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BIOMORPHIC DESIGN IN LANDSCAPE ARCHITECTURE: AN OVERVIEW AND APPLICATION VIA EXPERIMENTAL DESIGN INSPIRED BY SPECIES *Carica papaya* L.

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Abstract: Biomorphic shapes, often abstract, evoke the living forms which could be found in our environment, such as plants and other living organisms. The biomorphic design could be seen in many different design industries. In this paper, the potential application of the biomorphic design as a innovative design approach in landscape architecture is explored through the literature overview and experimental design study. This paper provides a modest contribution in order to develop the framework which could be applied in both the landscape architectural design and education. The aim of this research is to present the biomorphic design, a biologically-based approach, as innovative design framework finding its application in landscape architecture. The foundation of proposed design framework lies in a collected biological data, later processed by using advanced computational tools. In order to represent the biomorphic design framework application, an experimental design study is conducted. The nature-inspiration was found in the Botanical garden ,,Jevremovac'' in Belgrade. Species *Carica papaya* L. served as bioinspiration for conceptual biodesign solution presented in this paper. The conceptual biodesign solution is represented in a form of the biomorphic open space design with landscape architectural elements: pool, bench and bridge, as the result of this study. These three landscape architectural elements are modeled in Building Information Modeling (BIM) software to explore the possibilities of designing biomorphic shapes and patterns as different landscape architectural elements by applying the biomorphic design approach. Biomorphic design represent a innovative approach to landscape design. By drawing inspiration from the beauty of nature, created structures that are not only aesthetically pleasing but also sustainable, and harmonious with their surroundings.

Keywords: biomorphic design, landscape architecture, *Carica papaya* L.

БИОМОРФНИ ДИЗАЈН У ПЕЈЗАЖНОЈ АРХИТЕКТУРИ: ПРЕГЛЕД И ПРИМЕНА КРОЗ ЕКСПЕРИМЕНТАЛНИ ДИЗАЈН ИНСПИРИСАН ВРСТОМ *Carica papaya* L.

Извод: Биоморфни облици, често апстрактни, евоцирају ,,живе'' облике који се могу наћи у нашем окружењу, као што су биљке и други живи организми. Биоморфни дизајн се може наћи у многим различитим дизајнерским индустријама. У овом раду истражује се

потенцијална примена биоморфног дизајна као иновативног приступа дизајну у пејзажној архитектури кроз преглед литературе и студију експерименталног дизајна. Овај рад даје скроман допринос у развијању оквира који би се могао применити како у пејзажном архитектонском пројектовању тако и у образовању. Циљ овог истраживања јесте представљање биоморфног дизајна, биолошки заснованог приступа, као иновативног дизајнерског оквира који налази своју примену у пејзажној архитектури. Основа предложеног дизајнерског оквира лежи у прикупљеним биолошким подацима, који се касније обрађују коришћењем напредних рачунарских алата. Да би се представила примена биоморфног дизајнерског приступа, спроведено је истраживање кроз експериментални дизајн. Инспирација из природе пронађена је у Ботаничкој башти ,,Јевремовац'' у Београду. Врста *Carica papaya* L. послужила је као биоинспирација за концептуално биодизајнерско решење представљено у овом раду. Концептуално биодизајнерско решење је представљено у виду биоморфног дизајна отвореног простора са пејзажноархитектонским елементима: базен, клупа и мост, као резултат ове студије. Ова три пејзажноархитектонска елемента су моделована користећи Building Information Modeling (BIM) софтвер како би се истражиле могућности обликовања биоморфних облика и образаца као различитих пејзажно архитектонских елемената применом приступа биоморфног дизајна. Биоморфни дизајн представља иновативни приступ пејзажном дизајну. Црпећи инспирацију из лепоте природе, креиране структуре које нису само естетски угодне, већ и одрживе и хармоничне са околином.

Кључне речи: биоморфни дизајн, пејзажна архитектура, *Carica papaya* L.

1. INTRODUCTION

Different design professions often seeks for the inspiration in the nature. The potential of the nature forms and patterns is enormous as they could present source of inspiration for any design domain. The application of the nature forms and patterns in design is not new, but their usage isn't passing, as they are rooted in the long-established design practices. The inspiration could be found in plants, animals, humans, and today the inspiration could be found with the help of different types of microscopes (Ambrose, 2022).

Biomorphism presents a 20th-century art and design style in painting, sculpture, photography, architecture, landscape architecture and other designs (2024(a)). The Biomorphism emerged as an art of modeling on nature patterns and biological shapes found in our environment. Many biomorphic artworks were seen as abstracted derivations of reality, in which the form could be clear or not to recognize (Joye, 2006; Shelley, 2015; Fikriarini et al., 2016; Agkathidis, 2017; Čučaković et al., 2018; Jović et al., 2018; Ufodike et al., 2021; 2024(a)). As biomorphic shapes and patterns could be used in various arts, the roots of the biomorphic design approach could be identified in organic architecture. The principles of the organic architecture does not include simply replicating natural shapes, they more presents the philosophy of achieving the harmonious union of art and nature, to design the perfect integration of urban living in natural composition (Han, 2020; DelGaudio, 2024). The famous example of achieved organic architectural design is Fallingwater house by architect Frank Lloyd Wright, designed in 1935 in the USA (Joye, 2006; Shelley, 2015; Fikriarini et al., 2016; Agkathidis, 2017; Čučaković et al., 2018; Jović et al., 2018; Tagliari and Florio, 2019). Organic architecture is rooted in a passion for life, nature, and natural form, and is full of the vitality of the natural world with biological forms and processes (Pearson, 2001). In the Metaphoric architecture, during the mid-20th century, the biomorphic shapes could be found through symbolism and meta-

phors to communicate the artists ideas. Some of the examples of metaphoric architecture which finds its symbolism in nature elements are: Sydney Opera House in Australia, The Lotus Temple in India or Casa Batllo in Spain (Karatani, 1995; Feuerstein, 2002; Joye, 2006; Agkathidis, 2017; Bahauddin et al., 2019). It is possible that this architectural movement influenced the appearence of the term biomorphic architecture. The term biomorphic architecture could be found in the research papers in architecture education field (Feuerstein, 2002; Ozek et al., 2009; Agkathidis, 2016; Eren et al., 2018). Parametric and generative tools could help enhancing the bio-form finding techniques in order to model the best possible design solution. The research on these subject was conducted by Dr Agkathidis Asterios from University of Liverpool. The Proffesor of Digital Design explored the biomorphic structures designed by digital tools (Agkathidis, 2016; Agkathidis, 2017).

