



Form as Dialogue: Synthesis of Scientific and Artistic Knowledge in Contemporary Education of Architects and Designers

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Abstract

In the context of the growing importance of the STEAM (Science, Technology, Engineering, Arts, Mathematics) approach in higher education, conceptualizing the relationship between the arts and sciences is particularly relevant. This review examines the historical, theoretical, methodological, and pedagogical foundations for integrating a scientific worldview into curricula in sculpture, architectural design, art history, and architectural graphics. The authors substantiate the thesis that artistic form throughout history has not been reduced to pure subjectivity or embellishment, but has evolved inextricably linked with the study of natural phenomena, the laws of physics, and mathematical principles. The paper analyzes key historical examples of synthesis—from the universal explorations of Leonardo da Vinci and Goethe's morphological ideas to contemporary trends in bionics, parametric design, and environmental design. The focus is on concepts that serve as links between these "two cultures": biomorphology, the physics of materials properties, the theory of symmetry, spatial geometry, and principles of environmental sustainability. These categories offer the opportunity to transcend superficial imitation of nature and move toward a meaningful understanding of form as a product of the interplay of function, context, and design. The study concludes with potential educational methods aimed at developing students' synthesised thinking—the ability to recognize the aesthetic dimension in scientific data while simultaneously appreciating logic, statics, and functional validity in art and architecture. Such a synthetic perspective not only expands the horizons of art education but also fosters a holistic, responsible, and interdisciplinary consciousness, essential for responding to complex contemporary challenges—from environmental threats to the transformation of the living environment through technological means.

Keywords: STEAM pedagogy, teaching architecture, interdisciplinary synthesis, synesthesia of form.

Introduction

The relevance of this topic is determined by the ongoing confrontation between the "two cultures"—the natural sciences and the humanities—conceptually defined by Charles Percy Snow in the mid-20th century. As he stated in a famous 1959 lecture: "Representatives of both cultures experience mutual misunderstanding, and this is the tragedy of our time" [1]. This division, which gives rise to fragmented thinking and limited professional horizons, remains a challenge for modern higher education. In response to this challenge, the interdisciplinary STEAM (Science, Technology, Engineering, Arts, Mathematics) approach is gaining ground in global pedagogical practice. Within this approach, art is integrated not as an optional element, but as a system-forming element necessary for the development of holistic, innovative, and critical thinking.

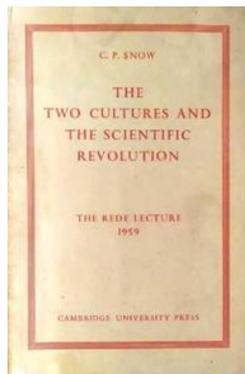
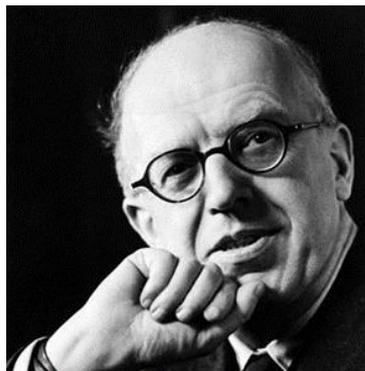


