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"Structural Factors in Biomimetic Grid-Shell Structures: A Comparative Study of Global Projects"

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Abstract: **-** Biomimetic grid-shell structures are a recent engineering and architectural innovation that enhances structural performance through the mimicry of natural patterns. The increased focus on designs that are sustainable and efficient makes it, therefore, important to learn how various structural factors are effective in impacting the efficiency and stability of such structures. In lieu of the foregoing, this study will seek to analyze the structural factors of biomimetic grid-shell structures based on the comparison of several of the world's leading projects. The research problem is: to what degree do key structural factors such as principal direction, stability, tessellation, and grid pattern influence the structural performance of biomimetic grid shell structures? Guiding this study is one central question: how could the efficiency and stability of biomimetic grid shell structures be improved by controlling these factors? To achieve the research aims, a data analysis methodology has been applied to the data collection from five global major projects: London Aquatic Centre (2012), Morpheus Hotel, China (2018), Kaohsiung Pop Music Centre, Taiwan (2021), Heydar Aliyev Centre, Azerbaijan (2012), and Złote Tarasy, Poland (2007). These data were grouped, and correlation analysis was done to measure the relationship between different structural factors. Results showed that the inclusion of design from both architecture and engineering sciences results in improved structural efficiency and stability. Also, balanced load distribution and minimized chances of distortion and collapse are some of the offerings by proper geometric tessellation and grid patternings. Biomimetic designs may provide innovative and effective solutions for the enhancement of structural performance. This research has concluded that efficiency and stability in biomimetic grid-shell structures can only be achieved by using modern techniques with greater integration between architectural and engineering aspects. The study also highlighted the importance of focusing on sustainability in design by adopting biomimetic principles that mimic natural patterns.

Keywords: Biomimetic grid-shell structures, structural efficiency, stability, geometrical tessellation, grid pattern, correlation analysis, sustainable design.

1. Introduction

Biomimetic grid-shell structures have emerged as a significant advancement in architectural and engineering design by imitating natural patterns to provide sustainable and efficient structural solutions. These systems are particularly valued for achieving a harmonious balance between structural efficiency and architectural aesthetics.

The central research problem investigates the extent to which key structural factors—namely, principal direction, stability, tessellation, and grid pattern—affect the performance and efficiency of biomimetic grid-shell structures. Accordingly, the research aims to formulate design recommendations to enhance the structural behavior of such systems.

To guide this investigation, the study proposes the following hypothesis:
There is a statistically significant relationship between the structural performance of biomimetic grid-shell structures and the four key design factors. Specifically, improved tessellation techniques and optimized principal directions are positively correlated with enhanced structural efficiency and stability.

The research methodology is based on a comparative analysis of five international case studies, using correlation analysis to examine the interrelationships between the

structural indicators. The report is organized as follows: (1) theoretical background on biomimetic grid-shell structures,
(2) analytical methodology,
(3) global case study analysis,
and (4) key findings and conclusions

2. Grid-Shell Structures and Their Types:

2.1 *Definition of Grid-Shell Structures*

Grid-shell structures are spatial structures constructed with linear elements arranged in a two or three-dimensional grid and networked orthogonally or diagonally. The grid can be flat, like a roof, or curved, like a dome. The loads in grid-shell structures are distributed in two or three directions, with forces concentrated at the nodes. The linear members bear axial tension or compression forces and sometimes bending forces, depending on the rigidity of the connections between the elements**.**

2.2 *Types of Grid-Shell Structures*

- **Single-Layer Grid**: These structures are made of single-layered grid elements, mostly in curved surfaces like domes or arches. A case in point is Buckminster Fuller's geodesic dome, which relies on equilateral triangles for their support and stiffening [24]

- **Double-Layer Grid**: In this type of structure, the individual flat elements are arranged in two layers – that is, in an upper and lower parallel [5]. The members connecting the two layers are either inclined or vertical. They lend stability to the structure and reduce torsional forces or bending moments. Such structures are widely used in flat or slightly curved surfaces [23].

- **Grid Shells of a Non-Standard Form**: These are essentially grids of a non-uniform shape and utilize modern methodologies of design. Such grid shells are in application in the field of biomimetic in architecture. The use of digital modeling primarily aids in the creation of such forms that imitate natural forms, supported by the invention of new techniques for cladding and tessellations [10].

