Technical and economic aspects of arborsculpture development

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Abstract. The art of arborsculpture is a hot topic in the modern architectural environment, related to sustainable landscape development: more than 750 arborsculptures (belonging to various categories and subcategories of applied use) appear in the cities throughout the world annually and play an active role in developing open/closed spaces. Still, this art is new and insufficiently tried in Russia. We observed the need in a technical and economic substantiation for the development of bionic objects to implement them in practice. The article discusses two ways of growing objects arborsculpture: a specialized nursery for plants and the actual formation (dislocations). Depending on the method and techniques of cultivation, as well as the typology of data of the objects specified in the "map of growth", there are four formulas for calculating the cost indicators for the formation of bionic objects (arborsculpture).

1. Introduction
The ecological situation in cities progressively becomes worse and reflects directly on the condition of woody plants and phytopathology.

"Humans have been closely connected to the environment on all stages of development. However, when the society had become highly industrialized, dangerous anthropogenic interventions into the nature worsened dramatically. The extent of these interventions has expanded ever since and is now threatening to become a global danger for the humankind..." [1].

Furthermore, according to calculations of the planted greenery per person in larger cities, a deficiency in landscaped and recreational spaces for the population is observed, particularly the deficiency in hardy-shrub species and natural landscape degradation.

In order to recreate the natural potential of the urban environment we suggest introducing arborsculptures (bionic objects) both to open spaces (street furniture, urban structures (urban landmarks, pavilions, campings, equipment for recreational spaces etc.)) and closed spaces (functional design objects, sculptures etc.).

According to the works of such scientists and arborsculptors as Axel Erlandson [1], K Kirsch [2], Ezekiel Golan [3], R Reames [4], B Gale [5], T Link [6], it has been observed that bionic urban development helps to achieve sustainable development of urbanized lands, improvement of quality and representation of urban landscapes and improvement of the environment on the micro- and meso-levels and in the long term on the macro-level. Furthermore, we ought to notice that "cultivation" (development) of arborsculptures is accompanied by improved aesthetic quality of the urban
environment and lays foundation to the environmentally friendly upbringing of the people. This promotes a more considerate, responsible and humane treatment of the wildlife elements.

However, despite active introduction of bionic land improvement technologies abroad as evidenced by P Cook and B Northey [7], H T Hartmann and D E. Kester [8], Ni Boonnetr [9], R and S Kerwood [10], Mr. Wu [11], J Ask [12], M Kalberer [13], Christopher Cattle [14], Konstantin Kirsch [15], Aharon Naveh [16], Hermann Block [17], Dan Ladd [18], for Russia the art of arborsculpture is new and insufficiently tried. The most significant research papers in Russia were written by A I Koveshnikov, N A Shiriaeva and M A Stavtsev [19]. The origins and development of arborsculpture have been discussed in the "Historical trend analysis of landscape design – arborsculpture" [20]. There are several methods of developing such objects [21,22] and introducing them to the eco-environment of Russian cities [23]; however, the cost of "cultivating" arborsculptures has been covered insufficiently. This confirms topicality of this study.

The 
**purpose of this study** was as follows: to determine technical and economic aspects (cost parameters) of arborsculpture development.

**Study objectives:**
1) to determine the primary cost components of developing bionic objects, and
2) to determine formulas to calculate the cost of arborsculpture development.

The novelty of this study consists in the fact that this is the first ever technical and economic justification of the possibility to improve urban lands in a bionic way.

2. Theoretical part
The cost of developing bionic objects *primarily* depends on the cost of the greenery element (a tree, a shrub or a plant). Let us assign a conditional designation to this cost - \((k)\). This cost varies by the type, age and amount of greenery elements (conditionally designated as \(n\) (pcs.)). The amount of greenery elements in an arborsculpture directly depends on the type of the bionic object. There are two primary types of configuration of arborsculptures: basic geometric primitive and polymetric structures.

The first type is characterized by a combination of homonymous geometric shapes. This type of configuration is further subdivided into *singular* and *composite* structures.

The first subcategory (*singular* structures) includes arborsculptures based on one geometric shape (monofactorial) or several unconnected similar geometric shapes, yet comprising a comprehensive pattern.

