Feduchi highlights the importance of the vault in Extremadura, describing it as the most distinctly Extremaduran [architectural] element, capable of individualising an architectural work and qualifying the skills of builders. He traces its origin to the preservation of techniques introduced and mastered by the Romans, and more specifically, perhaps, those developed during the Byzantine Empire (Feduchi 1984, 22).
García Mercadal (1981, 67-68) had already observed that from the Tagus to the Guadiana rivers, there was hardly a single horizontal wooden framework to be found, and that all the floor divisions in this area were composed of vaults, sometimes even roofs. He defined the vault as an essential element of the Extremaduran house, referring to the Byzantine term for vaults built without centering.
Albarrán (1885, 3) wrote a report aimed at promoting knowledge of the construction and execution of brick vaults in the province of Extremadura, about which works about classical construction said nothing. In Extremadura, all vaults are built

without centering, covering basements, cisterns, ground floor rooms, and farmhouses where the upper floor is used as a granary. These vaults are made in different spans and shapes, with beautiful and varied decorations.

Other authors could be cited, but they all agree on the unique importance of vaults in Lower Extremadura, noting a special characteristic, which is that all of them are built without centering. Some justify that by the supposed lack of wood in the region, which is a weak argument considering that in the same region, north of the Tagus, timber-framed architecture proliferates (Pizarro Gómez 1983, 51), while, with a few exceptions aside, vaulted constructions are topped with wooden roofs. In my book *Bóvedas Extremeñas* with Vicente Lopez Bernal (1998), we already noted their existence on both sides of the border and called them Extremaduran vaults. We can describe the Extremaduran vaults as a highly refined technical, constructive, and structural solution, with great economy of means and great versatility in their function.

RHA: You just mentioned they are built without centering. What does that mean? What are the differences between construction with and without centering?

MFL: Construction with centering involves creating two structures: one supporting and the other supported. As a consequence, this approach doubles the cost, since most of the time the auxiliary structure is more expensive than the permanent one. Construction without centering implies a very advanced technology to control gravity, with far-reaching repercussions on execution, costs, deadlines, safety, the guarantee of the work itself, and of course, the final result. It is approached uniquely from its conception, requiring its own specific design, calculation, planning, and execution, which is different from a [type of] construction requiring auxiliary means of support during execution. A construction without centering is constantly fighting for itself against the constant, stubborn action of gravity and represents significant savings by dispensing with an auxiliary structure. In addition to cutting costs, there is the advantage of reduced execution time, which sometimes can be more valuable than monetary costs.

Solving several problems at once with a single gesture is not the result of chance or luck, but of analysis, reflection, experience, and ingenuity. **[Fig. 3]**

RHA: Is this kind of brick vault, constructed without the use of centering, found in other areas of the Iberian Peninsula? Are there similar references to this technique being used elsewhere?

MFL: There are no references to this type of vault in the rest of the Iberian Peninsula, including during the Roman period, so we can rule out a Roman origin. To find refer-

Fig. 3 Vaulted South Project team meeting about types of vaults in Portugal and Spain, with Manuel Fortea Luna in Zafra, Spain. Source: Mafalda Batista Pacheco, 2023.

ences of this type, we really have to move to the Middle East. We find vaults of this type in Hagia Sophia in Istanbul, completed in the year 537 AD. But the oldest ones have been found south-west of ancient Nineveh, at Tell Rimah, the ancient Karana, a site built around 1800 BC, during the time of Shamshi-Adad I of Assyria. The entire complex is built with mud bricks and bricks and corresponds to a monumental building following the Babylonian tradition. It has brick vaults with a conical row arrangement, which is outstanding. This is a unique technique of construction without centering that would become popular 2000 years later in the Byzantine Empire.

In Egypt, the funerary temple of Ramses II, who ruled from 1289 to 1222 BC, located in the necropolis of Thebes, on the west bank of the Nile River opposite the city of Luxor, has warehouses surrounding the temple under vaults too. The warehouses were large and give us an idea of the huge amount of products stored in them. These are barrel vaults with a non-circular section (apparently an elliptical or catenary arch) composed of four brick layers. The rows are conical, meaning the bricks are inclined at an angle. This technique is clearly of Mesopotamian origin. Some authors doubt the origin of these vaults built between Egypt and Mesopotamia without centering. It is evident that they appear earlier in Mesopotamia (we already mentioned Karana), and it is also evident that they are found sporadically in Egypt.