The biomorphic forms could be found in another bio-disciplines: Biomimetics and Biomimicry. The process of imitating the life elements presents the base of these two interdisciplinary design approaches. The term *biomimetics* was coined by Otto H. Schmitt around 1950. The term *biomimicry* was popularized by author Janine Benyus in her book ,,*Biomimicry: Innovation Inspired by Nature*'' from 1997. Both design approaches studies models from nature as inspirations and then imitates and integrates in designs and processes to solve human problems (Benyus, 2002; Zari, 2007; Gruber, 2009; Asghar et al., 2019; Chayaamor-Heil, 2023). Beyond architecture, the biomorphic forms and shapes finds its place in the urbanism too. Biomorphic urbanism, as cities formed by life, represents the concept similar to the concept of biophilia. This urban concept offers a theoretical foundation for how cities could be designed and built inspired by biomorphic shapes and patterns found in nature (Orel, 2022).

The application of biomorphic design approach in architecture and landscape architecture, could have more benefits when biomorphic forms are connected with biophilia hypothesis and design. The biophilia hypothesis states that people are genetically predisposed to be attracted to nature (Grinde et al., 2009; Ryan et al. 2014; Abdeen, 2016; Makram, 2019; Cacique and Ou, 2022). As one of the 14 patterns of the biophilic design, the biomorphic forms and patterns belongs to types of nature analogies. Biomorphic Forms and Patterns are the symbolic representations of life applied in the artificial environments (Terrapin Bright Green, 2014; Frumkin et al., 2017; 2024(b)).

In this research, the biomorphic design approach and its application in the landscape architecture through the brief overview of literature and landscape design examples is presented. The experimental design using contemporary technologies to present the application of biomorphic design principles is conducted. The purpose of this research is to develop the design framework of biomorphic design approach applied in the landscape architecture as well as for educational purposes in domain of landscape architecture.

2. THEORETICAL REVIEW

To trace the beginning of the development of biomorphic design approach, the appearance of the terms ,,*biomorph*'' and ,,*biomorphism*'' was researched. The term ,,*biomorph*'' could be tracked to the British anthropologist and ethnologist Alfred Cort Haddon (1855-1940), who used this term in his book ,,*Evolution in Art: As Illustrated by the Life-histories of Designs*'' from 1895. In his book, the term *Biomorphs* refers to all representations of life forms (of living forms) (Haddon, 1895; Botar and Wunsche, 2011). The term ,,*biomorph*'' was used again, 40 years later, by British writer and poet Geoffrey Grigson (1905-1985). Grigson presented his

views of ,,*biomorph*'' as part of the abstract art, an opposite of geometric abstraction in 1935 (Geoffrey, 1935; Botar and Wunsche, 2011; 2024(h)). The term ,,*biomorphism*'' first emerged in 1936 when art historian and museum director, Alfred H. Barr used "biomorphic sculpture" for his exhibition ,,*Cubism and Abstract Art''* in his catalogue. The exhibition were emerged in New York's Museum of Modern Art. It represented the contrast of Geometrical abstract art and Non-geometrical abstract art (Geoffrey, 1935; Barr, 1936; Hochkirchen, 2017). Barr aimed to represent the new direction of the contemporary art, inspired by the arts of Joan Miró and Jean (Hans) Arp (Botar and Wunsche, 2011). Some of the artists recognised as exemplars in the period when biomorphism were identified as art movement were: Henri Matisse, Wassily Kandinsky, Joan Miró and Jean (Hans) Arp. The famous Jean Arp was German-French painter, sculptor and poet, and one of the founders of Dadaism, was recognized as biomorphic abstract sculptor, as he incorporated biomorphic shapes in his artworks. He developed the language of bulbous forms – the egg-like objects (Barr, 1936; Botar and Wunsche, 2011; Hochkirchen, 2017; 2024(f); 2024(g)). After Barr's exhibition in New York, abstract artworks inspired the young artists to find their own voice. The sculptures of Jean Arp inspired the two Mid-Century British sculptors: Henry Moore (1898-1986) and Barbara Hepworth (1903-1975). Moore used biomorphic forms to express the connection between nature and humanity in human figures. Hepworth used many different materials in its sculptural practice and expanded the language of biomorphic forms by using strings for example (Barr, 1936; Botar and Wunsche, 2011; 2024(g)).

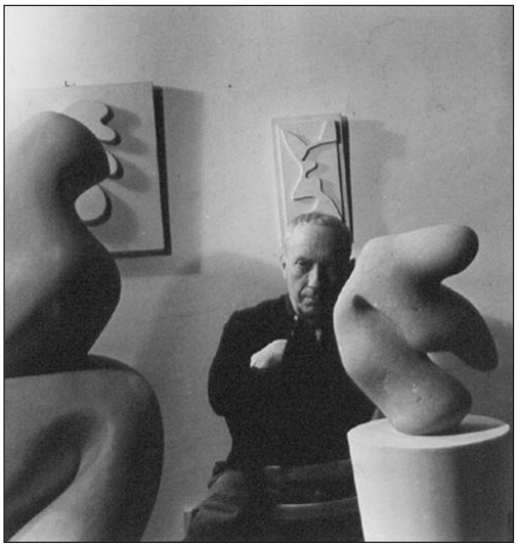

Figure 1. Jean Arp with his sculptures. (Source: Wikimedia Commons, 2024).
Слика 1. Ханс Арп и његове скулптуре (Извор: Wikimedia Commons, 2024).

