УДК 72.012

DOI:10.30857/2617-0272.2023.2.1.

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REALIZATION OF THE LAWS OF DYNAMIC SYMMETRY IN THE DESIGN OF THE ENVIRONMENT BY MEANS OF COMPUTER THREE-DIMENSIONAL MODELING

The purpose *of the study is to determine the possibilities of applying the laws of dynamic symmetry in the design of the environment through computer three-dimensional modeling.*

Methodology. *The study used methods of historical and logical analysis of the problem of the role of dynamic symmetry in nature, art, and design; methods of comparison, comparison, and generalization. According to the transdisciplinary approach, dynamic symmetry is considered as a phenomenon of nature, a concept of geometry, and a principle of forming in design.*

Results. *The concepts of "dynamic symmetry" and "phyllotaxis" in the research of D. Hambidge have been analyzed, and the peculiarities of using the above categories to analyze the proportions of art and design objects have been revealed. It has been established that modern methods of computer modeling make it possible to use the laws of dynamic symmetry in environmental design. On the examples of design developments of interior elements (lighting fixtures, spiral staircases), the methods of combining the patterns of change in the shape and size of model elements, orientation in space, and on the plane have been shown.*

The scientific novelty *of the research is in the implementation of approaches to the laws of dynamic symmetry in the design of the environment through computer three-dimensional modeling.*

Practical significance. *The results of the study can be used in the study of the disciplines "3D modeling in environmental design", "Fundamentals of computer design", "Environmental design", "Design of furniture and equipment".*

Keywords: *dynamic symmetry; three-dimensional modeling; geometry; environmental design; design; interior elements.*

Introduction. Modern design is in a state of constant development. The widespread use of three-dimensional computer modeling technologies may give the impression that the natural component in this process is secondary. However, natural processes and patterns have a significant impact on the development of design and its individual components. In any case, the knowledge of natural processes and patterns, the viability of which has been tested by evolution, is very important in the process of human creativity, which includes design. The tasks and problems of formative practices through three-dimensional computer modeling are determined by such a direction of form development as constructive geometry.

Analysis of previous research. The essence of geometry and proportions has been of interest to researchers and practitioners since the very beginning of the professional foundations of architecture and any kind of creativity. The works of such architects and scientists as M. Vitruvius [13], A. Dürer [12], L.B. Alberti [9] have become canons in the study and application of mathematical regularities in art. The work with geometry and the identification of the principles of its application in architecture and design continued in the twentieth century. In particular, the American architectural researcher D. Hambidge (1867–1924) was convinced that design was not a purely instinctive phenomenon; he spent most of his life searching for the technical foundations of design. He found the answer in dynamic symmetry, one of the most provocative and stimulating theories in the history of art. Hambidge's study of Greek art convinced him that the secret of beauty lies in the conscious use of dynamic symmetry, a law of natural design based on the symmetry of human and plant growth. In 1919, he published the work "Diagonal"; later, in 1967, his research was reprinted in the collection "Elements of Dynamic Symmetry" [11]. The French architect and scientist Le Corbusier made a significant contribution to the study of proportioning laws and the development of the theory of harmony in architecture [10].

Eventually, thanks to the works of J. Adler, G. Coxter, W. Schwabe, and several other scientists, a modern mathematical and biological theory of phyllotaxis was developed, a phenomenon that consists in the spiral-symmetrical arrangement of leaves on plant stems, branches on trees, and petals in inflorescences. The study of the golden section and non-Euclidean geometry in science and art is devoted to the works of O. Bodnar [1; 2]. The scientist initiated and implemented a separate scientific direction "The Path to Harmony: Art + Mathematics", which was attended by Ukrainian and foreign scientists – designers, architects, artists, art historians [8].

The prospects and relevance of the search for expressive and structural possibilities of geometry in design are confirmed by the research of modern Ukrainian practitioners and scientists – T. Bulgakova, N. Malysheva [5], O. Polyakova, S. Kysil, O. Shmelova [4], etc. Due to the inseparability of the design object design processes and three-dimensional computer modeling technologies, there is a significant need to consider such a direction as the use of geometric tools, in particular, the laws of dynamic symmetry in the creation of design objects.

