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# Form Finding in Architecture, Lessons from Heydar Aliyev Cultural Center

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**Abstract:** Form-finding in architecture is a process that determines an optimal form or shape for a building, to achieve dynamic stability, adaptability and sustainability, using a logical process inspired by what happens in nature. The three main categories of this process are physical, analytical and hybrid form-finding. In this paper, after defining form-finding and briefly describing its history, these three categories and the advantages and disadvantages of each are explained. This article delves into the intricate process of form-finding and its evaluation in the Heydar Aliyev Cultural Center. It explores the innovative architectural approaches and design principles employed to achieve a dynamic and visually striking structure. The study examines the methodologies used in generating and refining the form, focusing on the integration of advanced computational tools and sustainable design practices. Additionally, the paper highlights the challenges and solutions encountered during the project, offering insights into the practical application of form-finding techniques in contemporary architecture. Through a detailed analysis, this article aims to contribute to the broader discourse on form-finding and its potential to shape future architectural endeavors.

**Keywords**: Form-finding, Case study, Form-finding techniques, Heydar Aliyev Cultural Center.

## 1. Introduction

Architectural design is not limited to static, predetermined forms, but is a dynamic process that draws inspiration from natural forms, technological advances, and innovative practices. This is embodied in the process of form-finding - a method that allows architects to discover optimal structures that combine aesthetics with seamless functionality.

Formfinding departs from traditional architectural approaches, where forms were often dictated by convention. Rather, it involves a process in which form emerges logically and responds to environmental, structural, and material constraints. With the advent of computational tools and increasing emphasis on sustainability, form finding has emerged as a vital technique in modern architecture [1].

This article examines the multifaceted nature of form finding and its classification into physical and analytical approaches. Each category presents unique opportunities and challenges and shapes the way architects approach design (Table 1).

To contextualize these concepts, this article presents Heydar Aliyev Cultural Center as a case study. Designed by Zaha Hadid Architects, this iconic structure exemplifies the innovative application of form-finding techniques, resulting in a fluid and adaptive design that harmoniously integrates with its surroundings [2].

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## 2. Form Finding in Modern Architecture and Beyond

Form-finding is a fundamental concept in architecture where the shape and structure of a building or object emerge from the intrinsic forces acting upon it, such as gravity, tension, and compression. This approach results in designs that are optimized for structural efficiency. The evolution of form-finding has been marked by significant milestones, spanning from ancient civilizations to the modern era, each contributing to the development of architectural forms that are both functional and expressive. The following describes the methods of form-finding in the 19th century and beyond (Fig. 1).

### *2.1 19th Century: The Industrial Revolution and New Materials*

The 19th century brought about significant changes in architectural form-finding with the advent of new materials such as iron and glass, which enabled the creation of innovative structural forms. The Crystal Palace, designed by Joseph Paxton for the Great Exhibition of 1851, is a notable example of this era. The structure utilized prefabricated iron and glass components, allowing for a modular design that was both lightweight and efficient. The Crystal Palace represented a significant advancement in form-finding, as it demonstrated how new materials could be used to create forms that were previously unimaginable [3]. Gustave Eiffel's work on the Eiffel Tower (1887) further exemplified the use of form-finding in the 19th century. The tower's design, with its lattice structure of wrought iron, utilized innovative engineering techniques that foreshadowed modern approaches to form-finding. The Eiffel Tower's shape, derived from the need to distribute weight and resist wind forces, became a symbol of the possibilities of form-finding in the industrial age [4]. In the same period, the catenary arch became a focal point for architects and engineers exploring the relationship between form and structural efficiency [5]. Architect J. A. P. M. Van der Waals' use of the catenary curve in structural design in 1887 demonstrated how natural forms could be employed to create stable, efficient structures. This understanding of the catenary curve would later influence modern architecture, particularly in the design of long-span structures and arches [6].

