ART and STRUCTURAL FUNCIONALITY

by

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Abstract

The learning in architecture has a complexity that is a field that must be synthetize aesthetics and functionality. Somehow students are not very effective when they try to mix this terms, in most of the physical topics.

To reach this there is a subject " Applied Physics to Structures " that shows development of a unification process for learning, crucial to energetic parameters where Energy is the most fundamental parameter for all processes.

After the theoretical explanation, a practical application of this knowlodge is propose to existing buildings with a method that is applicable to rehabilitation and allows the study of structural elements without any kind of intervention, as show in the examples of this study as la Sagrada Familia, the Gotic Cathedral of Leon and an application to the cathedral of Vitoria and other buildings..

Key words: *Learning Architecture, Applied Physics to Structures, Study of structural elements , Rehabili tation,*

Traducción:

El aprendizaje en la arquitectura tiene la complejidad de ser un campo que debe sintetizar la estática y la funcionalidad. De alguna manera, los estudiantes no son muy eficaces cuando tratan de mezclar estos términos en la mayoría de temas prácticos. Para llegar a esto hay una asignatura " Física Aplicada a las Estructuras" que muestra el desarrollo de un problema de unificación para el aprendizaje, crucial por los parámetros energéticos, donde la energía es el parámetro fundamental de todos los procesos. Después de la explicación teórica, una aplicación práctica de este conocimiento se propone a edificios ya existentes con un método aplicable a la rehabilitación y que permite el estudio de los elementos estructurales sin signo de intervención, tal como se muestra en los ejemplos de este estudio: La Sagrada Familia, la Catedral Gótica de León y una aplicación a la Catedral de Vitoria.

1. Introduction

The teaching of the architecture is difficult due to the confrontation among two lines: aesthetics and functionality which the rationalism wanted to surpass by means of the lemma "the shape linked to function". The building would be a unity and it must show to the exterior what in the interior it is. Finally the architectonic space concept developed in the Bauhaus and other European centers of arts and architecture at the beginning of the last century integrated these lines. Also this confrontation is observed in the programs of matters of different countries. This difference appears due to cultural interpretations of the reality.

For instance, in Spain the architect must have a deep and big knowledge on aesthetics and functionality. Because a building is a unity and must also show to the exterior what in the interior it is, students of architecture have to integrate both forms of knowledge in "the design studies". Later when the paradigms of the space concept begin to evolve, the confrontation among the two lines, other time appears and new ideas and solutions must be proposed. In our opinion the space concept has been surpassed by the energy concept. For instance, when you ask from any European city if Beijing is far or near, the correct answer would be "it depends of the power of the plane o vehicle that you can use to travel to this city". In fact we must speak about the perceptive space in agreement with the painter Mondrian's, Gropius´s and of other people ideas [1,2]. Just from the perspective of the energy we can find a unified point of view in the learning of the architecture [3,4] The object of this paper is explaining our successful experience with an elective matter developed at Escuela Técnica Superior de Arquitectura de Barcelona using an unified perspective of the knowledge.

2. Conceptual tools

2.1. Conceptual tools applied in the work: synthesis and unification of knowledge.

Development of a unification process for learning has its crucial characteristic in energetic parameters. Energy is the most fundamental parameter for all processes, in fact, all is energy. For this reason, we can understand that inside materials working at compression, electric fields are generated that provoke electric currents and magnetic fields. If its structure is closed, stronger vector magnetic fields are measured. For example, in the Maxwell's tensor of stresses we can find an explanation of this concept as magnetic fields are associated to tensile stresses.

Consequently, we can pass flexural diagrams of any system of charges to the equation of the geometry of the arc by means of the relation:

$$M = y\, T_x$$

Where "M" is the value of the vector flexor moment of the charges system, "y" the value of the deformation of the arc and "T_x" is the horizontal component of the reaction

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in the arc. That is to say, we change the value of the moment of the charges system by the curved form of the arc.

Obviously in the study of the arcs and cable structures, we have always in mind three pillars for this knowledge field: equilibrium, material and shape (or geometry). In order to implement the integration of knowledge process we show how much important is to profit any situation or any matter to advance in this line. All these theoretical concepts have been applied to the analysis of a diversity of antique and modern buildings: Load systems, equilibrium and modelling through free body diagram.

