Title:
Process of Design and Materialisation of an Emergency Structure as part of a Methodological Proposal

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Keywords:
Modular triangular lattice structure. Digital model and physical prototype. Infographic simulation. CONINPRE Method.

DOI: 10.14733/cadconfP.2023.15-20

Introduction:
The search for form in design in general and in architecture has been continuously modified since the appearance of computer technologies, which in turn constantly modifies the methodology for assimilating and making the most of the new resources that always arise. That is why the research developed works around the generation of a method that allows, from the teaching-learning process, to produce an analysis of the form that assimilates all the possibilities of digital technology in its three main aspects: parametric design, digital simulation, and digital manufacturing (CAD/CAM) [1].
This text presents an example of what the Virtual Laboratory of Infographic Simulation and Materialisation for Design (LAVSIMAD from its acronym in Spanish) of the Metropolitan University, Xochimilco Campus Xochimilco, based on a method developed by the members of the laboratory, known as CONINPRE (Concurrent, Interdisciplinary, Parallel and Recursive), has developed as a form-finding process that can be based on any of the following three positions: 1) Continuous morphological deformations and polymorphisms of dynamic forces, 2) Formal complexity, derived from the interplay of spatial, structural, or other configurations such as bioclimatic forces and 3) Morpho-ecologies and morphogenetic design. [2]
The first is developed through the combination of quadratic equations and kinematic animation and 3D Morphing transformation; the other two, through parametric generative algorithms, using the graphic language Grasshopper, in conjunction with digital simulations of physical phenomena (structural aspects) and/or environmental, among others. In the development process of the prototype described in this document, it is important to highlight that it was possible to integrate students from the Architecture and Industrial Design degrees in a multidisciplinary work.

Main Section
The methodological proposal arises from the combination of proposals previously put forward by various authors who approach the design process in a more dynamic way, such as the design process proposed by M. Mutlu, Potapova, S. Silverstein, J. Sundberg, M. Watabe [3], who propose a collaborative collective work of interdisciplinary non-linear architectural design. Another design process is proposed by Marios C. Phocas [4] in which he proposes an open-loop methodology of interdisciplinary physical and digital investigations from conceptual development, through a process of refinement and detailing, to detailed physical prototyping, all based on concurrent engineering. From the study of

these methods and with the objective of solving the needs identified in the research, the CONINPRE method was developed.

CONINPRE method:

The method known as CONINPRE, a result of a research project by a group of professors from the Universidad Autónoma Metropolitana, consists of considering the disciplines involved in the design of an object, from the beginning of the prefiguration to the final design stage, in a concurrent, interdisciplinary, parallel, and recursive manner (hence the acronym in Spanish of the method). To achieve this, it is necessary to establish a series of strategies and technical and technological resources that allow the objectives of the method to be achieved. Of these strategies and resources, the management of digital models is used to generate the conceptual idea and experiment with it in its space-form-function-environment-technology relationship. The physical prototype is used to evaluate the digital model to detect possible design and assembly problems and propose improvements that can be implemented in the original model, defining an iterative and symbiotic optimisation process in which the digital and physical tools improve and complement each other. The bridge between these two stages is the digital simulation that allows the representation of real situations already studied and tested previously, through computer modelling, aiming to forecast and verify future stages.

Of the prototypes designed and fabricated based on the CONINPRE method, there is one specific of relevant importance, an emergency modular triangular lattice structure.

This prototype is intended to be used as an itinerant structure for various purposes such as shelter, primary care clinic, and classroom. For this purpose, as part of the various analyses that were carried out, a spatial study was developed with various functional possibilities of the rectangular-based grid structure. Several aspects were considered, such as linear dimensions, envelope, and footprint area, as well as the conditions of temporary habitability and interior comfort.