Setting objectives. The objectives of the study are to determine the possibilities of applying the laws of dynamic symmetry in the design of the environment, as well as to substantiate the means of computer three-dimensional modeling in the implementation of the identified laws.

The results of the research and their discussion. The term "dynamic symmetry" was first proposed by D. Hambidge, who defined it as the principle of proportioning in architecture [11]. In our study, the term "dynamic symmetry" refers to the regularity of natural forming, which includes proportioning. The historically formed direction of geometry, which in the field of architecture and art is motivated by the search for patterns of harmony, is focused on the study of natural objects. Artists are usually interested in the structural regularities of natural shaping, especially the golden ratio and Fibonacci numbers, which are known for their intriguing role in shaping. It is no coincidence that research architects so often pay attention to the botanical phenomenon of "phyllotaxis" – the laws of natural forming [2].

Philotaxis was the object of attention of the author of the first version of the concept of dynamic symmetry, D. Hambidge. As a result of studying this phenomenon, D. Hambidge derives the law of the so-called uniform growth and proposes its geometric interpretation – the spiral of uniform growth, or otherwise the "golden" spiral (Fig. 1). However, the main generalization made by D. Hambidge as a result of studying the laws of natural forming (phyllotaxis), as well as the proportions of classical architecture, comes down to the idea of architectural proportioning, which he calls dynamic symmetry. The scientist illustrates it with a simple geometric diagram (Fig. 2).

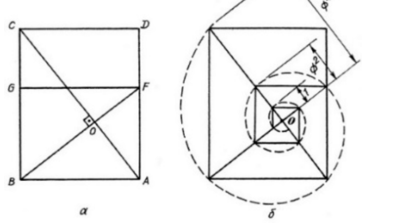


Fig. 1. Building a "golden" spiral

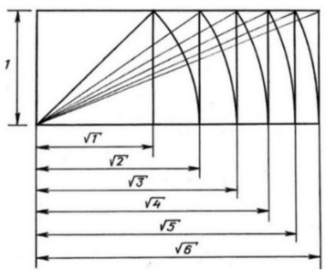


Fig. 2. Proportional system "Dynamic symmetry" According to D. Hambidge [11]

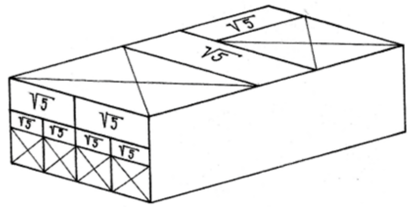
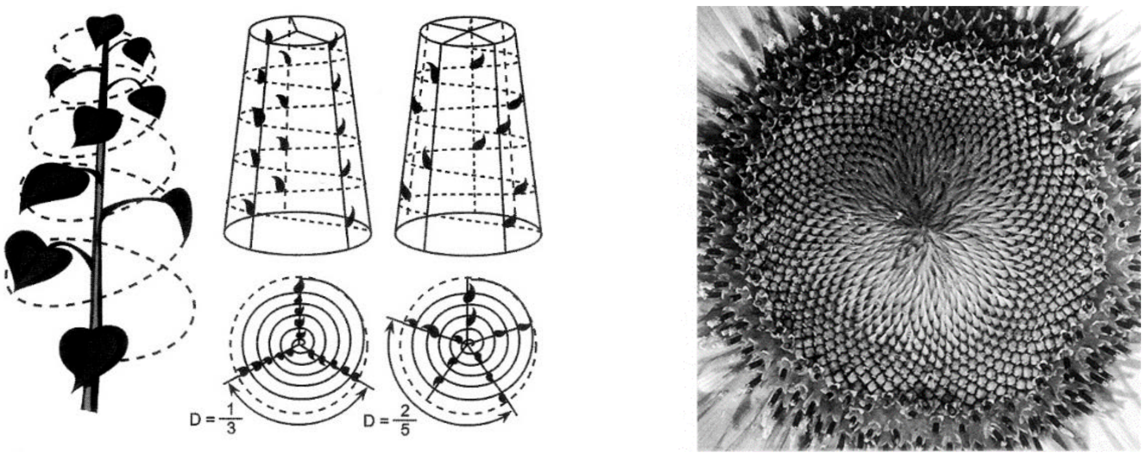