3. Structural Factors Affecting Grid-Shell Structures: Principal Direction, Stability, Tessellation, Grid Pattern

Grid-shell systems are complicated engineering structures that integrate structural performance with visual aesthetics. The success of designing such structures lies in numerous structural elements necessary for reaching the proper amount of stability, stability, and flexibility. In this regard, studying these structural factors deeply is important for making sure top performance in grid-shell structures [6]

In the following section, 4 crucial factors that at once affect the layout and overall performance of grid-shell systems are certain: primary direction, stability, tessellation, and grid sample. Each of these factors enhances the structure's ability to face up to carried out loads and creates a dynamic balance that ensures continuity and durability over time. These elements are in addition explored via current architectural examples, displaying their practical software in famend tasks.**3.1 Principal Direction:** The most important route in grid-shell structures defines how masses are dispersed and transmitted along the primary instructions of the structure to hold equilibrium and mitigate lateral hundreds, which includes wind. The layout of the essential course determines the exceptional paths for forces, ensuring structural stability and performance [24]

Swiss 30 St Mary Axe: This elliptical building configuration provides efficient force direction and distribution. The aerodynamic design improves the structure's efficiency and reduces wind impact, highlighting the relationship between stability and principal direction [15] [3]. As shown in Figure.(1)

3.1 *Water-Cube in Beijing:*

This project relies on a grid system that effectively directs forces without requiring additional support, emphasizing the principal direction's role in balancing load distribution. As shown in Figure (1). [18]**.**

3.2 *Stability:*

Stability in grid-shell structures refers to a structure's ability to withstand external loads without experiencing failure or severe deformations. Stability is achieved through regular load distribution and engineering designs that ensure force equilibrium across all sections of the structure [23]

Eden Project in London: This project uses hexagonal and pentagonal patterns to distribute loads evenly across the structure, enhancing stability against external stresses. As shown in Figure.(3)

Honeycomb Tessellation of Hexagon Structural Wall: This project relies on hexagonal patterns to achieve structural balance and stability by evenly distributing forces. As shown in Figure (4). [16]

3.3 *Tessellation:*

Tessellation in grid-shell structures refers to how the surface is divided into small units or geometric patterns. These units help distribute forces evenly and achieve structural stability. Tessellation can be regular or irregular, depending on functional and aesthetic needs [14]

Dragonfly Tessellation: This project uses irregular patterns inspired by dragonfly wings to achieve structural flexibility and dynamic performance. As shown in Figure(5). [14]

Tessellated Structures Pavilion Projects: These projects use complex shapes for effective structural assembly while maintaining tessellation accuracy for structural stability. As shown in Figure (6). [11]

3.4 *Grid Pattern:*

The grid pattern in grid-shell structures refers to the distribution of structural elements in a regular or irregular manner. Grid patterns, such as orthogonal and diagonal patterns, contribute to improved load distribution efficiency.

Swiss 30 St Mary Axe: This project features a steel grid pattern that balances lateral forces from the wind and distributes loads efficiently, enhancing structural stability. . As shown in Figure.(1)

Water-Cube in Beijing: This project uses a complex and repetitive grid pattern that provides strong structural support with minimal additional internal reinforcement. . As shown in Figure (2).

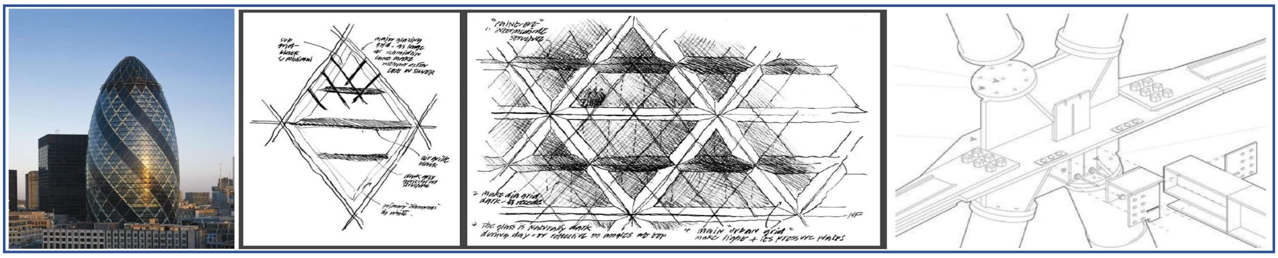

Figure 1: The Swiss 30 St Mary Axe, London. (Left) the external feature. (Middle) the concept sketch of diagrid structural system. (Right) the detail of diagrid. [13]

Figure 2: (Left) Weaire-Phelan foam structure. (Right) “Water-Cube” Beijing National Aquatics Centre [18][21]

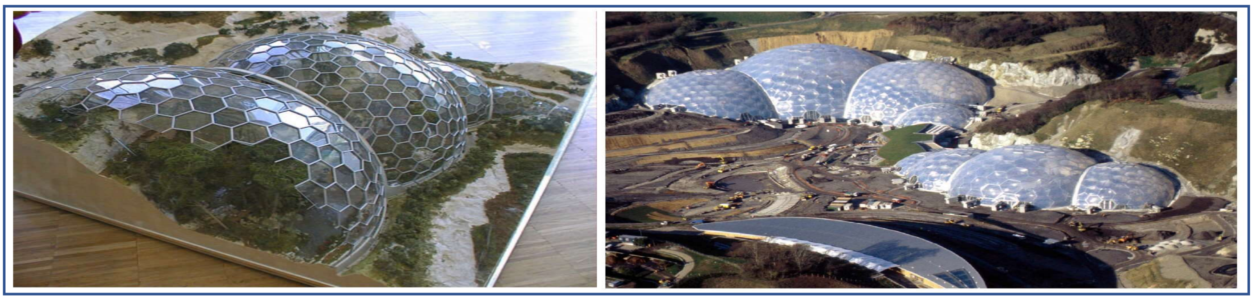

Figure 3: The Eden Project by Grimshaw architects. (Left) Interior night view showing the structural hexagonal system. (Right) ETFE materials covering the steel frames[12]

