DOI: 10.2478/sspjce-2025-0004

Optimization by RSM of reinforced concrete domes with meridian ribs, under static loading.

Logzit N.[1,2*], Raouache E.[3], Bentoumi M.[1,3], Bentoumi A.[2] and Khababa I.[2].

[1] LMSE Laboratory, University of Mohamed El Bachi El Ibrahimi of Bordj Bou Arreridj. Algeria.

[2] Civil Engineering Department, Faculty of Science and Technology, University of Mohamed El Bachir El Ibrahimi of Bordj Bou Arreridj. Algeria.

*e-mail : n_logzit@yahoo.fr.

[3] Mechanical Engineering Department, Faculty of Science and Technology, University of Mohamed El Bachi El Ibrahimi of Bordj Bou Arreridj. Algeria.

Abstract

Reinforced concrete domes with meridian ribs present a suitable solution for covering large spaces, but their optimization in terms of strength and stability remains a challenge not yet mastered. This work presents a new global mathematical approach to optimizing these structures, starting with a primary configuration braced at the top and bottom with ring beams. This configuration will undergo optimization via numerical simulation to ensure its mechanical performance. The main variables studied include dome diameter, rib spacing, thickness and supported load. A Response Surface Methodology (RSM) is then used to correlate these parameters. Ultimately, a cost-oriented objective function is derived, incorporating a load-bearing capacity coefficient. This approach proves effective and can serve as a valuable tool for designers seeking to optimize their projects.

Keywords: reinforced concrete domes, meridian ribs, optimization, RSM, global approach.

1. Introduction

To cover a space, you'll need a structural system that's adequate in terms of strength and stability, with pleasing architecture and sufficient durability. Several choices can be envisaged. And to technically optimize the choice to be adopted in terms of mechanical performance, a load-bearing coefficient [1] is used to measure the capacity of such a structural system. This coefficient is the ratio between the load supported by the system and the weight of the structure. The higher the coefficient, the higher the performance of the structural system. Three-dimensional thin-walled reinforced concrete structures offer a simple, economical solution, and are widely used in civil and industrial construction. However, they share the common characteristic of being among the most delicate structures to study.

Reinforced concrete dome structures reinforced with meridian ribs are one of the main components of this range of structures. The ribs are introduced into the system to give the structure additional rigidity against the stresses applied to it. When it comes to thin-plate roofing with meridian ribs for any structure, the designer is faced with the following two classic imperatives: Knowing how to analyze the structure in order to dimension it with sufficient safety, knowing how to design, plan and build the structure rationally and economically. But for civil engineers, in the field of thin shells, a third essential requirement arises: knowing how to choose optimal shapes. Before explaining our contribution to this work, it is important to review the little numerical and experimental research carried out on reinforced concrete domes.

In a recent article [2], experimental tests were carried out on a 60 cm diameter reinforced concrete dome model, showing the influence of the ring beam at the base of the dome on its overall mechanical behavior. This suggests the contribution of such a reinforcement at the base. Another numerical study using ANSYS [3] on reinforced concrete domes with several design variants of the structural system, shows that increasing the percentage of steel in the concrete has no significant influence on the mechanical performance of the dome. On the other hand, the presence of a meridian rib reinforcement with a ring beam at the base provides a significant reinforcement contribution. This study also reported a variation in stresses from an optimum dome diameter of 8 m.

An analytical study on reinforced concrete semi-spherical domes, in non-linearity [4], with and without meridian ribs, using SAP2000, concluded that the mechanical response of structural systems of pairs with meridian ribs is better than that of domes without meridian ribs, this finding being more pronounced at larger diameters. With regard to concrete strength class, a study of various cases of structural systems for reinforced concrete domes [5, 6], shows a minimal increase in mechanical performance when moving from a concrete class of 20 to 25 to one of 30 or 35 MPa.

Using Comsol Multiphysics, an optimization study [7] showed that the choice of optimization method significantly affects the mechanical response of domes, but is more dependent on the geometry and size of the finite elements. However, these results show that further research into optimizing the shape of these systems is possible. The initial shape of the spherical or semi-spherical dome has a considerable influence on the mechanical response of the structural system. The number of ribs has a significant influence on the dome's mechanical behavior: by going from two ribs to four, the breaking load increased by 25% [6]. It should also be noted that the spherical dome, despite its compression response, remains favorable for concrete, but the quantity of concrete is important here.

Parametric analysis is the key to optimizing a dome, a study led by Jain, Nayak, and Walke [8] presents a bibliographical synthesis of recent research on the subject in terms of analysis and design. The shape of the double-curved spherical dome with meridian ribs has been studied by N. A. Jasim et al [9], who showed that the ribs can be subject to tension, and also observed that the maximum displacement is not always located at the top. Finite element models of axisymmetric reinforced concrete domes with two rings were analyzed [10] by three software packages (Abaqus, FEAS, ARSAP). The results show a 30% difference between the analysis models, and a significant convergence between the three calculation codes. On the effect of shape, using the ratio of height to diameter, Peter Chacko et al [11] showed that the best shape for spherical domes to resist vertical and horizontal loads is between 0.3 and 0.35.

From a fatigue point of view, a recent study by LOGZIT et al [12] showed that these systems are subject to fatigue phenomena, with a direct relationship proposed between behavior under monotonic loading and fatigue loading. The subject of improving structural systems under wind load was studied by Ife Olorun O. and Ronggui L. [13], who showed that system materials can affect the mechanical behavior of the structure. The bibliographical references cited above provide advanced optimization methods for reinforced concrete domes with meridian ribs, and can serve as a starting point for further research in this field. But careful analysis of all the studies cited above shows the absence of a global approach integrating all the parameterized data to arrive at the final optimization solution. These studies use a straightforward approach to describe only the mechanical behavior of the domes under the influence of the various optimization variables. The designer will need a mathematical formulation linking all the parameters to meet a mechanical performance or economic objective. In this work, we propose a new optimization approach, targeting an objective through parameterized analysis, by means of a mathematical formulation, giving the numerical response prediction. This model will be able to give the final solution sought, knowing the variable parameters of the study. The importance of this model is that the constraints or optimization conditions are not included in the final formulation, but are taken into account in the preliminary phases of the approach.

2 Optimization parameters

Optimization is a mathematical process aimed at finding an objective function. It is used in many fields, its objective being to obtain the ideal variant of a study by including variables and conditions. A mathematical foundation for optimization theory and its applications in science is presented in an article by G. R. Sinha [14] and the book by M. Cavazzuti [15]. An example of the application of parametric optimization concepts using the design of experiments method on reinforced concrete beams is also discussed by Raouache et al [16].

In parametric shape optimization, the shape is governed by a small number of variable parameters. These parameters generally have a physical meaning, and the model's dependence on them is therefore explicit. They can be length, thickness, radius, angle or height. During optimization, the initial shape is modified through the evolution of the parameters assumed by the model. This approach has the effect of limiting exploration of the design space, since it does not offer any variation of the shape boundary or its topology. The optimal shape found will be similar to the initial one, but with different dimensions and layouts. As a first approximation, the initial shape in this new optimization approach (Figure 1) is deduced from experimentation by analyzing all theoretical and experimental studies to arrive at an ideal initial design solution. From previous studies, we can conclude that the best configuration of the reinforced concrete structural system is in the form of a low-profile or semi-spherical dome, with an annular beam at the top, and another at the base. These two annular beams are radially braced by a well-defined number of meridian ribs. This initial solution was deemed satisfactory in terms of both mechanical and economic performance.