The roots of the biomorphism could be tracked in Europe in the late 19th century. In this period artists could explore their personal interests and desires, especially thanks to the Technological Revolution (or Second Industrial Revolution) which brought the advancements in technology and enabled the faster communication between people (Atkeson, 2007; Bernal, 2011). Many art movements criticized the traditional styles and technology development, and new harmony was found in nature. The beginning of the 20th century was defined by Expressionist artists who wanted to represent and express the most deep emotional experiences through the poetry and paintings (Geoffrey, 1935; Barr, 1936; Muthesius, 1994; Boults and Sullivan, 2010; Botar and Wunsche, 2011; Haynes, 2013; Hochkirchen, 2017; 2024(a)). This brought a different understanding on human experiences, social and political environment, nature, aspect of abstraction and geometric forms, and all effected on the appearance of biomorphic design approach later.

The term ,,biomorphic'' have come from combining the two Greek words: ,,*bios*'' (life or living) and ,,*morphe*'' (form) (Benyus, 2002; Zari, 2007; Agkathidis, 2016). Biomorphic design is inspired by forms of biological world and uses the organic shapes which are more

free-form structured then the rigid Euclidean geometries. This shapes of life, were often described as ''silhouette of the amoeba'' or ,,water-worn-stone'' by Barr, and others defines them as abstract forms. The forms are also soft, curving and pure (Geoffrey, 1935; Barr, 1936; Botar and Wunsche, 2011). The visual experience of biomorphic shapes could be pleasant, but also could have the inner effect on people and its mental health. This specific people-nature relationship through recognition of biomorphic shapes are beyond their aesthetic purpose (Geoffrey, 1935; Kaplan, 1995; Grinde and Patil, 2009; Botar and Wunsche, 2011; Salingaros, 2012; Terrapin Bright Green, 2014; Alcock et al., 2014; Frumkin et al., 2017; 2024(d)).

In the biomorphic design approach, imitating the nature and interpreting the patterns to bring ,,natural'' into urban environment is highlighted. The biomorphic design is based on the biomorphic shapes and patterns, and it belongs to the bio-disciplines which use the various biological informations to generate different design products (Iouguina et al., 2014). With regards to the type of nature-inspirational model, biomorphism could be subdivided as anthropomorphism, zoomorphism, phytomorphism and micromorphism (Haddon, 1895; Botar and Wunsche, 2011).

2.1. The Biomorphic Design Approach in Landscape Architecture

According to the presented analysis, the roots of the biomorphic design approach in landscape architecture, could be found applied as curved shapes and naturally planting designs in 20th century. To understand what influenced on appearance of the biomorphic design approach in landscape architecture and its later development, in this paper was presented the short timeline (Figure 2).

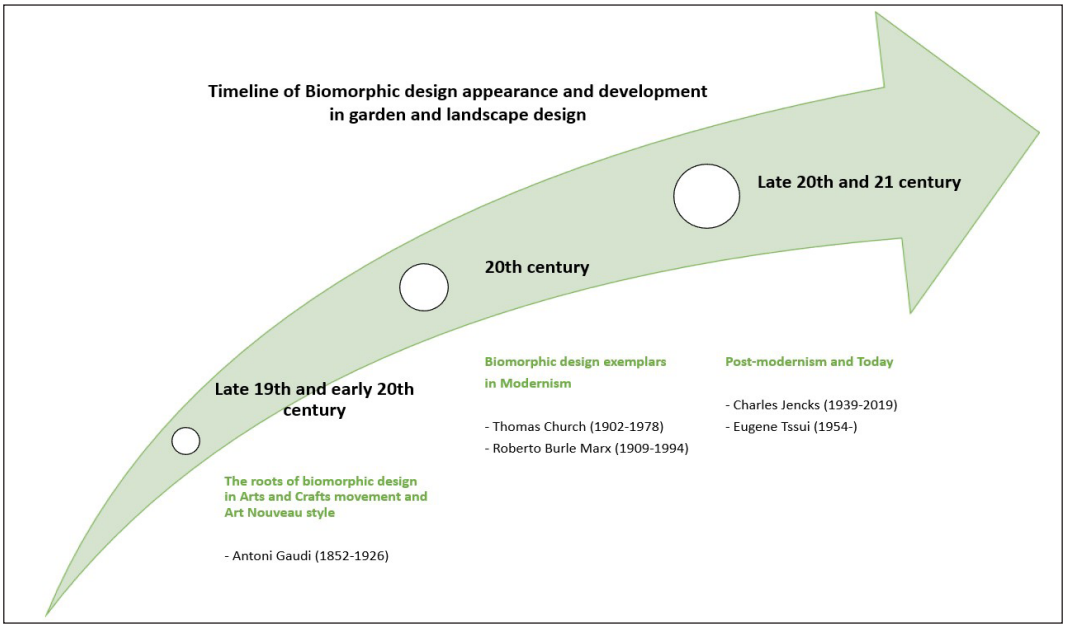

Figure 2. Timeline of Biomorphic design appearance and development in garden and landscape design (Source: Authors, 2024).
Слика 2. Временска анализа појаве и развоја биоморфног дизајна у пејзажној архитектури (Извор: Аутори, 2024).

In art movement Arts and Crafts, was the time when the traditional styles were critized in order to find the inner voice of the artist. As for the landscape architecture and garden designs of those times, the two changes were happened in Europe: the traditional, mostly geometrical garden style were slowly left behind, and the natural style were more and more applied; and the second were that garden design were recognized as a valuable part of architectural composition (Turner, 2005; Boults and Sullivan, 2010; Haynes, 2013). The garden designs made a harmonious environment with the architecture object, increasing its value. In this period, the British horticulturist, garden designer, craftswoman, photographer, writer and artist, Gertrude Jekyll created over 400 gardens in the United Kingdom, Europe and the United States. She was an artist of the planting design. Her sense for color, texture, shape were incredible. She was famous for the flower borders in her designs and she used the nature artistic elements in a form of plants. She worked closelly with English architect Edwin Lutyens (Turner, 2005; Boults and Sullivan, 2010; Haynes, 2013). On Figure 5, the plan of main flower-border was presented as an example of rich planting design of interesting natural forms.