Below is a series of images of the most suitable functional proposals-

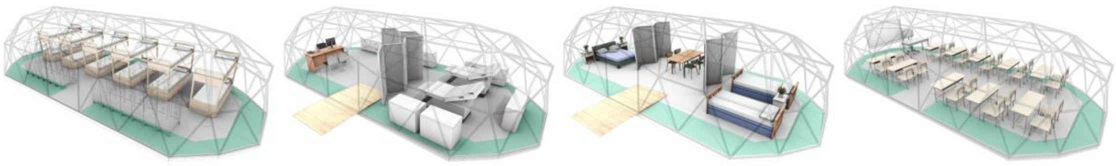

Fig. 1: Prototype Functional Proposals: Temporary Shelter, Temporary Primary Care Clinic, Emergency Housing, Temporary Classroom.

For this prototype it has been experimented with the shape, maintaining certain conditions such as ease of transport, lightness, and assembly and disassembly, so it has been sought to maintain the modular measures to create a larger space for the development of various activities.

This prototype consists of a triangular lattice structure with a rectangular base based on a frequency 2 geodesic dome 5 m wide by 12 m long. As it is based on a frequency 2 geodesic, 2 bar length measurements were used resulting in 84 bars of 1.54 m and 48 bars of 1.36 m, in addition to 32 bars that generate the 4 corners that give shape to the rectangular geometry, which was donated to a family of disasters victims in San Luis Tlaxialtemalco, in the municipality of Xochimilco, south of Mexico City.

The design process.

The LAVSIMAD team, assisted by social service providers and the research assistants, carried out an investigation and analysis of the design process, including the conditioning and determining factors of design production.

Once the previous phase was completed, the activity of formalising and prefiguring the design began. In this stage, based on the CONINPRE method, each of the members of the work team, from their specialties, contributed ideas, criteria, and strategies, which were organised to give coherence to each of the formal components of the design: space, composition, structure, environmental aspects, among others. Analogous studies of temporary structures were also carried out and the first conceptual and formal ideas were shaped, creating the first three-dimensional models.

Subsequently, using the graphical programming language Grasshopper© of Rhinoceros©, the geometric base of the original decagon of the geodesic dome was modified to obtain a rectangular base.

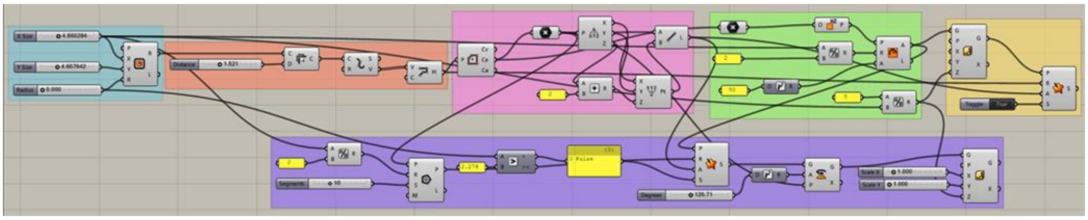

Fig. 2: Grasshopper script for the generation of the rectangular-based lattice structure.

From the new square shape and the modular design of the prototype in the chamfered corner, with the same script, it was possible to obtain both the rectangular base and other regular shapes such as the hexagon and octagon, resulting in the design of a modular corner that allows, from this, to configure various types of reticular structure of frequency 2. In this case, the CONINPRE methodological process was carried out for a reticular structure with a square base.

With this possibility of the dynamic geometric configuration of the base, it was possible to design a module (prototype) for the 4 chamfered corners that were modular in size and height and that, together with the rest of the structure, would behave structurally adequately within the tolerances set by the regulations for a temporary structure.