Figure 4: The Honeycomn Morphologies developed in EmTech, AA, 2004 [16]

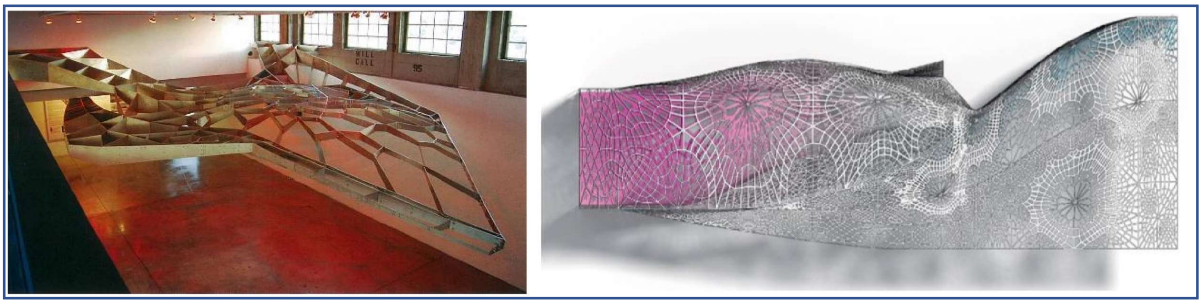

Figure 5: (Left) Dragonfly Installation. (Right) Technicolor morphological pattern variations.[14]

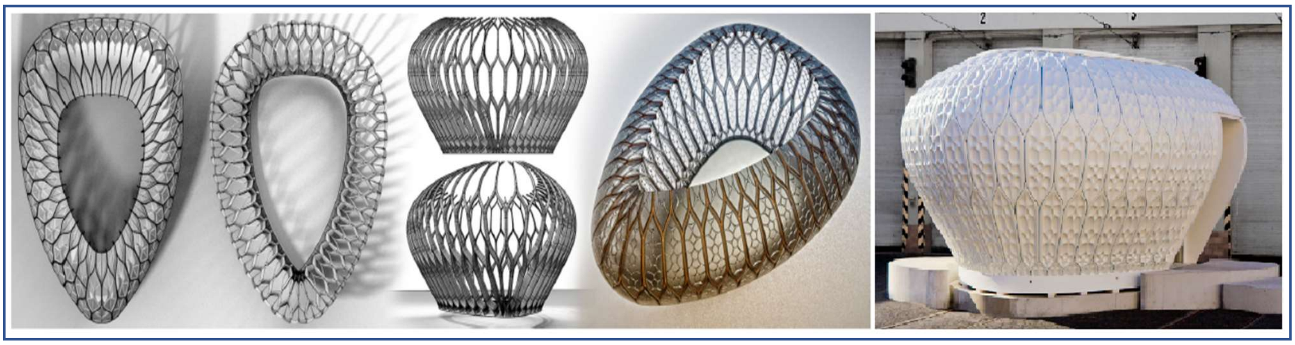

Figure 6: The Fischer's Pavilion, designed by Jan-Ruben Fischer, Bauhaus Universität Weimar Germany, 2012 [11]

4. The Connection between Biomimetic Design and Structural Efficiency

Biomimetic design is all about taking cues from nature to improve how buildings and structures perform. By mimicking the way natural systems work, architects and engineers can create structures that use materials more efficiently, distribute forces evenly, and maintain stability. Nature has perfected these systems over time, making it a valuable source of inspiration for sustainable and efficient designs. Incorporating those herbal concepts into grid-shell structures allows beautify both their capability and visible enchantment.

This phase highlights three key techniques stimulated with the aid of nature which have validated to enhance structural efficiency in architectural and engineering designs:

1. Delaunay Triangulation: This method creates a network of triangles that allows unfold forces flippantly in the course of a structure. By minimizing sharp angles, it guarantees the shape stays strong and strong [21]

• Delaunay Triangulation is powerful in stabilizing systems and directing forces in a way that reduces the chance of deformations or screw ups.

2. Voronoi Diagrams: Inspired by way of the way herbal styles shape, Voronoi Diagrams create grids that

resemble honeycombs. This approach enables stability hundreds and reduce material utilization, resulting in green and stable structures[21] [1].Voronoi Diagrams make contributions to green tessellation and grid patterns by means of dispensing forces frivolously and supporting the structure with minimal fabric.

