The Two-Way Effect of Slabs for the Reinforcement of Old Wooden Floors Sizing of Elements

Juan Carlos Gómez de Cózar, Íñigo Ariza López

***Abstract*—. One of the advantages of the instrumentation that is currently available to us[1] is its ability to quite accurately predict the behavior of the buildings we design.**

For new works, any predictive analysis can be made with knowledge of its materials and its context (climatic, social, economic, etc.).

However, for an old work, if it is intended to keep the old building systems, the current tools, though sophisticated, are useless. Also, the materials are generally known only in part for various reasons, so that, ultimately, the decisions taken by the architects do not usually take into account the potential of the old materials.

The case of preserving old wooden floors has been studied for years by hundreds of authors. These studies have been very much directed to obtaining the mechanical properties of the floors. However, when studies are sought that delve into obtaining real repair-restoration-rehabilitation solutions, material of immediate practical application is hard to find.

***Index Terms*—Heritage, Building Restoration, Floors, Wood.**

I. BACKGROUND. STATEMENT OF THE PROBLEM

The mechanical collaboration of an old wood–concrete composite section as a floor rehabilitation solution is a complex situation. In most cases there is insufficient knowledge about the wood, its full level of deterioration, or its remaining deflections, etc., all fundamental aspects for guaranteeing a solution with the desired result.

In addition, many constructive sections that are worthy of rehabilitation (Fig. 1) have elements such as battens, decorated wooden boards, tiled courses, etc., which prevent contact (required) between the upper slab and the wooden beam. This makes the behavior of the element of connection between two sections (old wood and concrete), with little contact, very questionable [2].

Years ago [3], [4], we developed a basic formula, for the collaboration between the wood floor structure and the concrete slab, which was based on the following premises:

1) The wood still has some resistant capacity and certain elastic properties that allow it to distort and recover from that deflection when the loads have ceased.
2) The concrete slab projects, supported around its whole perimeter by walls or resistant beams.
3) Where there is contact between the two elements, it is considered that the wood floor and the slab, when requested, present the same vertical deformation.
4) Therefore, the connectors are used as elements of transmission and load sharing between the wood floor and the slab.
5) In the event that the wood floor suffers a level of deterioration over time such that it could not assume load bearing tasks, the slab would take the entire load, and the connectors are used as security elements to keep the floor suspended from the slab.

Fig. 1. Different types of floor which preserve the boards as well as the beams.

The new formula which is proposed below reconsiders the

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[1] In the last 15 years, the software and hardware used by the majority of architects have evolved as never before. We call this evolution "Instrumental Revolution" [1].

problem, adapting it to the most common solutions to conserve floors where their own weight (beams plus boards with their elements), between the floor and the reinforcement slab, completely changes the result of the collaboration.

