WATER PHENOMENON – URBAN MORPHOLOGY TRANSFORMATION

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Abstract. This research paper deals with the mutual dependence of water phenomenon and urban morphology. Water is a basic subject matter of many analyses, and it is considered a principal existential and vital generator of the formation, sustainability and transformation of different types of cities. The water relevant facts are here presented from the aspect of elementary criteria of generative factors of typification of cities and relationship between urban landscapes and water.

By integrating well-known urban and technical factors with presence of water on a surface model, optimum results are obtained with respect to water percentage in cities. Overall results of the research represent an instruction for future transformations of urban structures encouraged by water presence.

Key words: water phenomenon, urban transformation, urban morphology, shape and form of a city, urban matrix.

1. INTRODUCTION

There is no permanent settlement on Earth without some kind of physical presence of water. This implies that water constitutes a deciding factor in selection of space disposition of a certain settlement, more precisely, its micro-location – site – formation as a sedentary settlement. Sustainability of settlements – micro-location position and spatio-temporal transformation all depend on water presence.

Therefore, water, as a conditioned phenomenon of continuity, represents a main threshold for growth and development of every settlement on Earth. By generating the urban forms and plan or project design elements, water affects the aesthetic quality of visual representation of the city's silhouette – urban matrix, it provides a course for future expansion, by its macro-spaces it defines the functionality and space size. Regarding the micro-plan, in urban plan or within physical structures as ambience units, water completely defines the visual character and ambient quality.
The aforementioned premises are the reasons why this paper is focused on finding possible scientific-theoretical and practical elements of the effects of water on transformation of urban-morphological landscape, as a basis for examination of traditional models of urban planning and design.

Morphology (Greek morphé: shape) of urban space, as a field of scientific discourse on built space, depending on the presence of water, endeavors to explain the nature of the "form" of a city. Form of a city is conditioned by the manner in which it is formed, its spatio-temporal transformations and genesis in general, and by several factors of recognizable planning and design methods, which affect the relevant process with their action. Water influences on urban morphology transformation enable formation of three (theoretically idealized) types of a city: longitudinal, concentric and irregular.

Given the aforementioned factors, scientific-empirical city typology, based on the presence of water phenomenon, can be considered a special discipline of urbanism.

2. CITY PLAN – SHAPE AND FORM OF A CITY AND WATER PHENOMENON

In order to define certain types of cities, it is important to explain theoretical elements of development, which cause transformations of urban morphology. They serve as a basis for defining city typology models from the aspect of water influence on the plan – city matrix.

City plan, that is, its functional organization and geometrical shape – morph, is comprised of the following elements: street network system and layout, city outline within its contours and relationship with the surrounding landscape.

The term regular refers to those urban formations whose space and plan composition complies with the geometric order. The more it approaches the basic geometric shapes, the higher the level of regularity is. All other urban structures, which do not satisfy such geometric requirement, are classified as irregular. Most of the cities are classified as geometrically irregular. Presence of water often disturbs the geometric austerity, which gives particular attraction to cities. Irregularities formed in such manner provide a city with specific urban morphology, making them authentic and unique.

The form of a city is its geometric shape and it directly depends on the achieved civilization level and urban culture of a certain people, tradition and construction style, natural terrain morphology, manner in which city spaces are organized, traffic network, technological and development requirements, etc. The form of a city expresses its individuality as a unique and authentic morphological formation, its aesthetic specificity and overall structural composition, as well as its uniqueness in the manner in which it functions. Geometric shape of a city can be "constant" within certain period, whereas social activities are historically changeable phenomena [1] which cause transformations. Therefore, the continuity of the form of a city and its genesis directly depend on the "qualitative transformation of people's manner of conduct within certain time period" [1].

Linear or non-linear presence of water within a city directly determines the form of the relevant city, or more precisely, it determines a recognizable geometric appearance of the physical structures. In this manner, it gives a specific particularity to authentic urban identity by means of numerous expressions of individual and collective morphological units, combined within a synthesis as an urban landscape with presence of a certain form
of water. Endeavors to treat water as an ever-lasting, irretreivable and essential resource of human existence, within the context of its qualitative (existential and formative) usage, are seen in its influence on the city geometry.

_Urban form_ refers to the manner in which city life is organized, regarding land distribution, functional and facility connections and distribution of human activities within urban environment. It depends on the social-historical context, ideology, economic power of a society, socio-political and cultural relationship of a social system, development level of technique and use of the latest modern technology. This form depends on the natural geomorphologic factors – natural micro-ambience, character and relief indentedness, climate and its characteristics.