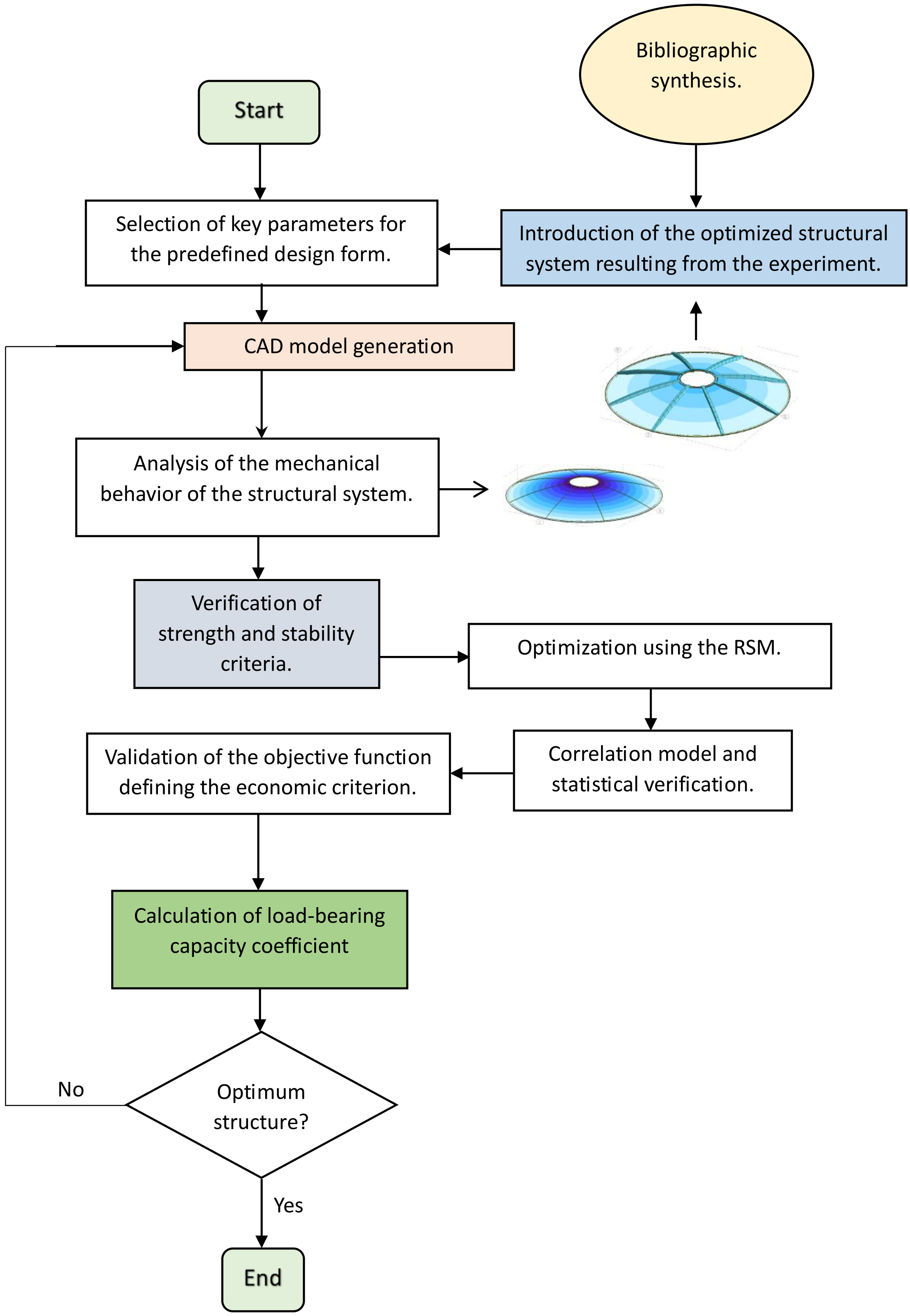


Figure 1: Global optimization approach.

This structural choice will be introduced into the optimization model in order to precede a second approximation aimed at finding the global approach relativizing the variable parameters by a global objective function.

Once the shape parameters have been chosen, an optimization procedure can be implemented. The general formulation of an optimization problem consists of three main parameters: the *objective function*, the set of admissible *variables*, and the n study *constraints.* Having posed the optimization problem, the next step is to adopt a strategy for solving it. Design-of-experiments and response-surface optimization are the most common approaches used in industry, shape and material design. However, this method is less widely used in structural systems optimization.

The objective function here is the ideal form and arrangement, which results in a design that meets the strength and stability requirements governed by reinforced concrete regulations [17], to which is added an economic concern representing a minimum quantity of concrete in the structure. To compare the mechanical performance of two or more configurations of the structural system, we adopt here the notion of the relative capacity coefficient of the structure [1]. As for the study variables, the design of the meridian-ribbed dome will be governed by four main parameters: dome thickness (*e*), distance between meridian ribs (*Esp*), dome diameter or span (*D*), and static load supported per m^2(*Q*).

The constraints or study conditions are the structural system strength and stability criteria to be verified before validating the selected design. They involve checking the maximum stresses at dome level against those tolerated by regulations, as well as checking the maximum displacements. At the end of these verifications, we arrive at configuration *i*, to which we add the verification of the weight of the structures in relation to configuration *i-1*. The best solution is the one with the minimum weight. In this way, the solution found at the end of the optimization process is quite different from a simple dimensioning: it will present the best configuration of the structural system among several verifying the dimensioning aspect.

The quantity to be minimized, called the *objective function* or *cost function*, is therefore the volume of the dome and ribs “V”. The dome (Fig. 1) consists of a thin shell of thickness “e”, radius “R” and deflection “*f*”, with arched ribs of cross-section “s”, length “l” and number “n”.In this configuration, the variables: e, R, f, s, l, and n are the set of optimization variables. In addition to the fixed diameter “D” of a given case, other *constraints* can be taken into account. Indeed, we can consider that the dome deflection *f* must remain within the interval *D/8* and *D/10* to be in the case of low-profile or semi-spherical domes. Since the optimization *variables* represent dimensions, mathematically it seems natural to choose the set of positive reals as the space of admissible *variables.* In other words, the variables (*e, R, f, s, l* and *n*) take their values in *R+*.

The variables: *e, R, f, s, l,* and n are the optimization *variables* that drive the shape of the dome. This classical optimization problem can be formalized mathematically by the following equation (1):

✓ Minimize : $V = 2\pi . R. f. e + (s. l. n)$

Such as: $(e, R, f, s, l, \text{et } n) \in R^6$

D = Fixed for the specific case.

Such that: f = between $D/8$ and $D/10$ (1)

✓ Verification of regulatory limits and constructive provisions.

To obtain the objective function, the RSM will be adopted, using stepwise approximation. This method determines the best configuration of meridian ribs to maximize the structure's strength and stiffness, while minimizing the amount of material used.

3 Numerical simulation

As a first step, and using the finite element method, several study cases of meridian ribbed domes were simulated by the software. The second stage consists of numerical analysis using the design of experiments method, with the results found in the first stage subsequently being exploited to design the final numerical model. The first step is to define the initial shape based on the geometric entities derived from the CAD models. Figure 2 shows the structural system model adopted, with the required variables. A computer program derived from the strength-of-materials formulas used for dimensioning was developed in direct connection with each CAD configuration. For this section, and before moving on to the RSM, the following assumptions were made in the numerical simulation:

- ✓ Reinforced concrete domes with meridian ribs,
- ✓ Dome diameter (span) is variable,
- ✓ Dome deflection “*f*” is between *D/8* and *D/10*.
- ✓ Concrete class 25 MPa.
- ✓ Linear elasticity analysis.
- ✓ Assume structure's own weight G.
- ✓ Uniform static load *Q* per m^2 on the dome of : 100 to 200 Kg/m^2. In accordance with standards and regulations, see e.g. reference [17].
- ✓ Load weighting according to regulations: $G + Q$ and $1.35\ G + 1.50\ Q$.
- ✓ As a first approximation, check load-bearing capacity.

