

# The effect of graphene nano-platelets on the stability study and artistic design of engineering architectural honeycomb nanocomposite structures

Qiang Xu<sup>1</sup>, X. Fee<sup>1</sup>, X. Shen\*<sup>1</sup> and A. Yvaz<sup>2</sup>

<sup>1</sup>Department of Culture and Art Management, Honam University, Gwangju, 62399, South Korea

<sup>2</sup>World-class research center "Advanced Digital Technologies", State Marine Technical University, Saint Petersburg, 190121 Russia

(Received September 1, 2024, Revised December 18, 2024, Accepted January 7, 2025)

**Abstract.** Nanotechnology has been integrated into architectural design, and the construction industry is experiencing new solutions that give better structural integrity, aesthetic value, and sustainability for buildings. This paper presents the stability behavior of an artistic design of engineering architectural structure consisting of a honeycomb nanocomposite annular plates reinforced by graphene platelets. A high-order deformation theory is used here for mathematical modeling of artistic design of engineering architectural structure, which can describe the behaviors of these annular plates. Then, a numerical procedure would be introduced to analysis of buckling characteristics of structure. Architectural structures with precisely constituted nanomaterials—carbon nanotubes and graphene derive strength and resilience unprecedented in their ability to withstand environmental stresses and human impacts. The results represent a valuable contribution to the continuing effort of improving our understanding of buckling phenomena in engineering architectural structure and provide a fundamental basis for designing their mechanical behavior, with the aim of enhancement in both geometry and material composition. It is the belief of the paper that in pointing out or highlighting the symbiotic relationship that exists between technology and artistry, it will be in a position to segue the community of architects to be more innovative, experiment with new ideas in the architectural design dimension.

**Keywords:** annular plates; artistic design of engineering architectural structure; honeycomb nanocomposite; numerical method; stability

## 1. Introduction

Architecture today uses technology coupled with creativity, spans new heights of innovation, and beauty. One such exciting development in this field is nanotechnology. This advanced technology associated with manipulating materials on an incredibly small scale is revolutionizing the way designs are made and buildings constructed. It's not just about the ability of making buildings stronger and more resilient against all odds; rather, it's about making them as beautiful as they can be functional. (Li *et al.* 2024, Liang *et al.* 2024, Zhang *et al.* 2024, Wang *et al.* 2024)

Imagine a skyscraper that could stand up against earthquakes and harsh weather, sleek in its own right. Or maybe a home that stays cool in summer and warm in winter, using materials that are as energy-efficient as they are environmentally friendly. That is what nanotechnology does for architecture. Combining tiny but remarkably powerful materials into their designs assists architects and engineers to build more durable, efficient, and inimitable structures to the eye than ever before. There are many works for structures such as Gao *et al.* (2022), Zhang *et al.* (2023), Huang *et al.* (2021) and Wu *et al.* (2023).

The real magic of nanotechnology lies in its ability to alter the very foundations of our world (Tan *et al.* 2020, Zhang *et al.* 2022). It is unimaginable what can be done to

the properties of materials through dealings at a nanoscale level: advance, stronger steel, resilient concrete, and self-cleaning glass. Such developments not only account for extended life spans with efficiency for buildings but also a completely new perspective toward creative expression. It is within the capacity of architects to play around with shapes, textures, and forms in trying to come up with designs of structures to increase frontier possibilities or become iconic buildings that usually turn out to be great testimonies of human ingenuity. Shu *et al.* (2023) investigated the new moment-resisting glulam beam-to-column connection reinforced with long self-tapping screws and long steel rods screwheads. Liu *et al.* (2024) presented and analysis mathematical modeling of the rolled tailor blank manufacturing procedure. It's not about the buildings on their own. Nanotechnology contributes much to making construction more sustainable. We lessen our ecological footprint by reducing the use of heavy, resource-consuming materials and increasing energy efficiency. This becomes very imperative as we move into a more sustainable future.

In the field of mathematical modeling of structures, Seo *et al.* (2024) quantified the vibrational behavior of small-scale flexoelectric multi-layer plates using modified porous EP-FG formulations to illustrate how nanomaterials improve the mechanical response of beams that embody such structures under various loading situations. Based on this, Arshid *et al.* (2024a) have provided comprehensive aero-hygro-thermoelastic analysis of NCMF-reinforced GNPs sector microplates placed between piezoelectric patches in supersonic flow. It examines the impact of

---

\*Corresponding author, Assistant Professor,  
E-mail: shen.shtu@gmail.com

surface stress effects on the performance of these new state-of-the-art materials in severe conditions. Likewise, Arshid *et al.* (2023a) employed a hybrid four-node quadrilateral doubly curvilinear approach to analyze poroelastic vibrations of light-weight functionally graded size-dependent shell structure flourishing with GNPs-reinforced composite coatings while considering thermal influence on vibrational characteristics. For stability, Arshid *et al.* (2023b) and (2024b) examined the thermal elastic buckling characteristic of FIPS with GPLs incorporated nano-composite patched shell potential to gain enhanced structural stability in different environmental conditions. Extending the studies on the dynamic behavior of FGP-reinforced nano-fillers annular sector microplates, Arshid *et al.* (2024c) investigated the aerodynamic stability and free vibration characteristics of the structure in supersonic flow. Zavari *et al.* (2024) carried out further investigation on their work by proposing a quasi-3D hyperbolic formulation to examine the buckling of metal foam microplates coated with GNPs-embedded nanocomposite patches, taking temperature variation into consideration. The vibrational behavior of high performance and low density polymeric foam sandwich plates reinforced with nanocomposite face layers placed on elastic foundations are also analyzed. Babaei *et al.* (2024) have also analyzed the dynamic behavior of such structures and defined the importance of substrate contact for the vibration performance. Kaveh *et al.* (2024) advanced this field by introducing a new porous-FGM formulation that includes the action of the flexoelectric effect in the analysis of vibrations of microplates used in the construction of sandwiches. For the computation of FGP layers in the more complex structural level of nano-advanced PM beams, Mousavi *et al.* (2021) derived the trigonometric solution for investigating the influence of initial curvature on the vibration characteristics of the PM beams incorporated with FGP layers in accurate curvilinear nanocomposite models. Arshid *et al.* (2022a) also investigated the response of higher-order hygro-magneto-electro-thermomechanical loads on FG-GNPs reinforced composite cylindrical shell using PEM layers in detail and offered multiple interaction fields in the nanocomposites. Furthermore, Arshid *et al.* (2022b) have performed the vibrational analysis of microplates with effects due to porosity wherein the importance of understanding porosity and its impacts on a material's response under various environments have been clearly described. This is in addition to the studies by Arshid *et al.* (2023c, d) which focused on the vibrations of FG GNPs-RPN annular plates with piezoelectric/metallic coatings on Kerr elastic substrates by accounting for size dependency and surface stress. The development of new structures of nanocomposites especially those with GNPs and CNTs will lead to optimal improvement of the nanocomposites leading to the work done by Arshid *et al.* (2020) on the static and dynamic characteristics of porous nanocomposite annular microplates reinforced by FG-GNPs using the MSGT theory. Givi *et al.* (2024) expanded this research by studying the free vibration and supersonic flutter of a sandwich cylindrical shell that carries CNT-reinforced honeycomb core sandwiched with piezoelectric layers and useful data for aerospace engineering.