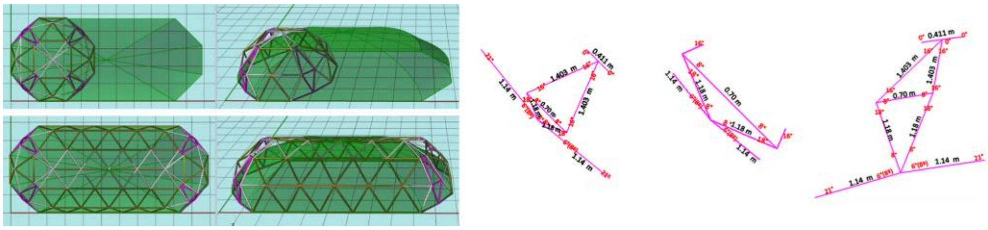

Fig. 3: Generation of chamfered rectangular base surfaces from the Grasshopper script and Final design of the prototype Lattice corner from geodesic dome transformation, frequency 2.

Physical modelling process and digital structural simulation

Based on the principles of the geodesic structure and the barrel vault, the morphological design of the structure was based on the combination of the typologies of a geodesic dome at the ends of the structure and a canyon in the middle part of the structure. In this sense, the polyhedrical and dihedral angles less than 45˚ work in tension, and those greater than 45˚ work in compression.

In this stage, the formal analysis and its relationship with the structural and spatial function were carried out. For this, *mecametría* was applied using digital computer graphics simulation (SAP 2000©, version 20 trial), considering the proposal of materials that met the structural and environmental criteria. Once the pertinent adjustments had been made in accordance with the results obtained by the simulation, three-dimensional impressions of the structure were made to corroborate the digital design, specifically, its shape, dimensions, number of bars, connection angles, and bending at the ends of the bars.

The results of the axial stress simulation (axial tension-compression force) under combined dead and live gravity loads show a maximum deformation of 1.4 cm at the apex of the structure, which is sufficient to absorb the combined load considered.

In this context, for the structural analysis based on computer simulation (digital) with SAP 2000, v 20, trial software, the structure was considered as a spatial mesh (truss) considering bending.

To guarantee the correct functioning and safety of the structure, gravity load, and wind force analyses were carried out.

Some of the most relevant values obtained in the structural analysis are shown below.

Mechanical properties	Values
Material	Galvanised steel 500, grade B (round)
Volumetric weight	8,004.77 kg/m³ (78499,977 N/m³)
Elastic Modulus (Young's modulus) and	2'038,935.8 kg/cm² (199,951.34 MPa)
Poisson's Coefficient (U)	0.3
Yield Strength of Steel (Fy)	2,953 kg/cm² (289.59 MPa)
Shear Modulus (G)	784206.1 kg/cm² (76,904.36 MPa)

Tab. 1: Mechanical properties of galvanised pipe bars.

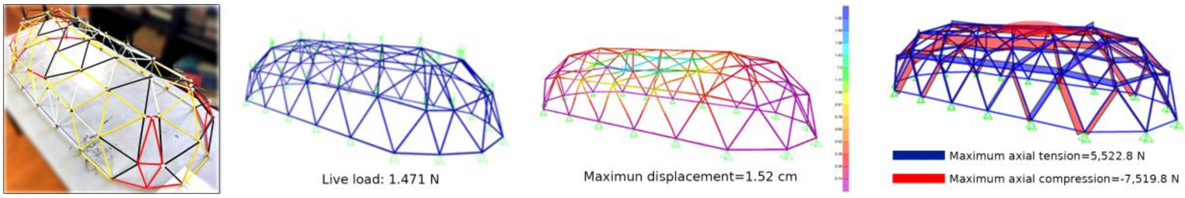

Fig. 4: Physical model (obtained by 3D printer), Non-linear structural simulation considering a live load of 1,471 N + the self-weight of the structure, as well as the result of the maximum displacement in cm and axial tension and compression forces.

Connectors

For the connection between bars (galvanised tubes), the direct connection connector was used, also known as the classic connector, which consists of flattening and drilling holes in each of the ends of the bars fixed with screws.

To obtain the angles of the internal triangles (isosceles and equilateral) of the bars, as well as the bending angles of the ends of the bars in the extreme and central part (barrel vault) of the lattice structure, trigonometric functions such as the law of cosines, Pythagorean theorem, among others, were used. In addition, the modular prototype design was also able to reduce the bending angles of the tube ends to 3 (the original 2 angles of the frequency 2, the geodesic dome of 16° and 18°, an angle of 8°, as well as having tubes with no bending, i.e. an angle of 0°).