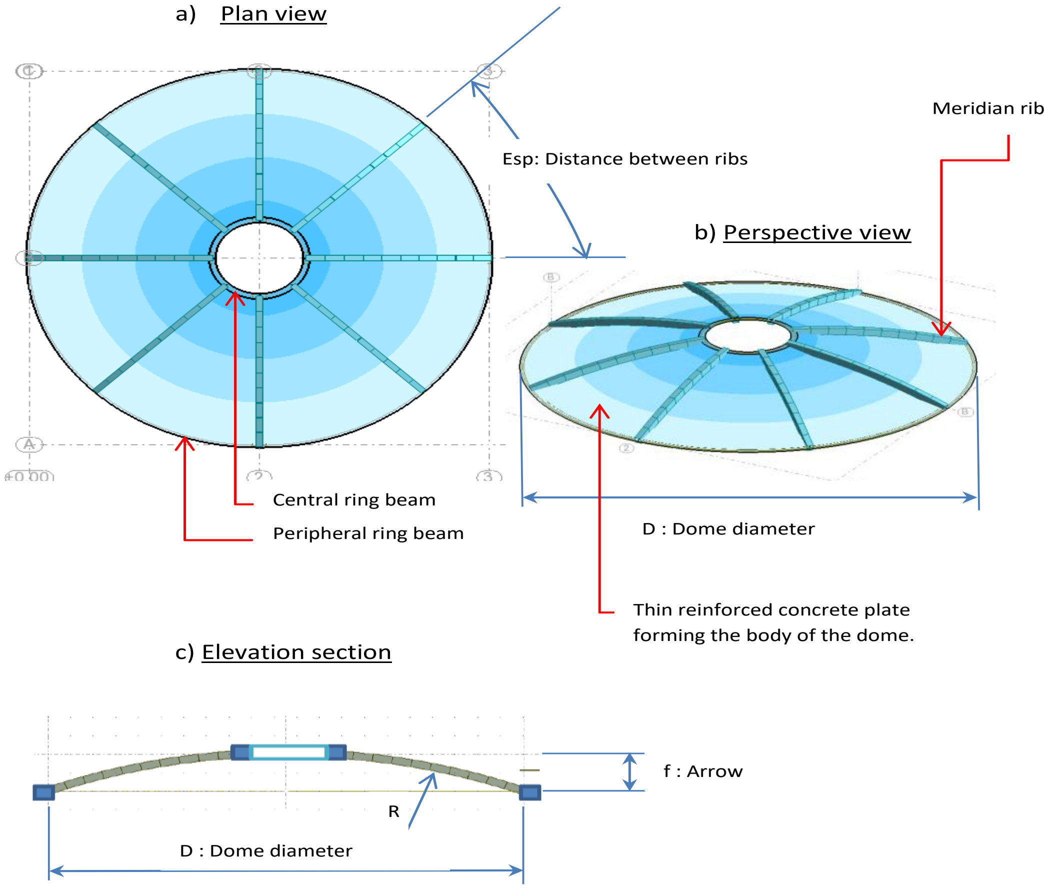
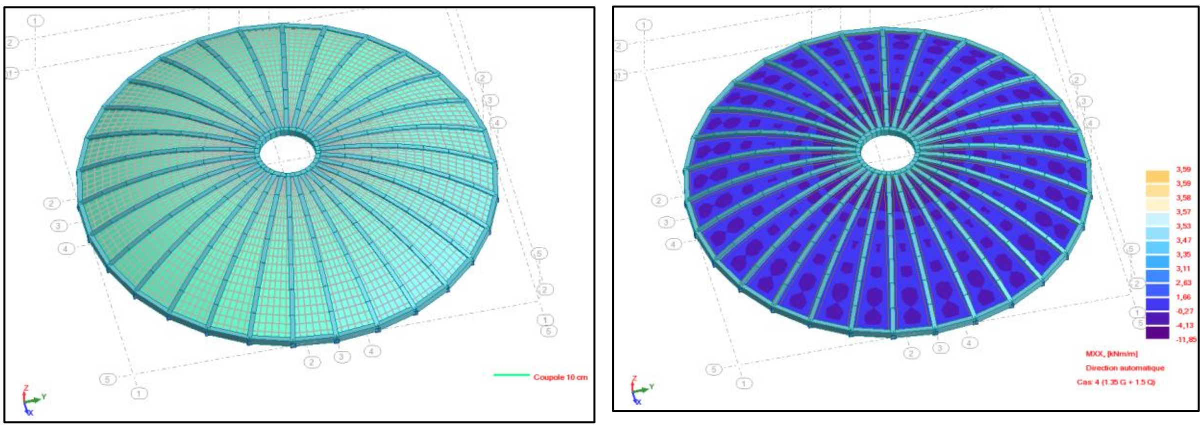


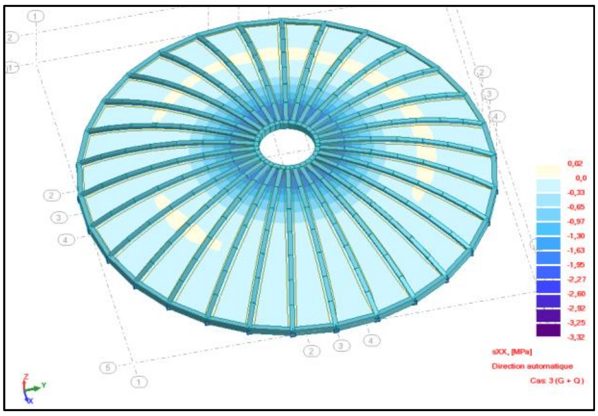
Figure 2: Geometric characteristics of the structural system adopted.

By analyzing 21 cases of domes with meridian ribs, and after verifying all the resistance and stability conditions, a graphical extract of the mechanical behavior of structural system No. 3 (see figure 4) is illustrated in figure 3.

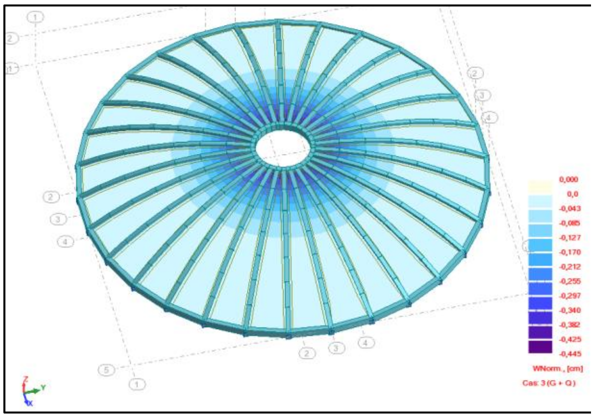


a) Mesh structure.

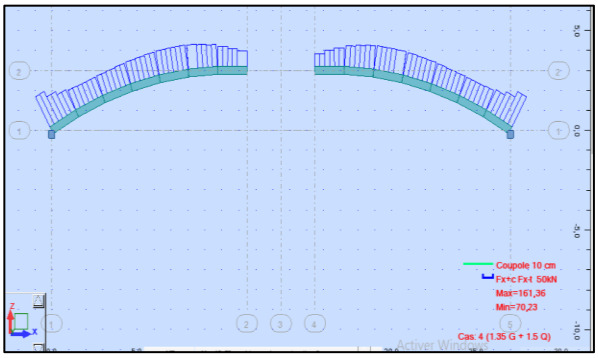
b) Moment under: 1,35 G + 1,5 Q.



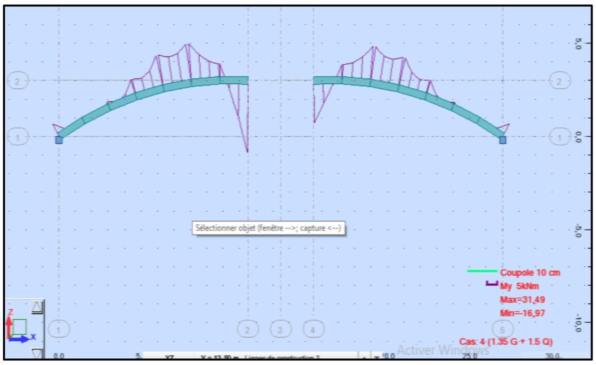
c) Constraints under: G + Q.



d) Move according to -Z under : G + Q.



e) N force in ribs under: 1.35 G + 1.5Q

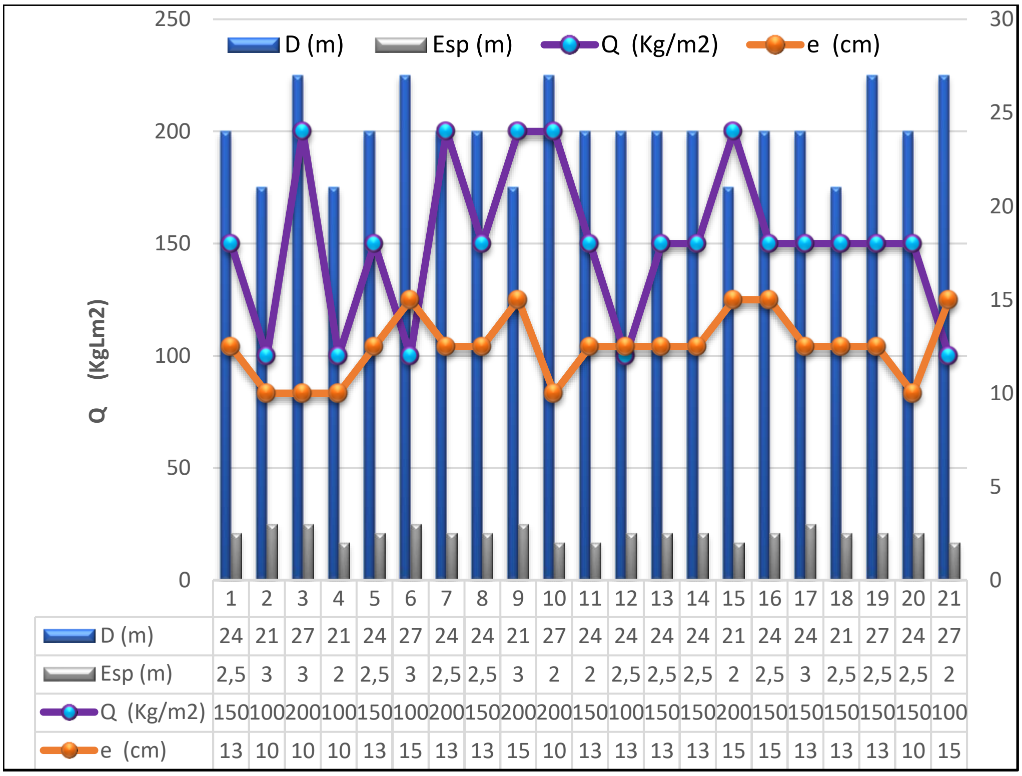


f) Moment in ribs under: 1.35 G + 1.5. Q.