2.2.- Description of the elective matter.

Name of the matter was Applied Physics to Structures. It was developed 4 hours week during 15 weeks. The matter was taught about 12 times (2003-2011, in a period of 8 years). A medium value of 60 students attended the matter each time. 60% of these students come from the second year (in parallel with Structures I, our most difficult matter), other 40% came from 3rd to 5th year. As a result of the good marks of the students coming from the second year, all the first topic was introduced as a compulsory matter in the first year (a selective year in Barcelona). The total number of works could be 450 nearly although some of them are applied to the same building in different years. Comprised topics were:
-       A first part devoted to shear forces diagrams, flexural (bending) moments' diagrams and frames deformation.
-       Second part was about inertia moments with an intuitive vision about the relation between first order moments (centroid) and second order moments (inertia) and the subjacent symmetry in these geometric concepts.
-       Third part treated arc, cable and dome architecture. Other time we have always in mind three pillars for this knowledge field: equilibrium, material and shape (or geometry).
    -   The fourth part consisted in a work developed by students where they have to apply learnt knowledge. This part is explained in the present paper. Following sections will show some examples of application for existing buildings.
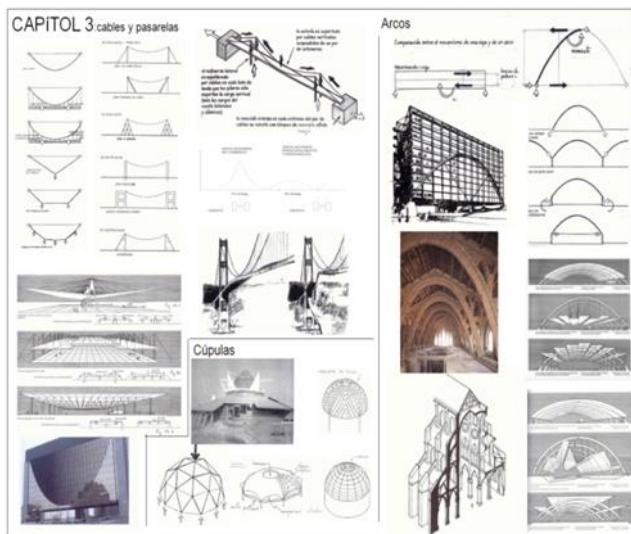

***Fig.1.* Materials of the elective matter Applied Physics to Structures**

3.-About the methodology of learning

Learning in the field of Architecture obliges to use an exigent methodology. This methodology does not exist for the moment. The complexity in the field that must synthesize aesthetics, functionality and energy save, explains it. For this reason, students not use to be very effective when they try to deep in most of the practical topics. Lack of the teacher's synthesis of the three lines of work (aesthetics and functionality and energy save) is the main problem. However when we want to look for the origin of the problem we find a deep error in the methodology of learning: There are too much subject to explain who students do not see like different aspects of a general methodology, but a lot of different and independent subjects. It is a general problem due to the lack of the development of a unification process based in energetic parameters.

For example, the study of thermal insulation problems needs three basic ideas
--equilibrium
--material
--shape (or geometry)

That would be applied to the Fourier's equation in stationary processes.
When light or acoustical effects and the associated perception conclusions are analysed, other time the triangle " equilibrium, material and geometry" must appear to improve the unification process in the mind of students. When the pure flexure is explained in order to construct the link between the statics and the materials resistance, the relation:

$$E(\text{Young module}) \ \sigma(\text{ stress})=M/\ I$$

appears where "E " and "σ" correspond to the material, M to the statics and I to the geometrical parameters. This methodology is essential to prepare the students to develop good projects because the integration of all knowledge in a building project just can be carried out very slowly. Finally all professors of different subjects are teaching "the design study" if they are able to use its classes to inform and to enrich the knowledge from a unified point of view.

Sometimes the aesthetics lines prefer to open the mind of students to new ideas breaking old perceptions of the reality. However usually they can not get alternative ideas or they just get empty ideas if students do not have a knowledge support in order to develop and to materialize these ideas in a rationalization process. These design projects just are "creative" and students just are at the beginning of the creative process in spite of they believe to be at end.