Fig. 1. Portrait of Charles Percy Snow

<http://бублuомека32.рф/?page=culture&action=show&id=4318&sheet=1>

The particular significance of such a synthesis for architecture, design, and the plastic arts stems from the very nature of these disciplines. Their fundamental categories—form, space, structure, material, and light—are simultaneously objects of aesthetic comprehension and scientific research. Form is subject to the laws of statics and mechanics, space is described by geometry, material dictates its physical and chemical properties, and light is studied by optics. As Kenneth Frampton noted, "architecture has always balanced between the autonomy of artistic expression and the necessity of constructive logic" [2]. Thus, architecture and design have inherently existed at the intersection of creative inquiry and precise knowledge, making them an ideal laboratory for bridging the gap between "two cultures." The purpose of this article is to comprehensively analyze the historical and theoretical foundations and specific pedagogical perspectives for integrating principles, methods, and knowledge from the natural sciences—such as physics, biology, ecology, and mathematics—into educational programs in the arts and architecture. The authors seek to demonstrate that such integration is not a mechanical addition of technical disciplines to the curriculum, but rather a methodological foundation for developing a new type of professional consciousness capable of perceiving form as a meaningful dialogue between art, technology, and science. The idea of an inextricable link between artistic creativity and scientific knowledge is not a modern invention. Historical analysis demonstrates that the rigid dichotomy between these spheres is a relatively recent phenomenon, whereas in deep tradition, they acted as complementary aspects of a single process of understanding the world. The Renaissance: Universalism and the Unity of Knowledge. The cultural ideal of the Renaissance, embodied in the figure of the "universal man" (*homo universale*), envisioned a holistic mastery of knowledge and skill. The most striking embodiment of this ideal was Leonardo da Vinci, for whom the boundaries between art and science were nonexistent. His artistic practice—from the *Mona Lisa* to the *Last Supper*—was a direct result of meticulous scientific research: anatomical studies ensured the impeccable plasticity of bodies, the study of geology and hydrodynamics ensured the realism of landscapes and the dynamics of draperies, and optics and the laws of perspective ensured the depth and persuasiveness of space. As Leonardo himself wrote in his *Treatise on Painting*: "Whoever criticizes painting for imitating the works of nature criticizes the existence of nature and the creative force that acts according to the laws of nature" [3]. Thus, for Leonardo, scientific analysis was not an auxiliary but a constitutive principle of creativity, establishing a model of synthesis in which form is born from an understanding of the inner laws of nature.

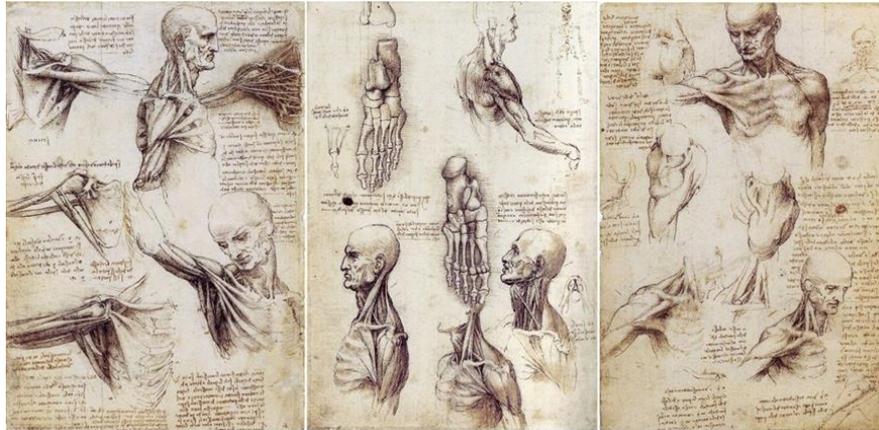


Fig. 2. Anatomical drawings by Leonardo da Vinci <https://in.pinterest.com/pin/294704369349893300/>

18th–19th Centuries: Phenomenology and Holistic Perception. During the Age of Enlightenment and Romanticism, Johann Wolfgang von Goethe made a significant contribution to the philosophy of synthesis. His 1810 Theory of Colours, written in polemics with Newton's physical approach, offered not so much a physical explanation as a phenomenological study of perception. Goethe insisted on subjective yet disciplined observation, where sensory experience and rational understanding are inseparable. "Color is nothing but a boundary, and it arises only where light and darkness meet," is how he formulated the essence of his method [4]. This approach, which prioritizes the holistic image of a phenomenon, had a profound influence on artists and thinkers, demonstrating that scientific and artistic knowledge can be different paths to the same truth. Goethe's approach paved the way for understanding form as a phenomenon simultaneously comprehended intuitively and analytically.