Figure 3: Mechanical behavior of the meridian-ribbed dome.
Case N°3: D = 27 m, f = 3 m, e = 10 cm, Esp = 3 m, and Q = 200 Kg/m2.

Figure 3 shows the mechanical response of the structural system under its own weight combined with an operating load of Q = 200 Kg/m^2. Figure (3,a) shows the finite element mesh, which is of the 4-node quadrangle type for surface elements, and of the 4-node tetrahedral type for volume elements. The element size is set at *0.5 m* max. Figure (3,b) shows the mapping of the moment in the dome under the combination 1.35 G + 1.5 Q, the moment varies from 3.59 to 11.85 KN.m, these relatively low values show that the system is loaded more in compression than in bending. Figure (3,c) shows stress mapping at the dome under G + Q, with a maximum value of 3.92 MPa, still below the tolerated limit. Figure (3,d) shows the displacement map under G + Q, with a maximum value of 0.445 cm at the top of the dome, well below the maximum tolerated deflection (*D/200*). Figures (3,e) and (3,f) show the normal force and bending moment, respectively, in the meridian ribs, which are subjected to compound bending in places. The 21 cases studied will follow the same process of monitoring mechanical behavior, and once the structural system has been validated, it can be considered as the result of numerical simulation.

The numerical simulation results representing the matrix of experiments are shown in Fig 4 and 5.



D (m)	e (cm)	Esp (m)	Q (Kg/m²)
24	12,5	2,5	150
21	10	3	100
27	10	3	200
21	10	2	100
24	12,5	2,5	150
27	15	3	100
24	12,5	2,5	200
24	12,5	2,5	150
21	15	3	200
27	10	2	200
24	12,5	2	150
24	12,5	2,5	100
24	12,5	2,5	150
24	12,5	2,5	150
21	15	2	200
24	15	2,5	150
24	12,5	3	150
21	12,5	2,5	150
27	12,5	2,5	150
24	10	2,5	150
27	15	2	100

Figure 4: Representation of the experiment matrix, part 1: Variables.

Figure 4 shows a graphical model of all the cases studied, with all the variable parameters. These numerical simulations have been validated to a first approximation. Figure 5 illustrates the mechanical response using a structure weight indicator, showing the linear increase in structure weight as a function of increasing dome diameter. A 29% increase in diameter results in a 64% increase in structure weight, which explains the sensitivity of structure weight to diameter variation.

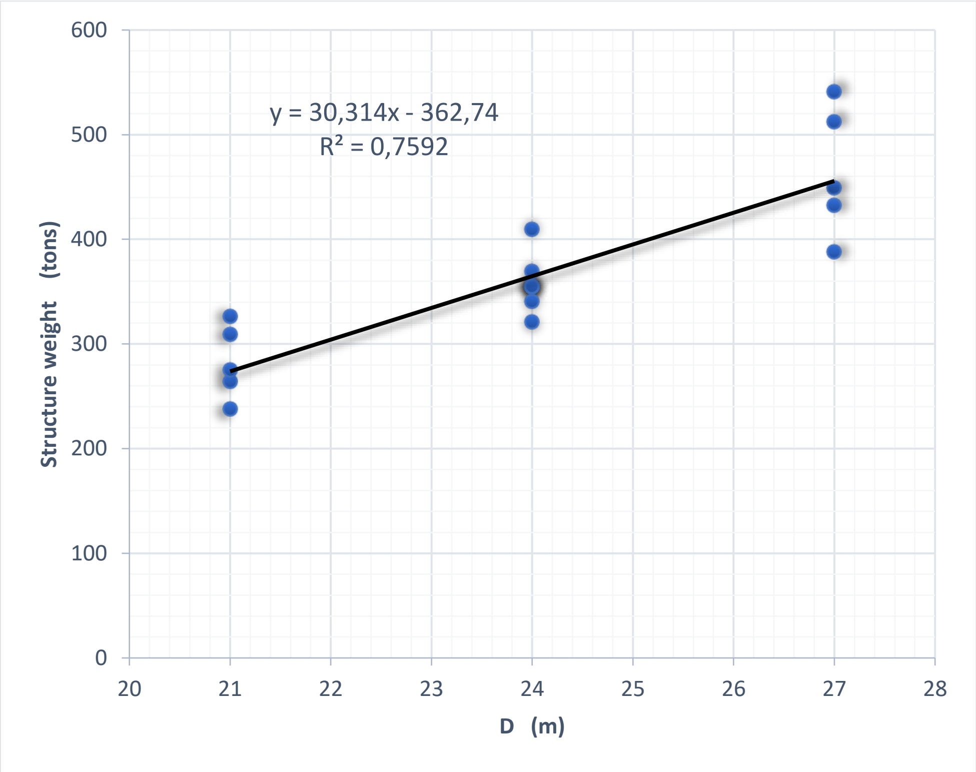


Figure 5: Experience matrix, part 2: Response.

Having characterized the various initial parameters of our study, we will then present, as a second approximation, the curves and graphs grouping the interactions of the data with the final optimization results of the ribbed domes. The optimization work will be elaborated by adopting the design of experiments method, using the Design - Expert 7.0.0 software. The aim of this step is to provide a precise numerical vision of the overall mathematical relationship between the various parameters.

4 Response surface methodology (RSM) and analysis of variance (ANOVA)

In this step, we will simulate the interaction of the various study parameters, using the results obtained in Figures 4 and 5. In our optimization study, we aim to optimize the number of trials and minimize the experimental factors in order to achieve maximum results. The aim of the study is to find out how we can set our parameters in order to get the best response for predicting the objective function. The predictive response models in this study were developed using RSM. The models' reliability was checked using analysis of variance (ANOVA). Response models produced might be linear or higher-degree polynomials as presented in a generalized format in Equations (2) and (3), respectively.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_n x_n + \epsilon \quad \textbf{(2)}$$

$$Y = \beta_0 + \sum_i^k \beta_i X_i + \sum_i^k \beta_{ii} {X_i}^2 + \sum_{ij}^k \beta_{ij} . X_i . X_j + \epsilon \quad \textbf{(3)}$$

where y denotes the desired response, β_0 is the regression coefficient for the constant term, whereas β_i, β_{ii}, and β_{ij} are the coefficients for linear, quadratic, and the interaction of x_i and x_j terms, respectively. The number of factors is denoted by k, while the random error is denoted by ϵ.

These parameters included dome diameter, dome thickness, rib spacing, and applied load, denoted A, B, C, and D in coded terms, respectively. Each factor value varied over five (5) levels, namely: axial points (-α /+α), factor points (-1/+1) and central point (0).

ANOVA is a statistical technique utilized to assess the significance and contribution of different factors in explaining the observed variability in responses. The implementation of ANOVA also facilitates the dissection of distinct effects from the variance observed in the measured response. It should be noted that ANOVA analysis was carried out using Expert Design Software 13.

Table 1 and 2 presents a comprehensive overview of the input variables employed in the experimental design, including their coding and corresponding actual levels.

Table 1: Coding and real levels for RSM

Variables	**Unit**	**Symbol**	**Coded factor levels**		
			-1	0	+1
Dome diameter	m	A	21	24	27
Dome thickness	m	B	0.10	0.125	0.15
Rib Spacing	m	C	2	2.5	3
Applied load	(kg/m^2)	D	100	150	200

Table 2: Numerical results

Number of tests	**A**	**B**	**C**	**D**	**Weight of the structural system (Tons)**
1	24**(0)**	0.125**(0)**	2.50**(0)**	150**(0)**	354.94
2	21**(-1)**	0.10**(-1)**	3**(+1)**	100**(-1)**	238.04
3	27**(+1)**	0.10 **(-1)**	3**(+1)**	200**(+1)**	388.18
4	21**(-1)**	0.10 **(-1)**	2**(-1)**	100**(-1)**	308.99
5	24**(0)**	0.125**(0)**	2.50**(0)**	150**(0)**	354.94
6	27**(+1)**	0.15**(+1)**	3**(+1)**	100**(-1)**	432.14
7	24**(0)**	0.125**(0)**	2.50**(0)**	200**(+1)**	354.94
8	24**(0)**	0.125**(0)**	2.50**(0)**	150**(0)**	354.94
9	21**(-1)**	0.15 **(+1)**	3**(+1)**	200**(+1)**	264.34
10	27**(+1)**	0.10**(-1)**	2**(-1)**	200**(+1)**	512.42
11	24**(0)**	0.125**(0)**	2**(-1)**	150**(0)**	409.50
12	24**(0)**	0.125**(0)**	2.50**(0)**	100**(-1)**	354.94
13	24**(0)**	0.125**(0)**	2.50**(0)**	150**(0)**	354.94
14	24**(0)**	0.125**(0)**	2.50**(0)**	150**(0)**	354.94
15	21**(-1)**	0.15**(+1)**	2.00**(-1)**	200**(+1)**	326.42

16	24**(0)**	0.15**(+1)**	2.50**(0)**	150**(0)**	369.55
17	24**(0)**	0.125**(0)**	3**(+1)**	150**(0)**	320.84
18	21**(-1)**	0.125**(0)**	2.50**(0)**	150**(0)**	275.38
19	27**(+1)**	0.125**(0)**	2.50**(0)**	150**(0)**	448.99
20	24**(0)**	0.10**(-1)**	2.50**(0)**	150**(0)**	340.33
21	27**(+1)**	0.15**(+1)**	2**(-1)**	100**(-1)**	540.85

ANOVA aimed to describe the individual and combined effects of each factor (dome diameter, dome thickness, rib spacing, and applied load) on the weight of the structural system. The quadratic mathematical model, obtained in terms of a coded factor developed by statistical software (Expert Design, Version 13), is expressed by equation (4).