3.Weaire-Phelan Foam Structure: This method, primarily based at the geometry of froth, uses elaborate cells to distribute forces frivolously at the same time as lowering material use. It’s a clever answer for large and complicated

systems that need to be both sturdy and lightweight [8]

•Weaire-Phelan Foam Structures offer a stability of excessive balance and performance by using the use of the least quantity of fabric necessary to gain strong structural aid.

By integrating these biomimetic strategies, architects and engineers can design buildings that aren't simplest structurally efficient but additionally price-powerful and sustainable. Delaunay Triangulation can be implemented to roofs and bridges to ensure forces are unfold flippantly, while Voronoi Diagrams are ideal for growing light-weight facades. The Weaire-Phelan Foam Structure is perfect for large-scale projects that need to maintain strength while minimizing material use.

Table 1 : The main indicators of the theoretical framework of Section Three (Grid-Shell Structures) (The researcher)

Grid-Shell Structures	Principal Directions	Two-dim. trusses
		Fully three-dim. triangulated space frame
	Stability	Self-Stability
		Braced-Stability
	Tessellation	Triangulated Tessellation
		Orthogonal Tessellation
		Hexagonal Tessellation
	Grid Pattern	Orthogonal grid pattern
		Diagonal grid pattern.

5. Global Case Studies:

This section provides a detailed analysis of how design indicators were applied in five notable global projects. The focus is on essential structural elements such as Principal Directions, Stability, Tessellation, and Grid Pattern. The analysis showcases how these indicators were used to enhance structural efficiency and achieve distinctive architectural designs in each project.

Five global case studies were carefully selected to ensure diversity in form, timeframe, and environmental context (2012–2021the sample includes projects from different geographical regions (Europe, Asia, the Middle East) and various structural systems, providing a balanced representation of biomimetic grid-shell structures.

London Aquatic Center, London (2012): The London Aquatic Center, a standout venue for the 2012 Olympic and Paralympic Games, features a distinctive wavy roof that mirrors the fluidity of water. As shown in Figure (7), (8) [6]

Principal Directions: The roof’s design effectively distributes loads using two-dimensional trusses, ensuring stability and resistance to wind forces.

Stability: The arched trusses provide strong support, enhancing the building's overall stability.

Tessellation: A straightforward orthogonal tessellation pattern helps distribute forces evenly across the roof.

Grid Pattern: The use of an orthogonal grid pattern ensures efficient load distribution and contributes to the structure's stability.

Morpheus Hotel, China (2018): The Morpheus Hotel, located in Macau's "City of Dreams" complex, is known for its unique exoskeleton design with irregular openings that add flexibility to its architecture. As shown in Figure (9) (10) [9]

Principal Directions: The complex three-dimensional grid design directs forces efficiently, enabling the building to handle various loads effectively.

Stability: Reinforced structural elements ensure the building remains stable against environmental stresses like wind and earthquakes.

Tessellation: Advanced hexagonal tessellation enhances load distribution and structural stability.

Grid Pattern: The use of an inclined grid pattern improves the building's structural efficiency, making it more resistant to lateral forces.

Kaohsiung Pop Centre, Taiwan (2021): The Kaohsiung Music Center, inspired by nature, offers a flexible design that includes concert halls, exhibitions, and parks. . As shown in Figure (11) (12)[20]

Principal Directions: The structure uses a complex grid pattern to evenly distribute loads, ensuring structural integrity.

Stability: The design relies on self-stability, allowing the building to withstand various environmental challenges.

Tessellation: Hexagonal tessellation supports even force distribution, contributing to the building's stability.

Grid Pattern: A combination of orthogonal and inclined grid patterns ensures balanced load distribution and structural efficiency.

Heydar Aliyev Centre, Azerbaijan (2012): The Heydar Aliyev Centre, a cultural landmark, is renowned for its flowing, curved design that breaks away from traditional architectural forms. . As shown in Figure (13) (14) [4] [1]

Principal Directions: An irregular grid pattern in the three-dimensional structure efficiently directs forces, enhancing flexibility.

Stability: A complex steel framework provides the necessary support, ensuring the building's stability.

Tessellation: The intricate hexagonal tessellation pattern helps distribute forces evenly, reinforcing the structure.

Grid Pattern: Inclined grid patterns were used to optimize structural efficiency and support the fluid design.

Złote Tarasy, Poland (2007): Złote Tarasy, a commercial complex in Warsaw, features a striking wavy glass roof that has become a city landmark. . As shown in Figure (15) (16) [17]

Principal Directions: Two-dimensional trusses effectively channel forces, contributing to efficient load distribution.

Stability: The grid structure enhances the building's ability to withstand lateral forces, improving stability.

Tessellation: A simple triangular tessellation pattern ensures even distribution of forces across the structure.

Grid Pattern: A aggregate of orthogonal and inclined grid styles ensures balanced load distribution and structural efficiency

Table 2: The descriptive analysis for the 5 international initiatives in keeping with the primary signs of the theoretical frameworks which might be abstracted from Section Three (The researcher).