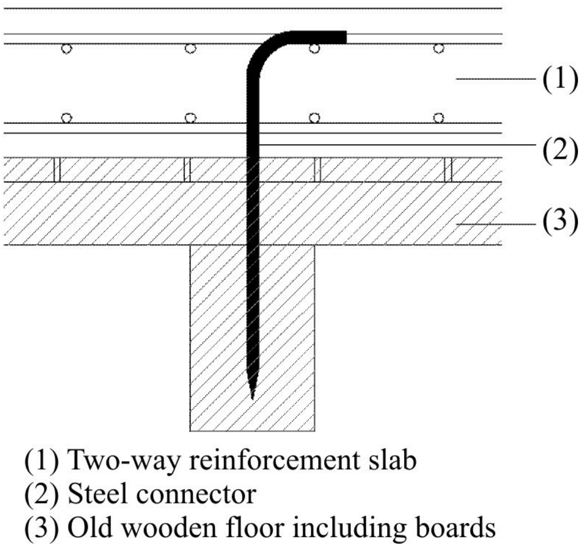

Fig.2. Type of section analyzed

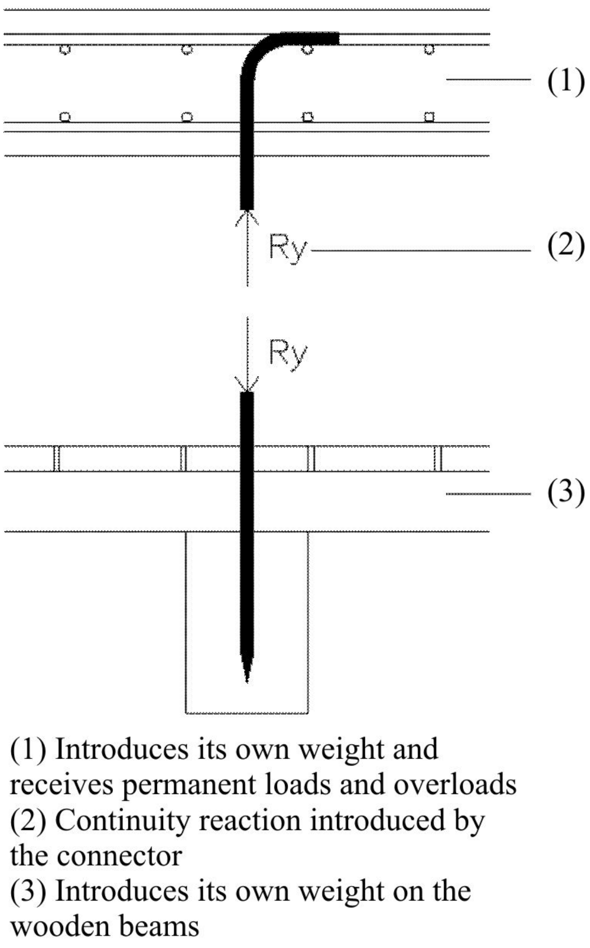

Fig.3. Loads to be taken into account.

Therefore, it is attempted to demonstrate the potential of a procedure which not only reinforces a floor by its section and connecting elements but also by its floor-plan ratios and, above all, by its two-way effect.

From a practical standpoint, in each case, the developed formula allows the required thickness of the concrete slab to be guaranteed (based on the knowledge of the state of the old wood).

II. DEVELOPED FORMULA

From the premises established in the previous section, we start with a section consisting of a concrete slab of constant thickness laid over old wooden beams. Sandwiched between these elements are the boards (or the specific constructive configuration intended to be preserved) of the wood floor.

The proposed solution suggests frequently placed connectors of weak section, with the capacity to work (basically) only in their axial direction (Fig. 2).

Thus posed, the proposed section introduces a load scheme in which the new, post-repair, permanent loads and overloads ($q = qx + qy$) are introduced on the reinforcement slab and the permanent loads of the old floor (qs) on the wooden beams (Fig. 3). The ratio of the value of the latter load with the forces received by the slab will define the way the connector works (compression, tension or zero). This will also depend on the rigidities of the elements (concrete/wood) and on the floor plan ratio of the room. Changing these parameters can result in the old floor either contributing something or being partially suspended from the concrete slab.

With this load configuration, the final scheme to be considered is shown in Fig. 4. As can be seen, the internal force (***Ry***) maintains the continuity and collaboration between elements.

As stated in the basic premises in the previous section, the fundamental compatibility condition between elements is the equality of vertical deformations: $fx = fy = fm$ (Fig. 5).

Each section has its component of rigidity, $(EI)_1$ for the slab and $(EI)_2$ for the wooden beam.

For a square plan of proportions Lx / Ly, Ly being the span parallel to the floor, the compatibility condition of deformation in the direction of the floor would be as follows[2]:

$$\frac{(qy - Ry)}{(EI)_1} = \frac{Ry + qs}{(EI)_2} \qquad (1)$$

Where ***k*** is the relative rigidity of the wood section with respect to the total section:

$$k = \frac{(EI)_2}{(EI)_1 + (EI)_2};\left(1 - k\right) = \frac{(EI)_1}{(EI)_1 + (EI)_2} \qquad (2)$$

With which the value of the internal force between the wooden floor, based on its rigidity, and that of the slab is:

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[2] The Grashof method was used to know the proportion of the total force transmitted in each direction, based on the equality of deflection. It must be made clear that the results obtained are approximate and always err on the side of caution.