4. From theory to practice: Application to existing buildings

The aim of the work is to apply their knowledge and to check that the theory developeded is correct and therefore it can be applied to any similar building. For instance, students must find the funicular line of a central arc and to compare with the real building. If they have found some difference they have to try or to find the interpretation of this difference.

Because loads of structural materials are performed as discrete loads, the flexors diagrams (funicular line) has been drawn in order to compare with the geometry of the

arcs however usually the modern Statics Laws have been used to calculate the value of physical reactions.

Six items are considered in detail:

*1-Motivation.-*Buildings have been selected by the students using personal criteria (affective, born place, ... or, just aesthetical valuation). Students have worked with gothic cathedrals, little Romanesque churches or modernist buildings (Gaudi and other contemporary architects), wine factories, modernist markets or, even, middle-ages bridges and domes of different countries or cultures. They have also studied recent buildings using their simplified methodology.

2.-Report of obtained results.- Results have been explained as an original research report on the specific building.

*3-Establishing links with people that use or enjoy the building.-*Students have been recommended to contact with local authorities or architects in the zone in order to obtain specific information on the building.

4-Testing degree of validity of the theory.- Theory has been applied and compared with "buildings" real data. If discrepancies appeared, students had to analyse the reasons.

5-Applying nowadays technical codes (even for antique buildings).- Loads have been calculated using nowadays technical codes for snow loads, for example. It means, we assume that buildings were done using ancient knowledge (including some kind of calculation) with a "common sense" resulting from deep empirical and/or theoretical knowledge. Long life of these buildings justifies our assumption.

6.-Conclusions

5.Results

Some examples of the works done by students are shown in following pages. We shall start for a very simple example previously published in [6])
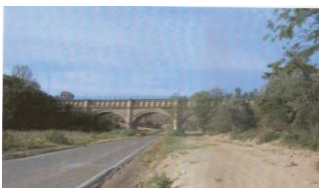

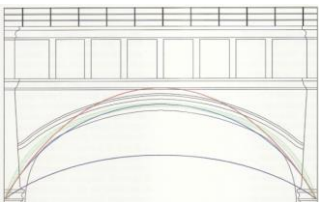**Fig.2. Photography of the Aqueduct of Binefar (Huesca, Spain).**

Fig.3. Photography and study for Aqueduct of Binefar middle level of water. Fuchsia line: dry (without water). *Students: Jesus Magallón and Adrián Trullenque (See* [6])

More complex buildings can also be studied using same methodology. Examples: The agricultural architecture at the end of the XIX century and at the beginning of the last century: Factories of wine build in different towns and cities of Cataluyna and other places of Spain. The Temple of Sagrada Familia, Middle Ages Cathedrals and others.

Fig.4. **Photography of Les Caves Codorniu and Section.**

Fig.5. **Photography of the interior Les Caves Codorniu.**

Student: Núria Sabaté Casanellas (2007-2008)

Fig.6. Table of weight of materials of the arc and free body diagram.
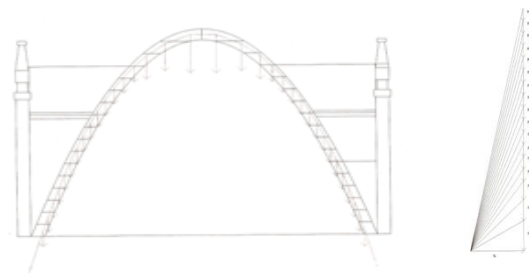

Fig. 7. **Comparation of the geometry of the arc and the funicular line.**

6.-*1.2.-Building:***Celler Cooperatiu de Pinell de Brain** (Tarragona,Spain)