Fig. 3. Three-dimensional model of the Parthenon proportions

This is a sequential system of rectangles, the first of which is a square, and each subsequent one is built on the side of the initial square and the diagonal of the previous rectangle. The result is a series of rectangles whose aspect ratio gives a series of √1, √2, √3, √4, √5, √6, ... In this series, D. Hambidge distinguishes between two types of rectangles – static and dynamic. In static rectangles, the aspect ratios are expressed as integers, while in dynamic rectangles they are expressed as irrational numbers. Dynamic rectangles, according to D. Hambidge, express the idea of growth, movement, and development. Among them, he first of all distinguishes three, in which the long sides are equal to √2, √3, √5. However, special significance is attached to the 1×√5 rectangle, which is directly related to the "golden rectangle". Following this, Hambidge carried out a thorough geometric study, establishing various manifestations of the golden ratio in the system of a 1×√5 rectangle. By studying the geometric properties of this rectangle, he showed the possibility of using it to analyze the proportions of objects of classical architecture and art (Fig. 3) [11]. This, in short, is the essence of D. Hambidge's idea of dynamic symmetry. As we can see, it does not follow directly from the properties of philotaxis. Hambidge, generally speaking, does not delve into the mathematics of philotaxis. In his various diagrams illustrating patterns of uniform growth, or some ideas of proportioning, he uses well-known numerical ratios characteristic of phyllotaxis, including the golden ratio.

Nevertheless, his idea of dynamic symmetry is original and, in its mathematical content, turns out to be an expression of the regularity of a rather general nature. It will be possible to demonstrate this after reading the study of phyllotaxis proposed below. However, before proceeding to its presentation, I would like to warn against possible "undesirable impressions" that representatives of various scientific fields may have when reading the text. We can foresee the possible dissatisfaction of biologists due to the schematic nature and insufficient terminological rigor of the biological description of the phenomenon; mathematicians who will find inconsistencies between the mathematical symbols used in the study of phyllotaxis and the generally accepted ones; art historians who will encounter an excessive mathematical bias in the study, as for the methodology of art history. We are fully aware of all the inconveniences that have arisen due to the interdisciplinary nature of the problem.

Let us briefly describe this research. It is well known in biology that the relative arrangement of a wide variety of embryos arising on shoot growth cones is characterized by spiral symmetry. This principle of arrangement, called phyllotaxis, is also clearly observed in dense inflorescences and fruits, for example, on sunflower heads, cones of conifers, and many other types of biomes (Fig. 4).



а б

Рис. 4. Examples of phyllotactic structures: a – leaf arrangements; б – sunflower disk [2]

On the surfaces of phyllotactic forms, especially in dense inflorescences and fruits, left- and right-twisted spiral rows of structural elements (embryos, seeds, leaves) are clearly distinguished. The ratio of the numbers corresponding to the number of left and right spirals is usually used to indicate the order of symmetry of phyllotactic forms. According to the laws of phyllotaxis, these ratios are described by combinations of numbers of recurrent series. The most common types of phyllotaxis are symmetric, described by the numbers of the Fibonacci series: ..., 0, 1, 1, 3, 5, 8, 13, 21, 34, ... Often, the numbers of the Luke's series are also realized in phyllotaxis: ..., 1, 3, 4, 7, 11, 18, 29, 34, ..., less often the numbers belonging to the series ..., 4, 5, 9, 14, 23, ... The order of symmetry in the case of Fibonacci phyllotaxis (phyllotaxis) is expressed by the following ratios: ½, 2/3, 3/5, 5/8, 8/13, ...