This vault system was not used by the Western Romans in the Iberian Peninsula; so I believe it is a technology imported from the Near East, of unknown date and itinerary.

RHA: Does this construction technique with conical rows without centering appear in the Iberian Peninsula?

MFL: The secret of this system lies in tilting the rows without exceeding their angle of attrition, thus ensuring their stability without any other support. In a barrel vault with a circular section, the inclined rows are ellipses, and the construction begins from two opposite ends simultaneously until they meet at the closure. These vaults and the ones described by the mentioned authors are found in Extremadura and are still seen relatively frequently today.
Auguste Choisy ([1899], 335-336), in his *History of Architecture*, explains the technique of conical rows, mentioning that Byzantine vaults, like Persian vaults, are executed, as far as possible, without auxiliary supports. In Syria and Armenia, vaults were almost exclusively built of stone, and the advantages of construction without centering were limited to the domes. But the Byzantine building tradition, which systematically used brick, built its vaults 'directly in space', and the new types of vaults added to the ancient Persian repertoire are the groin vault, which the Persians never practised, and the dome on spherical triangles instead of the dome on squinches, the only one known to the Persians. In the method of conical rows, the rows are constructed in order from the walls towards the centre, successively overlapping.

RHA: Another technique to build vaults in the south of Portugal and Spain is characterised by placing bricks with the underside showing, known as *abobadilha alentejana* and *bóveda tabicada* (timbrel vault), also without centering. What is the difference from the ones we were speaking about previously?

MFL: There are only two known techniques for constructing vaults without centering in the world: one is what I call Byzantine construction, and the other is the timbrel vault. The Byzantine vault is made of brick masonry in a single layer, held together with lime mortar, with a thickness of no less than half a foot. The timbrel vault is a mechanism made of a thin layer of brick, no thicker than the edge of the brick, held together with gypsum plaster and other materials.
Neither of them requires centering. The Byzantine vault is supported during construction by the skilful placement of the pieces. The timbrel vault is supported by quickly setting the gypsum plaster. The timbrel vault is a refined evolution of the Byzantine vault with the incorporation of a new material into the process, the gypsum plaster.
The timbrel vault cannot be understood without crossing the borders of the medieval Christian kingdoms of the Iberian Peninsula. It is necessary to delve into Muslim Spain to deepen its origin, knowledge, and evolution. In a place where knowledge and mastery of gypsum plaster existed, it is easy to imagine the advantages of this material being exploited to save resources, both human (by requiring less labour time) and material (by requiring fewer bricks). That is to say, the tim-

brel vault emerged as the optimised version of the brick vault, called *bóveda de rosca* ('screw' vault). In Extremadura, we can find the same vault geometries built into the brick masonry version and the timbrel vault version.
In the west of the Peninsula, there are no gypsum quarries, so its use has been very restricted historically. On the contrary, gypsum is abundant in the eastern part, and consequently its use was very widespread. We can see that the timbrel vault emerged there. The area is rich in lime, but not so much in gypsum. The proliferation of timbrel vaults came with the railway, when transporting a material like gypsum from other regions became cheaper. The construction process of timbrel vaults is simpler, as gypsum allows for quick setting and therefore makes the process simpler. It is no longer necessary to use the technique of conical rows of circular and inclined planes.

RHA: You mentioned the 'Lusitanian vault' in a recent talk, 'Vaults: A Historical Technique with a Future'. What makes it stand out?

MFL: In eastern Portugal and western Spain there exists a unique geometry in vaults, sitting between the sail vault and the groin vault. Its first characteristic is composite geometry, formed by the intersection of several simple geometric figures or surfaces composing it, which gives it a double curvature.
That no breath-taking works have made use of this type of vault may justify the lack of detailed studies about it. Be that as it may, the fact is that this geometric pattern has not received much attention and has simply been defined as groin, lunettes, or other names of standardised geometry. These vaults have also been called *bóvedas peraltadas* (stilted vaults). We can find them in Gothic architecture. They are truly double-curvature vaults. They can be classified as such, but they do have a subtle difference that, while not easily noticeable, is crucial for their performance, which is the double curvature.
So, the 'Lusitanian vaults' have a very unique geometry. They are groin vaults with one singularity, which is that the keystone of the vault sits higher than the keystones of the perimeter arches. The groin vault is the intersection of two straight semi-cylinders. The 'Lusitanian vault' becomes the intersection of two semi-toroids. Since the structural behaviour of the vaults depends fundamentally on geometry, and not so much on materials, we can conclude that the 'Lusitanian vault' behaves structurally between the groin vault and the sail vault, since its geometry is at the intersection of both.
The second characteristic is that they are executed 'above in the air'. This means that a complete centering of the entire surface of the vault is not required, although it may be used occasionally to execute the auxiliary arches. **[Figs. 4 and 5]**

