Conceptual design in the years of the numerical revolution: risks and perspectives

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ABSTRACT: Since digital transition, the acceptance of computer tools is rather poorly perceived by architects. The question today, as Antoine Picon points out in his book "Digital Culture and Architecture", is no longer to know if digital is a good or a bad thing for design. But rather to understand where the architecture of tomorrow is heading. With these technological innovations, machine learning algorithms, AIs, the only certainty we can have, it's this change in our way of thinking will be important. In order to compare the importance and innovation of digital, these new technologies extend well beyond mere formal and structural qualities. Some conceptual experiments are developed in case studies, to confront the logical thoughts of mental thinking and the more contemporary thoughts of computational thinking. This conceptual approach will lead us to contemporary thinking. From these digital instruments, how can we design such a project today?

1 INTRODUCTION

This paper is a reflection on the use of new numerical technologies by architects and, more specifically, by architecture students. In fact, today, topological and structural optimization programs are becoming a normal use among students, which often use structural analysis software without having the necessary basis. In addition, extremely powerful computer codes based on the Grasshopper platform are more used by architecture students than by engineering students, who do not have the necessary basis to use programs such as Rhinoceros, that is necessary to use Grasshopper.

We are living in a transition era in which engineering schools teach the fundamentals of structural computing, using classic programming codes (FORTRAN, MATLAB, PHYTON) and finite element analysis software (ADINA, ABAQUS), that are created specifically to solve engineering problems. On the other hand, schools of architecture do not teach the necessary basis to use software of computational mechanics, but this software is hidden within other platforms more related to the world of architecture.

It is evident today how easy it is to produce a finite element analysis from a BIM (Revit) model of a building or to produce a topological optimization of the structure using Grasshopper, Karamba3D or Kangaroo.

What was achieved with knowledge, study and creation of a relationship between structure and architecture can now be performed in one click, even by people who are not able to fully understand the complexity of the problem. This paper wish to explore the danger of this "computational" approach when it is implemented without a clear definition of the relationship between architecture and structure.

To achieve this purpose, two structures of two great architects and engineers will be examined: Mies van der Rohe and Pier Luigi Nervi. Mies van der Rohe was chosen for his ability to create architecture with structures that are used consciously but also in a simple way. Pier Luigi Nervi was chosen for his pioneering studies on structural topology optimization when there was still no possibility of using an electronic calculator. The paper does not intend to be an exhaustive study on these two important figures, but only to recall some traits of their thought (mental thinking) and some computational remarks (computational thinking).

It will show how, with the help of a finite element code (ADINA) is now extremely easy to reproduce the topological optimization studied by Nervi and will propose a provocative study: how would the National Gallery of Berlin have been if the architect had used, in an arbitrary manner, a code of structural topological optimization? Evidently, the quality of an architecture must not be based solely on the availability of new electronic calculators.

2 CASE STUDIES

2.1 *Pier Luigi Nervi*

Nervi is considered one of the most significant engineers and architects of the twentieth century. His inventions, particularly in the field of reinforced concrete, have allowed him to aesthetically solve architectural values hitherto insoluble. He made use of ferrocement, a material which he perfected to build molds in which he could cast slabs made rigid by curved ribs, oriented in the most logical directions so that the transfer of load is normally from the slab to the posts. These ribs curve, also have an aesthetic role (Salvadori, 2015). Initially used only to make complex molds for pouring reinforced concrete elements, it was later transformed by Nervi into a structural material. Some of Nervi's masterpieces owe their elegance and efficiency to the use of ferrocement, which in France is still called "Voile Mince".