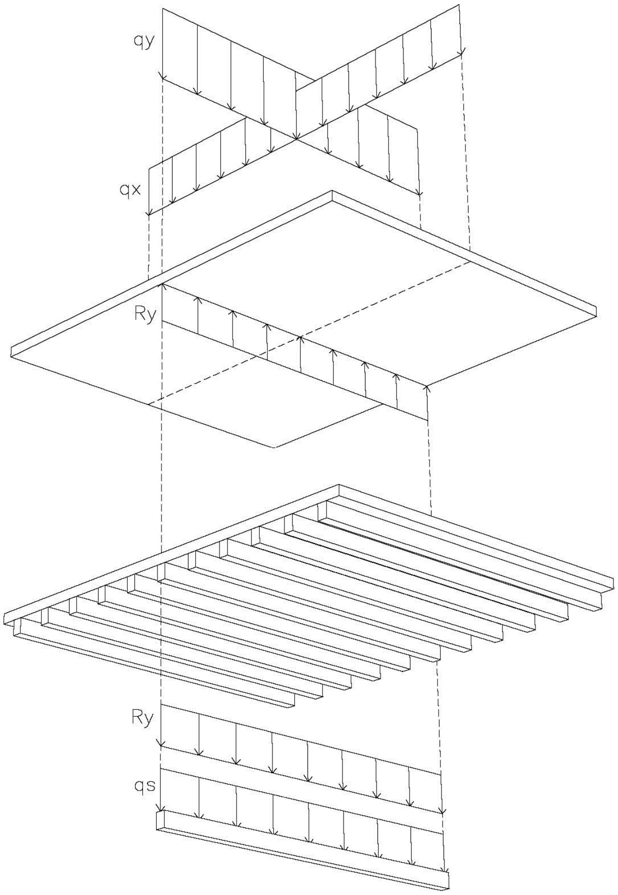

Fig.4. Final load scheme.

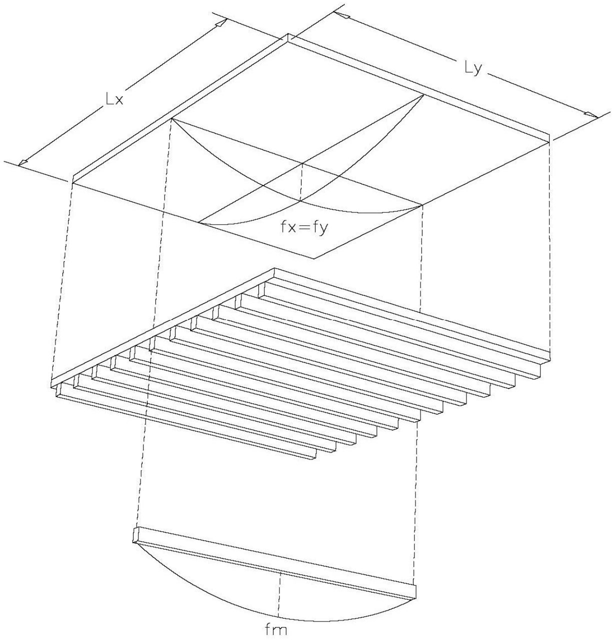

Fig.5. Compatibility of vertical deformations.

$$Ry = kqy - (1-k)qs \tag{3}$$

Therefore, the force that is finally transmitted to the wooden floor is:

$$Ry + qs = k(qy + qs) \tag{4}$$

The above expression shows that without considering if the two-way effect of transmission of forces and deformations that are contributed by the concrete slab are not taken into account, the total force received by the wooden beam would be proportional to the total load. With its relative rigidity ***k*** being, obviously, the scaling factor.

In order to know the final value of ***Ry*** it is necessary to know the part of the load on the slab (***qy***) that is transmitted in the direction of the wood floor.

The following expression can be established as a compatibility condition of vertical deformation between the two directions of the slab:

$$qxLx^4 = (qy - Ry)Ly^4 \tag{5}$$

Calculating, introducing the first condition, the following expressions are obtained:

$$\alpha = \frac{Lx}{Ly}; \quad qx = q - qy$$

$$qy - Ry = (q - Ry)\frac{\alpha^4}{1+\alpha^4} \tag{6}$$

$$qx = (q - Ry)\frac{1}{1+\alpha^4}$$

These last two expressions for the loads borne by the slab, show the behavior of the slab and its capacity to transmit the forces it receives (***q-R***) in both directions.

Calculating, the value of ***Ry*** is obtained:

$$Ry = q\frac{k\alpha^4}{(1-k)+\alpha^4} - qs\frac{(1-k)(1+\alpha^4)}{(1-k)+\alpha^4} \tag{7}$$

The above expression demonstrates the work of the connectors. Depending on the load values, the rigidities of the elements and the floor plan ratios, the connectors can work by compression, tension or none at all.