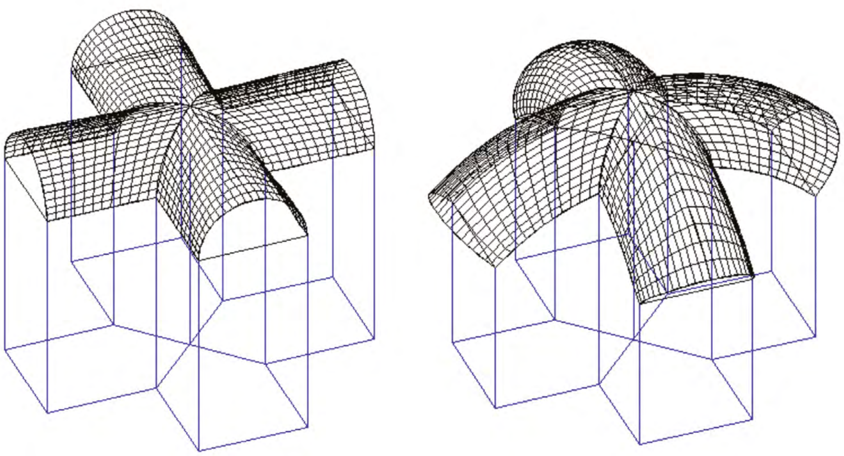

Fig. 4 Geometries of vaults: groin vault (left) and 'Lusitanian vault' (right). Source: Manuel Fortea Luna, 2023.

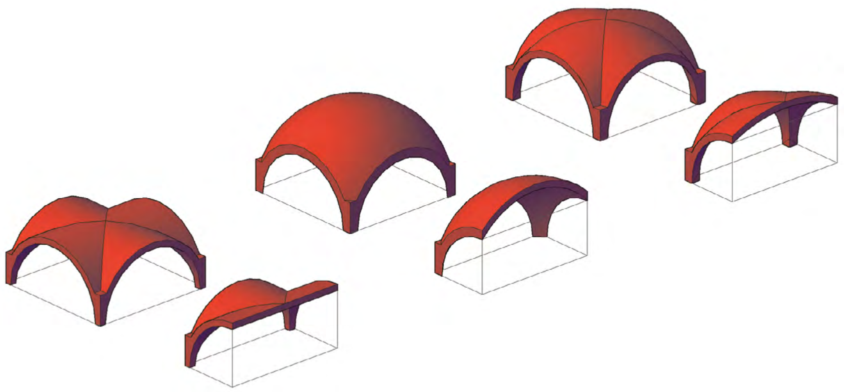

Fig. 5 Tri-dimensional models of vaults: groin vault (left), sail vault (centre), and 'Lusitanian vault' (right). Source: Manuel Fortea Luna, 2023.

RHA: What does the construction process of 'Lusitanian vaults' consist of?

MFL: These vaults are constructed using the conical rows technique. They are usually built on four existing perimeter walls, determined by the starting points and the height difference between the starting points and the keystone of the lateral arches, called the *punto* (point). With these references, the four arches that will form the sides of the vault are drawn up. Once the arches are marked on the walls, two perpendicular strings are placed, connecting the keystones of the opposite arches. The crossing point is raised by a few centimetres (this is called *retumbo* in Spanish), and from this point, a plumb line is hung to serve as a reference for the builder. The 'point' plus the *retumbo*, that is, the rise (the height between the starting points of the vault and the central keystone), should not exceed approximately 1,50 meters, so that all operations can be carried out with a single scaffold, keeping the work plane at an accessible height for the worker standing on it.