2.1.1 *Gatti Wool Factory*

Nervi's wool factory in Rome in 1951 is one of his most emblematic works. The slabs of this project, made by these complex molds, create concrete veins along a multiple isostatic line. Today the wool factory is now transformed into a garage for Lancias and Fiats instead the wool factory, (Architecturefarm, 2017) widely spaced columns manage the turning rays of cars as well as forklifts handled in the 1950s. Nervi realizes a perfect example of topological optimization, namely the made of an excellent conformation and the performance which affect to the constraints of the assigned project: the implementation of the odds, which increases from the pillars as a mushroom, it is not only decorative, but corresponds to the trend of isostatic fold lines, namely the trajectories of the main stresses. Although the structural behavior on which the isostatic vein patterns are based has been highlighted by Nervi, the way in which these patterns have been generated, is an important subject of multiple and varied discussions. This section explores the methods of experimental and theoretical analysis outlined in Nervi's writing and the application of these analytical techniques to isostatic production.

2.1.1.1 *Mental thinking*

The iconic isostatic slab combines the construction technique with the expressive static shape. Each slab of 5m x 5m is supported by a central column, the ribs really want to flow like a river, flowing into the nearest column. Nervi was able to build this more elaborate form by setting up molds for each unique shape and having wire mesh working in traction on them, after which he puts up a thin layer of cement on the mesh, burying and guaranteeing all the slabs assembled monolithically along the peripheral edges. The result is efficient in terms of static performance, and very expressive. In the structures, Nervi identifies two domains of experimental stress analysis: strain gauge methods and photo elasticity. Strain gauge methods rest on devices capable of measuring deformation by mechanical, optical, electrical, acoustic and pneumatic methods to determine displacements and stresses at the points of a small-scale model. Nervi first used mechanical strain gauges to determine the size of the stresses in the veins of a scale model for the 1935 Orvieto hangars. To find the stress field on the surface of a flat slab, it is necessary to use three-element strain gauge rosettes. These rosettes comprise three strain gauges, each oriented at a different angle to the two axes (x and y) in the plane, which provide three deformation measures corresponding to the three orientation angles. Using deformation transforming equations, we can calculate the three Cartesian components of the deformation and find the main deformation direction at the location of the measurement. Although the calculation of the main stress directions from the rosette readings is simple, the experimental preparations and the procedure are expensive and consuming a lot of time. More rosettes would be needed to obtain sufficient data to clearly represent the complete field of the main force trajectories. Since this method does not provide a more accessible means of obtaining isostatic than theoretical calculations, the strain gauge methods could not have been the initial means of Nervi to find isostatic. Nervi's fascination with the visualization of forces in photo elasticity experiments (conducted by Danusso at Milan Polytechnic) suggests that Nervi could use photo elasticity to generate isostatic effects. Photo elasticity is derived from the laws of tension and optics of stress. In 1816, Brewster invent the term photo elasticity due to the color pattern produced in clear glass when underlined and examined under polarized light. When certain transparent materials undergo forces, the material has a bi-refractive effect. When polarized light passes through the material, the rays refer to and separate into two perpendicular components, each parallel to the main refractive indices of the material. These conditions of the laws of constraint optics indicate that these principal indices correspond to the principal directions of constraint (Moody and Phillips, 1967; Halpern et al., 2013).

2.1.1.2 *Computational thinking*

Nervi relied on theoretical calculations to determine the isostatics of the principal moments for flat slabs, and contemporary engineers can now use the computer to calculate the forces in the slabs. These slabs have been designed to withstand uniformly distributed load conditions, and scaling does not change the directions of the major bending moments, each system is evaluated under uniformly distributed loads. This coherence in applied load models leaves unbiased principal bending moments in order to highlight how alterations in dimensions and boundary conditions influence isostatic veins patterns. It is possible to calculate such grids for a regular irregular arrangement of the beam slab with computer support.
Figure 1 shows an analysis performed using the finite element code ADINA, used by the authors for research and didactic (Sgambi et al. 2013). A quarter of one of the slab fields between the pillars has been modeled using shell elements. The pillar has been modeled as a support while constraints of symmetry have been placed on the sides. The analysis shows the main stress directions identified by Nervi with photoelastic methods. Through his study and reflections, Nervi was able to propose an optimized structure that today can be identified by numerical study of structural optimization (Sgambi et al. 2014).