Architect:CésarMartinell

Fig. 8. **Photography of the exterior of the building.**

Fig. 9. **Photography of the interior of the building.**

Fig. 10. **Loads of structural materials are performed as discrete loads**.
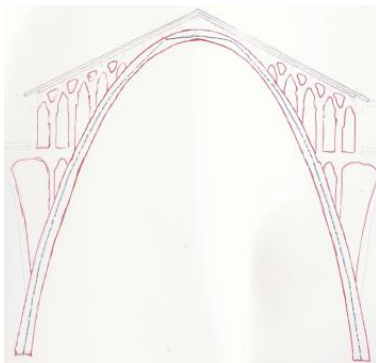
Students: Vladimir Lamothe, FranciscoTabanera(2006)

Fig.11.The funicular line of the arc

7.-2.1.-*Building:* *La Sagrada Familia (Barcelona, Spain)*

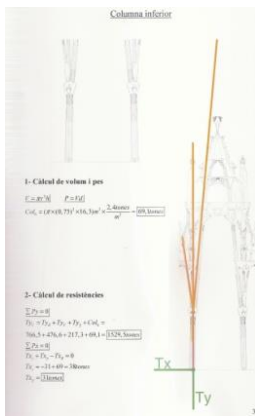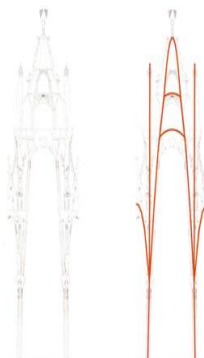*Fig. 12.* **Photography of the exterior of the building.**

*Fig13.-***Reactions in the free body diagram of the building.**

Fig. 14. - **Funicular Line of all arcs.** *Student: Adrià Rieradevall*

7.-2.2.-*Building: The gotic Cathedral of Leon (Spain)*

2.2.1.-Comments on the calculations of the load of gotics cathedrals

In the study of gotic cathedrals usually appear a problem when we want to know the load of the pìtched roof supported by the arc. In the spanish architecture the transmission of the load to the arc is direct, this is, the truss of the roof touch the arc and the load is transmitted directly to the arc. In the french gotic cathedrals we can find a beam of wood in the middle of the wood truss and the arc. For that reason is difficulter to evaluate the load of the truss and the roof transmitted to the arc.

In the spanish gotic cathedrals we have evaluated the proportion of the load supported by the arc by means of a hypothesis that theoretical and calculations confirms. In fact we consider an hyperstatic problem where two columns are in both sides of the arc and the parallel components of the areas of the keystone of the arc would be equals to the areas of section of the two lateral columns. Finally we would conclude the load of the arc is double of the load of the lateral columns
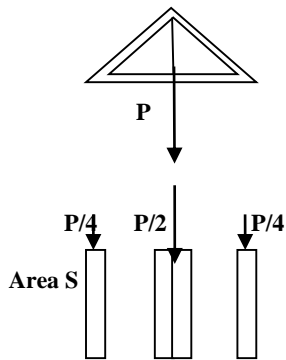

Fig. 15. .**Loads distribution on the arc and on the columns, so**

that the stress of material keeps its constant value.

2.2.2.-Study of the cathedral

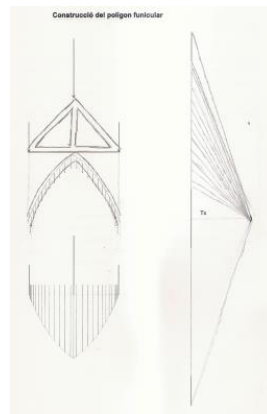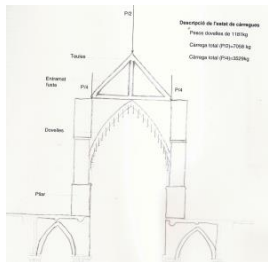*Fig. 16.* **The exterior and the interior of the cathedral**.