### *2.2 Early 20th Century: The Rise of Modernism*

The early 20th century marked a pivotal moment in the evolution of form-finding, particularly with the rise of the Modernist movement. The Bauhaus, founded in 1919, emphasized the relationship between form and function, promoting a rational approach to design that laid the groundwork for later explorations in form-finding. The Bauhaus movement advocated for simplicity and the use of geometric forms, which were often derived from the intrinsic properties of materials and the forces acting upon them [7]. During the 1930s, Buckminster Fuller introduced the concept of the geodesic dome, a structure that efficiently distributes stress and load through its geometric configuration [8]. Fuller's work on the geodesic dome was a significant advancement in form-finding, as it demonstrated how lightweight structures could be designed to achieve maximum strength with minimal material use. The geodesic dome would later become an iconic symbol of efficient design [9].

### *2.3 Mid to Late 20th Century: Innovations in Lightweight Structures*

The mid-20th century saw further innovations in form-finding, particularly through the work of architects and engineers like Frei Otto and Heinz Isler. The 1960s marked a significant period in the evolution of form-finding, characterized by a focus on lightweight structures and innovative approaches to design. Frei Otto, a pioneer in lightweight structures, began extensive research on tensile forms in the early 1960s. His work emphasized the relationship between form and structural efficiency, often using physical models to explore how forces could shape architectural forms [10]. Otto's designs, such as the Munich Olympic Stadium (1972), utilized cable-net structures and membranes to create lightweight, flexible forms that responded to the forces acting upon them [11]. His work exemplified the principles of form-finding, where the structure's shape emerged naturally

from the interplay of tension and compression [12]. Heinz Isler, another influential figure of this period, developed techniques for form-finding using physical models, particularly in the design of thin-shell structures. Isler's innovative use of funicular forms, where the shape of the structure is derived from the forces acting upon it, allowed for the creation of elegant, efficient designs [13]. His work on the Shell Roof for the Sports Hall in Zurich (1968) is a notable example of how form-finding can be applied to achieve both aesthetic beauty and structural integrity [14].

### *2.4 Late 20th Century: The Digital Revolution*

The late 20th century witnessed the emergence of computer-aided design (CAD) tools, which revolutionized the process of form-finding. The development of CAD in the 1970s and 1980s allowed architects to experiment with complex geometries and forms that were previously impossible to achieve [15]. This era also saw the rise of structural engineers like Fazlur Rahman Khan, who explored innovative structural systems that challenged traditional approaches to form-finding [16]. The introduction of algorithmic design tools, such as Rhino and Grasshopper in the 1990s, further expanded the possibilities of form-finding [17]. These tools enabled architects to manipulate forms based on various parameters, leading to the creation of organic, fluid shapes that responded to both aesthetic and structural considerations. Frank Gehry's Guggenheim Museum in Bilbao (1997) is a prime example of how digital tools can be used to create complex, expressive forms that push the boundaries of architectural design [18].

### *2.5 21st Century Digital Fabrication and Beyond*

The 21st century has seen continued advancements in form-finding, driven by developments in digital fabrication, materials science, and computational design. Architects like Zaha Hadid and Bjarke Ingels have utilized these technologies to create dynamic, responsive structures that reflect the evolving nature of form-finding. Zaha Hadid's work, characterized by its fluid, organic forms, often employed physical models and digital tools to explore the possibilities of form-finding. Her designs, such as the MAXXI Museum (2010) and the Guangzhou Opera House (2010), exemplify the integration of form-finding with advanced computational techniques, resulting in structures that are both visually striking and structurally efficient [19].

The rise of 3D printing technology in the 2010s has further revolutionized form-finding by enabling rapid prototyping [20] and the creation of complex geometries that were previously difficult to achieve. This technology has allowed architects to experiment with new forms and materials, pushing the boundaries of what is possible in architectural design [21].