With the four former arches in place, four holes are made in the corners, where the pendentives will be put in place. These are the four corner pieces where the vault starts. They are really part of the wall from a construction point of view, so for their correct execution, a hole is opened in the wall, and the bricks are interlocked with the wall. These pieces support themselves without the need for centering, with the bricks overlapping each other. The pendentives are made in brick and lime mortar, with 4 to 6 horizontal rows. The lie down of the brick, or wedge, shapes the angle between the horizontal and the tangent to the arch where the first row of the vault will be placed.

The vault is constructed in a circle with rows supported on the pendentives and the perimeter walls. The rows are circular and inclined at an angle, resembling an oven, where the edge is produced as a result of the intersection of the rows from the four sides.

A groove is made in the arch drawn on the wall, and then an arch consisting of one row of brick is executed, slightly embedded in it and supported on the pendentive. The bonding mortar is lime, which is slower to harden. The stability of the bricks in each row during execution lies in the inclination. Once each row is complete, it supports itself. This construction technique without centering is also known as 'building on air', reminding one of a void, with no support or attachment, as if the vault were a balancing on a trapeze.

Without centering and with no other [architectural] reference besides the four lateral arches, the builder uses a plumb line, called *pesillo*, located in the centre of the vault. The vault is then closed with consecutive rows on all four sides. Great skill is required for this, as there are no auxiliary means for the correct placement other than using your eyes and hands. Obviously, these rows are applied using plaster, and each brick must be held by hand until the gypsum plaster makes it hold.

Once the vault is closed, the cavities are filled up to approximately half the height with heavy material (usually soil and stones). This operation of loading the extrados of the vault is called *hombrear la bóveda* ('shouldering the vault'). Until the load is completed, it has no resistance. At this point, the vault offers a flat surface at the extrados, except for the central part, where an almost spherical bulge stands out. To achieve a walkable surface, it is necessary to fill up to the level of the central keystone. This filling uses lightweight material, to avoid overloading the vault. Since the appearance of the railway, soot has been used in this place. **[Fig. 6]**

RHA: The 'Lusitanian vault' structurally behaves between a groin vault and a sail vault as a result of geometry. Does this have an impact on structural behaviour? What are the mechanical properties of these vaults?

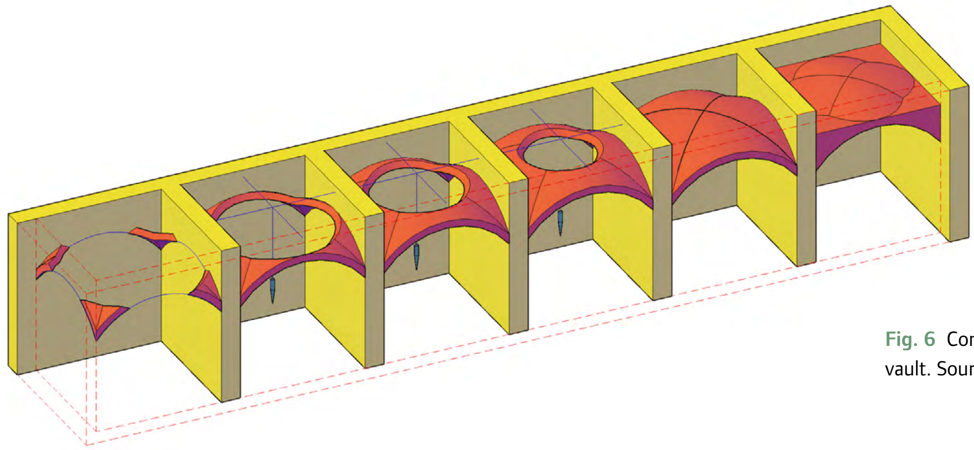

Fig. 6 Construction process of a ''Lusitanian vault. Source: Manuel Fortea Luna, 2023.

MFL: This means that when needed, the 'Lusitanian vault' will work as a sail vault, which is essentially a dome sectioned by four vertical planes, and when needed it can also work as a groin vault. This gives it great versatility as the push can be directed in different directions. Its geometry allows it to behave in very versatile ways. The most convenient mode will be used according to need, depending on the loads and the capacity of the supports, following a basic principle of entropy. The thrusts of a sail vault are distributed around the entire perimeter; in a groin vault, they are concentrated in the corners, and in a 'Lusitanian vault', they work in an intermediate position. **[Fig. 7]**

RHA: If the geometry of the 'Lusitanian vaults' is in between geometries, what is its structural behaviour? Is there any tendency for structural problems?