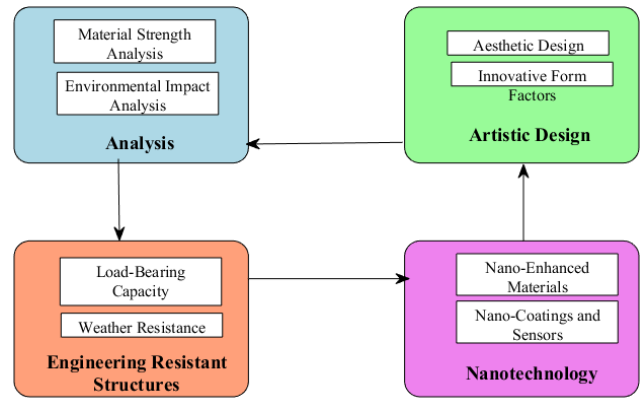


Fig. 1 A schematic figure of integrating nanotechnology into analysis and artistic design for engineering-resistant architecture

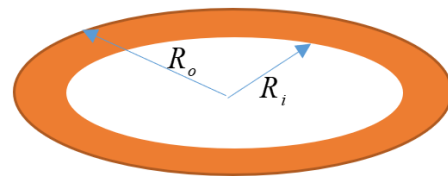


Fig. 2 The schematic of conical shells in architectural structures

This paper is going to look into how nanotechnology creates resilient architectural structures that at the same time are works of art. We shall consider specific examples of nanomaterials and techniques and how they are transforming the preference towards designing and constructing. A look into how technology is married to creativity in the opening of a new Age of Architecture: one in which beauty aligns effortlessly at one and the same time with strength and sustainability.

## 2. Formulation of the problem

Below is a schematic figure (Fig. 1) of integrating nanotechnology into analysis and artistic design for engineering-resistant architecture. The graphical representation illustrates the interlocking components that go into making an architectural design beautiful and strong in this cutting edge creation.

**A- Analysis:** This module gives emphasis on Material strength analysis and Environmental impact analysis to make sure that the materials chosen can sustain all kinds of stressors and also contribute positively towards the environment.

**B-Artistic Design:** This is that part of the design that writes about esthetics, breaking right through the form factor to develop structures that are most please able to the eye but have a number of innovative design kinds integrated.

**C-Structures Resistant to Impact and Weather:** This is the section for load-bearing capacity and weather resistance, ensuring that structures can sustain physical and environmental challenges.

D-Nanotechnology just stands for the use of nano-enhanced materials and nano-coatings and sensors, using high-tech technological measures to improve performance and durability characteristics of these kinds of structures.

The arrows show a flux and relation between these elements: each one contributes to the comprehensive design and analysis of engineering-resistant architectures with the help of nanotechnology.

Nanomaterials have many advantages over traditional construction materials. For example, carbon nanotubes are well known to have high strength and elasticity; hence, they can be very useful concrete and steel reinforcement materials. Nanocomposites, a mixture of nanoparticles and traditional materials, may highly enhance a lot of kinds of properties, like thermal resistance, electric conductivity, mechanical strength, and so on. Almost nano-coatings have the potential to enhance self-cleaning, anti-corrosion properties, and UV resistance attributes on the surface, which in turn decrease the cost of maintenance and increase the lifetime of the structure. (Wang *et al.* 2024, Jin *et al.* 2024, Peng *et al.* 2024)

In order to study the effect of nano-materials on the architecture structures, presentation of mathematical modeling and analytical solution is essential. As shown in Fig. 2, annular plate offers large aesthetic benefits, allowing the architect to create visual effects and iconic constructions.

The strain energy of the structure is:

$$U_b = \frac{1}{2} \int_{\Omega} (\sigma_{ij} \varepsilon_{jk}) dV \quad (1)$$

where  $\varepsilon_{ij}$  and  $\sigma_{ij}$  denote the strain and stress, respectively. Based on two-variable refined plate we have (Berghouti *et al.* 2023):

$$U(r, z) = u(r) - z \frac{dw_b(r)}{dr} + f(z) \frac{dw_s(r)}{dr}, \quad (2)$$

$$V(r, z) = 0, \quad (3)$$

$$W(r, z) = w_b(r) + w_s(r), \quad (4)$$

where  $u$ ,  $w_b$  and  $w_s$  are mid-plane displacements, respectively and  $f(z) = \frac{h}{\pi} \left[ \sin\left(\frac{\pi z}{h}\right) \right]$ . The stress relations is:

$$\begin{Bmatrix} \sigma_{rr} \\ \sigma_{\theta\theta} \\ \sigma_{rz} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{21} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_{rr} \\ \varepsilon_{\theta\theta} \\ \varepsilon_{rz} \end{Bmatrix} \quad (5)$$