Based on this, the conditions are established as shown in (8).

It is fairly intuitive to emphasize how for large values of ***α*** (the slab effect disappears) the quotient that groups them tends to 1 and is no longer a variable to be taken into account. However, for floor plans with ratios close to a square, the ratio between rigidities is multiplied by half by the two-way effect of the slab. This is because it reduces the work of the connector and can take advantage of the residual strength of the wood.

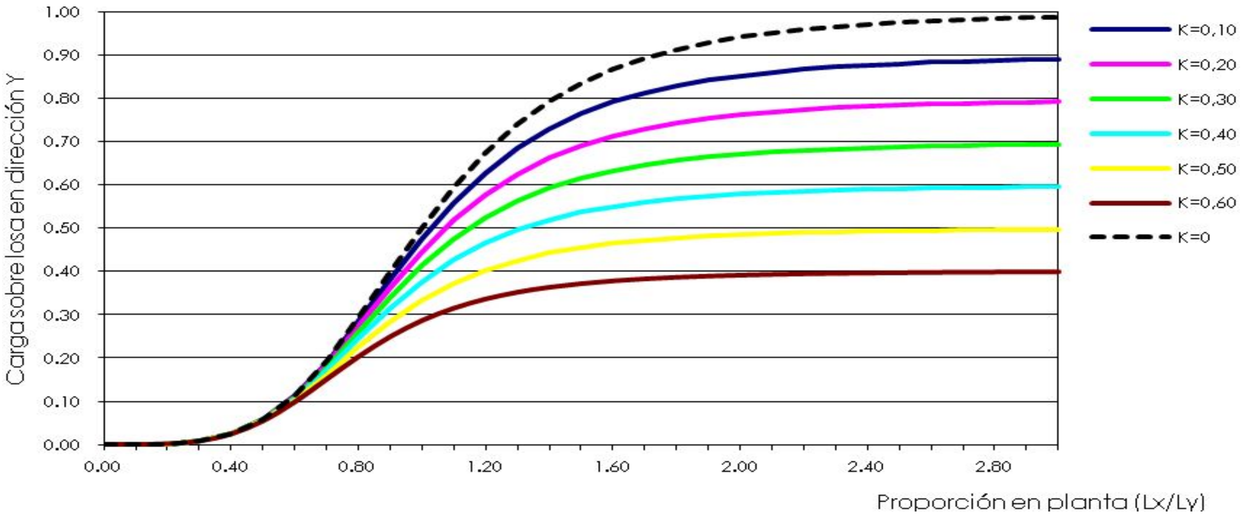

Fig. 6. Load on the slab in the direction Y (***qy-Ry/q+qs***) against floor plan ratio.