Fig.17.-Loads and funicular of the arc

8.-Aplication of the last conclusions. Analysis of the Cathedral of Vitoria

Building: Catedral Vieja de Santa María de Vitoria (Vitoria, Spain) (Old Cathedral of Vitoria). *Students*: **Pedro García Figuera and Alain González Montejo**

This cathedral has a lot of pathologies and from many years ago a strong rehabilitation process tries to rebuild it.
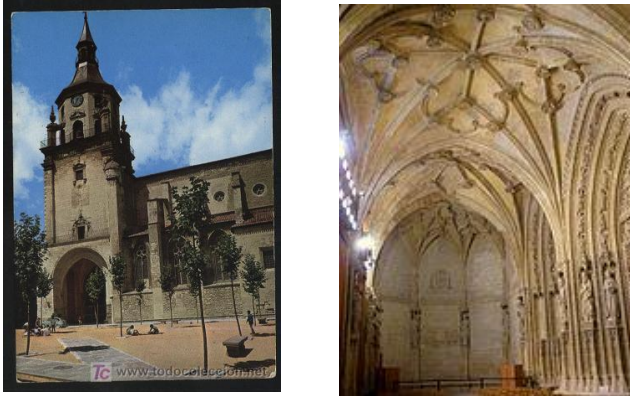

Fig. 20. **Photography of the exterior and interior of the building.**

An improper design of the central arc causes a deformation of the building due to the motion and rotation of the lateral columns supporting the base of the arcs.

In the first design of the building an important part of loads of the roof are applied on the arc and the barrel was of wood. Later the barrel wood is eliminated to build a barrel of a heavy material and stiff. Two students analyzed the origin of the problem by means of the funicular line:

-->First hypothesis:

The first funicular line is drawn with the value of the loads from the roof and the model of the last paragraph. This is, the load of the arc would be P/2.
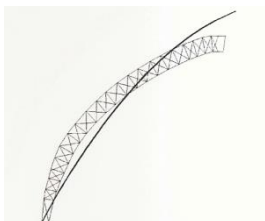
 Fig 21.-Funicular line of the central arcs when the load of the roof has the value P and the load of the arc has the value P/2.

However this result is no correct. A new calculation in different conditions must be carried out to obtain a second funicular of the central arc

-->Second hypothesis: The load of the central arc has the value 2P/3.

Fig. 22.-Funicular line of the central arc when the load of the roof has the value 2P/3.

The new results can not be accepted and the second hypothesis must be rejected.

-->Third hypothesis: Finally the first hypothesis is accepted. Besides a new load is considered to have a strong influence: wastes in the space among the arc and the column and perhaps there was never this waste.

A density of 1200 kg/m3 is the value hypothesized. The new funicular line with the last hypothesis could be an explanation of the origin of pathologies of this cathedral

Fig. 23.-Funicular line of the third hypothesis.

Conclusion: The lack of wastes between the arc and the column could be the first origin of the problem or if there was some waste a bad rehabilitation when wastes were draw out.

9.- Sustainability and advantages of the objectives.

1. Described method is readily applicable to rehabilitation.
2. Taking apart obtained docent results, our methodology allows studying structural elements without any kind of intervention. It is, work is done in a non destructive way.
3. Previously [6] we have described optimal work conditions for an aqueduct in function of used water flow. Conclusions are qualitative and quantitative.
4. A direct application is to correct errors in a previous rehabilitation [6].

10.-A reference applied to the study of Guastavino Vaults [6]

General conclusions about the behaviour and technologies of the masonry tile structures built by R. Guastavino Company (Spanish architect emigrated to USA) in USA has been studied by Megan Rees. The thesis studies the behaviour and pathologies of these structures in order to provide recommendations on their analysis and assessment. Structural analyses of two specific geometries (domes and barrel vaults) were carried out with equilibrium and elastic methods to determine how well each assesses the safety of Guastavino shells. Results show that stresses are relatively low in these structures, so they are unlikely to fail due to inadequate material capacity. The safety, then, is dependent on the stability of the structure than its material strength. Analysis by means of the funicular line should demonstrate its stability, and graphical equilibrium analysis is well suited in this task.

Guastavino shells exhibit behaviour similar to other masonry structures, but have an additional characteristic that sets them apart; soffit tiles can debone and fall as a result

of a cracking or water damage. Falling tiles pose a serious mortal danger but do not necessarily threaten a structure's safety. Nonetheless, they elicit dramatic structural repairs and retrofits.

10. Conclusions

Motivation, clarity, intuition and rigor in the theoretical foundations and applications to the real problems are the methodological tools which permit to obtain good results despite of the number of students has been very high.

In other words, besides of motivation we must combine intuition and rationality.

Acknowledgment

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