where

$$\varepsilon_{rr} = \frac{\partial}{\partial r} u(r) - z \cdot \frac{\partial^2}{\partial r^2} w_b(r) + f(z) \cdot \frac{\partial^2}{\partial r^2} w_s(r), \quad (6)$$

$$\varepsilon_{\theta\theta} = \frac{u(r)}{r} - \frac{z}{r} \cdot \frac{\partial}{\partial r} w_b(r) + \frac{f(z)}{r} w_s(r), \quad (7)$$

$$\varepsilon_{rz} = \frac{\partial w_s(r)}{\partial r} + \left( \frac{\partial f(z)}{\partial z} \right) \left( \frac{\partial w_s(r)}{\partial r} \right). \quad (8)$$

in Eq. (5), the elastic constants are related to Young's modulus which can be written for honeycomb structures as (Mehar and Panda 2023, Pandey *et al.* 2023):

$$E_{11}^c = E \left( \frac{t}{l} \right)^3 \frac{\cos \theta}{\left( \frac{d}{l} + \sin \theta \right) \sin^2 \theta}, \quad (9)$$

$$E_{22}^c = E \left( \frac{t}{l} \right)^3 \frac{\left( \frac{d}{l} + \sin \theta \right)}{\cos^3 \theta},$$

$$\nu_{12}^c = \frac{\cos^2 \theta}{\left( \frac{d}{l} + \sin \theta \right) \sin \theta}, \quad (10)$$

$$G_{12}^c = E \left( \frac{t}{l} \right)^3 \frac{\left( \frac{d}{l} + \sin \theta \right)}{\left( \frac{d}{l} \right)^2 \left( 1 + 2 \frac{d}{l} \right) \cos \theta},$$

$$G_{13}^c = G \left( \frac{t}{l} \right) \frac{\cos \theta}{\frac{d}{l} + \sin \theta}, \quad (11)$$

$$G_{23}^c = G \left( \frac{t}{l} \right) \frac{1 + 2 \sin^2 \theta}{2 \cos \theta \left( \frac{d}{l} + \sin \theta \right)},$$

where  $E^c$ ,  $G^c$  and  $\rho^c$  are the core Young's moduli, shear moduli and mass density of the origin material, respectively. The energy relations for the structure are:

$$U = \frac{1}{2} \int \sigma_{ij} \varepsilon_{ij} dV \quad (12)$$

$$K = \frac{\rho}{2} \int (\dot{u}^2 + \dot{v}^2 + \dot{w}^2) dV, \quad (13)$$

$$W = \int f w dA \quad (14)$$

where (Huo *et al.* 2021):

$$\begin{aligned} F_V &= k_w w + c_d \dot{w} - \frac{1}{r} \frac{\partial}{\partial r} \left( r k_g \frac{\partial w}{\partial r} \right) \\ &- \frac{1}{r^2} \frac{\partial}{\partial \theta} \left( k_g \frac{\partial w}{\partial \theta} \right), \end{aligned} \quad (15)$$

$$F_f = \mu_f F_V, \quad (16)$$

$$\begin{aligned} F_T &= k_{t1} \gamma - r^{-1} \frac{\partial}{\partial r} \left( r k_{t2} \frac{\partial \gamma}{\partial r} \right) \gamma = \frac{\partial v}{\partial r} \\ F_T &= k_{t1} \frac{\partial v}{\partial r} - r^{-1} \frac{\partial}{\partial r} \left( r k_{t2} \frac{\partial^2 \gamma}{\partial r^2} \right), \end{aligned} \quad (17)$$

where  $k_w$ ,  $c_d$ ,  $k_g$  and  $k_{t1}$ ,  $k_{t2}$  are normal spring, damp, shear and torsional constants of the elastic medium. In order to obtain the governing equations, virtual displacement method is used as:

$$\int_0^t (\delta \Pi) dt = \int_0^t (\delta U - \delta W_r) dt = 0 \quad (18)$$

where  $\delta$  is variation operator;  $\Pi$  is the total potential energy of the nanostructure. Finally we have:

$$\delta U: \frac{1}{r} \left\{ \frac{\partial}{\partial r} [r N_{rr}(r)] - N_{\theta\theta}(r) \right\} = 0, \quad (19)$$

$$\delta w_b: \frac{1}{r} \left\{ \begin{array}{l} \frac{\partial^2}{\partial r^2} [r M_{rb}(r)] - \frac{\partial}{\partial r} M_{\theta b}(r) + \\ \frac{\partial}{\partial r} \left[ N_{rm} r \left( \frac{\partial}{\partial r} [w_b(r) + w_s(r)] \right) \right] + \\ N_{\theta m} \frac{\partial}{\partial r} w_b(r) \end{array} \right\} - F_v = 0 \quad (20)$$

$$\delta w_s: \frac{1}{r} \left\{ \begin{array}{l} \frac{\partial}{\partial r} M_{\theta s}(r) + \frac{\partial}{\partial r} [r \cdot N_{rz}(r)] + \\ \frac{\partial}{\partial r} \left[ N_{rm} r \left( \frac{\partial}{\partial r} [w_b(r) + w_s(r)] \right) \right] + \\ N_{\theta m} \frac{\partial}{\partial r} w_s(r) + \frac{\partial}{\partial r} [r \cdot Q_{rz}] - \\ \frac{\partial^2}{\partial r^2} [r \cdot M_{rs}(r)] \end{array} \right\} - F_v = 0 \quad (21)$$

where

$$(N_r, M_{rb}, M_{rs}) = \int_{-h/2}^{h/2} \sigma_{rr}(1, z, f(z)) dz, \quad (22)$$

$$(N_{\theta}, M_{\theta b}, M_{\theta s}) = \int_{-h/2}^{h/2} \sigma_{\theta\theta}(1, z, f(z)) dz, \quad (23)$$

$$(N_{rz}, Q_{rz}) = \int_{-h/2}^{h/2} \sigma_{rz} \left( 1, \frac{df(z)}{dz} \right) dz, \quad (24)$$

In this present work, simply supported boundary condition is used as:

$$u = w_b = w_s = M_{rb} = M_{rs} = 0 \text{ at } r = R_i, R_o \quad (25)$$

Nanotechnology has enormous aesthetic promise in the field of architecture. In the long term, nano-engineered materials will make it possible to engineer their interaction with light in particular ways and engender surfaces that change either in color or transparency, depending on changing environmental conditions. Therein, architects have the ability to design buildings that are dynamic and responsive to their setting while enhancing functionality and aesthetic value.