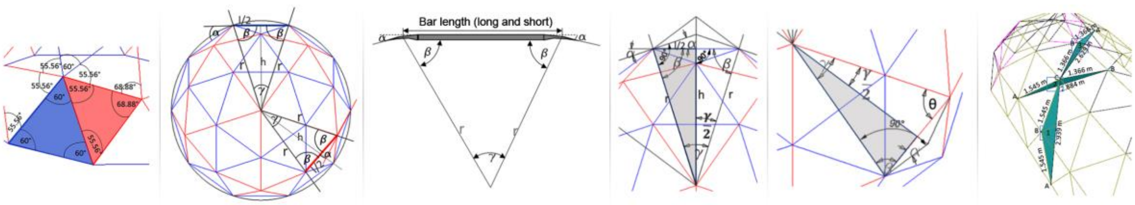

Fig. 5: Angular dimensions of the geodesic dome part.

For the design of the access and ventilation shafts, a design based primarily on achieving cross ventilation regardless of the orientation of the structure was considered to achieve an adequate temperature inside the structure.

The main access was located in the center of one of the longest sides of the structure, with a ventilation shaft on the opposite side. A similar case was made with the ventilation openings located on the short sides of the structures. Despite the above, the fact of placing a plastic tarp as a cover caused the interior temperature to increase in summer, decreasing thermal comfort. This was translated in part of the recursiveness in the experimental process that demanded reconsidering the choice of materials for future covers.

Assembly and mounting process of the structure based on the chamfered corner prototype.
As a final design stage, the full-scale assembly of the rectangular base structures was executed. The purpose of this stage was to corroborate that both the digital design and the analysis in the physical model and structural analysis were as expected. In addition to assembling the rectangular-based structure, a square-based structure was assembled with the same tubes as the geodesic, frequency 2. Although the disassembly and assembly of the square-based structure presented some problems in the transition from one process to another, it was possible to verify that different typologies can be assembled with the same tubes based on the modular prototype of the chamfered corner.

Also at this stage, as part of the research, teaching strategy, and as an experimental workshop, students from the architecture and industrial design courses were involved in the construction of this structure under the supervision of the LAVSIMAD members.

The final cost of the structure already assembled at the donation site was USD 1,169 for a floor area of 47.5 m2 and an envelope area of 83.5 m2 respectively. The assembly, as mentioned above, was carried out with the collaboration of students and professors who participated voluntarily, reducing the cost of the construction.

Finally, although this prototype was part of a research project that started in 2016, the development and construction of this structure took approximately 2 weeks and the assembly on site took only one day.

Fig. 6: Assembly of the temporary structure with rectangular base.

Conclusions

Parametric design, regardless of the technique used, has allowed LAVSIMAD to experiment in the search for new three-dimensional geometric shapes known as geometric polymorphs, adding factors that allow the analysis of different situations that must be contemplated for the prototypes to be developed in the most satisfactory way possible.

The CONINPRE method contributed with a coordinated work that took advantage of all the resources available: different specialists working in an interdisciplinary way, different programmes that allow infographic analysis, the use of physical models to achieve the formal search until obtaining, as a result, the temporary triangular lattice structure with a rectangular base, also giving rise to a prototype of corners that will allow generating new structural forms of lattice, which meet the functional requirements of comfort, adaptation to environmental conditions, economic viability and structural safety. The interdisciplinary transmission of knowledge to students of two undergraduate degrees: Architecture and Industrial Design was also achieved, allowing the collaboration and active participation of students and members of LAVSIMAD, also generating a positive social impact since its materialisation on a real scale was used as emergency housing for victims of the earthquake of

September 2017, thus closing the cycle that includes the entire design process of a structure, from prefiguration to materialisation and use.

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