Weight of the structural system (Tons) = + 354.33 + 86.81A +14.61B - 45.46C + 3.58AB - 12.49AC + 0.095AD + 3.05BC - 5.17BD - 0.83CD +8.37A^2 +1.12B^2 +11.35C^2 + 1.12D^2 (4)

Table 3: Analysis of variance (ANOVA) of Weight of the structural system.

Source	**Sum of Squares**	**df**	**Mean Square**	**F-Value**	***p-value*** **Prob > F**	**Significance**
Model	1.09E+05	14	7780.26	6388.94	< 0.0001	**Yes**
A-Domediameter	15070.22	1	15070.22	12375.25	< 0.0001	**Yes**
B-Domethickness	426.9	1	426.9	350.56	< 0.0001	**Yes**
C-RibSpacing	20669.75	1	20669.75	16973.44	< 0.0001	**Yes**
D-Appliedload	0	1	0	0	1	**No**
AB	20.53	1	20.53	16.86	0.0063	**Yes**
AC	1248	1	1248	1024.82	< 0.0001	**Yes**
AD	0.014	1	0.014	0.012	0.9168	**No**
BC	74.42	1	74.42	61.11	0.0002	**Yes**
BD	42.77	1	42.77	35.12	0.001	**Yes**
CD	5.54	1	5.54	4.55	0.0768	**No**
A^2	178.76	1	178.76	146.8	< 0.0001	**Yes**
B^2	3.22	1	3.22	2.64	0.155	**No**
C^2	329.04	1	329.04	270.2	< 0.0001	**Yes**
D^2	3.22	1	3.22	2.64	0.155	**No**
Residual	7.31	6	1.22			
Lack of Fit	7.31	2	3.65			
Pure Error	0	4	0			
Cor Total	1.09E+05	20				
Standard of deviation.		1.1	**R-Squared**		0.9999	
Mean		364.79	**Adjusted R-Squared**		0.9998	
Coefficient of variation. %		0.3	**Predicted R-Squared**		0.9879	
Predicted residual error of sum of squares		1322.89	**AdequatePrecision**		324.069	

The model F-value of 6388.94 implies the model is significant. There is only a 0.01% chance that a "model F-value" this large could occur due to noise. Values of "Prob > *F*" less than 0.0500 indicate model terms are significant. In this case, *A, B, C, AB, AC, BC, BD,* A^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Pred R-Squared" of 0.9879 is in reasonable agreement with the "Adj R-Squared" of 0.9998. "Adeq Precision" measures the signal-to-noise ratio. A ratio greater than 4 is desirable. Your ratio of 324.069 indicates an adequate signal. This model can be used to navigate the design space.

From the probability distribution of the experimental values as a function of the predicted values presented in **Figure 6**, we can see that the cloud of responses is very close to the regression line. This indicates that the developed models are adequate in terms of the chosen factors.

Figure 7 reveals that factor A on the positive side (+1) and factor C on the negative side (-1) have a positive influence on the increase in the weight of the structural system. On the contrary, the reverse direction has a negative influence. On the other hand, both factors B and D are slightly increased on the positive side (+1).

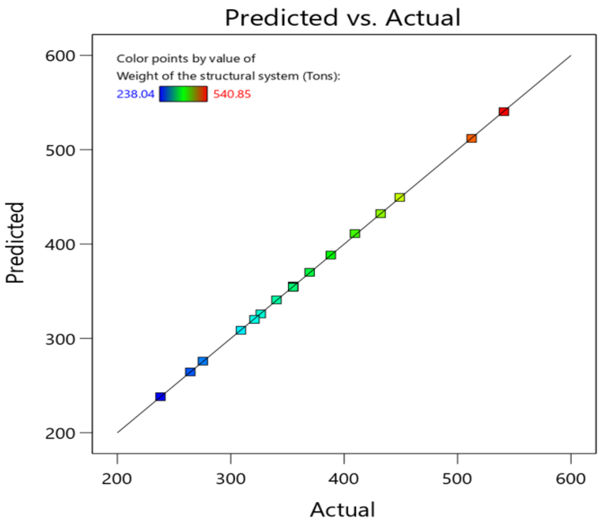


Figure 6: Probability distribution plot for Weight of the structural system.

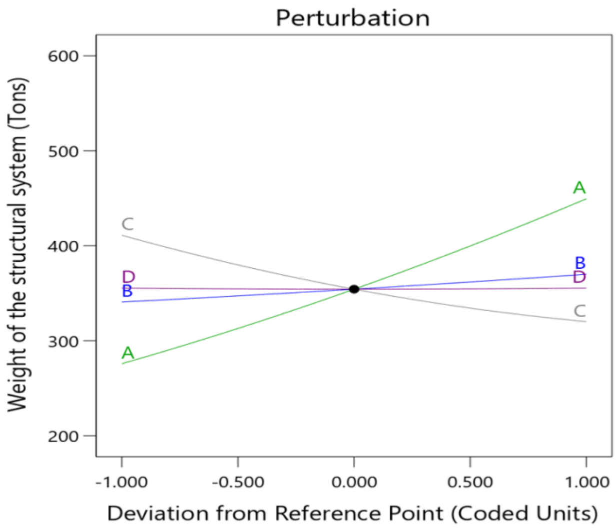
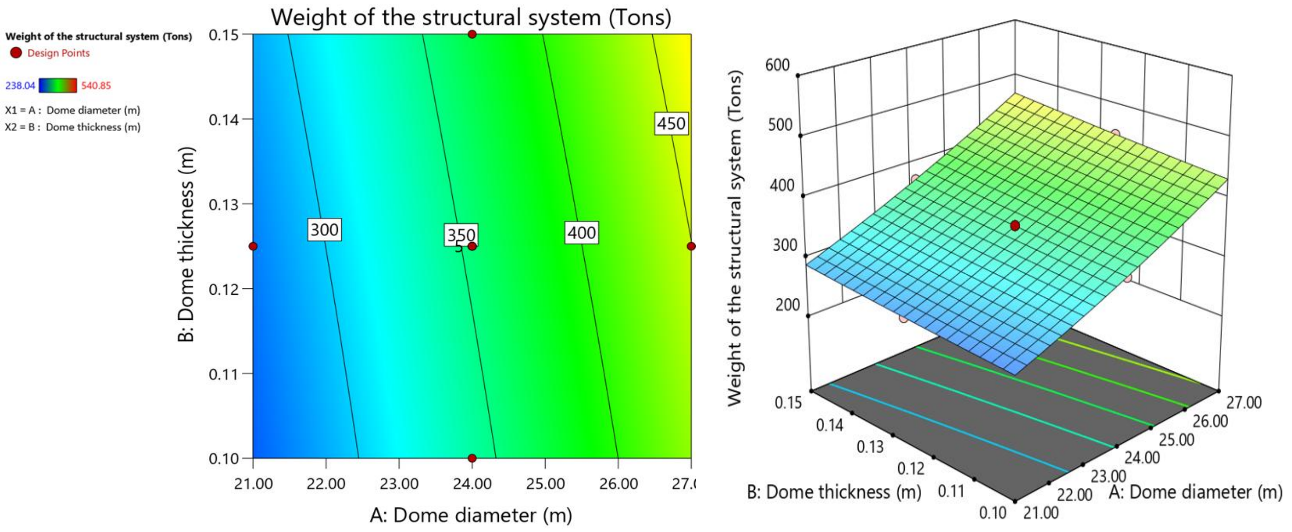