Table 1: Comparison between form-finding methods.

| Form-Finding Methods | Simplicity of Perception | Ease of Application | Precision | Quick Execution | Providing High Details |
|---|---|---|---|---|---|
| Hanging Chain | ✓ | | | | |
| Wet and Frozen Fabric | ✓ | ✓ | | | |
| Soap Bubbles | ✓ | ✓ | | ✓ | |
| Cable-Stayed Model | ✓ | | ✓ | | |
| Force Density | | | | ✓ | ✓ |
| Dynamic Internal | | | ✓ | ✓ | ✓ |
| Graphic Statics | ✓ | ✓ | ✓ | ✓ | ✓ |
| Computer-aided Design (CAD) | ✓ | | ✓ | ✓ | ✓ |
| Geometric Modeling | ✓ | | ✓ | ✓ | ✓ |
| Form Finding Software | ✓ | | ✓ | ✓ | ✓ |
| Nature-Inspired Design | | | ✓ | | ✓ |
| Parametric Design | ✓ | | ✓ | ✓ | ✓ |
| 3D Printing | ✓ | | ✓ | | ✓ |
| AI and Machine Learning | | | ✓ | | ✓ |

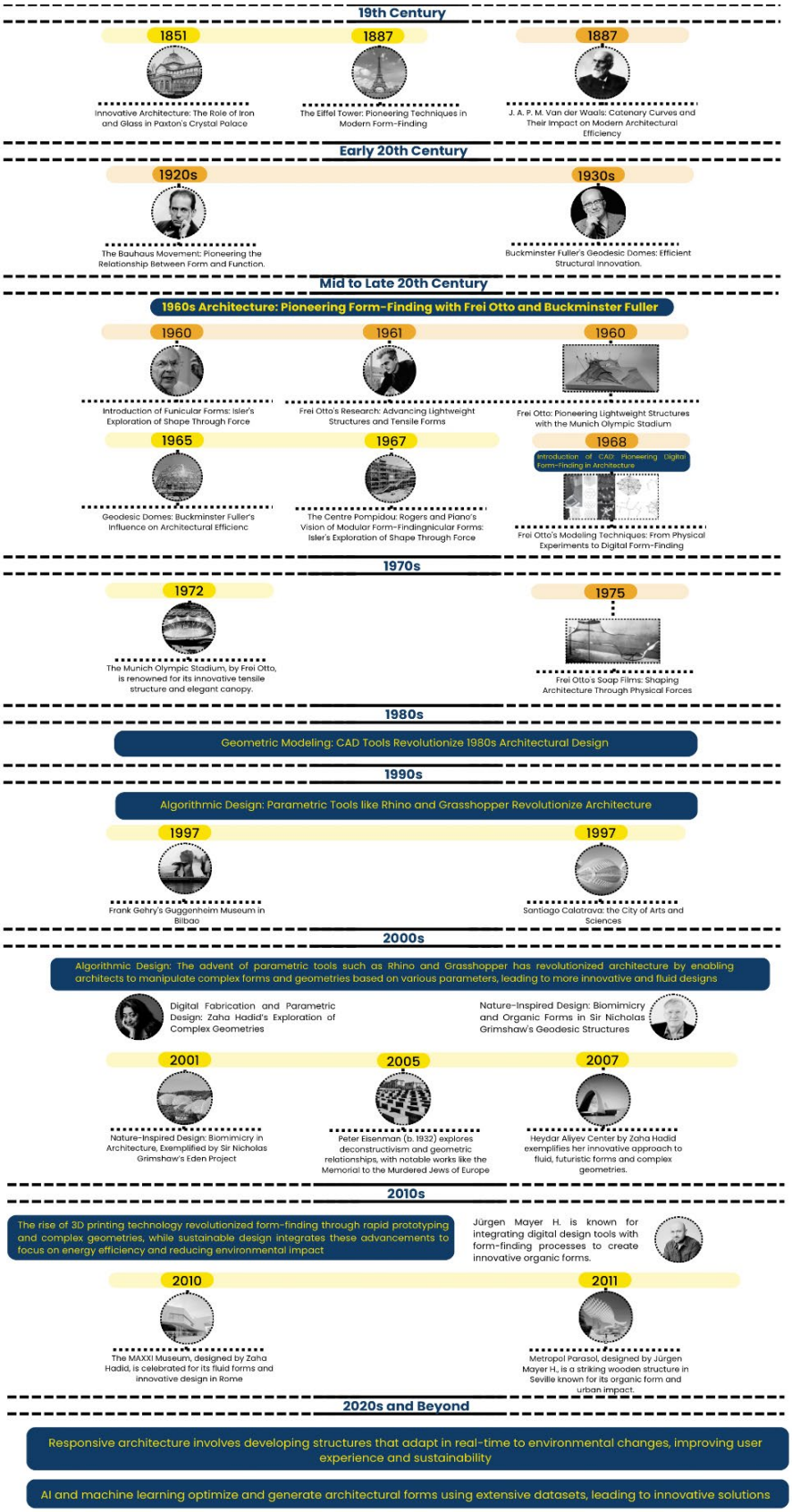


Figure 1. Timeline of form finding in architecture

### 3. Case study: Heydar Aliyev Cultural Center

The Heydar Aliyev Cultural Center, inaugurated in 2011 in Baku, is celebrated for its unique architecture designed by Iraqi-born architect Zaha Hadid. Its striking curves and pristine white materials create a bold contrast with the surrounding Soviet-era architecture, characterized by, rectangular brown buildings (Fig. 2). The Cultural Center's design features expansive white panels that form stairs and walkways, seamlessly integrating the outdoor landscape with the structure. These panels symbolize Azerbaijan's topography, transitioning from mountains to midlands to sea. The building's facade has three folds representing its main functions: library, theater, and museum, a theme that extends throughout its interior design. This innovative structure distinguishes itself from Baku's traditional Old City, which showcases rectangular buildings reflecting Soviet influence. The Cultural Center's modern design solidifies its status as a pioneering architectural landmark in Azerbaijan, enhanced by Zaha Hadid's involvement [22].

Figure 2. Heydar Aliyev Culture Centre, Azerbaijan [23]

The Heydar Aliyev Center exemplifies a design philosophy that seeks to harmonize the building with its surrounding landscape through the use of dynamic curves. These fluid forms appear to organically emerge from the site, shaping the structure's walls and creating a seamless integration between architecture and environment. This intentional blurring of boundaries challenges conventional distinctions among architecture and landscape, form and ground, as well as interior and exterior spaces, thereby redefining the relationship between private and public realms [24].