			London Aquatic Center	Morpheus Hotel	Kaohsiung Pop Centre	Heydar Aliyev Centre	Zlote Tarasy
			LONDON	CHINA	Taiwan	AZERBAIJAN	POLAND
			2012	2018	2021	2012	2007
Grid-Shell Structures	*Principal Directions*	Two-dim. trusses	O	O		O	O
		Fully three-dim. triangulated space frame			O	O	
	Stability	Self-Stability			O		O
		Braced-Stability	O	O		O	
	Tessellation	Triangulated Tessellation		O			O
		Orthogonal Tessellation	O			O	
		Hexagonal Tessellation			O		
	Grid Pattern	Orthogonal grid pattern	O		O	O	
		Diagonal grid pattern.		O	O		O

6. Data Analysis

6.1 Methodology Description: This segment outlines the approach used to research the data and explore the connection between 4 key structural elements: Principal Direction, Stability, Tessellation, and Grid Pattern. The procedure commenced with the aid of amassing facts from five global architectural tasks and categorizing them based totally on these structural signs. The statistics turned into then prepared into tables, making it easier to conduct a correlation analysis among the elements. The correlation analysis helped look at the relationships among those factors and decide their impact on the structural overall performance of the initiatives. Finally, the consequences were offered through tables and visual aids, presenting a clearer understanding of ways these factors impact structural performance and stability.

Correlation Analysis: The correlation analysis aimed to measure the relationships among the primary structural elements studied in the preceding initiatives. By making use of this evaluation, we ought to see how every aspect is associated with the others and the way they together impact the structural performance and stability of the tasks.

Common statistics analysis gear like SPSS and Excel had been used to conduct the evaluation. The desk (three), determine (7) below illustrates the correlations between the 4 key factors: Principal Direction, Stability, Tessellation, and Grid Pattern.Notes:

r = Indicates the value of the correlation coefficient.

1.00 Represents a perfect correlation between the factor and itself.

This table illustrates the mutual relationships between the different factors, providing a better understanding of how

Each factor impacts structural efficiency and stability.

Table 3: Showing Correlation Relationships between Structural Factors.

		principal direction	stability	tesselation	grid pattern
principal direction	Pearson Correlation	1	.102	.535	-.134
	Sig. (2-tailed)		.870	.353	.830
stability	Pearson Correlation	.102	1	-.218	-.764
	Sig. (2-tailed)	.870		.724	.133
tesselation	Pearson Correlation	.535	-.218	1	.286
	Sig. (2-tailed)	.353	.724		.641
grid pattern	Pearson Correlation	-.134	-.764	.286	1
	Sig. (2-tailed)	.830	.133	.641	

7. Discussion of Correlations:

Principal Direction and Stability:

The correlation between Principal Direction and Stability is weak (r = 0.102) and not statistically significant (Sig = 0.870). This suggests that the orientation of the structural elements doesn't strongly influence the structure's ability to remain stable under stress figure (18).

Principal Direction and Tessellation:

Positive or negative values represent the strength of the relationship between the different structural factors. Values close to +1 or -1 indicate a strong correlation, while values close to zero indicate a weak correlation

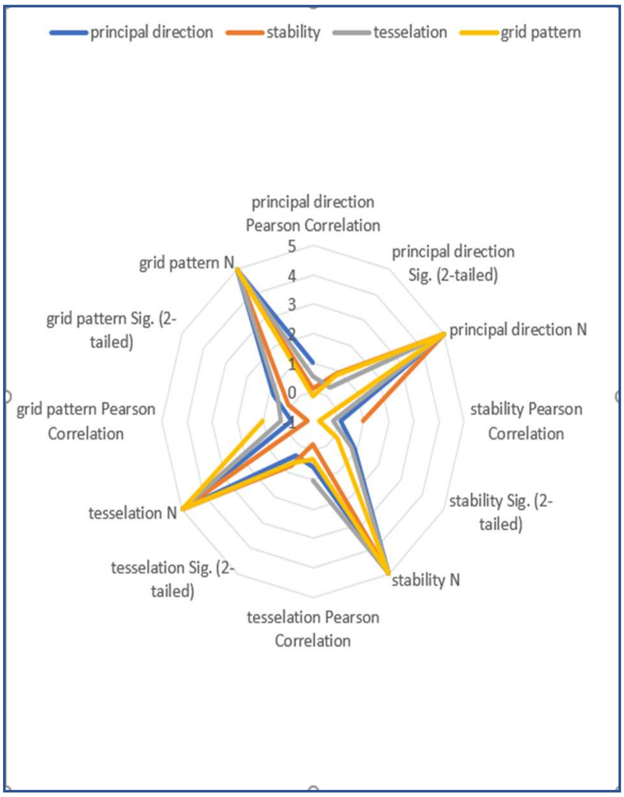

Figure 17: Showing Correlation Relationships between Structural Factors.