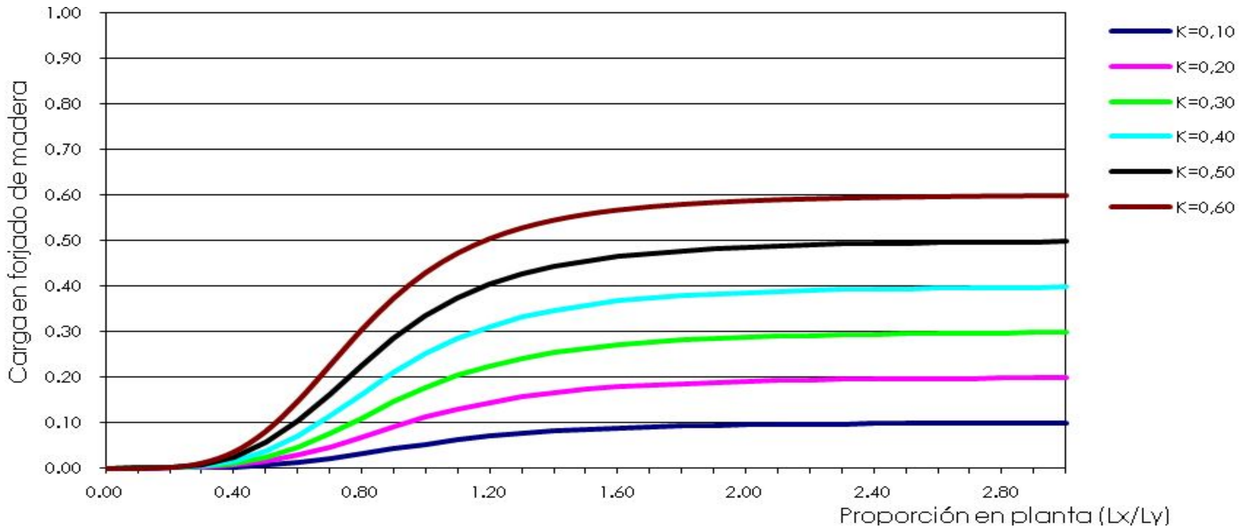

Fig. 7. Load on the wood floor (***qs+Ry/q+qs***) against floor plan ratio.

$$qs < q\frac{EI_2}{EI_1}\frac{\alpha^4}{\left(1+\alpha^4\right)} \rightarrow \text{COMPRESSION}$$
$$qs = q\frac{EI_2}{EI_1}\frac{\alpha^4}{\left(1+\alpha^4\right)} \rightarrow \text{NO FORCE} \qquad (8)$$
$$qs > q\frac{EI_2}{EI_1}\frac{\alpha^4}{\left(1+\alpha^4\right)} \rightarrow \text{TENSION}$$

The ratio between the rigidities of the two elements will have approximate values between 0.25 and 0.50. The remaining loads of the floor to be preserved, and the new use of the building, will end up affecting the ***q/qs*** ratio. Considering that the period of use of the refurbished item can be very long, we recommend to size the connectors for the worst case scenario.

Once ***Ry*** is known, the other expressions can be obtained:

$$\left(qy - Ry\right) = \left(q + qs\right)\frac{\alpha^4\left(1-k\right)}{\left(1-k\right)+\alpha^4}$$
$$qx = \left(q + qs\right)\frac{\left(1-k\right)}{\left(1-k\right)+\alpha^4} \qquad (9)$$
$$\left(qs + Ry\right) = \left(q + qs\right)\frac{k\alpha^4}{\left(1-k\right)+\alpha^4}$$

The first two expressions give the loads that the concrete slab will finally take.

The last expression gives the load that is transmitted (or subtracted from) to the wooden floor.

Fig. 6 plots the expression obtained for the load assumed by the slab in the direction of the floor (***qy-Ry***). It can be seen that for small values of (***k***), for thick concrete slabs, the behaviour is very similar to that of a free slab (***k = 0***). As the slab

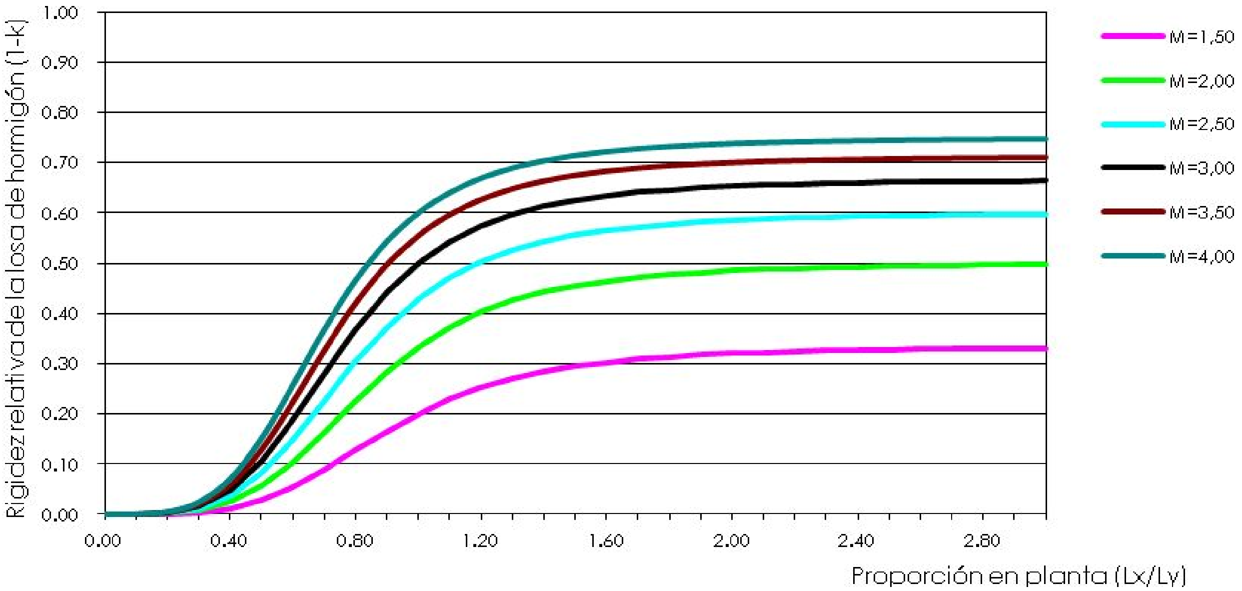

Fig. 8. Relative rigidity of the concrete slab (***1-k***) against floor plan ratio.