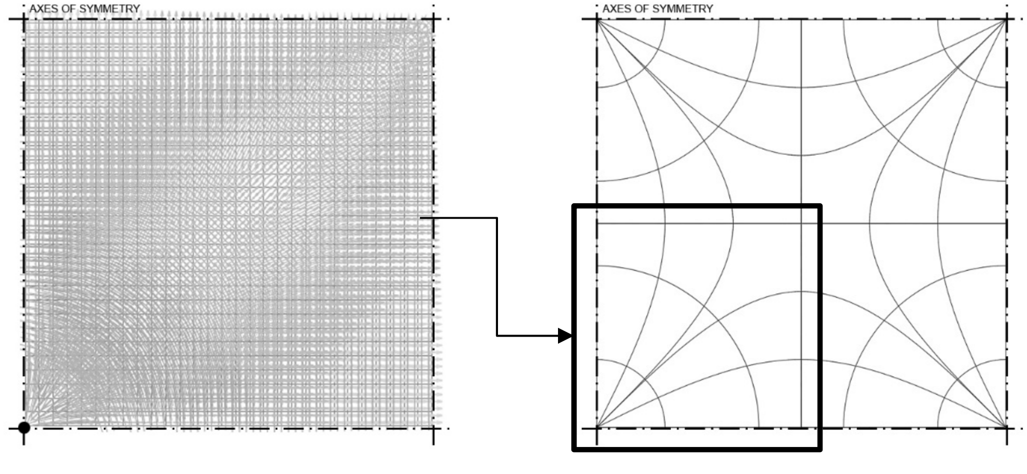

Figure 1. Finite elements models (left) and expression of results in the form of the slab of Nervi (right).

Numerical architecture and the use of parametric, over the last ten or fifteen years, there has been a tendency to characterize digital architecture by an affirmed experimental dimension in order to distinguish it from the mass of realized projects using the computer. A certain confusion was introduced at the same time between the qualifiers of numerical and experimental. The use is often sophisticated software is done by young architects who have been immersed in digital culture very early on. The computer tool nevertheless influenced the course taken by the digital architecture. Since the first steps of the assisted design, all sorts of new and spectacular forms have appeared on the screens. Some of them have even begun to transform the built environment. (Picon, 2010)

2.2 *Ludwig Mies Van Der Rohe*

Mies is famous for its creations of neutral spaces, contemplative thanks to an architecture based on the honesty of the materials and the structural integrity. His achievements bear witness to his strong interest in the internal-external relationship. The outdoor space is indeed considered as an extension of the interior space.

Its architecture is also marked by the dissociation of the envelope and the structure. In the last twenty years of her life, Mies has achieved her vision of a slender, slender architecture. His latest achievements are the outcome of a life dedicated to the idea of a simplified universal architecture.

2.2.1 *Neue National Galerie*

It is the only building built by the architect in Germany. The building, considered a pioneer of modern architecture, is inspired by plans from the 1950s for an office building in Cuba and never executed because of the Cuban Revolution.

The actual museum halls are underground, inside the basement dressed in granite. The pavilion above is a true architectural and technical feat: no walls and only eight pylons and glass walls support a huge coffered roof. For Mies, the architecture has become more accurate and newer after having evolved in the recent knowledge with the use of steel, the columns seem to impose a whole perimeter denser and opaque to the whole building.

These columns at the edge of the building seem to transmit forces with a thickness approximates to that of the beams themselves. The building elements, reduced to the essential, give the impression of extreme lightness. Mies has the preference to minimize the steel and its assembly, the precise manner of each connection is done in a disciplined manner (Mies Van der Rohe, 1986).

Then comes the question of structural clarity and what more needs to be done with the structural steel technique.

2.2.1.1 *Mental thinking*

The analysis of the behavior of the slab of Mies from the plans and projects of Mies Van Der Rohe are characterized by clear forms and the intensive use of glass, steel and concrete. His work laid the foundations for the construction of large buildings with glass facades. The mesh of beams is supported by 8 columns, the structure distributes the charges on the 4 sides of the architecture.