Research in the field of nanotechnology involves the extremely accurate development of material properties with regard to their size, shape, and composition at scales smaller than the wavelength of light. In this way, it allows for the opening to nanostructures exhibiting unique optical, mechanical, and electrical properties with very far-reaching diversified applications in areas as wide-ranging as electronics, medicine, and sustainable energy. For example, the interactions of nanoparticles with light at different wavelengths can be designed to interact with their color and reflectivity, much like pigments in traditional artistic media.

With respect to the relation of stress and strain as:

$$\sigma = C \varepsilon \quad (26)$$

and this point that  $C$  is the elastic constant, the effect of nanoparticles can be assumed by mixture method as:

$$C = C_m V_m + C_n V_n \quad (27)$$

where  $V_m$  and  $V_n$  are the volume percent of matrix and

Table 1 Hill's elastic modulus for CNTs

Values	Hill's elastic modulus
30 GPa	$k_r$
10 GPa	$l_r$
1 GPa	$m_r$
450 GPa	$n_r$
1 GPa	$p_r$

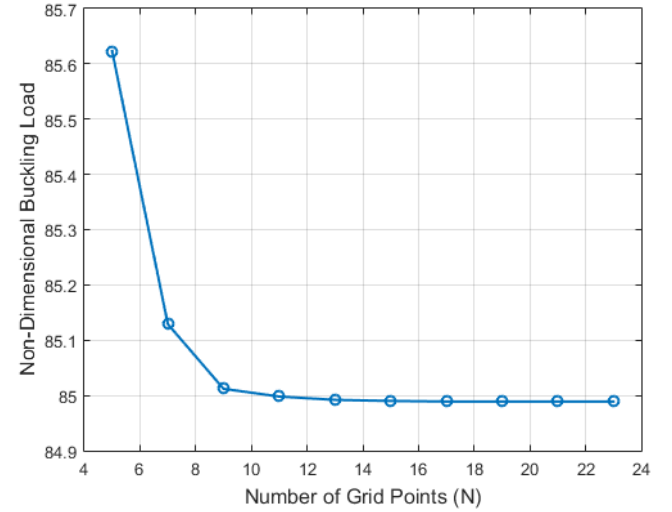


Fig. 3 The effect of convergence point on the dimensionless buckling load

nanoparticle.

Based on numerical method, we have:

$$\left\{ \begin{array}{cc} [K_{bb} & K_{bd}] \\ [K_{db} & K_{dd}] \end{array} \right\} + p \left\{ \begin{array}{cc} [K_{gbb} & K_{gbd}] \\ [K_{gdb} & K_{gdd}] \end{array} \right\} \left\{ \begin{array}{c} [y_b] \\ [y_d] \end{array} \right\} = \left\{ \begin{array}{c} [0] \\ [0] \end{array} \right\} \quad (28)$$

where  $y = [u, w_b, w_s]$ ;  $b$  and  $d$  indexes are associated to boundary and domain points, respectively;  $[K]$  and  $[K_g]$  are stiffness and geometrical coefficients, respectively.

### 3. Numerical results

An annular nanoplate is chosen with the inner-to-outer radius of  $R_i/R_o = 0.6$  and ratio of thickness-to-outer radius is set to be,  $h/R_o = 0.05$ . Applied to architecture, nanotechnology is one very promising path for resilient artistic buildings. This paper considers discussions on different case studies about the applications of nanoparticles or nanomaterials applied for practical and additional benefits in architectural engineering. Accompanying problems in terms of cost and special knowledge and apparatus needed after their adoption are brought with advantages that these technologies bring. If nanotechnology is to realize its full potential in architectural structures, further papers and development in this field is essential to function beyond these barriers. The Hill's elastic modulus for CNT are reported in Table 1.

Convergence and accuracy of the present formulation are essential for a higher order to ensure the reliability of numerical solution. Due to the nature of the numerical