The Heydar Aliyev Center features two structural systems: reinforced concrete for the inner walls and a double-layer grid (DLG) steel space frame structure that includes steel columns and beams. This combination enhances the rigidity of the space frame and supports the glass walls, ensuring their structural integrity. The integration of concrete and steel also leads to the formation of steel bridges connecting internal utilities on the upper floors. The cladding and ceiling materials consist of Glass Fiber Reinforced Concrete (GFRC) and Glass Fiber Reinforced Plastic (GFRP), which together improve overall structural performance by mitigating each material's limitations [25]. The project's most complex aspect was designing the external façade, which required a unified material for both the plaza flooring and building envelope cladding, necessitating geometric flexibility and specific qualities such as color, sheen, texture, UV protection, graffiti resistance, and slip

resistance. GFRC was chosen for its suitability to the free-form architectural vision. It is produced through a specialized extrusion process that incorporates layers of glass fibers within a concrete matrix, resulting in slender elements that can withstand stress despite a thickness of just 8-13 mm. The GFRC panels are categorized into three geometric types: flat-planar, single curvature, and double curvature [24].

## 4. Form-Finding

Zaha Hadid's architectural designs are profoundly influenced by various artistic and cultural traditions, which she skillfully integrates into her innovative form-finding systems. One of the key inspirations she drew from was the fading technique in Chinese painting, where the layering of space creates a sense of infinite depth and boundless freedom. This technique significantly influenced her approach to landscaping, where she designs buildings that naturally conform to the shape of the land, minimizing human interference and preserving the natural landscape. For instance, in many of her projects, Hadid employs a single color for the exterior, with pavements matching this color, creating an ambiguity about the boundary between the building and the site. This strategy is particularly evident in the Heydar Aliyev Cultural Center in Azerbaijan, where the walls expand and fold to seamlessly integrate with the site's pavement, enhancing the connection to the earth [26].