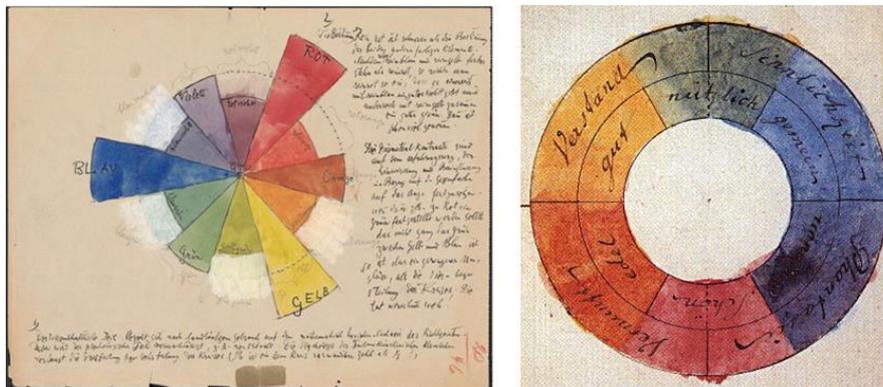


Fig. 3. Johann Wolfgang Goethe, color wheel

https://artchive.ru/publications/3140~Ot_prerafaelitov_do_Baukhauza_Kak_11_khudozhestvennykh_tech_enij_poluchili_svoi_nazvaniya

Early 20th Century: Mathematization of Morphology and Scientific Biomorphology. The fundamental breakthrough that laid the foundations of the modern dialogue was made by the Scottish biologist and mathematician D'Arcy Wentworth Thompson in his 1917 treatise "On Growth and Form." By demonstrating that the infinite variety of biological forms—from the spiral of the nautilus shell to the skeletal structure of the radiolarian—can be described and modeled in the language of mathematical transformations, that is, coordinate grids and the laws of mechanics, physics, and chemistry, Thompson bridged the gap between descriptive biology and the exact sciences. His famous formulation became the manifesto of the new approach: "In the last analysis, form is a function of force" [5]. His work marked the beginning of scientific biomorphology, establishing the key thesis: the beauty and purposefulness of natural form are a direct consequence of the action of objective physical and mathematical laws. This idea became the cornerstone for subsequent generations of architects and designers, who sought in nature not just a model to imitate, but a logical and calculated basis for innovative form-building.

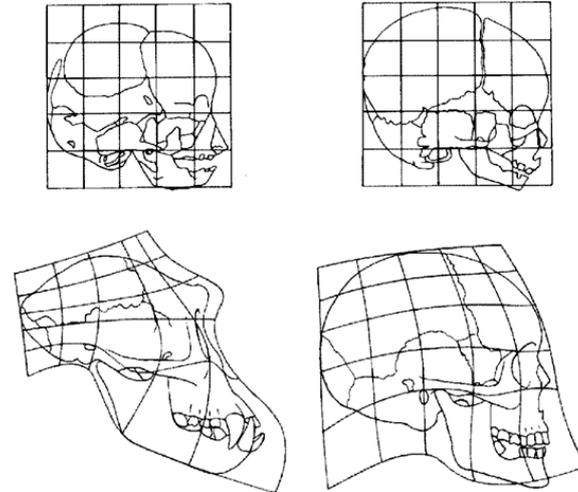


Fig. 4. 2 Transformation grids for the chimpanzee (left) and human (right) skull during growth
<https://www.researchgate.net/figure/Transformation-grids-for-the-chimpanzee-left-and-human-right-skull-during-growth-fig1-313025941>

Thus, a historical retrospective reveals a strong tradition in which art and science developed in constant dialogue. From the universalism of the Renaissance through Goethe's phenomenology to Thompson's mathematical biology, the path to a contemporary understanding of form as a phenomenon requiring synthetic, interdisciplinary cognition can be traced.

To realize this synthesis in theory and pedagogical practice, specific conceptual categories are necessary, serving as connecting links between the language of the natural sciences and the process of artistic and design form-making. These categories overcome the superficial borrowing of natural images, enabling a transition to a meaningful dialogue.

Biomorphology: a principle, not an image. Developing the ideas of D'Arcy Thompson, modern biomorphology views the form of living organisms not as random or purely decorative, but as an optimal solution, developed by evolution under the influence of physical forces, environmental constraints, and the need to conserve materials. As Janine Benyus emphasizes, "nature doesn't reinvent the wheel—it refines solutions over 3.8 billion years of evolution" [6]. For an architect or designer, this means moving beyond mimicking appearances (for example, a flower-shaped building) to analyzing and applying the principles of natural morphology: branching to distribute loads and flows, minimal surfaces to conserve material when creating shells, porosity and cellularity to regulate the environment and ensure strength with low weight. Biomorphology thus becomes a method that links biological knowledge with engineering logic and aesthetics.