The explanation of the perimeter column seems to have less to do with the question of structural clarity, and even more so with the practicality of steel construction. An overhang cannot be made in a steel structure at the edge of a floor without introducing a downstream longitudinal spar parallel to the edge of the building on the center line of the perimeter columns. This is necessary to connect the cantilevered edge to the floor with the raised from the edge.

Mies said a preference for the discipline of steel. Distrusting the messy and somewhat random process of pouring concrete into a mold. Perhaps it was surprising that Mies was so versatile when it became necessary to choose concrete as a structural material.

2.2.1.2 *Computational thinking*

If Nervi studied the geometry of his slabs by photoelastic methods and structural reasoning, we have highlighted how easy is today to achieve the same results through a finite element analysis or a structural optimization (par. 2.1.1.2). Today we live in an era where computational tools are available to everyone. This leads to two fundamental situations. On the one hand, there is the possibility to study structures and projects with an unimaginable accuracy. But, on the other hand, engineers and architects can develop structural calculations and optimization procedures without ever having studied such topics. In fact, many programs used almost exclusively by architects (Autocad, Rhinoceros, Grasshopper, etc.) have been enriched with applications of structural analysis. This can lead to the development of architecture founded more on computational codes than on mental thinking with the consequent loss of quality.

As a provocation, we have used the same “mental” or “computational thinking” used by Nervi (par. 2.1.1.1 and 2.1.1.2) to redesign the Neue National Galerie of Mies Van Der Rohe. The Figure 2 left shows the finite element model of a quarter of the pavilion roof developed with the ADINA calculation code and shell elements. As shown in Figure 1 for the Nervi plate, Figure 2 shows the paths of the main directions of stress, i.e. the optimal geometry that the beams should have.

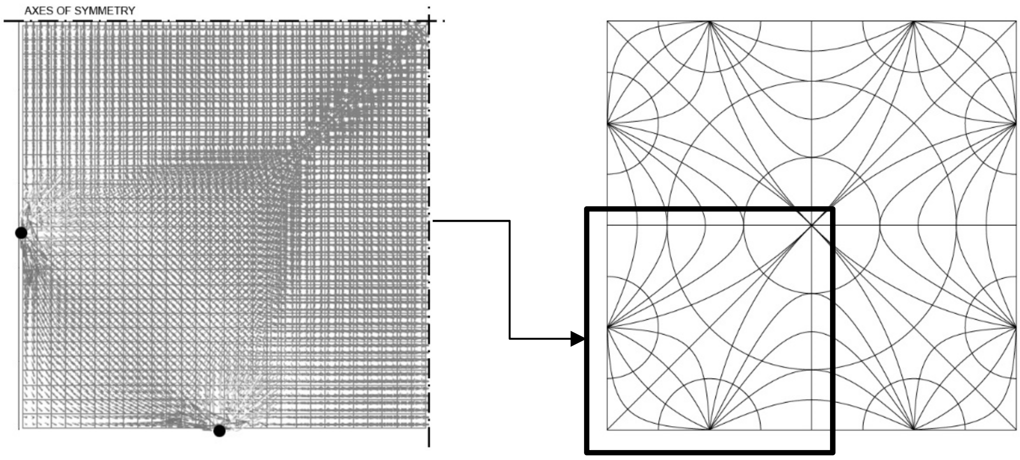

Figure 2. Finite elements model (left) and expression of results in the form of the slab of Mies (right).

By developing a finite element beams model of the beams grid, it can be demonstrated that the optimized solution allows the beam height to be reduced by 20 cm (with the same loads and vertical deformation). From the results show in Figure 2 right, it is possible to notice that the “redesign” is very far from the architectural paradigm of Mies Van der Rohe. It is easy to understand that the pavilion, redesigned with the structure optimized in this way, loses all its expressiveness.

Structural optimization by physical modeling was monoparametric and marked a trajectory towards multiparameter which aims to interact with heterogeneous data: geometry, dynamics, forces, environment, social data. Compared to the optimization of things, we have the risk of losing at the root of the idea of architecture, but with the same requirement and the same function, we can keep the root idea, the architectural approach takes precedence over the optimization calculation.