### *4.1 Landscaping the Surroundings*

Landscaping in architecture is about integrating a building within its surrounding environment, making it a complementary part of the urban or natural context. Rather than designing in isolation, architects like Zaha Hadid work to embed their projects into the landscape by considering relationships with topography and the broader site. For instance, the design of buildings like the Regium Waterfront in Reggio and the Dubai Opera House reflects the shape of the land or urban grids, blending the structure seamlessly with its surroundings [27].

Hadid's approach to landscaping often minimizes human interference with nature, achieving a smooth connection between the building and the site. She frequently uses a single color for the building's exterior and applies pavements that match the surfaces of the site, creating a sense of "uncertainty" where the boundary between building and land is indistinct. Another strategy is wall extension, where the walls fold and extend into the pavement, further blurring the line between structure and earth. Examples of this approach are seen in the Heydar Aliyev Center and the Stone Towers in Cairo. These strategies aim to reduce the visual distinction between architecture and its environment, creating a harmonious blend with the land [27].

Hadid's design philosophy extends to how she approaches the site and environment, where she landscapes the building as an integral part of its surroundings rather than an isolated entity (Fig. 3). Her projects are carefully embedded within their urban context by considering various articulated relationships, such as topography and landscape, to ensure that the building complements the broader urban zone’s image [28]. The Heydar Aliyev Cultural Center exemplifies this approach, where the fluid form of the building emerges by folding the landscape's natural topography. The exterior skin of the building acts as a single continuous surface that wraps around to define the individual functions of the Center, while also providing each element with its own identity and privacy. This design allows the museum to face out into the landscape with a glass facade that bathes the galleries in natural light, enhancing the connection between the interior and the surrounding environment [29].

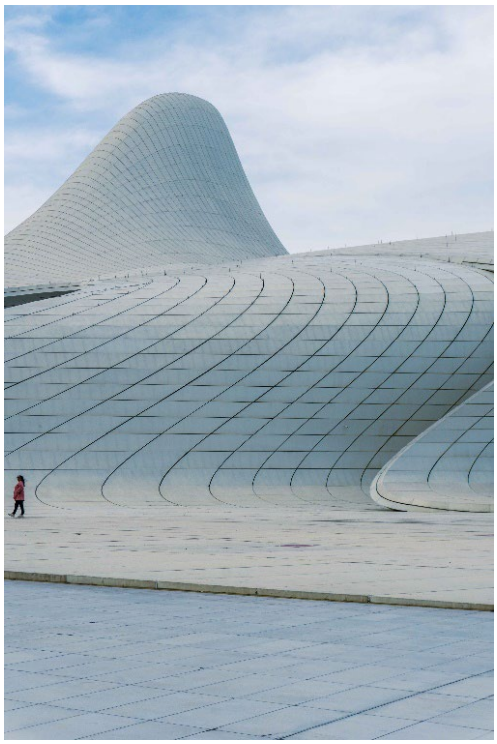

Figure 3. Landscaping the Surroundings [30]

*4.2 Topographic Forms*

Topography, derived from the Greek words "topos" (place) and "graphein" (to write), is the study of land surface features and their effects on natural processes like erosion, drainage, and ecological systems. While architects often focus on building design, understanding topography is crucial, as it influences decisions on site planning, building placement, and orientation. By interpreting topographic maps and site surveys, architects assess the landscape's shape and elevation, which helps manage water flow, mitigate flood risks, and integrate buildings seamlessly with the environment. Architects coordinate with other specialists to ensure the site's unique topography is addressed effectively in the design (Fig. 4) [31].