The curves as a form of a park designs becomes very common in landscape projects. The Birkenhead Park, Liverpool, is a major public park in England. It was designed by Joseph Paxton, an English gardener and architect, and the park was officially opened on 5 April 1847. This park inspired the American landscape architect Frederick Law Olmsted, who has impressed by its aesthetic form where *art had been employed to obtain the nature's beauty*. Eight years later, in 1858, the landscape design for the new park in New York, won the competition – today known as Central Park (Turner, 2005; Boults and Sullivan, 2010; Haynes, 2013).

The late 19th and the early 20th century was a time period of great importance for the landscape architecture proffesion: (1) The first idea of a Garden city was developed by Ebenezer Howard in 1898 (in his book ,,*To-morrow: A Peaceful Path to Real Reform*''; ''*Garden Cities of To-morrow*'' from 1902). Soon, this urban design concept further developed in the 20th century, and examples of this model could be found all over the world (Clark, 2003; Clevenger and Andrews, 2017); (2) The American Society of Landscape Architects (ASLA) were founded in 1899 (Dorsey Vernon, 1987; Mozingo and Jewell, 2012); and (3) The International Federation of Landscape Architects (IFLA) was founded in England with Sir Geoffrey Jellicoe as its first President in 1948 (2024(h)).

The planting design with visual elements, curves as path and ornaments, all of them could present the nature-inspired design in landscape architecture. But clear application of the biomorphic shapes and forms could be found in the art movement of Art Nouveau, with the Antonio Gaudí (1852-1926), the most famous architect. Gaudis' works were part of the organic architecture, and as example of biomorphic shapes in landscape architecture, the Parc Güell in Barcelona, Spain, was presented as the only major example of Art Nouveau garden design. Park Güell was a privatized park with many gardens and nature-inspired architectural elements. The park was raised between 1900-1914 but it was open as public park in 1926. As a work of very famous architect, this park has declared as UNESCO World Heritage Site in 1984. The park structure fully incorporates the various natural forms: sea serpent as the main terrace and a long bench tiled in order to dry up quickly after it rains; bird nests in the terrace walls which imitates the trees to support a wide variety of wildlife; and the roadway which resembles the pine trees in the park (Turner, 2005; Boults and Sullivan, 2010; Haynes, 2013; 2024(e)).

When the modernism came with the abstract art, the ornaments and decorative arts were forgotten. Modernism in landscape architecture demanded the rejection of traditional garden styles and approaches and the embrace of architectural functionalism. In the period of the Modernism, the abstract art finds its way

Figure 3. Park Güell by Gaudí in Barcelona, Spain (Source: Wikimedia Commons, 2024).
Слика 3. Парк Güell дело Гаудија у Барселони, Шпанија (Извор: Wikimedia Commons, 2024).

into the landscape architecture. The new aesthetic of landscape design were omnidirectional with abstract shapes and sculptures for pure aesthetic impact. The biomorphic forms could be recognized in the projects of the Thomas Church (1902-1978) and Roberto Burle Marx (1909-1994) (Turner, 2005; Boults and Sullivan, 2010; Haynes, 2013; 2024(e)).

The conceptual project of biomorphic design applied in landscape architecture were the Donnell Garden in USA by landscape architect Thomas Church. Garden project was completed in 1948, and became famous for its unusual, abstracted forms, especially the biomorphic kidney-shaped pool with Adaline Kent sculpture and the floating deck designed to preserve existing trees and extending the outdoor space. This is a Modernist icon of its time (Turner, 2005; Boults and Sullivan, 2010; Haynes, 2013; 2024(c); 2024(e)).

The landscape architectural project - the promenade design of the Copacabana beach in Rio de Janeiro, Brazil, were done by landscape architect Roberto Burle Marx. The Copacabana promenade with pavement landscape, 4 km long beach, were one of the examples of the curve forms applied as biomorphic form. The inspiration from nature for this public space were the meandering rivers of Brazil. The project were done in 1970 (Turner, 2005; Boults and Sullivan, 2010; Haynes, 2013; 2024(c); 2024(f)). Burle Marx was very interesting landscape architect. With the cooperation with architect Luis Barragan, they set modern precedents for approaching the landscape as a work of art, by mixing the *botany knowledge and*