We must also know how to check its optimization, how to move from a 3D model of reality is not simple. The shortcomings of the proposed solution, identified by the evaluation, are rectified through the automatic or manual generation of a new design and a better alternative design. This visualization technology creates many design opportunities and saves time and energy for the architect / engineer.

2.3 *What we win and what we lose*

This way of doing and thinking is not very common in the world of engineers and still months at the architects. First of all, by a certain complexity of the tool but becoming easier and easier to use with the years, and this by the performance of our equipment as well as our programs more and more pushed on the study of materials and structures.

Today where digital dominates the architectural representation, we most likely have some crisis of immediacy between the brain and the hand, partly lost in the drawing. Other phenomena with the arrival of digital as the loss of scale in architectural drawing, we no longer know what scale is represented by a digital drawing. The zoom and un-zoom are daily and become a basic function on our supports, which gives us the feeling that it is neither too small nor too big. This crisis of the ethics of design takes on a new dimension with the digital and the new means of representation.

Other practices emerge, they came to enrich the vocabulary of the architect. This is one of the characteristics of the architect to be as versatile in the tools rather than in other domains, tomorrow the architect may also be a programmer with the evolution of digital, where programming will be part of our design tools (Picon, 2018). Lots of things appear, while others disappear.

This crisis of the traditional ethics of architecture, for example, the constructive truth, we are witnessing a revival of the desire for sympathetic collaboration with the matter. It's not about following the pattern of imposing a form on the matter, but a collaborating of the subject to allow the emergence of the form. They are the common way in digital fabrication and form interesting propositions with the emergence of computation.

2.4 *Aided Design*

Architects have always begun to draw their ideas before building, the draw organizes ideas, designs space, defines needs (Tedeschi, 2014). Computer-aided design assistance brings a certain comfort in architectural design, structural calculation, sunshine, urban flow, views, space.

The nature of the design of some complex form, no longer specifically call on engineers, but mathematicians, programmers, able to use certain data such as opens data to generate optimized urban planning and project.

Therefore, a better knowledge of tools would make it possible to evolve with the technique and to be much more effective for certain very repetitive action.

3 CONCLUSION

The utilization of these tools in architecture has transformed the way we think, conceive and improve our architectural understanding.

Our thinking about architecture is changing with new ways of representation, analysis, and design. The arrival of digital tools completely transforms the traditional ethic of drawing by hand to focus on computational design in the future.

By reflecting on the past, speculating on the present and exploring the future of digital architecture, we come to a multidisciplinary approach in a technological context of architecture combining design, programming and architecture.

We need to work with more mathematicians or developers, in a world where technology allows us to live better and optimize our resources.

This proliferation of computer tools leads to a transformation of the design. We seek a morphological and optimal design of the performances. Multiple digital generations of architectural prototypes analyze the benefits and costs, significantly improving the digital to physical design process.

With these optimizations, we can save on a project some calculation time, but also keep a big advantage on the construction. We are only at the beginning of this revolution, and so much remains to be accomplished. This progress will allow for the future to establish tangible connections on the evolution of the digital process necessary to ensure the success of automated construction for humanity.

While the power of computers, parametric design and optimization algorithms is evident, the role that schools of architecture and engineering are less evident. With the computing power of modern computers, it has proven how easy it is to produce topological optimization of a structure even with a finite element program. The relationship between structure and architecture cannot, however, be based solely on structural optimisation, but must refer to deeper concepts that are more closely linked to the quality of the space.

The danger of using optimization codes, without having the basis, remains that of being driven to use optimal solutions simply because they are conceived through a computer. But the architecture has shown us that topological optimization of a structure is not always the best choice for the quality of the generated space. Optimization is a tool that architects and engineers must learn to use to exploit its potential, but without being subjected to it.

In this context, it is clear that schools of architecture must begin to introduce basic courses in computational mechanics and programming, so that future architects can consciously use programs such as Grasshopper, Karamba3D or Kangaroo to search for new relationships between structure and architecture, with a critical thought to both the architectural and the engineering aspects.

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