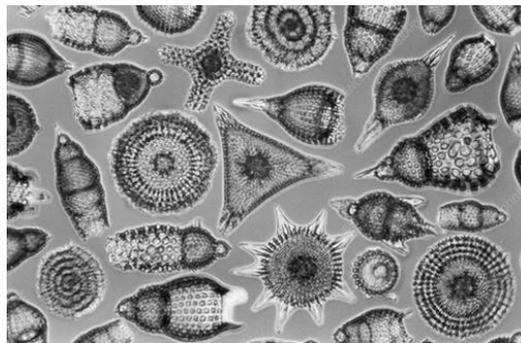


Fig. 5. Various radiolaria <https://www.sciencephoto.com/media/1110822/view/various-radiolaria-light-micrograph>

The Physics of Material Properties: A Dialogue with Substance. Any material form is subject to the laws of physics. Understanding the mechanical properties (strength, elasticity, plasticity), thermal characteristics (thermal conductivity, expansion), and behavior of materials under load transforms working with materials from a mere craft operation into meaningful design. As Kenneth Frampton notes in his work "Studies in Tectonic Culture," "tectonics is a poetics of construction where material honesty becomes the source of aesthetic expression" [7]. The shape of a concrete shell, the bending of a wooden beam, the sagging of a fabric membrane—all these are visualizations of internal stresses



and physical laws. Integrating this knowledge into education teaches us to see the final form not simply as an image, but as a materialized diagram of forces, where aesthetics is born from an honest and effective dialogue with the physics of the material.

The study of symmetry and spatial geometry: the language of harmony and organization. Mathematics provides a universal toolkit for describing and generating form. As Hermann Weyl wrote in his classic 1952 work, *Symmetry*: "Symmetry, as we understand it today, is the idea by which man has tried throughout the ages to explain and create order, beauty, and perfection" [8]. Symmetry (axial, translational, radial) and its violations underlie the perception of harmony and rhythm in both natural crystals and classical architecture. Spatial geometry (Euclidean and then projective, topology, non-Euclidean geometries) shapes the very fabric of architectural and artistic space. From the golden ratio to fractal growth algorithms and parametric NURBS surfaces, mathematical regularities serve as an abstract framework linking pure logic with the sensory perception of space and proportion.

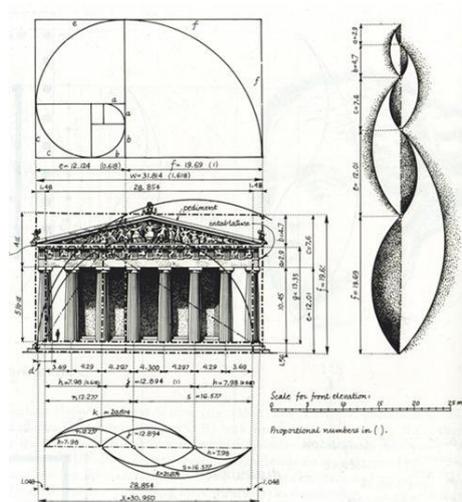


Fig. 5. The golden ratio in architecture <https://za.pinterest.com/grayalleycat/golden-ratio/>

Principles of Environmental Sustainability: An Ethical Imperative for Form-Creation. In the contemporary context, ecology is not simply a technical requirement, but a conceptual foundation for the creation of form. Sustainability principles—energy efficiency, waste minimization, life cycle analysis, adaptability, and the circular economy—are becoming powerful drivers of form-creation. As Rodney Harrison rightly notes, "heritage and sustainable development must be seen as mutually reinforcing processes, where the past informs the future, and the future reinterprets the past" [9]. Form, in this sense, is an optimized answer to questions such as: how to minimize energy consumption (passive house)? How to integrate resource recycling? How to design an environment that evolves with the climate? Ecology connects the micro-level of material and structure with the macro-level of landscape and global systems, transforming design into an act of ethical and scientifically grounded responsibility. These four conceptual bridges form the methodological foundation upon which contemporary education can be built, nurturing specialists capable of thinking simultaneously as scientists, engineers, and artists. The current stage of interaction between science and art in architecture and design is characterized by a shift from intuitive analogies to systemic methodological synthesis. This process is realized through several key areas, each of which draws on scientific knowledge as a direct source of innovative form-making and design solutions. Biomimetics (bionics): from metaphor to method. Contemporary biomimetics has transcended the stage of simple visual imitation of natural forms ("biomorphism"), moving toward extracting and embedding the deep functional principles of living systems. Architecture and design borrow from nature algorithms for optimization, adaptation, and sustainability. Classic examples include the passive ventilation system of the Eastgate Centre building in Harare, designed by architect Mick Pearce, modeled on the principle of self-regulating termite mounds; adaptive "scaly" facades, similar to pine cones or fish scales, that respond to changes in light and temperature. As Michael Pavlin notes, "biomimetics allows architects to move beyond conventional approaches to sustainable design and create transformative solutions inspired by 3.8 billion years of evolutionary research into nature" [10]. Nature thus acts as an unprecedented research laboratory, offering ready-made solutions for energy efficiency, resource conservation, and sustainability.