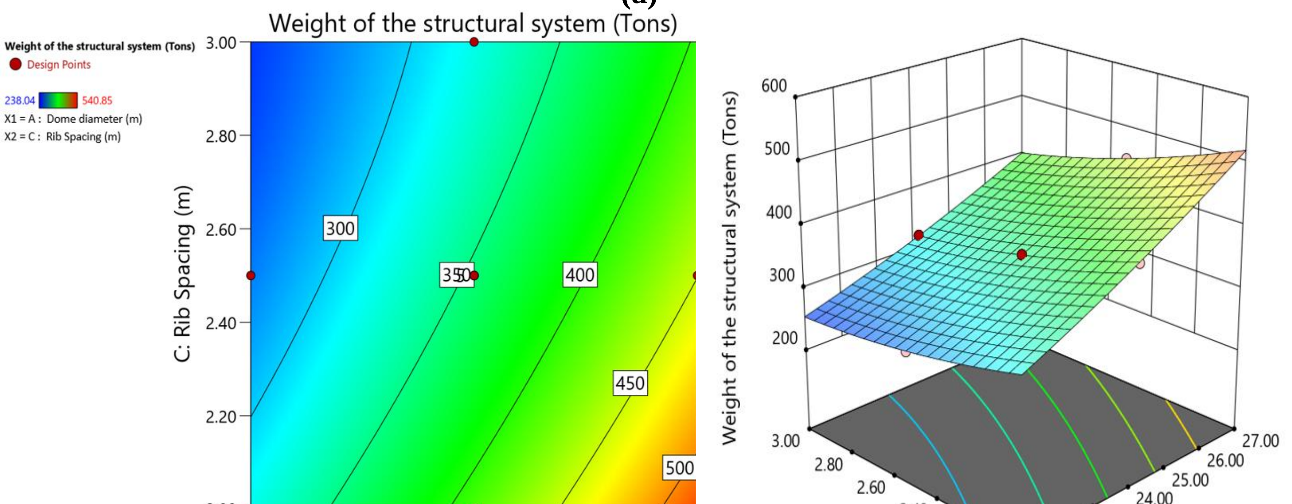
Figure 7: Perturbation plot for Weight of the structural system.

Figure 8 shows that the 2D contour and 3D surface curves are used to visualize the response surface and evaluate any potential interactive relationship. These graphics aim to establish the values of the response variables under study and the desirable operating conditions and can provide a clearer picture of the response surface.

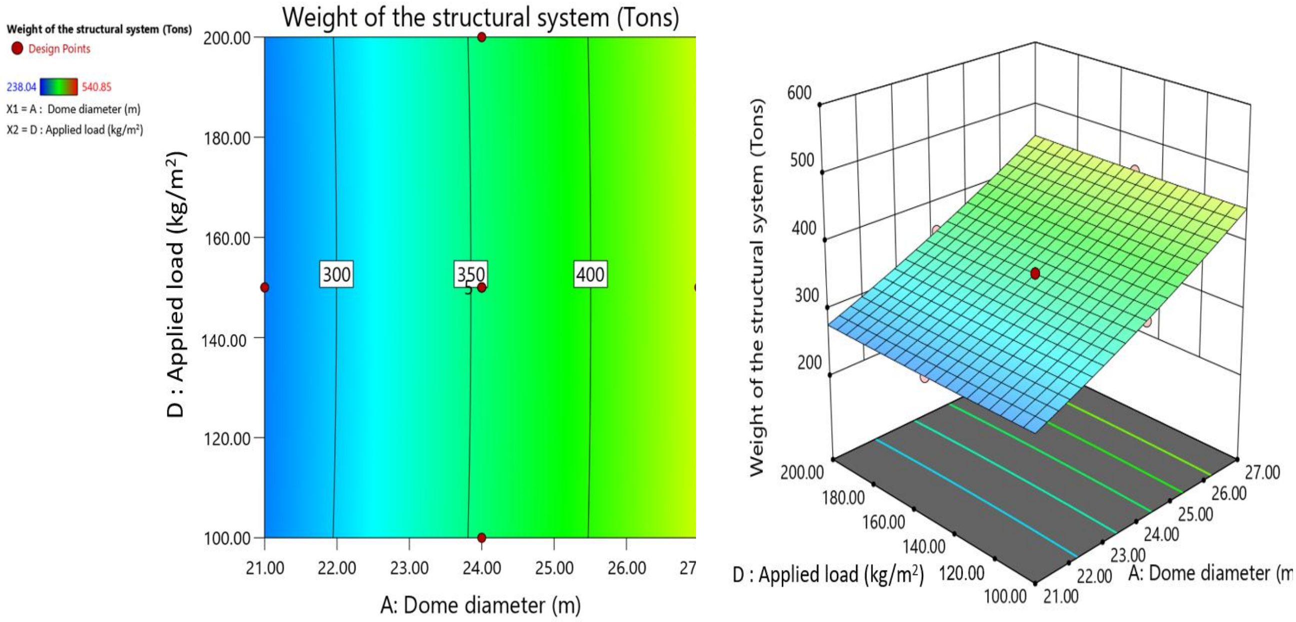
The results obtained from **Figure 8(a)** demonstrate that an increase in diameter of approximately 27 m and a decrease in thickness of the dome of approximately 0.1 m lead to high values of the structural weight of the system (up to 450 t). As shown in **Figure 8(b)**, it is also clear that an increase in the dome's diameter by approximately 27 m and a decrease in rib spacing by about 2 m result in an increase in the structural system's weight values (up to 500 t).



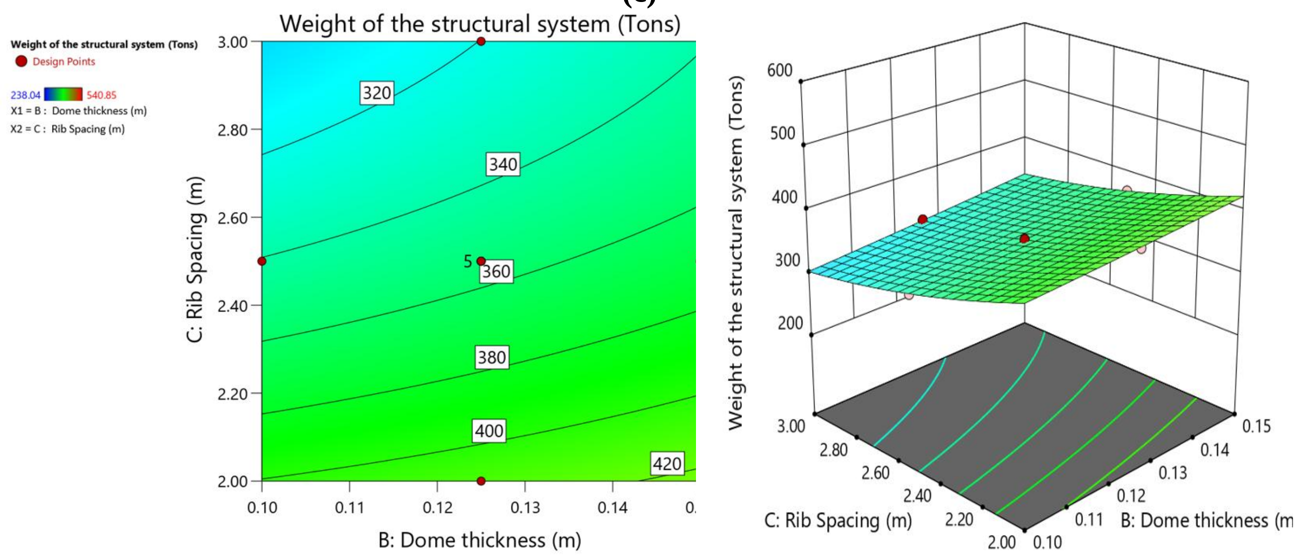
(a)



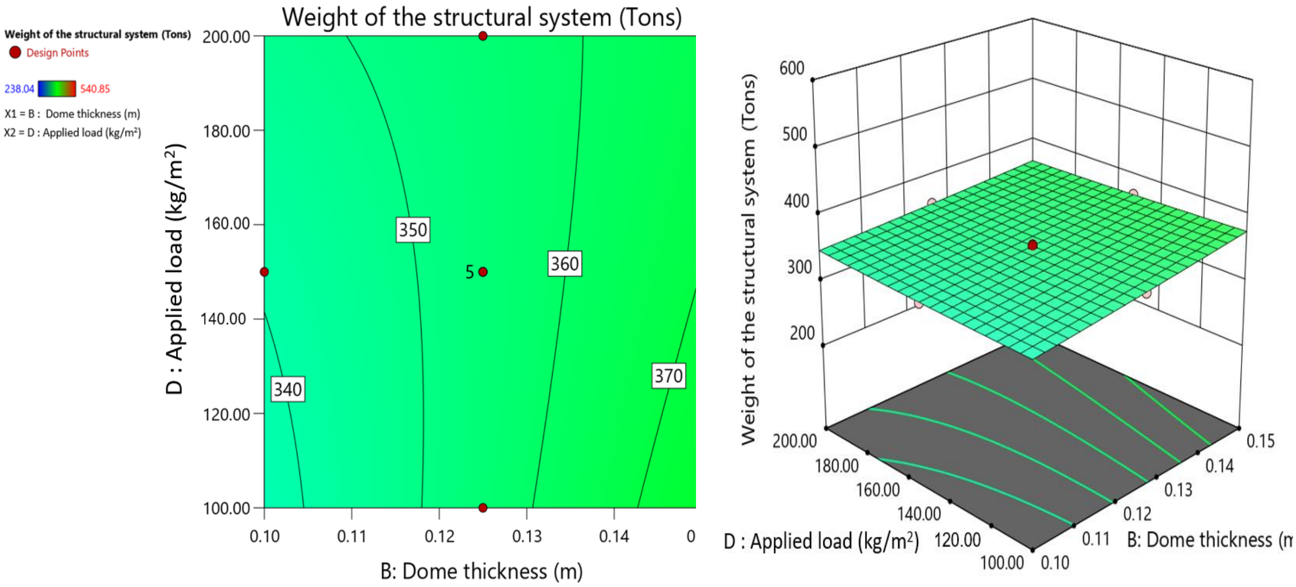
(b)