Note that the symmetry notation always uses adjacent numbers in a row. In certain cases, when three groups of spirals are distinguished on the surface of a shape, symmetry is indicated by three numbers. As a rule, low orders of symmetry are characteristic of plant and tree sprouts, and high orders of symmetry are characteristic of dense inflorescences and fruits. In sunflowers, for example, the order of symmetry can reach values of 55/89 89/144 and even 144/233.

A characteristic indicator of phyllotactic structures is the so-called divergence D, the angle of divergence of two consecutive sprouts. The divergence, measured in fractions of a circle, in the case of F-phyllotaxis is always expressed by the same number as the order of symmetry of the shape, i.e. it can be equal to ½, 3/5, 5/8, 8/13, ... This series of fractions is known to converge to a limit of ≈ 0.618 circles, at which the full plane angle is divided in the ratio of the golden ratio F.

Some types of phyllotactic forms consistently change (increase) the order of their symmetry during growth. It is this property of phyllotaxis that we call dynamic symmetry. An example is the sunflower. Sunflower heads located at different levels of the same stem have different symmetries: the higher the level, i.e. the older the disk, the higher the order of its symmetry. In the dynamics of symmetry, a sequence is realized: ... → 5/8 → 8/13 → 13/21 → 21/34 → ... .

As the symmetry changes, the divergence angle changes accordingly. At the same time, on all disks, regardless of the number of spirals, the so-called conformal (angular) characteristics of spiral ornaments are the same: the spirals intersect at a constant angle. We repeat that this phenomenon of phyllotaxis has been tested by evolution and can therefore be considered perfect. It has been studied and continues to be studied not only by mathematicians but also by designers.

The next step in the research was to combine the theory of dynamic symmetry with environmental design using three-dimensional computer modeling technologies. The application of the theory of dynamic symmetry in nature and environmental design has been implemented in the process of teaching three-dimensional computer modeling to students of the Department of Interior and Furniture Design.

An interior or landscape environment can be created by placing objects in a certain pattern or along a given trajectory. Computer three-dimensional modeling has the appropriate tools to create and place objects according to the designer's intent. When creating environmental design objects, it is usually easier to model symmetrical shapes. This is due to a more widespread perception of the harmony of the environment, both in the natural world and in most works of architects and designers. However, human consciousness reacts more strongly to what is not commonplace, but is unusual or original. That is why the design of the environment is increasingly using shapes with dynamic symmetry. This is complemented by the three-dimensional modeling capabilities of most computer programs, which allow you to create complex models with simple tools.

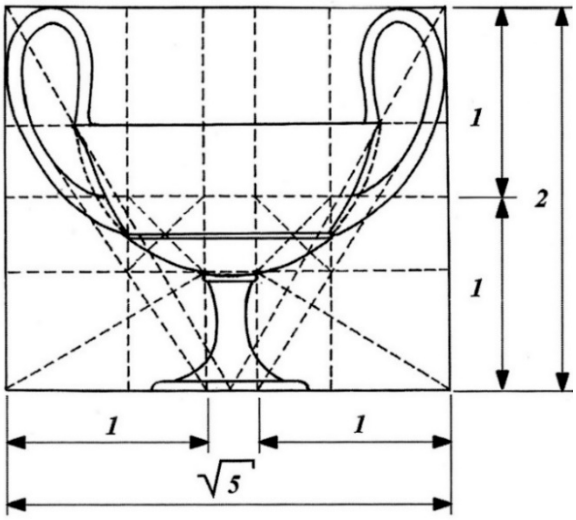


Fig. 5. Diagram of proportions of the Greek vase "kantharos" (after D. Hambidge) [11]

Fig. 6. Three-dimensional model of a Greek vase. Made by D. Oleksiuk, 3rd year, Department of Interior and Furniture Design