Fig. 6. Eastgate Centre in Harare, Zimbabwe <https://heroesofadventure.com/listing/eastgate-centre-harare/>

Parametric and Algorithmic Design: Form as Computation. This approach directly links form-making with mathematical laws and computational processes. Rather than specifying rigid geometry, the architect defines a system of variables (parameters) and logical relationships between them (an algorithm), which enables the generation of complex, dynamic forms governed by the same principles as natural systems: gravity, growth, flow, and erosion. As Greg Lynn wrote in his work "Animate Form" (1999), the parametric approach allows "form to be viewed as a process rather than a static object, where geometry becomes the bearer of dynamic forces and temporal transformations" [11]. The work of Zaha Hadid Architects, such as the Heydar Aliyev Center in Baku, showcases forms inspired by landscape forces and smooth topological transitions. Works by MAD Architects and Enric Ruiz-Geli's Pavilion of Reflections use algorithms that mimic the growth of corals or cellular structures to create organic, nonlinear spaces. This approach makes the design process akin to a scientific experiment, where form is a "computed" response to a set of conditions.



Fig. 7. Exterior of the Heydar Aliyev Center in Baku <https://realty.rbc.ru/news/652914899a7947378600874a>

Digital Manufacturing and New Materials: Materializing Complexity. Theoretical and digital models are being realized thanks to a revolution in manufacturing and materials science. Digital manufacturing—3D printing of concrete, metal, and composites; robotic milling; and frame knitting—allows for the cost-effective creation of unique, custom elements and complex geometries that were previously impossible or prohibitively expensive. At the same time, the development of new materials with programmable properties—aerogels, hydrogels, phase-change materials, and shape-memory composites—expands the architect's palette, allowing the material to actively participate in the functioning of a building: regulating light, accumulating energy, and changing state. As Neri Oxman notes, "the materials of the future will possess multiple, gradient properties, like biological tissue, where function and form are inseparable" [12]. Technologies are becoming the "bridge" that allows the synthesis of scientific ideas and artistic designs to be translated into the realm of physical, material reality.

Together, these approaches form a new paradigm in which the architect and designer act as researchers, analysts, and interpreters of natural and mathematical laws, and form becomes the material evidence of this profound interdisciplinary dialogue.

Achieving a synthesis of scientific and artistic knowledge requires specific pedagogical strategies that transform the content and teaching methods of key disciplines in educational programs for architects and designers. The goal is not to add separate scientific courses, but to fundamentally rethink creative disciplines through the prism of interdisciplinary approach.



In courses on sculpture, graphics, and composition: from life studies to structural analysis. The traditional study of form is complemented by methods of scientific analysis of natural objects. Students are encouraged to examine a shell, bone, tree trunk, or mineral not only as an aesthetic image, but also as an engineering system. As Rudolf Arnheim emphasizes in "Art and Visual Perception," "the perception of form always includes an understanding of the forces that generated it; "We see not just a contour, but the dynamics of stress and equilibrium" [13]. The tasks include the analysis of structural mechanics: load distribution, bending/compression work, identification of fractal patterns of self-similarity in branching or veins, understanding the principles of material optimization: minimal surfaces, porous structures. The practical result is the creation of an artistic object or model, where plastic expressiveness is a direct consequence of a meaningful constructive and material logic borrowed from nature.