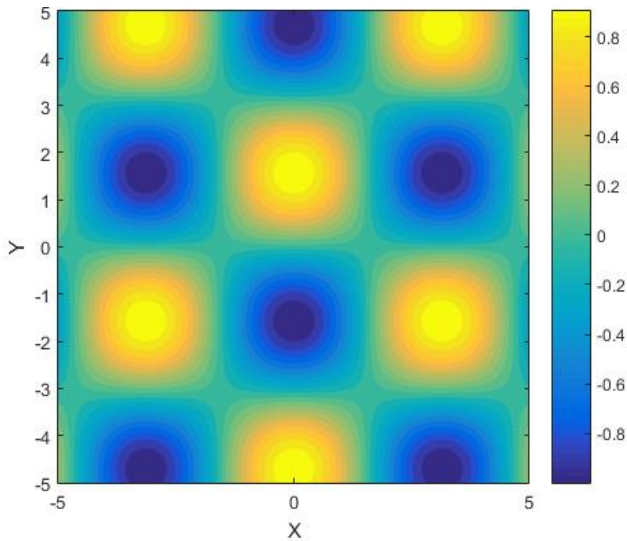


Fig. 4 Nanomaterial integration in art design

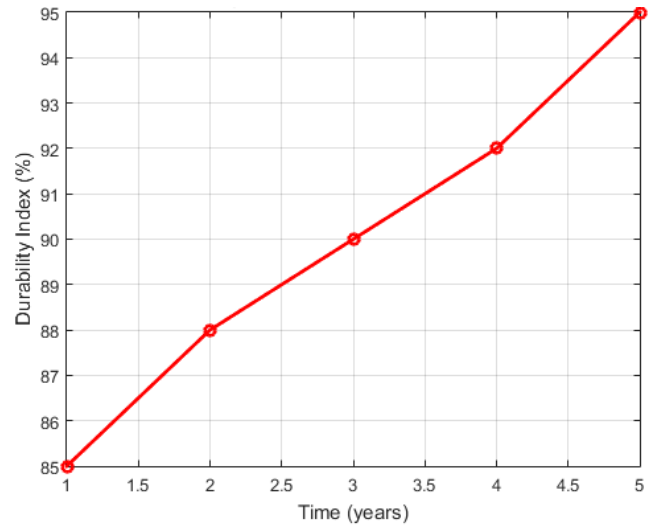


Fig. 6 Durability improvement with different nanoparticles

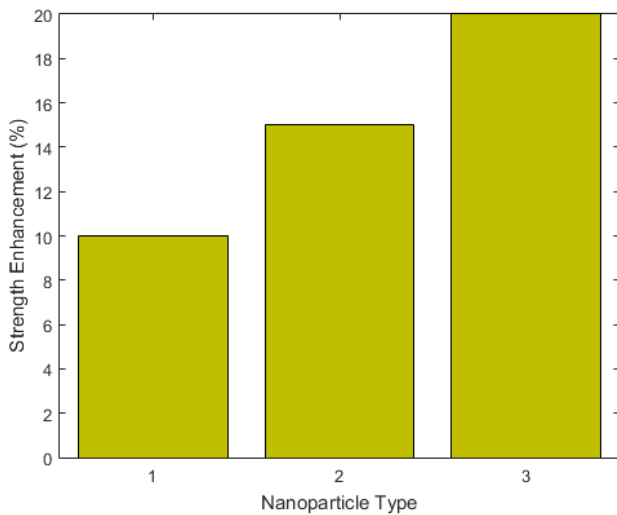


Fig. 5 Strength improvement with different nanoparticles

solution method being sensitive to the number of the grid points, a systematic convergence analysis is performed to establish the best grid density for obtaining reliable outcomes. The test determines the nondimensional buckling load ( $\lambda$ ) of annular and circular nanoplates across various grid points is shown in Fig. 3.

The results of the convergence test are summarized and discussed to study the convergence behavior of the determined buckling loads as  $N$  is incremented. From the comparison it can be observed that as the  $N$  increases, the non-dimensional buckling load slowly reaches the stable value, which means that increasing  $N$  has very small impact on the results. The convergence test will therefore show that numerical method is a powerful and accurate approach to model the buckling response of nanoplates while at the same time indicating that the choice of the appropriate number of grid points for such formulations is crucial.

Fig. 4 is a plot of materials properties with respect to nanomaterials concerning surface patterns and textures of architectural designs. In this contour plot, the nanotechnology transformative capacity is constrained for both

functionalities and aesthetics of the architectural component. Colorfully represented changes at the surface describe a change in texture and appearance caused by nanomaterials on building materials. It even goes beyond traditional construction materials to give new options for lightweight, durable, environmentally responsive designs. These contour lines are attuned to shifts in surface characteristics through the use of nanotechnology, thus demonstrating patterns both visually striking and structurally advantageous. The latter will not only mean an improvement in terms of material performance—that is, being able to make materials stronger and more resistant—but also, architects will be able to create new design expressions that combine technological sophistication with artistic creativity. Ultimately, Fig. 4 emphasizes that nanotechnology will play a very crucial role in the future architectural aesthetic and functional development because it may present the potentiality of recollecting architectural possibilities through improved material capabilities and enhanced overall aesthetic appeal.

Fig. 5 is bar chart expressing the exact percentage of strength that each type of nanoparticles—Nanoparticle Carbon Nanotubes, Nano-Silica, and Nano-Clay—renders to architectural materials upon incorporating these kinds of nanoparticles in said materials. All bars refer to another nanoparticle and in total represent a value showing the degree by which that particular nanoparticle improves the strength of the materials. It manages to bring out a clean comparative analysis, allowing the view to make relative conclusions about the effectiveness of each variant nanoparticle in enhancing strength properties. This is an important kind of visual display for architects, engineers, and researchers targeting an understanding and harnessing of the potential benefits of nanotechnology in improving the mechanical performance of architectural structures. Quantitative views into these improvements are given in Fig. 1, thus revealing how huge the potential is for nanoparticles to become one of the most vivid ways to improve construction material durability and reliability, hence a resilient and sustainable built environment.

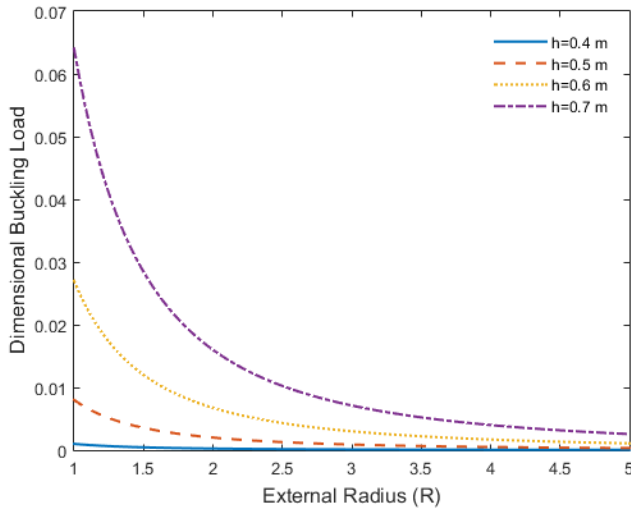


Fig. 7 The effect of external radius and thickness on the dimensional buckling load