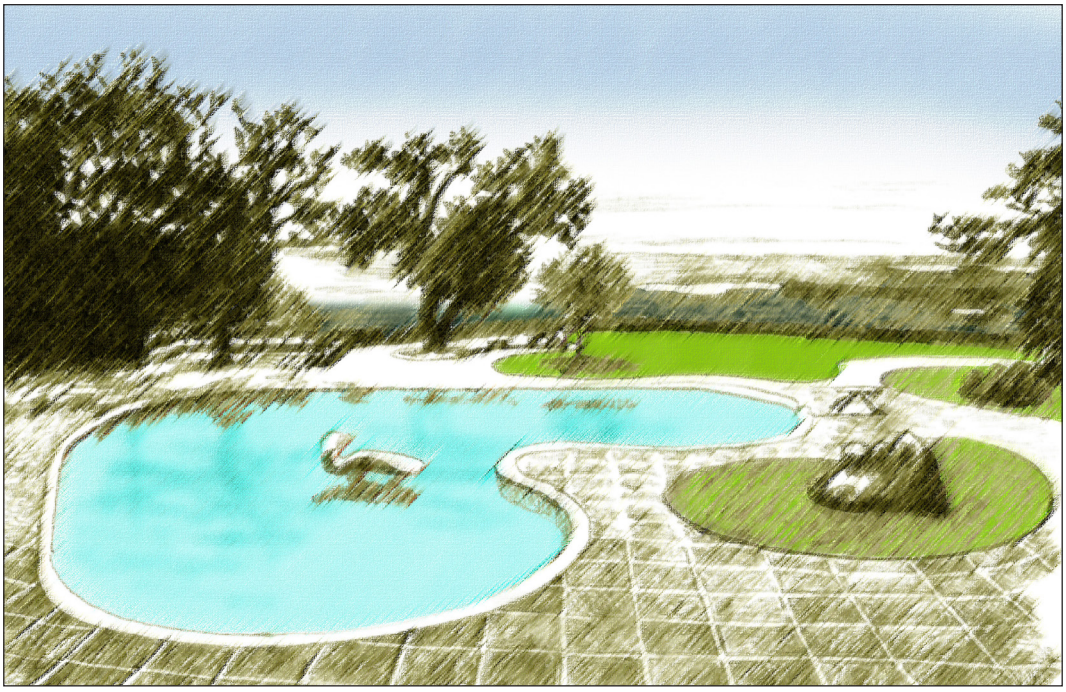

Figure 4. The Donnell Garden in USA by Thomas Church
(Source: Wikimedia Commons - drawing by Prof Mihailo Grbic, 2024).
Слика 4. Врт Донели у САД дело Томаса Черча
(Извор: Wikimedia Commons - цртеж проф. Михаила Грбића, 2024).

artistic expresion. Marx was interested in botany and painting, and he was a master in mixing these interests. For the landscape design at the Edmundo Cavanellas Residence, near Petropolis, Brazil, from 1954, Burle Marx was inspired by biomorphic shapes on paintings of artist Jean Arp (Teuscher and Würtenberger, 2018; UNESKO, 2021).

In the late 20th and 21st century, the artistic approach and nature inspiration continued to be present. Landscape designer and architectural historian Charles Jencks (1939-2019) designed the famous Garden of Cosmic Speculation (design started 1988) with his second wife Maggie Keswick Jencks. The Garden of Cosmic Speculation presents the sculpture garden on designers' land in Scotland. This garden was inspired by modern cosmology and various nature patterns, and elegantly combines natural symbols and artificial symmetry and curves in a garden with no accent on plants (Boults and Sullivan, 2010; Farrell, 2020).

The advanced computer tools improved the design methods as many generative design solutions could be created in order to find the best landscape design solution (Čučaković, 2016; Jović, 2020). The biomorphic design, as also by folding and blob architecture, was aided by advanced computer tools (Jencks, 2002). Computer design enabled the form-finding and form-generating process of complex geometries and patterns from nature. Sustainability development marks the 21st century, as a conserving of natural resources and providing ecological life - design thinking way. The connection of sustainability strategies and computer-aided design approaches could be shown through the biomimicry design method. This design method relies on the imitation process of natural patterns, models or systems (Benyus, 2002;

Figure 5. The Copacabana beach in Rio de Janeiro, Brazil by Marx (Source: Wikimedia Commons, 2024).
Слика 5. Плажа Копакабана у Рио де Жанеиру, Бразил дело Маркса (Извор: Wikimedia Commons, 2024).

Zari, 2007; Chayaamor-Heil, 2023). The architect who is famous for the incredible works of application on the biomimicry design method in build environment is Eugene Tssui (1954-). Tssui is an American architect who uses the principles of ,,biological'' design (bio-inspired design) and environmental design to create the build environment which corresponds with its nature environment with no environmental damages. His architectural style (biomimetic architecture) include the curvilinear forms and spherical, egg-shapes structures, all as nature-inspirational patterns. Tssui's biomimetic architecture work - ,,The Fish House'' (Ojo del Sol- the Sun's Eye), was designed in 1993 and constructed from 1994 to 1995 in Berkeley, USA. This building design presents the nature-inspired environment which connects the building and its garden as inseparable parts. The biology model was the tardigrade – a microscopic animals, also known as water bears. Tssui consulted zoology experts and learned that the tardigrade is the most indestructible creature on the planet, so he designed the house based on its morphology. The planting design followed the architecture morphology (Bhatia and Hejib, 2018; Ambrose, 2022).

3. METHODOLOGY

The methodology used in this research was presented on Figure 6, it was based on the biology-influencing design according to Zari (2007), and two steps of the proposed design approach by Jović *et al.* (2020) – Biological and Geometrical, which were expanded by the experimental digital design framework. In this research, the design approach for the generation of the biomorphic shapes and patterns was proposed. The aim is to explore the biomorphic design approach in landscape architecture modeling practice, based on the one plant source, species *Carica papaya* L.

The proposed design approach consisted of three steps: *Biological* – which included the plant material gathering or collecting the image data; *Geometric* – in which the digital image sources were used in a geometric processing and parametric modeling; and *Technical* – which includes the materialization of the generated design (Јовић *et al*., 2020).

First step was Biology data collection as it is necessary to gather various plant materials or image sources from the defined location. The pre-defined locations to conduct this research step could be various, as it depends of the biology source preferences. Green spaces, urban forests, arboretums could be just some of possible options. For this research, inspired by Roberto Marx, the Botanical Garden ,,Jevremovac'' in Belgrade was chosen. The requests for the biological source – the plant specie for this research, was from the morphology aspect – curve shaped. Selected plant species, which is not very common in Serbia, was a representative example for the educational purposes. In this research, the type of applied biomorphic design is *phytomorphism*, as it was utilized morphological properties of plant fruit and leaf - *Carica papaya* L. as a bio-inspiration. The Botanical Garden "Jevremovac" come to be a proper botanical resource to conduct the first step. This is a famous Botanical Garden in Belgrade, Serbia, which was founded in 1874 by the Ministry of Education of the Principality of Serbia at the proposal of Josif Pančić, the historical Serbian botanist, who extensively documented the flora of Serbia (Јованović, 1998; Анастасијевић *et al.*, 2012; Бумбаширевић, 2017; Univezitet u Beogradu *et al.*, 2020). The tropical species *Carica papaya* L. (Pawpaw tree), is non-native to Serbia, but indigenous to some African countries like Kenya. The Papaya is native to Costarica, Mexico and the United States, but it grows well in other tropical regions of the world. In city of Belgrade, a specially grown Papaya plant can be found in the greenhouse of the Botanical Garden ''Jevremovac''. It does not grow well in Serbia and Europe, because as a tropical species