The second subcategory (*composite* structures) includes the arborsculptures comprised of several interconnected similar geometric shapes (multifactorial). Types of singular structures: "circular" (subtypes: "circular, vertical plane", "circular, horizontal plane) and "arched". Types of composite structures: "circular, vertical plane", "arched" and "rectangular". Circular structures may have not only a round shape, but also an oval or elliptical shape. Arched structures are open-ended parabolic surfaces with the focus of the parabola located in the bud union for grafted branches of one or more greenery elements. Circular structures may have not only a round shape, but also an oval or elliptical shape. Rectangular structures may be not only rectangular, but also square- or diamond-shaped. Geometrically, it is a polyhedron represented by a cube.

On the other hand, polymetric structures include arborsculptures based on several interconnected different geometric shapes. A polymetric arborsculpture is essentially a combination of different geometric shapes. Polymetric structures are further subdivided into zigzag, symbolic and character structures. Zigzag structures combine complex curvilinear surfaces (both singular and composite). Geometrically, they are constructed of several interconnected parabolas. Symbolic structures include configurations of arborsculptures shaped as symbols and are represented by a combination of different geometric shapes. They are further subdivided into symbolic/character, symbolic/abstract and human-shaped structures. Symbolic/character structures include symbolic arborsculptures in the form of a character, e.g. in the form of a heart, digital codes (letters, figures etc.) etc. Symbolic/abstract structures include arborsculptures whose external configuration depict an object in an abstract way.
Symbolic/abstract structures include search structures comprising experimental forms of bionic objects. Human-shaped structures are represented primarily by circular, rectangular and arched types, the combination of which resembles a human shape. Character structures include a combination of different geometric shapes united into arboriculture configurations representing full-size street furniture: boats, chairs, fences etc. [24].

A developed "growth map" is required to calculate the precise amount of greenery elements.

The "growth map" demonstrates the required amount of techniques used for shaping and alternative options of replacing certain techniques with other, including the amount of techniques and materials used for shaping.

Such architectural/technical measures as grafting consist in a set of dendrological works based on the need to unite trunks and/or branches of several trees and preserve their shape throughout the further growth.

Trimming helps to change the direction of branch growth, whereas cropping is used to remove branches up to the offshoot base.

Framing consists in using various elements, such as wood, steel, metal and plastic pipes etc., as supporting materials and/or a part of the design concept in the common structure of arboriculture. Formwork (for molding) determinates visual tectonics of the plant throughout its growth.

Bend is a corrected condition of a tree trunk in comparison with the original shape. We suggest recording the process of public space development on the basis of arboriculture in a "growth map"; it is a comprehensive chart reflecting step-by-step development of arboriculture over time with dimension lines and guidelines for using basic and alternative techniques, as well as the recommended method of shaping of bionic objects on the basis of the identified humane plant growth correction principles [25, 26].

Secondly, the cost includes the labor of an arboriculturist within the estimated shaping period; it consists of the following:
The cost of techniques (conditionally designated as \( t \) (rubles)) varying from the amount of techniques (conditionally designated as \( n_1 \) (years)). Here we may consider the second calculation option that does not take into account the duration of shaping (\( n_1 \) (years)); only techniques (fixed cost) and their amount are considered. However, the first option is more reasonable as it shows the dependence of the arboriculture type (complexity of "cultivation") on the duration of shaping and considers the inflation.

1. The cost of plant care measures (conditionally designated as \( y \) (rubles)) varying from the amount of required plant care measures \( n_4 \) [27].

It has been observed that the anthropogenic urban environment affects the condition of hardy-shrub species unfavorably [28], which is why it is necessary to follow three main principles of humane "cultivation" of bionic objects:

The compensation principle - it is necessary to compensate forced control of growth and shape of the bionic structure by means of timely comprehensive care.

The principle of the least contact of woody plants with foreign objects - eco-friendly and/or natural materials should be used as attachments, molding (formwork) and supporting elements when shaping plants in a certain configuration.

The principle of the least damage to the woody structure - it is necessary to minimize the amount of the measures altering the woody structure to identify, if possible, the alternative options eliminating the risk of altering large areas of plant trunks.

2. The cost of fixing members (rubber straps, organic ropes, paper-coated wiring etc.) (conditionally designated as \( f \) (pcs.)) varying from the amount of fixing members (conditionally designated as \( n_5 \) (pcs.)).
3. The cost of the formwork (materials) (conditionally designated as \( op \) (rubles)), the cost of the framing (materials) (conditionally designated as \( ob \) (rubles)) if the developed "growth map" contains these materials as per the design. According to the "growth map", either formwork or framing may be employed or a combination of these tree shaping techniques may be employed, which is why the final formula may contain one or two variables.