Fig. 8. Relative rigidity of the concrete slab (1-k) against floor plan ratio

thickness reduces (higher values of ***k***) the load transmitted to the slab decreases due to the collaboration effect of the floor.

For floor plan ratios close to one, the two-way effect is observed perfectly. For example, where ***k = 0.3*** the slab would take 0.41 (***q + qs***) in each direction and the floor 0.17 (***q + qs***). However for a floor plan ratio much higher than one, the slab would take 0.7 (***q + qs***) only in the direction of the floor and the floor 0.30 (***q + qs***). So that, logically, from floor plan ratios greater than 2.00, the analyzed effect is diluted. Extrapolating this ratio, all the curves in Fig. 6 tend to the relative rigidity of the slab (***1-k***).

The graph in Fig. 7 shows the loads received by the wood floor in terms of its relative rigidity and floor plan ratios. It can be seen how, logically, all the curves tend to ***k*** as we saw earlier in this section.

The two-way effect in this case is very clear. For floor plan ratios close to 1.00, the work of the wood floor is greatly reduced.

The developed formula has a great potential if it is combined with procedures that allow the mechanical properties of the wooded floor to be rehabilitated to be obtained either in-situ or in the laboratory. There are many types of procedure that allow the required parameters to be obtained with more or less reliability. It is usual to combine low or non-destructive procedures with effective destructive techniques which allow the classification of the resistant margin and the parameters of the subject floor.

Once the resistant margin of the floor (***qmax***) is known, then the necessary rigidity of the slab to be used, and hence its thickness, can be calculated. Thus, the problem is completely solved.

$$M = \gamma \frac{q + qs}{q \max} \qquad (10)$$

$$\left(1 - k\right) = 1 - \frac{1 + \alpha^4}{1 + M\alpha^4} \qquad (11)$$

In the previous expression, when obtaining the load parameter (***M***), a safety factor (γ) was used which depends on the degree of reliability of obtaining the mechanical parameters of the floor.

Fig. 8 shows graphically the evolution of the rigidity required for the slab (***1-k***) depending on the load parameter (***M***) and the floor plan ratios.

CONCLUSIONS

As deeper as the knowledge of the item to repair, restore, rehabilitate, more likely a correct solution will be proposed. In most cases, composite solutions that are presented for the repair of floors are not valid.

In those cases where cooperation is not possible as a composite section between concrete and wood as a result of the constructive configuration and of the conservation status of the old wooden floor, the method proposed is very effective.

The real collaboration that is possible between the wood and the concrete will vary over time depending on the level of the wooden deterioration. The proposed method allows variations in the behavior of the sections, from collaborating situations, to suspending floors from the slab when the wood has lost its bearing capacity.

Depending on the floor plan ratios, having the two-way effect of the slab means reducing its thickness, and reducing the transmission of loads to the wood floor.

We currently work on an original software that predicts the behavior of the repaired floor and verifies (combined with in-situ testing) the effectiveness of the repair upon completion.

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As a specialist in historical buildings (in 2001 developed the method of calculation called *CONDITIONAL ECCENTRICITIES*, giving the surface of thrust in space of any vault) it has conducted several studies analyzing the mechanical behavior of medieval churches as a scientific basis for future interventions (Fábricas de la Iglesia de San Miguel de Jerez de la Frontera, Cádiz, 2004; Bóvedas y Elementos de Sustento del Claustro Grande de la Cartuja de Ntra. Sra. De la Defensión en Jerez de la Frontera, Cádiz, 2007; Fábricas de la Iglesia de San Miguel de Morón de la Frontera, Sevilla, 2009).

The type of projects and works of architecture that has developed have been the result of a constant search for new solutions towards a more sustainable and with higher quality architecture.

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