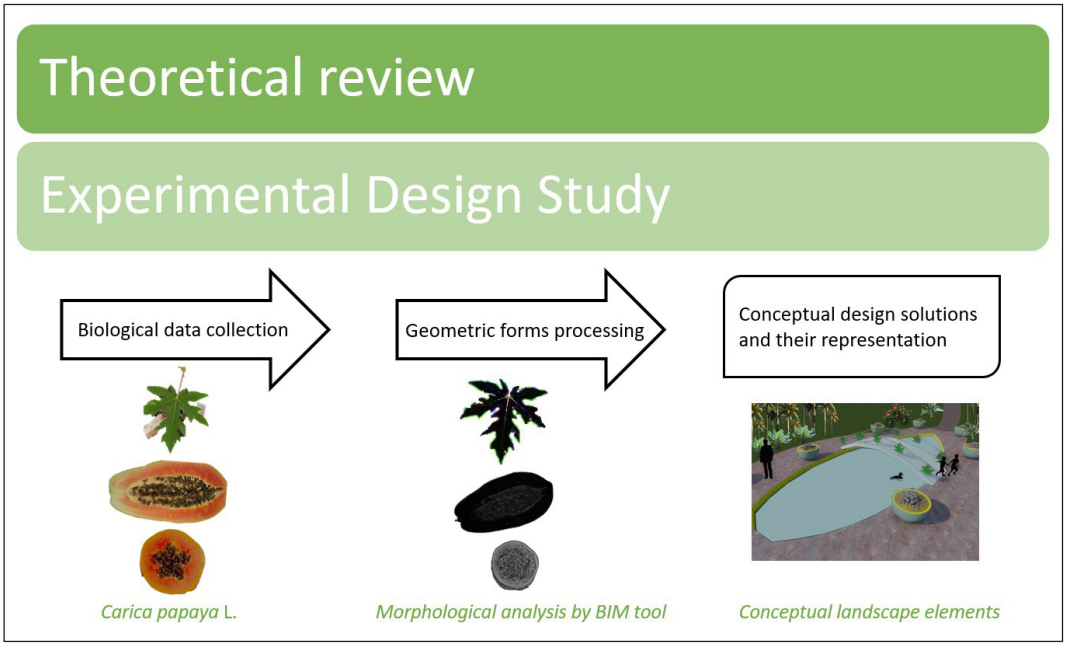

Figure 6. The methodology of this research (Source: Authors, 2024).
Слика 6. Методолошки оквир спроведеног истраживања (Извор: Аутори, 2024).

it cannot survive winter periods. This is the reason why this plant specimen is grown inside the glasshouse at Botanical Garden ''Jevremovac'' (Beentje, 1994; Orwa *et al*., 2009; Kwok, 2019; Ocokoljić *et al*., 2021; Magdalita *et al*., 2021; Wadekar *et al.*, 2021; 2024(d)).

The morphological characteristics that were chosen for the next step were the fruit and leaf of the Papaya. The Papaya has unique leaves that are deeply palatably lobed. The pawpaw leaf is rough in texture and dark green in color, with prominent yellow veining spreading throughout the 5-9 lobes. The Papaya fruit is commonly spherical to cylindrical in form, around 75 to 500 mm or even more in length, and sometimes weighs as much as 9 to 11.5 kg. The very juicy flesh is deep yellow or orange to salmon-colored. Along the walls of the large central cavity are attached the numerous, round, wrinkled black seeds. The unripe fruit contains a milky juice in which is present a protein-digesting enzyme known as papain, which greatly resembles the animal enzyme pepsin in its digestive action (Orwa *et al.* 2009). The image materials needed for the modeling process were the image of the leaf from the Botanical Garden ,,Jevremovac'' and the publicly available images of the fruit as the fruit were unavailable to find in Botanical Garden.

As the second step of the proposed design framework demands the digital modeling of the chosen plant morphological characteristics, the fruit and leaf of *Carica papaya* L. were analyzed to assess their geometric patterns. The computer tool which was used in this research was ArchiCAD software. The digital modeling process based on a geometric forms of the leaf and fruit included the similar digital interpretation as in previous research (Čučaković *et al*., 2016; Čučaković *et al.*, 2018; Jović *et al.*, 2019; Jović *et al.*, 2020; Jović *et al.*, 2021a; Jović *et al.*, 2021b; Jović *et al.*, 2023).

Papaya fruit biomorphic modeling process: The first step was to analyse the geometric patterns in the fruit. Then on ArchiCAD's 2D platform, a first landscape feature, namely a pond in the shape of a pawpaw fruit was drawn using the line tool and slab tool. Different slabs with different textures were used in designing the water of the pond and the pavement around the pool. The pond was drawn in the shape of an oblong-shaped papaya fruit. The design was then viewed and adjusted further on the 3D platform. The second landscape feature - the benches around the pool were then created, based on the spherical shape of the lower half of a papaya fruit. Using the hemisphere tool in ArchiCAD, an upward-facing hemisphere was created. Next, a thin and flat circular slab

Figure 7. The leaf of *Carica papaya* L. (Source: Benjamin Chemarum, 2024).
Слика 7. Лист врсте *Carica papaya* L. (Извор: Benjamin Chemarum, 2024).

(a) The fruit of *Carica papaya* L. – horizontal section

(b) The fruit of *Carica papaya* L. – frontal section

Figure 8. The fruit of *Carica papaya* L.
(Source: Wikimedia Commons, 2024).
Слика 8. Плод врсте *Carica papaya* L.
(Извор: Wikimedia Commons, 2024).

was placed on top of the hemisphere, whose colour is yellow like the pulp of papaya fruit. This slab had the same diameter as that of the hemisphere below it. The hemisphere itself was given the green colour of the skin of papaya fruit. Finally, several small dark-grey spheres were scattered above the hemisphere using the Sphere tool of ArchiCAD. These represent the seeds of papaya fruit, and function as a backrest for the bench, and perhaps the place wherein sockets for charging mobile phones may be attached. Once one bench was completed, the 'drag multiple copies' feature was used to create eight copies of the bench, distributing them strategically around the pond.