MFL: As a result of its geometry, the 'Lusitanian vaults' structural behaviour sits between groin and sail vaults. Its pathology is also between the two. These characteristics affect its mechanics, way of working, and the system of transmitting the forces from the vault to the wall, offering multiple possibilities, and allowing it to choose the most convenient according to the applied loads and conditions. The fact that the forces from the construction's weight and the overloads, which must reach the ground without violence to achieve permanent stability, have multiple paths, gives it an added safety coefficient that is difficult to surpass unless a major mistake is committed.
A double-curvature vault like the 'Lusitanian vault' can be considered under two assumptions regarding behaviour: 1) That it works like a groin vault, that is, considering that we divide each panel into independent arches that rest on the groins, transmitting to them the thrusts, both vertical and horizontal, running along them

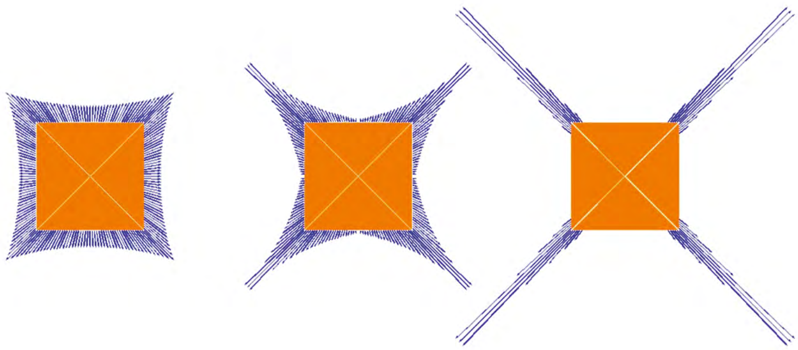

Fig. 7 Different behaviours of the horizontal thrusts in vaults: sail vault with evenly distributed thrusts (left); groin vault with heterogeneous thrusts concentrated in the corners (right); and 'Lusitanian vault' with an intermediate behaviour (centre). Source: Manuel Fortea Luna, 2023.

to the starts, where all the force is pushed to; 2) That it works like a dome, that is, if we divided the vault into radial segments, transmitting force to each base, some on the perimeter wall and others on the starts. Logically, the dimension of the thrusts depends on the dimension of the spherical cap to which it belongs.

RHA: In a 2012 article, 'Comparative Analysis Based on Sustainability Between Masonry Vaults and Concrete Structures', with Justo García and Antonio Reys, you approached vaulted construction from the point of view of sustainability. What are the advantages and disadvantages of using vaults compared to concrete construction?

MFL: In that study, we compared from a sustainability perspective the environmental impact of a horizontal masonry structure using a groin vault and a structural reinforced concrete slab of the waffle type, using Life Cycle Analysis techniques to quantify the energy consumed in the process of manufacturing the materials and erecting the structure. Generally speaking, it was found that the vault uses 75% less energy than concrete in the construction process, emits 69% less CO2 into the atmosphere, and has an average manufacturing cost for small spans – similar to that of a conventional slab and lower when it comes to large spans. It generates 171% less packaging waste on-site, although it requires more labour, and that labour is specialised.
The manufacture of construction materials causes environmental impact due to the extraction of natural resources and energy consumption. The resulting toxic emissions into the atmosphere are polluting, corrosive, and harmful to health. Vaulted structures use less energy than waffle concrete slab structures. For a 6x6 structural module, a vault consumes 10,914 MJ, while a waffle concrete slab consumes 48,655 MJ for the manufacturing and construction. As the distance between slab pillars increases, the energy required for vaulted structures decreases proportionally compared to waffle concrete slabs. It has been found that, from the