Thirdly, the cost depends on the shaping site. The first option is to "cultivate" plants at a specialized nursery, i.e. in special greenhouse complexes (heated during the cold season) fit for year-round tree shaping. However, it has been observed that not all bionic objects may be shaped this way. E.g., urban structures, particularly, pedestrian bridges, and street furniture, such as long play structures, cannot be "cultivated" off-site due to large dimensions, as transportation of a bionic object to the deployment site is infeasible and root system adaptation is complicated.

The second option is to "cultivate" plants on-site and it features a range of advantages in comparison with the first option, such as:

- no need in repotting the arborsculpture;
- no restriction on the selection of arborsculptures from the category of practical use techniques;
- control of bionic object shaping.

If a bionic object is shaped at a specialized "plant nursery", the cost includes the following:

- The cost of maintenance at a plant nursery (conditionally designated as \( s \) (rubles)) throughout the shaping period (conditionally designated as \( n_s \) (years)).
- The cost of arborsculpture transportation to the deployment site (conditionally designated as \( tr \) (rubles)). The cost of transportation is directly dependent on the amount and age of greenery elements, as well as the transportation distance.
- The cost of repotting of greenery elements from the plant nursery to the deployment site (conditionally designated as \( p \) (rubles)).

If the arborsculpture is shaped on-site, then the cost includes the following:

- The cost of decoration of the bionic object (conditionally designated as \( d \) (rubles)) throughout the shaping period (conditionally designated as \( n_d \) (years)).
- The cost of arborsculptor transportation to the deployment site and back (conditionally designated as \( tr_z \) (rubles)) throughout the shaping period (conditionally designated as \( n_{tr_z} \) (years)).

3. Findings

3 aspects are crucial to the technical and economic justification of arborsculpture development:

- Amount, type, age and growth rate of the hardy-shrub species making up arborsculpture objects.
- Cost of labor of an arborsculptor.
- Bionic object deployment site.

The primary formulas for calculating the final cost of shaping a bionic object based on the above described parameters affecting the cost of arborsculpture development are as follows:

1. The arborsculpture is developed at a specialized plant nursery and the growth map does not mention such techniques as formwork and framing (1):

   \[
   \sum_{i=1}^{n_k} k + \sum_{i=1}^{n_f} f + \sum_{i=1}^{n_y} y + \sum_{i=1}^{n_s} s + tr + p
   \]

2. The arborsculpture is developed at a specialized plant nursery and the growth map mentions such techniques as formwork and framing (2):
\[ \sum_{i=1}^{n_1} k + \sum_{i=1}^{n_2} t + \sum_{i=1}^{n_3} y + \sum_{i=1}^{n_4} f + \sum_{i=1}^{n_5} s + \sum_{i=1}^{n_6} f + \sum_{i=1}^{n_7} d + \sum_{i=1}^{n_8} p \]  

(2)

3. The arborsculpture is developed on-site and the growth map does not mention such techniques as formwork and framing (3):

\[ \sum_{i=1}^{n_1} k + \sum_{i=1}^{n_2} t + \sum_{i=1}^{n_3} y + \sum_{i=1}^{n_4} f + \sum_{i=1}^{n_5} d + \sum_{i=1}^{n_6} r_2 \]  

(3)

4. The arborsculpture is developed on-site and the growth map mentions such techniques as formwork and framing (4):

\[ \sum_{i=1}^{n_1} k + \sum_{i=1}^{n_2} t + \sum_{i=1}^{n_3} y + \sum_{i=1}^{n_4} f + \sum_{i=1}^{n_5} d + \sum_{i=1}^{n_6} r_2 \]  

(4)

4. Conclusion

The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in table 2 should be used. This study demonstrates landscape- and ecology-oriented approaches to the development of urban objects, street furniture and interior objects. Comprehensive arborsculpture development, possibility of using these objects in closed/open spaces allows fulfilling eco-friendly approaches to the urban environment development.

The proposed science-based formulas for calculating the cost of arborsculpture development will allow fulfilling these approaches in practice. In the long term, this will help to improve the quality of urban forestry, as it fundamentally changes the attitude towards planted greenery and lays the foundation of environmental awareness of the population.

"Education primarily forms a new outlook and new views towards the nature not as the environment centered around the man who acts as a master entitled to alter and use the surrounding world at his own discretion only, but as an inseparable part of the world where the man is a part of nature, has a moral obligation towards it and should seek to protect it..." [29].

Approbation of the results obtained in the course of the study is fulfilled in the form of a developed and patented Arbor software package [30]. This study targeted practical activities in the sphere of landscape design and architecture.

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