Papaya leaf biomorphic modeling process: On the Y axis of ArchiCAD, using the Morph tool, a 2D representation of the outline of the leaf of papaya was drawn. The intention was to

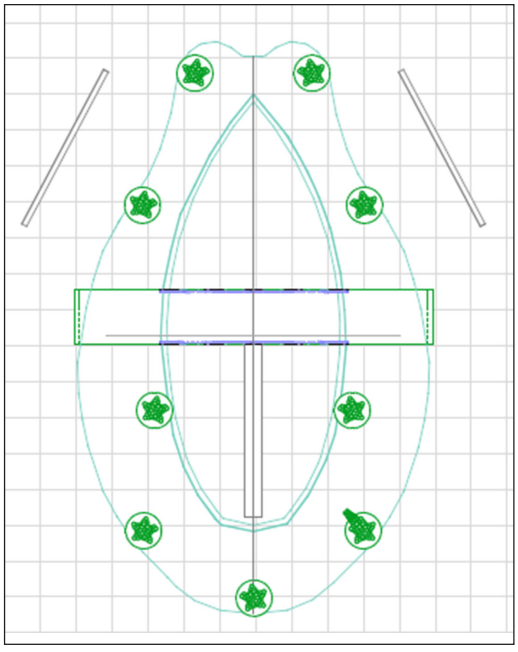

Figure 9. The 2D view of biomorphic pool design solution with bences around
(Source: Benjamin Chemarum, 2024).
Слика 9. 2Д поглед на решење за дизајн биоморфног базена са клупама около
(Извор: Benjamin Chemarum, 2024).

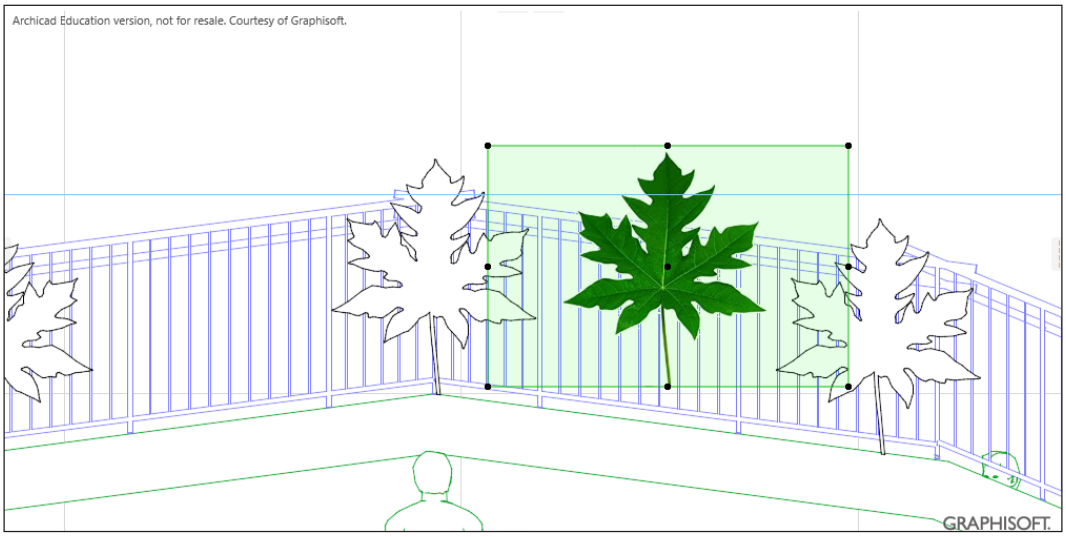

Figure 10. The decorative element on the bridge (Source: Benjamin Chemarum, 2024).
Слика 10. Декоративни елемент на мосту (Извор: Benjamin Chemarum, 2024).

apply it on the railing design of the bridge that passes across the center of the pond – biomorphic decorative element. A photo of the leaf of papaya was copied and pasted onto the Y axis of ArchiCAD. Then, using ArchiCAD's line tool, the geometric outline of the leaf was traced on top of the photo. After the shape was created, the 'Extrude' feature was used to give thickness to the morph of the leaf. Finally, the papaya leaf was multiplied using 'drag multiple copies' feature, to eventually have five leaves on either side of the bridge.

4. RESULTS WITH DISCUSSION

The result of digital and biomorphic modeling process present the biomorphic garden design (open space design) as 3D conceptual (Building Information Modeling) BIM model with three biomorphic elements of landscape design: pond, bench and bridge. The garden design was inspired by the Donnell Garden in USA by Thomas Church. The plan was shaped as horizontal section of the fruit of selected plant source. The main landscape element is the pool, and other biomorphic design elements are the bridge with its decorative nature-inspired element and the nine benches around. The external leaf form was as decoration element for the bridge, the horizontal section of the fruit as a garden plan and the frontal section of the fruit with the seeds in a form of a small balls for the bench design. Different materials and colors were considered in making the 3D models, considering the aesthetic characteristics observed on the fruit and leaf of this species (Čučaković *et al.*, 2016; Čučaković *et al*., 2018; Jović *et al*., 2019; Jović *et al*., 2020; Jović *et al*., 2021a; Jović *et al.*, 2021b; Jović *et al.,* 2023). The three landscape elements were modeled in BIM software in order to inspect the possibilities of designing biomorphic shapes and patterns as different landscape architectural structures.