perspective of environmental sustainability, the use of vaults becomes more interesting the larger the spans that need covering.
Gas emissions into the atmosphere, measured in kilograms of CO2 equivalent emissions, indicate the global warming potential (GWP) of the planet due to various gases being emitted during the production and construction of greenhouse gas (GHG) generating materials: carbon dioxide (CO2), carbon monoxide (CO), methane (CH4), nitrogen oxides (NOx), ozone (O3), sulphur dioxide (SO2), and chlorofluorocarbons (CFC). In vaulted structures, CO2 emissions during the manufacturing process of materials, transportation, placement, and handling are lower than in waffle concrete slab structures. Emissions of other greenhouse gases such as NOx, SOx, and CO were also analysed and found to be lower in vaulted construction compared to waffle concrete slabs. Also, waste from constructing vaulted structures is lower than from waffle concrete slabs structures, mainly due to packaging waste (which is 177.78% [higher]) and the construction process. This is because part of the recycled debris from ceramic materials, being inert materials, can be used to fill in the cavities of the vaulted extrados.
Regarding the energy used in the vaulting construction process, the energy required – including that used in manufacturing the materials – more than meets current sustainability demands, CO2 emissions, and waste production. Not all countries have the same regulations in this matter, and in some the negative effects on the environment attract higher penalties than in others.
As to insulation, it has been found that vaults with filled cavities in the extrados corners provide excellent thermal insulation when compared to other structural systems due to their mass. Additionally, thermal insulation increases with the number of layers and their thickness. Similarly, vaults offer excellent acoustic insulation compared to other structural systems for two reasons. Firstly, because the vault is composed of discontinuous elements that stop sound waves from propagating, especially those produced by impact. Secondly, because their mass is greater than in any other structural system.

RHA: But there is still more to consider than environmental sustainability. What about the economic factor of vault construction?

MFL: The cost of executing the structures is the variable that indicates the economic viability of their use. The cost of the construction process, known as the Project Execution Model (PEM), includes the labour required for its execution, the cost of materials, and the auxiliary means used.
When vaulted structures are compared to waffle concrete slab structures based on modulation, the labour hours required in the construction process are higher

in all cases analysed. Additionally, it has been shown that the labour required to build vaults must be more specialised than that for the waffle concrete slab. Highly skilled labour reduces execution time, while unskilled labour substantially increases it, and untrained labour would never be able to do the work.
On the other hand, constructing the vault without centering elements increases the risk of building accidents, so safety and surveillance measures must be enhanced during this phase, especially until the first layer of the vault has been finished. In contrast, the materials that make up the vault consume less energy in their manufacturing and assembly process, with lower emissions of greenhouse gases into the atmosphere and less acidifying effect.
The construction cost of vaulted structures is lower than that for waffle concrete slab structures, due to the lower price of the materials used, such as lime, plaster, and masonry, compared to cement and steel. The value corresponds to the Spanish market, although data will obviously vary depending on the location where the structure is built, mainly due to the impact of labour costs, as more labour is required for the vaults. Functionally, both structures are equivalent in terms of their load-bearing capacity, but quantitatively they are not homogeneous in terms of environmental balance.
We demonstrated that vaulted construction more than meets current demands in terms of sustainability, and this construction technique can coexist with the technology of modern society, resulting in a product with high economic, functional, and energy performance.

RHA: Coming back to your talk in Lisbon, how do you see the future of this 'historical technique'?

MFL: New construction methods are so overwhelmingly imposed on us that traditional techniques have been relegated to oblivion, as if they belonged to a distant past, when in reality they have been applied in some areas of our region well past the post-war period, that is, in the context of modern economic development.
Let us approach these pieces of architecture with respect and admiration, aware of the value and knowledge held in them, which has been so often left in the shadows, at times due to a lack of concern with cultural transmission, and at others due to arrogance, where one's own work is the only work valued, disdaining what is foreign, spatially and temporally.
The Alentejo and Extremadura regions are rich in vaults and domes, to the point of having their own technology of great scientific and cultural value, which has not been sufficiently disseminated and exploited.
The loss of knowledge is always regrettable as it represents a [form of] cultural amputation, the denial of the past, and making additional efforts in the future.

Therefore, our main endeavour is to ensure that knowledge of these techniques does not disappear, regardless of their utilitarian value today. No construction or structural system is the ultimate solution for global building. Each of them has its merits and limitations, making them more suitable in some cases and less in others.
In the course of my research, I came to the conclusion that the use of vaults, as masonry structures, is to be advised except for in high-rise buildings. This construction technique can even coexist with the high technology of modern society, resulting in a product with high economic, functional, and energy performance, and it is possible to replace conventional slab structures with vaulted ones.

Transcribed and translated from Spanish by Mafalda Batista Pacheco,
revised by Tiago Viúla de Faria.[1]

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