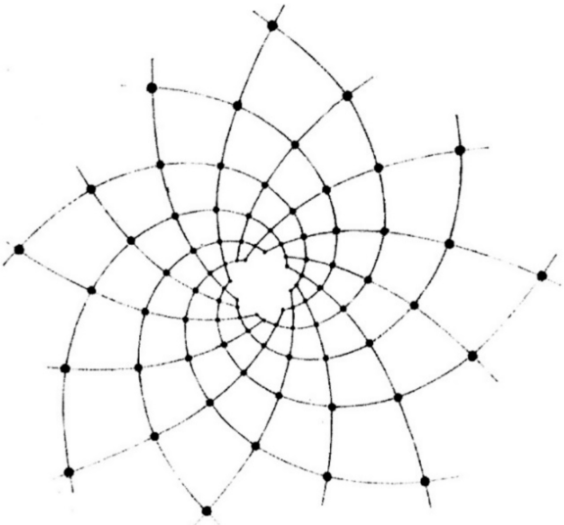


Fig. 7. An example of a natural lattice with symmetry 8 : 13 [2]

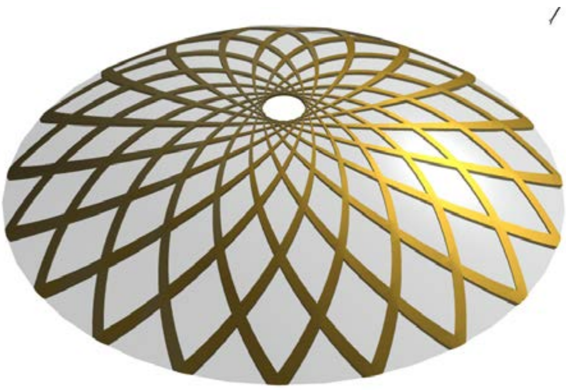


Fig. 8. Model of the lamp shade. Made by A. Bader, 2nd year, Department of Interior and Furniture Design

Fig. 9. Models of spiral staircases in the interior decoration of a cafe. Made by K. Kolomeets, 3rd year, Department of Interior and Furniture Design

Rotation surfaces, which we see in the natural and architectural environment, are a very common form that can be created using a computer modeling program, in particular, 3ds Max The modeling process consists of building a generating line and selecting the rotation parameters (axis and angle of rotation). It is the shape of the generating line that sets the harmonious proportion of the entire model. In addition to the surfaces of rotation, it is common to form a shape by extruding the contour in the appropriate direction and distance. For the model of the Greek Kanfar vase (Fig. 6), the shape of the formative line of the surface of rotation and the contours of the graceful handles of the extrusion surface was calculated in accordance with the diagram of proportions of the "golden section" (Fig. 5).

The original shapes of design objects can be obtained using the functions of reproduction (duplication) of the constituent elements that form the lattice. Computer modeling tools, in particular, ArhiCad programs, have a wide range of commands for replicating basic objects by moving, rotating, and scaling. This allows you to create models that change shape and position.

Let us recall the essence of the existing ideas about the geometric properties of conical phyllotaxis lattices and the dynamic mechanism of their formation. It is generally accepted that the structure of conical phyllotaxis lattices (the location of the vertices) obeys the law of the logarithmic spiral. According to this law, logarithmic spirals include parastichy that forms a lattice on conical and disk-shaped forms, and the so-called base (or genetic) spiral that consistently penetrates all the vertices of the lattice. Such lattices are called logarithmic lattices.

The results of our study of cylindrical phyllotaxis [1] lead to a fundamentally new idea of modeling conical lattices. It consists of the fact that the fundamental regularity of the structural organization of conical phyllotaxis is a composite (not logarithmic) spiral. Parastichs are composite spirals. The genetic spiral is the same. According to the law of the composite spiral, the transverse circle of the cone is also transformed. Lattices formed according to the principle of the composite helix are called natural lattices (Fig. 7). They look very similar to logarithmic lattices, but are fundamentally incompatible with them.

The implementation of the principles of dynamic symmetry in the modeling of a luminaire shade, based on the scheme of a natural lattice with symmetry, is shown in Fig. 8. The lattice shape of the model is created by rotation with a certain step, and the symmetry of the constituent element that changes in its cross-section.