A moderate positive correlation (r = 0.535) exists between Principal Direction and Tessellation, indicating that the design of tessellation patterns may be more influenced by the principal direction of forces. This correlation highlights how force distribution along the main directions can impact the organization and stability of tessellation in structures figure (19).

Stability and Grid Pattern:

An inverse correlation (r = -0.764) between Stability and Grid Pattern suggests that structures relying heavily on grid patterns may struggle to maintain stability under stress. This could be due to uneven stress distribution within grid structures, leading to decreased stability figure (20).

Tessellation and Grid Pattern:

Although the positive correlation (r = 0.286) between Tessellation and Grid Pattern is weak, it implies that tessellation designs and grid patterns can complement each other under stress. This interaction helps distribute loads more effectively, enhancing the structure's ability to handle pressure figure (21).

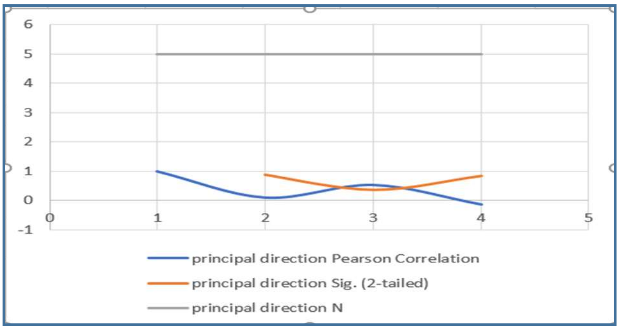

Figure 18: illustrates the correlation between the principal direction and stability.

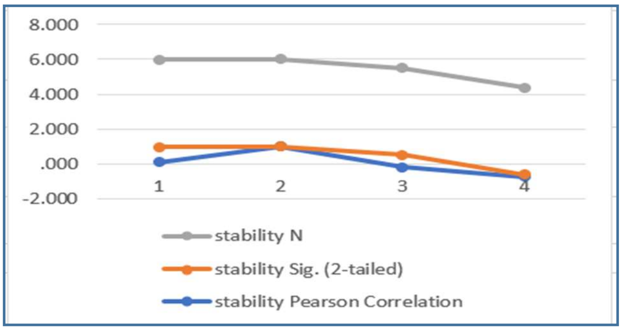

Figure 19: illustrates the correlation between the principal direction and tessellation.

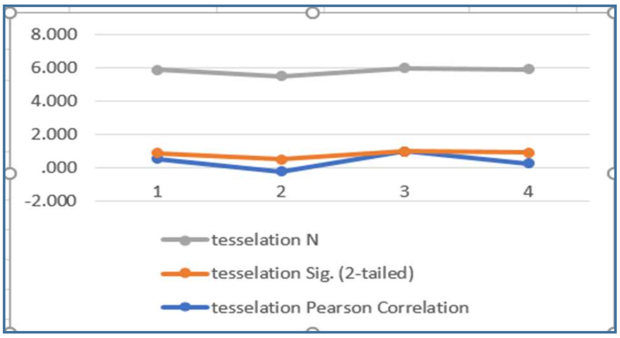

Figure 20: illustrates the correlation between stability and grid pattern.

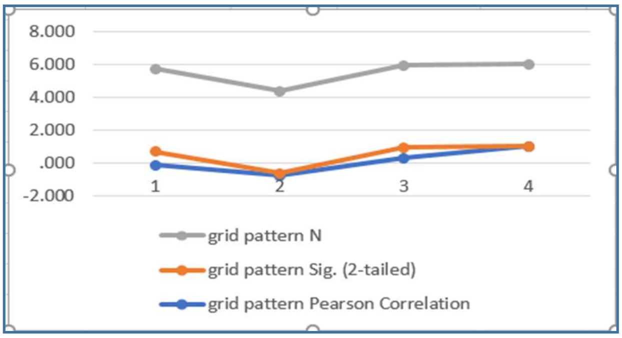

Figure 21: illustrates the correlation between tessellation and grid pattern.

8. Based on the research findings and analysis, several important conclusions can be drawn about how to improve structural design to achieve maximum efficiency and stability:

Focusing on Principal Direction: The results demonstrate that directing forces along the primary structural directions is crucial for achieving structural balance and stability. Designs that prioritize proper force direction achieve better stability and minimize lateral effects like wind and seismic forces.

Enhancing Stability through Load Distribution: The findings suggest that structural stability is best achieved through even load distribution and the use of biomimetic design techniques, such as hexagonal and pentagonal patterns. These patterns help achieve structural balance and reduce deformations.

Tessellation Enhances Structural Efficiency: Both ordinary and irregular geometric tessellations play a key function in enhancing structural efficiency by dispensing forces lightly and minimizing cloth use. Nature-inspired styles, like dragonfly wings or hexagonal cells, successfully enhance flexibility and balance.Importance of Grid Patterns: Organizing structural elements in balanced grid patterns is essential for effective force distribution and stability. Orthogonal and inclined patterns have proven effective in resisting various loads and providing high structural efficiency.