Weight of the structural system (Tons)
Design Points
238.04
540.85
X1 = A : Dome diameter (m)
X2 = D : Applied load (kg/m²)
Weight of the structural system (Tons)
D : Applied load (kg/m²)
A: Dome diameter (m)
300
350
400
5
Weight of the structural system (Tons)
D : Applied load (kg/m²)
A: Dome diameter (m

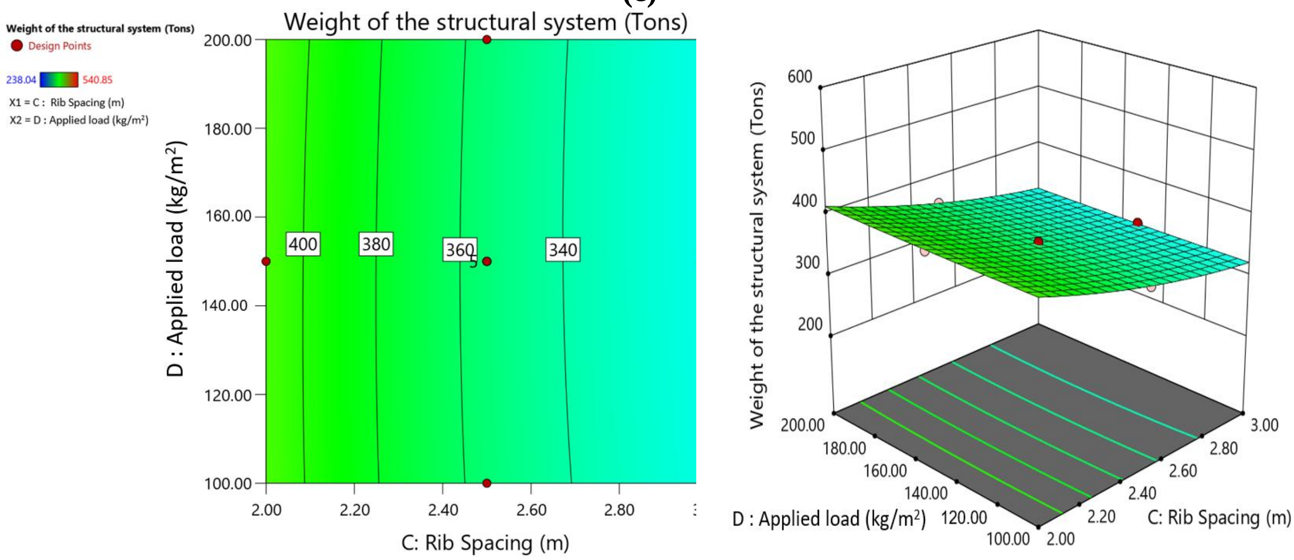
(c)


Weight of the structural system (Tons)
Design Points
238.04
540.85
X1 = B : Dome thickness (m)
X2 = C : Rib Spacing (m)
Weight of the structural system (Tons)
C: Rib Spacing (m)
B: Dome thickness (m)
320
340
360
380
400
420
5
Weight of the structural system (Tons)
C: Rib Spacing (m)
B: Dome thickness (m

(d)



(e)



(f)

Figure 8: RSM analysis diagrams for Weight of the structural system.

According to **Figure 8(c)**, high values of the structural system's weight (up to 400 tonnes),were obtained with a dome diameter of approximately 27 m. However, the applied load is nearly constant, even though it varies between 100 and 200 kg/m^2.Based on response surface plots presented in **figure 8(d)**, high values of the structural system weight (up to 420 tonnes), were obtained with a dome diameter of approximately 27 m. On the other hand, the thickness of the dome remains almost constant, even though it varies between 0.1 and 0.15 m.The results obtained from **Figure 8(e)** demonstrate that an increase in the thickness of the dome by approximately 0.15 m, leads to low values of the weight of the structural system (up to 370 tonnes). On the other hand, the applied load remains almost constant, even if it varies between 100 and 200 kg/m^2.As shown in **Figure 8(f)**, demonstrate that a decrease in rib spacing by approximately 2 m, leads to an increase in the values of the weight of the structural system (up to 400 tons). On the other hand, the applied load remains almost constant, even if it varies between 100 and 200 kg/m^2. We also note that the key parameter of the structural system is the diameter of the dome, the other parameters do not have a direct significant influence on the mechanical response of the system. Other studies [4], [5], [18] have confirmed the same behavior.

5 Optimization of results

To improve the functional relationships between variables (factors) and responses, optimization analysis was conducted using the established mathematical model to determine the optimal values for dome diameter, dome thickness, rib spacing, and applied load. This optimization process is necessary because it involves the simultaneous evaluation of different responses. The optimization standards for the structural system's weight are detailed in **Table 4**.

Table 4: Optimization standards of individual responses for Weight of the structural system (Tons).

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A : Domediameter	Maximize	21	27	1	1	3
B : Domethickness	Maximize	0.1	0.15	1	1	3
C : RibSpacing	Minimize	2	3	1	1	3
D : Appliedload	Maximize	100	200	1	1	3
Weight of the structural system (Tons)	Maximize	238.04	540.85	1	1	3

We used a multi-objective numerical optimization approach to determine the optimal parameters, such as the dome diameter, dome thickness, rib spacing, and applied load, in order to maximize the weight of the structural system. The primary objective of this optimization study was to identify the ideal values of the independent variables to achieve the optimization goals. To enhance the response, the RSM technique was employed since these responses were influenced by multiple variables. The summary of the optimal solutions obtained using the RSM method is presented in **Table 4**. The most favorable optimal solution, corresponding to trials 1 to 6, was 0.993598. Each optimization method was designed based on the importance or weight assigned to each factor. **Figure 9** illustrates solution 1 out of 87.

The **figure 10** presents the graphical representation of the optimized responses. It highlights that the optimal parameters for multi-objective optimization of the results are as follows: a dome diameter of 27 m, a dome thickness of 0.15 m, rib spacing of 2 m, and an applied load of 199.77 kg/m^2. The optimal weight of the structural system amounts to 531.963 tons. In this study, the response in terms of the weight of the structural system has been identified as the primary research objective, and the optimal solutions have shown an opportunity of 0.994.

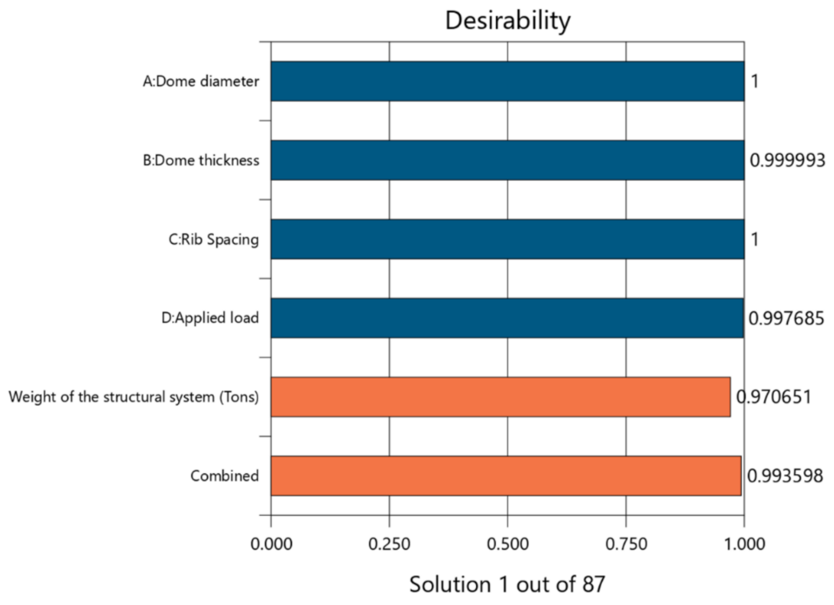


Figure. 9: Optimization solution 1 out of 87.