When creating models of environmental design objects, a variety of lines are used, the mathematical description of which is laid down in computer modeling programs. These lines can be used in the model as an element of direct shaping or direction of placement of other objects. A very common element of interior design is a spiral staircase, which is created not only as a functional object but also as a decoration of the room due to its proportions and harmony. The spiral staircase model (Fig. 9) is created by placing the elements of the steps and balusters along a spiral trajectory (with the appropriate angular pitch and vertical offset). The helical line is also a trajectory for cross-sections of the corresponding shape, which forms models of railings and stair supports. You can create models with dynamic symmetry by changing the size of the model elements, their shape, orientation in space or plane, texture, and color. The application of the theory of dynamic symmetry, in particular in interior decoration, allows you to get a variety of original shapes.

Conclusions. The study is based on the understanding the continuous development of material culture and the tendency of design creativity to symmetry up to the beginning of the twentieth century. However, the peculiarities of human perception inevitably had to lead to the emergence of new and more original solutions, one of which can be considered dynamic symmetry. With the help of the developments of D. Hambidge and O. Bodnar, it is shown that it consists of natural changes in objects: their size, shape, location, texture, and color.

The experience of applying the laws of dynamic symmetry took place in the design developments of students of the Department of Interior Design and Furniture of KNUTD, namely, in the creation of subject content and interior elements through three-dimensional computer modeling. Thanks to three-dimensional modeling, it is possible to realize the above components in design, while obtaining original objects that can enrich the human environment. The use of three-dimensional models that have dynamic symmetry in their shaping develops computer modeling skills and allows future environmental designers to realize various ideas in their projects. In further developments, the authors will focus on studying the possibilities of combining texture and color effects with the geometric principles of shaping design objects using computer technology.

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РЕАЛІЗАЦІЯ ЗАКОНОМІРНОСТЕЙ ДИНАМІЧНОЇ СИМЕТРІЇ В ДИЗАЙНІ СЕРЕДОВИЩА ЗАСОБАМИ КОМП'ЮТЕРНОГО ТРИВИМІРНОГО МОДЕЛЮВАННЯ

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Мета дослідження – визначити можливості застосування закономірностей динамічної симетрії в дизайні середовища засобами комп'ютерного тривимірного моделювання.

Методологія. У дослідженні використано методи історичного і логічного аналізу проблеми ролі динамічної симетрії в природі, мистецтві та дизайні; методи порівняння, співставлення та узагальнення. Відповідно до трансдисциплінарного підходу динамічна симетрія розглядається як явище природи, поняття геометрії та принцип формотворення в дизайні.

Результати. Проаналізовано поняття «динамічна симетрія» і «філотаксис» у дослідженнях Д. Хембиджа, виявлено особливості застосування вищеназваних категорій для аналізу пропорцій об'єктів мистецтва і дизайну. Встановлено, що сучасні методи комп'ютерного моделювання дають змогу використовувати закономірності динамічної симетрії у дизайні середовища. На прикладах проєктних розробок елементів предметного наповнення інтер'єру (освітлювального прибору, гвинтових сходів) показано методи поєднання закономірностей зміни форми та розміру елементів моделі, орієнтації у просторі та на площині.

Наукова новизна наукового дослідження полягає у реалізації підходів щодо закономірностей динамічної симетрії в дизайні середовища засобами комп'ютерного тривимірного моделювання.

Практична значущість. Результати дослідження можуть бути використанні при вивченні дисциплін «3D моделювання в дизайні середовища», «Основи комп'ютерного проєктування», «Дизайн середовища», «Проєктування меблів та обладнання».

Ключові слова: *динамічна симетрія; тривимірне моделювання; геометрія; дизайн середовища; проєктування; елементи інтер'єру.*

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https://doi.org/10.30857/2617-0272.2023.2.1

Цитування за ДСТУ: Bodnar O. Y., Vyshnevska O. V. Realization of the laws of dynamic symmetry in the design of the environment by means of computer three-dimensional modeling. *Art and design*. 2023. №2(22). P. 11–19.

Citation APA: Bodnar, O. Y., Vyshnevska, O. V. **(2023)** Realization of the laws of dynamic symmetry in the design of the environment by means of computer three-dimensional modeling. *Art and design*. 2(22). 11–19.