Integrating Biomimetic and Structural Design: Utilizing biomimetic processes, such as Delaunay Triangulation and Voronoi Diagrams, leads to significant improvements in the structural performance and aesthetics of buildings. These techniques offer innovative solutions for maximizing efficiency and stability while minimizing material consumption.

9. Conclusions:

The Value of Architectural and Structural Integration: This studies underscores the significance of integrating architectural and structural considerations in designing complex homes. Advanced engineering answers can aid aesthetic forms while enhancing structural overall performance

.Biomimetic Design as a Tool for Efficiency: Biomimetic tactics have established powerful in boosting structural efficiency and balance through mimicking herbal styles. These techniques provide progressive ways to lessen cloth use and optimize load distribution.

Achieving Stability thru Effective Load Distribution: Balanced load distribution throughout numerous grid styles appreciably improves structural balance, reducing the chance of collapse or most important deformations.

The Role of Tessellation and Grid Planning: Geometric tessellation and grid planning are critical to structural efficiency, as they evenly distribute loads. Successful structural design often depends on selecting the appropriate tessellation and grid patterns.

5. Lessons from Global Projects: Comparative evaluation of global projects presents precious insights that can be implemented to other initiatives to attain structural improvements, which includes the use of 3-dimensional grid structures and biomimetic techniques to decorate stability and performance.

6.A Shift Toward Sustainable Design: The results advise that designs that balance aesthetics with structural sustainability are more a hit in meeting user needs and keeping the surroundings. This highlights the importance of adopting layout methodologies that prioritize sustainability**.**

For future research, it is recommended to adopt numerical simulation tools such as SAP2000 for structural analysis and Rhino with Grasshopper for parametric form generation. These tools will complement the current statistical approach by enabling dynamic testing of various geometric configurations, material properties, and load conditions. This will provide a more comprehensive understanding of how biomimetic design principles can be optimized in real-time environments and complex architectural contexts.

Figure 7: London Aquatic Centre in London, 2012, designed by: Zaha Hadid Architects [9]

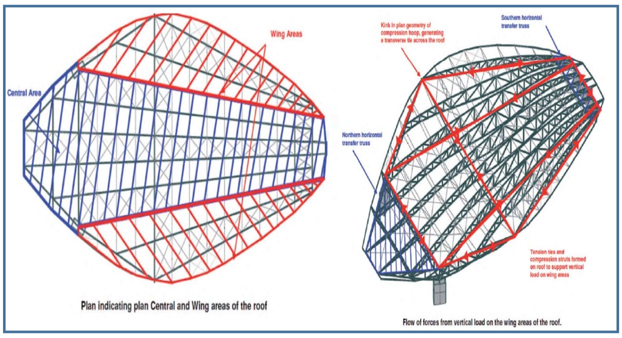

Figure 8: The combination between primary trusses and a more complex arching that flank the central zone [9]

Figure 9: Morpheus Hotel in MACAU, 2018, designed by: Zaha Hadid Architects [9]

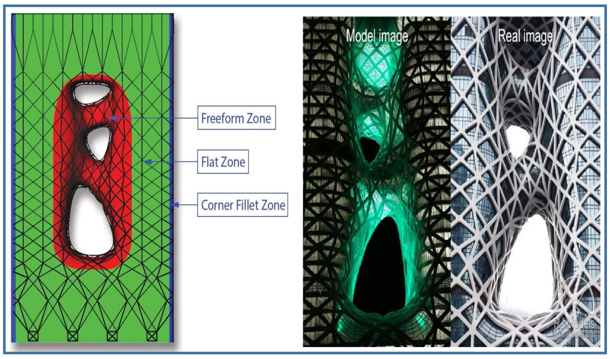

Figure 10: (Left) the exoskeleton zones. (Right) the model and real image [24]

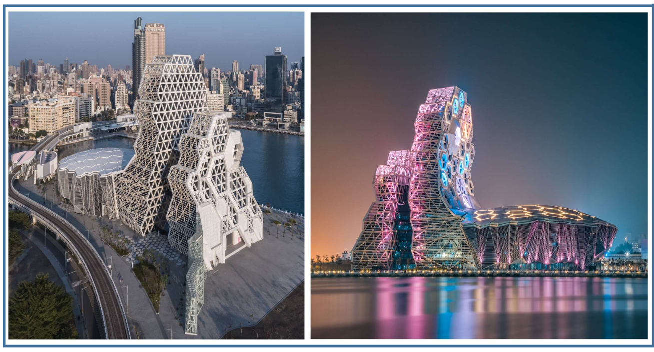

Figure 11: The Kaohsiung Pop Music Center, 2021, designed by: Manuel Monteserin [20]