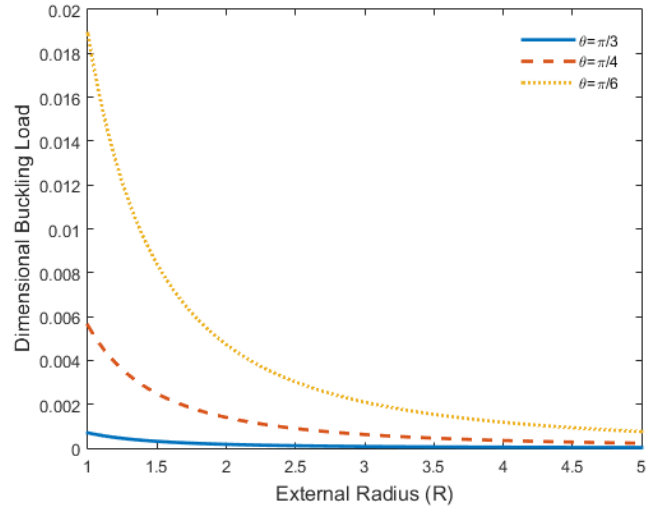


Fig. 9 The effect of honeycomb angle on the dimensionless buckling load

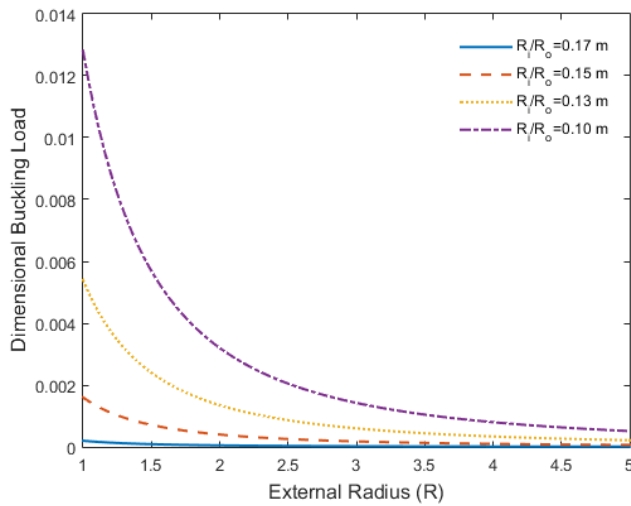


Fig. 8 The effect of ratio of internal radius to external radius on the dimensionless buckling load

This plot, shown in Fig. 6, is a line of tempo showing increased durability of architectural structures treated with nanoparticles. Along the horizontal axes, there is time, and along the vertical one, durability index—tracking and methodically showing how, with time, the structural integrity has changed for these materials. This example plot of durability index obviously shows increasing uptrend, proving that with the years, resilience goes higher and higher for architectural materials fabricated with nanoparticles, thus their lifetime. Such graphical representations are very useful tools to show practical advantages of nanoparticle treatments. Fig. 2 conveys more meaning than the data points, showing the long-term efficacy of integrated nanoparticles in elongating lifetime and making architectural structures more reliable. The concept therefore underlines the contribution that nanotechnology is making toward establishing resilient and sustainable building practices for the future.

The variations of the two major design parameters, external radius and thickness, on the dimensional buckling

load are shown in Fig. 7. Using quantitative analysis, the changes in those parameters are studied to determine the structural implications on the system. The results reveal a distinct trend. This behavior shows that larger external radii reduce structural stiffness and increase the susceptibility of the system to buckle under the applied loads. On the other hand, the increase in thickness leads to a considerably large improvement in the buckling load. This observation shows that higher rigidity of structures provides better buckling resistance making structures more stable and healthier to the loading conditions impressed on them. The results presented here confirm that the external radius and thickness design parameters have to be fine-tuned in order to meet the structural design and stability requirements simultaneously.

The variation of the ratio internal radius to the external radius on the dimensional buckling load is shown in Fig. 8. The analysis of this ratio in details shows that it has a direct impact upon the structural stiffness and the buckling mode of the system. The results presented in the figure demonstrate a clear trend: further, as the internal radius to the external radius increases, the buckling load also increases. This observation suggests that higher ratios are beneficial for increasing structural stiffness and also for increasing the ability of a structure to resist buckling loads. Nonetheless, these results support the argument of the critical aspect of adjusting the internal radius relative to the external radius for the direct improvement of structural characteristics. Such adjustments definitely cause enhanced stability and reliability which are important in an application. This analysis throws the light on how geometric parameters can be used to develop systems with a better buckling load and stability.

The variation of the honeycomb angle on the dimensionless buckling load of the annular plate is shown in Fig. 9. Analysis of the impact of different honeycomb angles on structural behavior and Plate Buckling Characteristics is presented. The results clearly show a trend: It is also that the dimensionless buckling load reduces with the honeycomb angle. This infers that, the present design of honeycombs

Table 2 The effect of CNTs on the buckling load

$c_r$	Buckling load, P
0	9.2213
0.5%	8.8812
1.0%	8.1255
1.5%	7.9822
2%	7.8211

with increased honeycomb angles poses less stability as well as lower load bearing capacity to engineered buckling force. These results are indicative of the importance of the honeycomb angle in particular in the overall stability and performance of the annular plate and as such, highlights the importance of appropriate assessment of this parameter in the design and optimization process.

Table 2 provides the trend of the buckling load as influenced by CNT volume percent and thus show that greater incorporation of CNT improves the structural load bearing capability under critical load. At the physical level this accrues from the fact that carbon nanotubes possess a very high Young's modulus, tensile strength and aspect ratio. CNTs found within the matrix act as reinforcements by bearing stresses as a result of a good interface between the matrix and itself. With the increase in the volume percent of CNT, the graphical representation shows the satisfactory magnitude of stiffness and relatively low deformation, which in turn also shows the improved capability against buckling. Also, through improved loading dispersion through CNTs, the load is effectively distributed in the matrix thereby helping in reducing concentrations of stress which if highly concentrated will cause failure. This combined action A between the CNTs and the matrix represents the reason why the buckling load has improved; this shows the importance of CNT volume fraction depends on to improve the structural stability of the nanocomposite system.