Figure 4: Topographic Forms [32]

In addition to abstraction and fragmentation, Hadid often drew inspiration from the earth's natural formations when designing her projects. Her interest in "landscape, topography, and geography" led her to develop shapes inspired by the contours, ridges, dunes, floodplains, and cliffs of the earth's surface. By considering site inclinations and directions, she created architectural forms that harmonize with the surrounding landscape. This approach is clearly demonstrated in the Heydar Aliyev Cultural Center, where the form is

generated by withdrawing the landscape of the site into four topographically formed slices [33]. The ground surface of the museum folds and reaches its peak, forming a ridge on top of the uppermost gallery level, with all other mezzanine floors packed under this primary fold. Suspended ceilings above each level provide a major treatment surface for acoustical interventions, further enhancing the functionality of the space [29].

*4.3 Seamlessness and Fluidity*

Fluid forms, though challenging to construct, have been used by only a few architects due to their complex nature. The extensive curved geometries give these forms a unique expression and ensure a harmonious integration with the environment, as natural forms often embody fluidity [34].

Seamlessness and fluidity are other critical aspects of Hadid's architectural style (Fig. 5). These characteristics are especially prominent in her recent works, where they are easily recognizable. Hadid drew inspiration from the seamless patterns of the Sumerian village landscapes in Iraq, where natural elements like sand, reeds, and water combine to create a visually striking environment [35]. In her architecture, concrete is often used to realize these seamless curvatures, avoiding sharp 90-degree corners and instead curving surfaces to maintain a continuous fluid space. This technique, which she learned from the intricacy and beauty of natural forms, allows for more convertible and visible surfaces through which natural light can enter the building, creating a dynamic and immersive experience for those inside [36, 37].

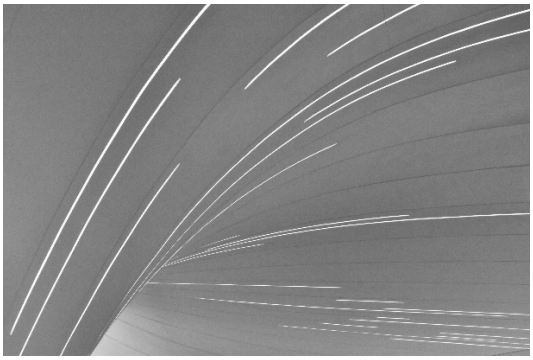

Figure 5: Seamlessness and Fluidity [38]

*4.4 Light and Masses*

Hadid's attention to the play of light and masses is evident in the interior design of the Heydar Aliyev Cultural Center. She strongly considered the impact of light in both the interior spaces and the building's exterior elevations. By developing techniques that enhance the three-dimensionality of forms and surfaces, she dramatically reinforces the spatial qualities of her designs. For example, the lighting in the auditorium, a full timber structure, accentuates the texture of the timber fins, creating a mesmerizing spatial experience. The strip lines along the exterior of the lavish lobby, which doubles as a meeting point for all primary spaces, provide indirect lighting and subtly model the skin of the building [39].

*4.5 Layering Technique*

Layering refers to treating the building's floors as separate layers or levels, subtly disregarding the grid of the lower floor and manipulating the boundaries of the ground. Hadid stated that the complexities and energy of the modern lifecycle "cannot be cast into the simple orthogonal grids and blocks of the 20$^{th}$-century architecture of Henry Ford's era". Therefore, layering involves manipulating the positions of floors through superposition to create energetic forms, such as in the Peak project. She learned this approach to space from Chinese art painting and the morphology of erosion in nature.

Hadid admires their way of painting space in layers "into infinity, giving us a sense of unexplored depth and boundless freedom" [27].

Layering is another technique Hadid employs to create voids, complex fluid surfaces, and a strong connection between the interior and exterior of her buildings. In the Heydar Aliyev Cultural Center, this technique enabled Hadid to manipulate the interior wall borders and clad the volumes of the main foyer in pristine white tiles, enhancing the fluidity and seamlessness of the interior spaces [40].