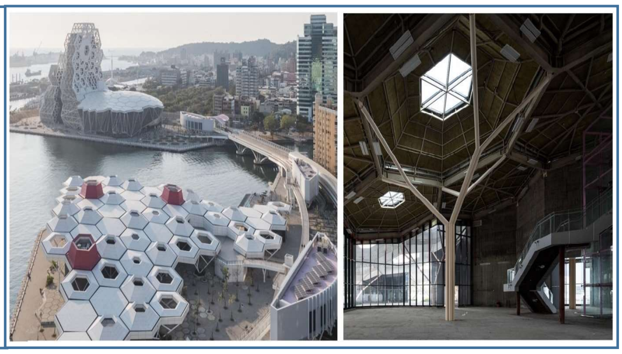

Figure 12: (**Left**) The Coral is a large roof made up of hexagonal umbrellas supported by branched pillars. (**Right**) The branched pillar supports [20]

Figure 13: The construction of the centre illustrates the three different structural systems [22]

Figure 14: The canopy of steel space frame with double curved freeform geometry and triangular modules [22]

Figure 15: Złote Tarasy, Warsaw/ POLAND, 2007, Designed by: the Jerde Partnership [17]

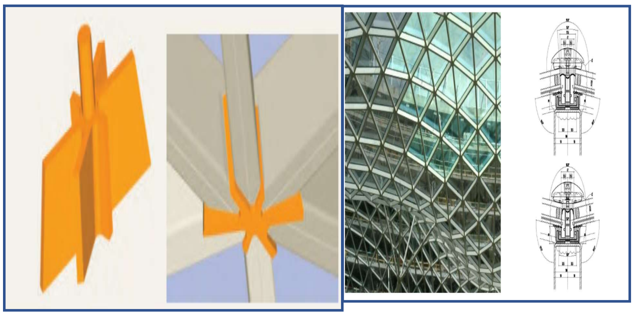

Figure 16: (Left) node visualization. (Right) The potential of the angular node variations to achieve the wave-shape geometry [17]

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العوامل المنشئية للهياكل الشبكية البيوميمتيكية: دراسة مقارنة للمشاريع العالمية"

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الخلاصة – تعد الهياكل الشبكية البيوميمتيكية واحدة من الابتكارات الهندسية والمعمارية الحديثة التي تهدف إلى تحسين الأداء الهيكلي من خلال محاكاة الأنماط الطبيعية. مع تزايد الاهتمام بالتصميمات المستدامة والفعالة، أصبح من الضروري فهم كيفية تأثير العوامل الهيكلية المختلفة على الكفاءة والاستقرار في هذه الهياكل. بناءً على ذلك، تهدف هذه الدراسة إلى تحليل العوامل الهيكلية للهياكل الشبكية البيوميمتيكية من خلال دراسة مقارنة لعدة مشاريع عالمية بارزة. تتمثل مشكلة البحث في تحديد مدى تأثير العوامل الهيكلية الأساسية - وهي الاتجاه الرئيسي، الاستقرار، التغطية، والنمط الشبكي - على الأداء الهيكلي للهياكل الشبكية البيوميمتيكية. تسعى الدراسة إلى الإجابة على سؤال رئيسي: كيف يمكن تحسين الكفاءة والاستقرار في الهياكل الشبكية البيوميمتيكية من خلال التحكم في هذه العوامل؟ لتحقيق أهداف الدراسة، تم اعتماد منهجية تحليل البيانات التي تشمل جمع البيانات من خمسة مشاريع عالمية بارزة: مركز لندن للألعاب المائية (2012)، فندق مورفيوس في الصين (2018)، مركز كاوشيونغ للموسيقى في تايوان (2021)، مركز حيدر علييف في أذربيجان (2012)، ومشروع زلوتي تاراسي في بولندا (2007). تم تنظيم البيانات وتحليلها باستخدام تحليل الارتباط لقياس العلاقة بين العوامل الهيكلية المختلفة. أظهرت النتائج أن تكامل التصميم المعماري والهندسي يلعب دورًا حاسمًا في تحسين الكفاءة الهيكلية والاستقرار. كما أظهرت النتائج أن التغطية الهندسية المناسبة والنمط الشبكي الملائم يسهمان في توزيع الأحمال بشكل متوازن وتقليل مخاطر التشوهات والانهيار. بالإضافة إلى ذلك، أشارت النتائج إلى أن التصميمات البيوميمتيكية يمكن أن تقدم حلولًا مبتكرة وفعالة لتحسين الأداء الهيكلي. خلصت الدراسة إلى أن تحقيق الكفاءة والاستقرار في الهياكل الشبكية البيوميمتيكية يتطلب استخدام تقنيات حديثة وتكاملًا قويًا بين الجوانب المعمارية والهندسية. كما أكدت على أهمية التركيز على الاستدامة في التصميم من خلال تبني المبادئ البيوميمتيكية التي تحاكي الأنماط الطبيعية.

الكلمات الرئيسية – الهياكل الشبكية البيوميمتيكية، الكفاءة الهيكلية، الاستقرار، التغطية الهندسية، النمط الشبكي، تحليل الارتباط، التصميم المستدام.