#### 4. Conclusions

This research was able to provide a thorough study the stability of an advanced engineering architectural design with honeycomb core panel and graphene enhanced annular plates. Here in this work, high-order deformation theory was used in the analysis of the annular plate to improve on the test results by adopting the real world structural analysis of the material under various loading schemes. A numerical solution technique was adopted to obtain and gain insights on the buckling and stability response of the structure. The systematic study gave useful information regarding the behaviour of essential design parameters, especially the inner radius and adding of GPL into the composite matrix. Thus, it was concluded that stability load dropped off when the ratio of inner radius to outer radius of the cylinder was established, and the greater the ratio, the higher the stability loads. Furthermore, this study revealed that incorporation of graphene platelets and CNT into the composite structure increased the stability, and achieved the maximum stability

load in the investigation. These results also highlight the application of nanomaterials in enhancing the mechanical characteristics and durability of architectural engineering namely in the advanced composite materials. The findings of this study thereby enrich the existing literature on the mechanical response of sandwich structures reinforced with nanomaterial, and provide guidelines for the improved design of these structures in various engineering and architectural contexts.

#### Acknowledgment

The research is partially funded by the Ministry of Science and Higher Education of the Russian Federation as part of World-class Research Center program: Advanced Digital Technologies (contract No. 075-15-2022-312 dated 20.04.2022)

#### References

- Arshid, E., Amir, S. and Loghman, A. (2020), "Static and dynamic analyses of FG-GNPs reinforced porous nanocomposite annular micro-plates based on MSGT", *Int. J. Mech. Sci.*, **180**, 105656, <https://doi.org/10.1016/j.ijmecsci.2020.105656>.
- Arshid, E., Soleimani-Javid, Z., Amir, S. and Duc, N.D. (2022a), "Higher-order hygro-magneto-electro-thermomechanical analysis of FG-GNPs-reinforced composite cylindrical shells embedded in PEM layers", *Aerosp. Sci. Technol.*, **126**, 107573, <https://doi.org/10.1016/j.ast.2022.107573>.
- Arshid, E., Khorasani, M., Soleimani-Javid, Z., Amir, S. and Tounsi, A. (2022b), "Porosity-dependent vibration analysis of FG microplates embedded by polymeric nanocomposite patches considering hygrothermal effect via an innovative plate theory", *Eng. Comput.*, **38**(Suppl 5), 4051-4072, <https://doi.org/10.1007/s00366-021-01382-y>.
- Arshid, E., Momeni Nia, M.J., Ghorbani, M.A., Civalek, Ö. and Kumar, A. (2023a), "On the poroelastic vibrations of lightweight FGSP doubly-curved shells integrated with GNPs-reinforced composite coatings in thermal atmospheres", *Appl. Math. Modell.*, **124**, 122-141, <https://doi.org/10.1016/j.apm.2023.07.036>.
- Arshid, E., Ghorbani, M.A., Momeni Nia, M.J., Civalek, Ö. and Kumar, A. (2023b), "Thermo-elastic buckling behaviors of advanced fluid-infiltrated porous shells integrated with GPLs-reinforced nanocomposite patches", *Mech. Adv. Mater. Struct.*, **31**(26), 7853-7869, <https://doi.org/10.1080/15376494.2023.2251015>.
- Arshid, E., Amir, S. and Loghman, A. (2023c), "On the vibrations of FG GNPs-RPN annular plates with piezoelectric/metallic coatings on Kerr elastic substrate considering size dependency and surface stress effects", *Acta Mech*, **234**, 4035-4076, <https://doi.org/10.1007/s00707-023-03593-4>.
- Arshid, E., Amir, S. and Loghman, A. (2023d), "Thermoelastic vibration characteristics of asymmetric annular porous reinforced with nano-fillers microplates embedded in an elastic medium: CNTs Vs. GNPs", *Archiv. Civ. Mech. Eng.*, **23**, 100, <https://doi.org/10.1007/s43452-023-00624-8>.
- Arshid, E., Amir, S. and Loghman, A. (2024a), "Aero-Hygro-Thermoelastic size-dependent analysis of NCMF-reinforced GNPs sector microplates located between piezoelectric patches in supersonic flow considering surface stress effects", *Mech. Based Des. Struct.*, **52**(9), 6911-6972, <https://doi.org/10.1080/15397734.2023.2295532>.