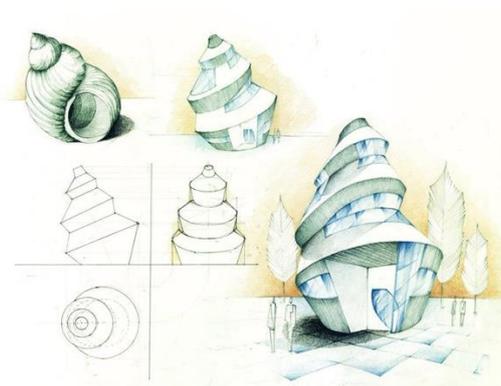


Fig. 9. Sketch combining natural form and architectural scheme
<https://ru.pinterest.com/pin/746823550685811454/>

In the history of art and architecture: art in the context of scientific revolutions. The historical and theoretical block is enriched with an interdisciplinary contextual analysis. The article examines how the change of scientific paradigms directly influenced visual language and spatial concepts. For example: the influence of crystallography and the theory of the structure of matter on the geometric abstraction of Kazemir Malevich's Suprematism and structural analysis in Vladimir Tatlin's Constructivism; the connection between the theory of relativity and non-Euclidean geometry with the deformation of space and the multiplicity of points of view in the Cubism of Pablo Picasso and Georges Braque; the reflection of the ideas of synergetics, chaos theory, and fractal geometry in the nonlinear, dynamic forms of architecture and media art of the late 20th – early 21st centuries. As William J.R. Curtis notes, "architecture has always been a discipline in which technical knowledge and artistic imagination exist in dialogue, not in opposition" [14]. This allows students to perceive styles and trends not as mere aesthetic preferences, but as profound intellectual responses to a worldview.

In design engineering: ecology and materials science as form generators. The design studio becomes a testing ground for applying scientific principles to solving complex problems. The methodology incorporates life cycle analysis (LCA) tools for assessing a project's ecological footprint, as well as cradle-to-cradle principles, requiring design with the future disassembly and recycling of materials in mind. The laws of thermal physics and climatology underlie passive energy efficiency, where the form, orientation, and organization of the building envelope become the primary tools for energy conservation. Thus, environmental and material responsibility cease to be a set of technical requirements, but become a powerful source of form-creating concepts.

Developing Synthetic (Synesthetic) Thinking: The Ultimate Goal. The cumulative result of the described methods should be the development of a special type of professional consciousness—synthetic (synesthetic) thinking. This is the ability to analyze any environmental object with a single, holistic act of perception: to see a diagram of forces in a sculpture, the imprint of a scientific picture of an era in a historical monument, a climate machine and a material passport in a building's façade, and perfect structural logic in a natural landscape. As A.S. Shchenkov puts it, "architectural form is a materialized dialogue between cultural memory, physical laws, and social expectations" [15]. Such thinking erases the artificial boundaries between beauty and logic, image and calculation, art and technology, preparing specialists capable of creating not just objects, but holistic, sustainable, and meaningful environments adequate to the complexity of the modern world.

Conclusion



The presented analysis demonstrates that integrating scientific and artistic knowledge in the education of architects and designers is not an intellectual fad, but a strategic imperative of our time. In the face of growing environmental threats, resource constraints, and rapid technological transformation, fragmented, highly specialized knowledge proves insufficient. The synthesis embodied in the STEAM approach offers a path to a holistic understanding of the world, where aesthetics is inseparable from ethics, and the creative act is based on the objective laws of nature.

Architecture and design, inherently operating in the borderland between matter and spirit, technology and culture, provide an ideal platform for bridging these gaps. Here, scientific categories—force, energy, entropy, growth—find direct material and spatial expression, and the artistic image acquires persuasiveness and depth through constructive logic and ecological awareness. Historical retrospect and contemporary practice unanimously confirm that the most significant and lasting creations were born precisely from this dialogue.

Therefore, the key task of modern professional education is to shift from training narrow performers to cultivating creators and synthesizers. It is essential to cultivate systems thinking that enables one to see the interconnections between the cultural context, the physical model, and the ecosystem; environmental responsibility, understood as an integral part of design culture; and, finally, the capacity for innovative synthesis—the ability to recognize and connect ideas from various disciplines to generate new, viable solutions. It is precisely this holistic intellectual and professional profile that will enable future environmental creators to respond to the complex challenges of the 21st century, transforming architecture and design from tools for shaping the world into disciplines for its creative and sustainable transformation.

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