Figure 6: Layering Technique [41]

Table 2. Form finding techniques used in Heydar Aliyev Cultural Center

| Technique | Description | Impact on Design |
|---|---|---|
| Landscaping the Surroundings | Embedding architecture within the environment by integrating topography and surroundings. | Harmonizes the building with nature; minimizes human interference; blurs the boundary between building and land. |
| Topographic Forms | Using land surface features like ridges, dunes, and inclines to inspire architectural shapes | Reflects natural formations; integrates site inclinations for better functionality and environmental compatibility. |
| Seamlessness and Fluidity | Creating smooth, continuous forms inspired by natural curvatures. | Avoids sharp edges; maximizes natural light entry; and enhances immersive spatial experiences. |
| Light and Masses | Leveraging light to emphasize textures and spatial qualities within forms. | Enhances the three-dimensionality of spaces; uses lighting for dramatic visual effects, especially on surfaces like timber fins or tiled interiors. |
| Layering Technique | Manipulating building layers to create depth, voids, and fluid spaces. | Breaks traditional grids; adds dynamic layering inspired by Chinese art and erosion patterns to enhance depth and spatial freedom. |
| Technique | Description | Impact on Design |
| Landscaping the Surroundings | Embedding architecture within the environment by integrating topography and surroundings. | Harmonizes the building with nature; minimizes human interference; blurs the boundary between building and land. |
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| Seamlessness and Fluidity | Creating smooth, continuous forms inspired by natural curvatures. | Avoids sharp edges; maximizes natural light entry; enhances immersive spatial experiences. |
| Light and Masses | Leveraging light to emphasize textures and spatial qualities within forms. | Enhances the three-dimensionality of spaces; uses lighting for dramatic visual effects, especially on surfaces like timber fins or tiled interiors. |
| Layering Technique | Manipulating building layers to create depth, voids, and fluid spaces. | Breaks traditional grids; adds dynamic layering inspired by Chinese art and erosion patterns to enhance depth and spatial freedom. |

## 5. Conclusion

The evolution of form-finding in architecture reflects a continuous interplay between innovation, material science, and aesthetic vision. From the ancient geometries of pyramids and Gothic cathedrals to the intricate modern forms shaped by digital tools, form-finding has profoundly influenced architectural design, emphasizing both structural efficiency and artistic expression. This ongoing progression highlights how architects adapt to both technological advancements and the ever-evolving relationship between form and function.

The Heydar Aliyev Cultural Center stands as a remarkable testament to the principles of form-finding, embodying the seamless integration of architecture with its surroundings. The building's fluid curves and continuous surfaces blur the distinctions between interior and exterior, offering a unique spatial experience that harmonizes with the natural topography of Azerbaijan. The visionary use of advanced materials and techniques, such as Glass Fiber Reinforced Concrete, underscores the potential of modern architecture to create innovative, functional, and visually striking forms, while maintaining structural integrity.

As we advance into the 21st century, emerging technologies like AI, digital fabrication, and computational design are expanding the possibilities of architectural form-finding. These tools enable architects to explore innovative and sustainable designs while maintaining precision and efficiency. The Heydar Aliyev Cultural Center serves as an example of how contemporary architecture can leverage such advancements. Its seamless integration of form and environment illustrates valuable lessons in blending innovative design with functional and contextual sensitivity. Rather than being a definitive benchmark, the building highlights the potential for architecture to harmonize with natural and urban landscapes, offering inspiration for future explorations in form-finding.

The principles demonstrated in Hadid's work—seamlessness, fluidity, and the play of light and masses—will continue to inspire and shape the future of architecture. As technology evolves, these principles will be amplified, allowing architects to explore new ways of blending built environments with natural landscapes and creating spaces that push the boundaries of both form and function. The exploration of form-finding remains an ever-evolving journey, one that will redefine the role of architecture in the future.

**Declaration of Generative AI and AI-assisted Technologies in the Writing Process.**

During the preparation of this work, the authors used wordvice.ai/tools/paraphrasing to enhance the readability and language of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article

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