- Arshid, E., Azimi, M., Moradi, M., El Ouni, M. H. and Alashker, Y. (2024b), "Mathematical solution for vibrational response of shear and normal deformable advanced metal foam CMBS treated with nanocomposite actuators", *Int. J. Struct. Stabil. Dyn.*, In press. <https://doi.org/10.1142/S0219455425501184>.
- Arshid, E., Amir, S., Loghman, A. and Civalek, Ö. (2024c), "Aerodynamic stability and free vibration of FGP-Reinforced nano-fillers annular sector microplates exposed to supersonic flow", *Thin Wall. Struct.*, **197**, 111610. <https://doi.org/10.1016/j.tws.2024.111610>.
- Babaei, H., Zavari, S., Kaveh, A., Arshid, E. and Civalek, Ö. (2024), "Dynamic response of advanced lightweight porous plates integrated with nanocomposite face sheets resting on elastic substrate", *Int. J. Struct. Stabil. Dyn.*, In press. <https://doi.org/10.1142/S0219455425501329>.
- Berghouti, H., Adda Bedia, E., Benkhedda, A. and Tounsi, A. (2023), "Vibration analysis of nonlocal porous nanobeams made of functionally graded material", *Adv. Nano Res.*, **7**(5), 351-364. <http://doi.org/10.12989/anr.2023.7.5.351>.
- Gao, Q., Ding, Z. and Liao, W. (2022), "Effective elastic properties of irregular auxetic structures", *Compos. Struct.*, **287**, 115269. <https://doi.org/10.1016/j.compstruct.2022.115269>
- Givi, S., Ghorbanpour Arani, A., Khoddami Maraghi, Z. and Arshid, E. (2024), "Free vibration and supersonic flutter analyses of a sandwich cylindrical shell with CNT-reinforced honeycomb core integrated with piezoelectric layers", *Mech. Based. Des. Struct.*, 1-29. <https://doi.org/10.1080/15397734.2024.2422413>.
- Huang, H., Yuan, Y., Zhang, W. and Zhu, L. (2021), "Property assessment of high-performance concrete containing three types of fibers", *Int. J. Concr. Struct. Mater.*, **15**(1), 39. <https://doi.org/10.1186/s40069-021-00476-7>
- Huo, J., Zhang, G., Ghabussi, A. and Habibi, M. (2021), "Bending analysis of FG-GPLRC axisymmetric circular/annular sector plates by considering elastic foundation and horizontal friction force using 3D-poroelasticity theory", *Compos. Struct.*, **276**, 114438. <https://doi.org/10.1016/j.compstruct.2021.114438>.
- Jin, L., Li, L., Xu, F. and Zhang, J. (2024), "The synthesis and application of L-cysteine graphene quantum dots for quantitative analysis of nitrite content in water", *Physica Scripta*, **99**(6), 065124. <https://doi.org/10.1088/1402-4896/ad4c24>
- Kaveh, A., Babaei, H., Zavari, S., Arshid, E. and Civalek, Ö. (2024), "Vibrational response of a sandwich microplate considering the impact of flexoelectricity and based on a novel porous-FGM formulation", *Mech. Based. Des. Struct.*, **52**(11), 9122-9143. <https://doi.org/10.1080/15397734.2024.2337913>.
- Li, F., Gan, J., Zhang, L., Tan, H., Li, E. and Li, B. (2024), "Enhancing impact resistance of hybrid structures designed with triply periodic minimal surfaces", *Compos. Sci. Technol.*, **245**, 110365. <https://doi.org/10.1016/j.compscitech.2023.110365>
- Liang, K., Sun, P. and Wang, D. (2024), "Quantitative analysis of deformation performance for skew slab based on deformation energy decomposition method of triangular prism element", *Structures*, **63**, 106447. <https://doi.org/10.1016/j.istruc.2024.106447>
- Liu, Y., Liu, Y., Wang, T., Wang, Z. and Huang, Q. (2024), "Mathematical modeling and analysis of the tailor rolled blank manufacturing process", *Int. J. Mech. Sci.*, **266**, 108991. <https://doi.org/10.1016/j.ijmecsci.2024.108991>
- Mehar, K. and Panda, S.K. (2023), "Multiscale modeling approach for thermal buckling analysis of nanocomposite curved structure", *Adv. Nano Res.*, **7**(3), 181. <http://doi.org/10.12989/anr.2023.7.3.181>.
- Mousavi, S.B., Amir, S., Jafari, A. and Arshid, E. (2021), "Analytical solution for analyzing initial curvature effect on vibrational behavior of PM beams integrated with FGP layers based on trigonometric theories", *Adv. Nano Res.*, **10**(3), 235-251. <https://doi.org/10.12989/anr.2021.10.3.235>.
- Pandey, H.K., Hirwani, C.K., Sharma, N., Katariya, P.V., Dewangan, H.C. and Panda, S.K. (2023), "Effect of nano glass cenosphere filler on hybrid composite eigenfrequency responses- An FEM approach and experimental verification", *Adv. Nano Res.*, **7**(6), 419-429. <http://doi.org/10.12989/anr.2023.7.6.419>.
- Peng, X., Han, Y., Liu, G., Li, J., Yi, B., Sa, G. and Jiang, S. (2024), "Effect of manufacturing process parameters on the compression and energy absorption properties of 4D-printed deformable honeycomb structure", *Smart Mater. Struct.*, **33**(7), 075035. <https://doi.org/10.1088/1361-665X/ad56e7>
- Seo, Y.S., Jeong, W.B., Yoo, W.S., and Jeong, H.K. (2015), "Frequency response analysis of cylindrical shells conveying fluid using finite element method." *J. Mech. Sci. Tech.*, **19**, 625-633. <https://doi.org/10.1007/BF02916184>.
- Shu, Z., Ning, B., Chen, J., Li, Z., He, M., Luo, J., Dong, H. (2023), "Reinforced moment-resisting glulam bolted connection with coupled long steel rod with screwheads for modern timber frame structures", *Earthq. Eng. Struct. Dyn.*, **52**(4), 845-864. <https://doi.org/10.1002/eqe.3789>
- Tan, X., Zhu, Sh., Wang, B., Yao, K., Chen, Sh., Xu, P., Wang, L. and Sun, Y. (2020), "Mechanical response of negative stiffness truncated-conical shell systems: Experiment, numerical simulation and empirical model", *Compos. Part B Eng.*, **188**, 107898. <https://doi.org/10.1016/j.compositesb.2020.107898>
- Wang, C., Song, Z. and Fan, H. (2024), "Novel evidence theory-based reliability analysis of functionally graded plate considering thermal stress behavior", *Aerosp. Sci. Technol.*, **146**, 108936. <https://doi.org/10.1016/j.ast.2024.108936>
- Wang, Y., Han, Z., Xu, X. and Luo, Y. (2024), "Topology optimization of active tensegrity structures", *Comput. Struct.*, **305**, 107513. <https://doi.org/10.1016/j.compstruct.2024.107513>
- Wu, Y., Wu, H., Zhao, Y., Jiang, G., Shi, J., Guo, C., Jin, Z. (2023), "Metastable structures with composition fluctuation in cuprate superconducting films grown by transient liquid-phase assisted ultra-fast heteroepitaxy", *Mater. Today Nano*, **24**, 100429. <https://doi.org/10.1016/j.mtnano.2023.100429>
- Zhang, C., Khorshidi, H., Najafi, E. and Ghasemi, M. (2023), "Fresh, mechanical and microstructural properties of alkali-activated composites incorporating nanomaterials: A comprehensive review", *J. Clean. Prod.*, **384**, 135390. <https://doi.org/10.1016/j.jclepro.2022.135390>
- Zhang, C., Shu, J., Zhang, H., Ning, Y. and Yu, Y. (2024), "Estimation of load-carrying capacity of cracked RC beams using 3D digital twin model integrated with point clouds and images", *Eng. Struct.*, **310**, 118126. <https://doi.org/10.1016/j.engstruct.2024.118126>
- Zhang, P., Du, Ch., Zhao, W. and Zhang, D. (2022), "Hydraulic fracture simulation of concrete using the SBFEM-FVM model", *Struct. Eng. Mech.*, **80**(5), 553-562.