The biomorphic design approach presents a nature-based concept that integrates biological data into design solutions generation. This research presented an design experimental study in order to explore the biomorphic design approach applied in landscape architecture. Many research were conducted on these bio-inspired

methods in architecture and construction education field (Agkathidis, 2016; Eren *et al*., 2018; The Biomimicry Institute, 2024). In the landscape architecture, some of research papers on this topic are: Eren *et al*., 2018, Jović *et al.*, 2019 and Eren *et al.*, 2021. The research titled ,,*Biomorphic Design Approaches in Landscape Design and Construction Course Studio",* Eren *et al*. from 2021 presents the research in which the biomorphic design approach were applied in landscape architecture higher education. The differences of methodological approach from research of Eren *et al*. (2021) and proposed research design in this paper were in number of design solutions (in Eren *et al*. (2021) research were more student design solutions as in this research one case study were presented), and in final step of the process (in Eren *et al*. (2021) research a final step was presented as detailed design of biomorphic solutions, while in this research it was in a conceptual level in order to develop the visualization skills through digital design solutions).

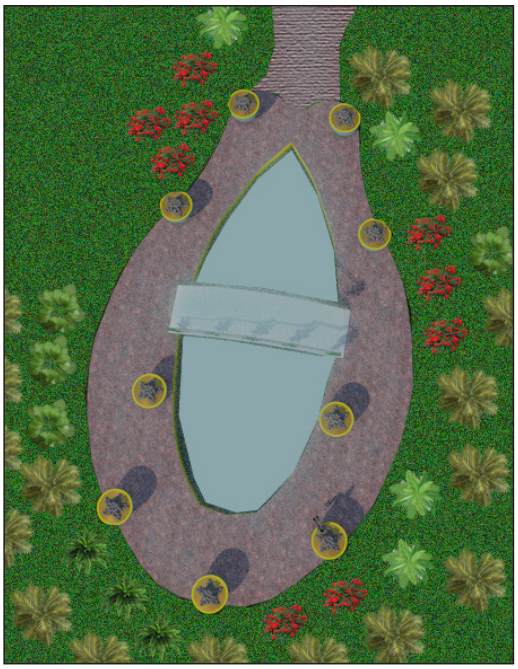

Figure 11. The biomorphic garden design plan (Source: Benjamin Chemarum, 2024).
Слика 11. План дизајна биоморфне баште (Извор: Benjamin Chemarum, 2024).

The biomorphic approach exemplers in landscape architecture had few similar approaches in their design process - Thomas Church (1902-1978) and Roberto Burle Marx (1909-1994), which served in developing the biomorphic design approach. They were both inspired by abstract biomorphic shapes of biomorphic artists – Church applied biomorphic sculpture at the center of the pool and Marx were inspired by Arps artworks. They both aspired to incorporate their landscape designs in the environment by using nature materials, autochthonous plants or nature shapes and forms. Marx was a great

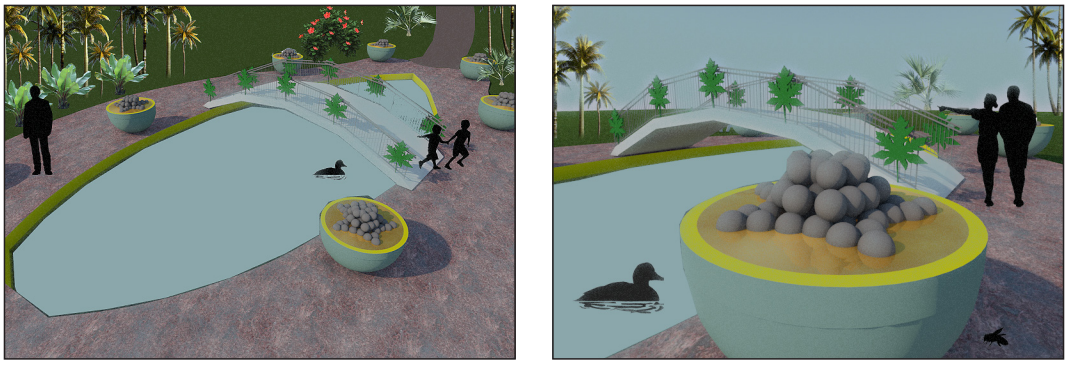

Figure 12. The landscape elements of the biomorphic open space (Source: Benjamin Chemarum, 2024).
Слика 12. Пејзажноархитектонски елементи биоморфног отвореног простора (Извор: Benjamin Chemarum, 2024).

landscape artists of planting design. (Turner, 2005; Boults and Sullivan, 2010; Haynes, 2013; Teuscher and Würtenberger, 2018; UNESKO, 2021). Today, thanks to the development of advanced digital tools, it is possible to design very complex biomorphic shapes, even in a micro level like architect Tssui (Bhatia and Hejib, 2018; Ambrose, 2022).

The biomorphic shapes and patterns have a bigger purpose then just aesthetic. The integration of the biomorphic design in spaces where there is not so much green and nature spaces could be of the great benefits, as it was already recognized by founders of Biophilia design (Terrapin Bright Green, 2014; Frumkin *et al*., 2017). This design approach belongs to the family of nature-inspired design which purpose is to restore the connection between people and nature (Benyus, 2002; Joye, 2006; Zari, 2007; Shelley, 2015; Fikriarini *et al.*, 2016; Agkathidis, 2017; Ufodike *et al.*, 2021).

5. CONCLUSIONS

In this paper, it is point out the basic concept of the biomorphic design, its beginnings, principles and examples in the domain of landscape architecture. The design experimental study were conducted in order to develop the design framework using it in domain of the landscape architecture. The initial work process involved the defining the nature inspiration – species *Carica papaya* L., the location for gathering the image materials for the further identification of the morphological characteristics of the selected botanical species – botanical step. The geometric analysis and transformation of biomorphological forms with 3D modeling presents - the geometrical step with digital modeling process. The result was a conceptual design solution – a biomorphic design space with its landscape features. The advantages of the biomorphic design in landscape architecture could be seen through biophilia theory and sustainable design strategies – in educating of biodiversity, bringing the indirect nature elements in very dense urban environments. Currents of further research is directed towards the using digital tools of advanced contemporary technology like generative AI tools, mobile applications, 3D printing technologies and other innovative digital tools.

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