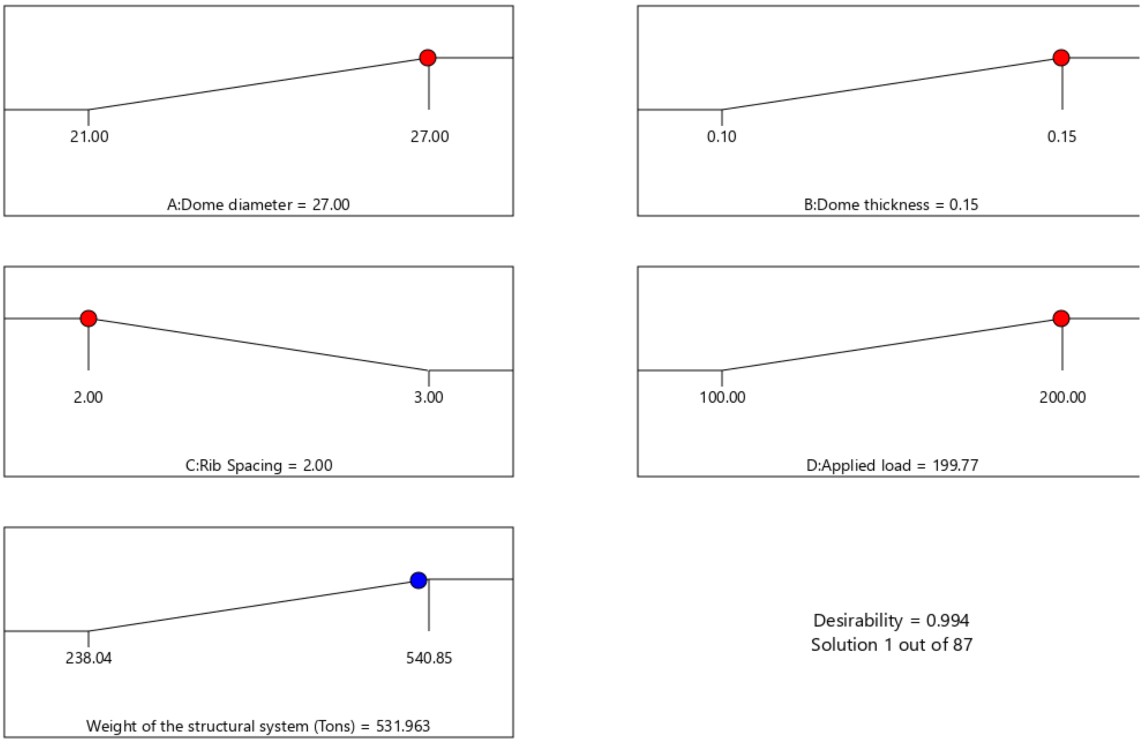


Figure. 10: Numerical optimization ramps with desirability 0.994 and solution 1 out of 87.

The model (formula 4) will be definitively validated with a numerical simulation calculation, losing an example of an intermidiary case that does not appear in the matrix of experiments.

Consider a dome with meridian ribs, with geopmetric characteristics of the structural system as follows: D = 21.5 m , e = 11.7 cm, Esp = 2.85 m. The weight of the dome using optimization formula (3) is : P =264.67 t. The dome weight using numerical simulation is P = 260.29 t. This represents a model deviation of the order of 1.7%, a very close approximation. The usefulness of the model resulting from the global approach is to obtain a direct and rapid answer concerning an objective function, which reflects a targeted economic aspect. This function satisfies the constraints and conditions laid down at the start of the problem. The designer is thus faced with a rapid technical choice, according to the design parameters available, without having to go through the tedious verifications of the optimization problem.

6 Conclusion

Starting with a structural system of meridian-ribbed domes that represents an economical solution for covering large spaces, and going through several optimization approximations, the approach proposed in this article has given satisfaction. The proposed model can provide the designer and builder at the same time with the optimum solution for such a structural system, and its usefulness lies not only in its simplicity, but also in the fact that the constraints of the problem and the optimization conditions do not appear in the objective function, which makes the task much easier. The work carried out in this article presents an approach aimed at targeting the main stages that need to be the subject of a global optimization, which cannot be of use to either the designer or the builder, without taking into account mechanical performance linked directly with economic concerns. It is important to point out that, although the scope of this study remains narrow, the reference diameter of the cases studied is between 21 and 27 m, but the principle of the proposed approach remains the same, and can serve as a guide to widening the scope of validation of the study in subsequent research.

7 References

[1] Logzit N. et Kebiche K. , (May 2020), « Numerical Model for High Relative Capacity of Tensegrity Cable Domes », Civil Engineering Dimension 22(1):29-36, DOI: 10.9744/ced.22.1.29-36.

[2] Aamer N. Abbas, ThamerA.Taha, January (2020), « Effect of Steel Bracing on the Structural Behavior of SphericalDomes », International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137 Volume –05, Issue – 01, PP – 11-22.

[3] Laith N. Hussain, Ahlam S. Mohammed, Ahmed A. Mansor, (2020) « Finite element analysis of large-scale reinforced concrete shell of domes », Journal of Engineering Science and Technology Vol. 15, No. 4 (2020) 2712 – 2729.

[4] Shoib Bashir Wani, (2020) « Analytical Study on the Influence of Rib Beams on the Stability of RCC Dome Structures », International Journal of Innovative Technology and Interdisciplinary Sciences, ISSN:2613-7305 Volume 3, Issue 3, pp. 480-489, 2020, DOI: https://doi.org/10.15157/IJITIS.2020.3.3.480-489.

[5] Hani Aziz Ameen, (2010), « The impact of diameter, number of ribs, percentage of steel, compressive strength and cover thickness on the large concretedome », American journal of scientific and industrial research, doi:10.5251/ajsir.2010.1.3.472.495.

[6] Ansa T Varghese, Manju George, (2015), « Study on Effect of Diameter, Compressive Strength and Number of Ribs on the Large Concrete Monolithic Dome », International Journal of Engineering Development and Research, Volume 3, Issue 4, ISSN: 2321-9939.

[7] Ermakova, E.;Elberdov, T.; Rynkovskaya, M. , (2022), « Shape Optimization of a Shell in ComsolMultiphysics », Computation, 10, 54. https://doi.org/10.3390/ computation10040054.

[8] M. A. Jain, C. B. Nayak, et S. B. Walke, (2016), « Parametric Study of Dome: A Review », International Journal for Scientific Research&Development, Vol. 4, Issue 03, ISSN (online): 2321-0613.

[9] Nabeel Abdulrazzaq Jasim, Ihab Sabri Saleh, Saddam Khalaf Faleh, (2017) « Structural Analysis of Ribbed Domes Using Finite Element Method », International Journal of Civil Engineering Research. ISSN 2278-3652 Volume 8, Number 2 (2017), pp. 113-130.

[10] PCzumaj, S Dudziak and Z Kacprzyk, (2021) , « Analysis of a reinforcedconcretedome », Materials Science and Engineering, 1015 (2021) 012006, doi:10.1088/1757-899X/1015/1/012006.

[11] Peter Chacko, Dipu V S, Manju.P.M, (2014), « FiniteElementAnalysis of RibbedDome », International Journal of Engineering Research and Applications (IJERA), Trends and RecentAdvances in Civil Engineering (TRACE- 24th-25th January 2014).

[12] Logzit N. et al. (2023), "Fatigue Life Prediction for Reinforced-Concrete Low Domes" Selected Scientific Papers - Journal of Civil Engineering, vol. 18, no. 1, Sciendo, 2023, https://doi.org/10.2478/sspjce-2023-0014.

[13] Olofin, IfeOlorun, and Ronggui Liu. (2023), "Harmonic Response of CFRP Tensegrity System in a Suspen-dome" Selected Scientific Papers - Journal of Civil Engineering, vol. 18, no. 1, Sciendo, 2023, https://doi.org/10.2478/sspjce-2023-0011

[14] Sinha, G.R. (2020)« Modern Optimization Methods for Science », Engineering and Technology; Institute of Physics Publishing: Bristol, UK, 2020; pp. 1–18.

[15] Cavazzuti, M. (2013), « Optimization Methods : From Theory to Design »; Springer: Berlin/Heidelberg, Germany, 2013; p. 257.

[16] E.Raouache, N. Logzit, Z. Driss, and F. Khalfallah, (2018), “Optimizationby RSM of reinforcedconcretebeam process parameters », Am. J. Mech. Eng., vol. 6, pp. 66–74.

[17] DTRF, “Specification of general technical clauses applicable to public contracts for civil engineering works, Fascicle 74, Construction of concrete tanks and rehabilitation of concrete or masonry tanks” Version 4.01 – May 2021.

[18] Ivana Mekjavić, (2012), « Static and Buckling Analysis of Concrete Spherical Shells », Journal of Civil Engineering and Architecture, Volume 6, No. 7 (Serial No. 56), pp. 899–905.