The form of a city and "water phenomenon" are directly related because of the fact that the first human settlements were created around water springs, and consequentially related to the existence of one social community. In time, human needs became more complex, accompanied by the change in social conditions, economic power, then the technique and technology developed, etc. Besides its principal purpose, which is exploitation in order to survive, water, as a natural resource, with its specific manifestation at certain geographic areas, became a means of communication, and it also encouraged development of the functions which depend on it; furthermore, it directly determined the methods of construction of buildings and settlements and individual macro-endeavors in planning of certain important infrastructural interventions in the city development.

### 3. MORPHOLOGICAL MATRIX OF A CITY

Urban matrix originates from the functional, spontaneous and planned composition, which becomes the essence of the city plan form, and in which the character of the unit with mutual relationship with its elements is defined. The element of the relevant composition expresses the character of the urban matrix, and those can be blocks, squares, streets and individual buildings in the structure hierarchy. The mutual relationship between the number and size of city blocks, squares, streets and individual buildings oscillates, seeking to reach the optimum balance with respect to their roles within the unit. The matrix is not repeated within the composition due to its authentic and specific factors, because every segment of the space is unique for its nature and relationship with the whole unit.

City's territory is expanded by making the initial matrix composition geographically more complex, preserving at all stages the uniqueness and individuality of the parts with respect to the whole unit. Simultaneously, the freedom of an architect/urban planner to select appropriate methods for transformation of urban morphology is proportionally increased, with obligation to preserve the existing form coherences.

Water, as the principal generative element of urban matrix, affects the transformation of the spatial micro-ambience and built structures, non-built surfaces and linear elements of city expansion. Urban spaces, with successive sensations, become either dynamic or static, depending whether they are "cut" by the water, or water is their constituent part. Unequal elements are in mutual balance created by the dynamic or static impressions of new spatial possibilities.
3.1. Existing matrix system of urban morphology

Graphical presentation of urban matrices with respect to street network and its physical structure is often used in urban practice. It is used to present the urban form which is related to the water influence, its spatio-temporal transformation and line of expansion. Analysis indicates that it is possible to classify several types of cities with respect to water influence within the context of urban morphology transformation, and thus recognize cities which run parallel with one or both river banks, sea coast, or located around natural or artificial lakes (L_a, b, c, d, e, f, h), estuaries, (L_e, f), springs (L_i), oases (L_j), or island cities (L_k). (Fig. 3).

The elementary plan as an urban morphology matrix can be presented graphically, as it follows below (Fig. 1). We notice significantly greater number of manners in which urban morphology can be articulated. They are related to the rationalization of the urban form units in relation to the geomorphology type of matrices.

![Fig. 1 Usual urban matrix systems of structures (UM)](image)

The mutual denominator of the course of expansion and final form of a city is related to the size and amount of the water present, its abundance and morphology of the surrounding terrains, which are affected by its influence.

By comparing these matrices of cities to three basic prototypes L_1, L_2 and L_3, (Fig. 2) the urban matrix systems from the previous illustration (Fig. 1), adapt the best to UM_5, UM_6, UM_7 and UM_9, and rarely to UM_4.

![Fig. 2 Three basic prototypes of the matrix model of cities](image)
3.2. Elements for modeling of city morphology matrix – percentage (%)

Integration of the well-known urban-technical factors with water presence enabled the analysis of water percentage (%), with appropriate coefficients regarding the land use.

The results obtained upon the analysis show numeric indicators, which refer to percentage of water, distance of city facilities in relation to the gravitation focus towards the line/corridor of the water. Those numeric indicators give us a rough insight into the urban-technical indicators \((Gn, Pr, Ki)\). They determine the selection of the specific, well-known model for analysis of the urban structure matrix transformations from the aspect of water presence. The percentage of water surface, in relation to gross surface area of the entire space subject to urban transformation, refers to the water presence.

3.2.1 Urban-technical factors used in comparison

**Built residential surface** is the sum of the surfaces of the ground floor dimensions of all residential buildings in the relevant area or complex, including the external outlines of the walls together with built annexes.

**Population density** is a ratio of population (people) in a certain territory and the territory itself. It is obtained by dividing the total number of people at a certain area \((S)\) with certain city surface \((P)\), using the following expression:

\[
Gn = \frac{br. \, st.}{površina} \quad \text{or} \quad Gn = \frac{S}{P} \text{[st/ha]}
\]

**Percentage of built area** \((Pr)\) is the ratio of the surface which lies under the buildings \((P_o)\) per certain residential surface \((P_j)\).

\[
Pr = \frac{P_o \times 100}{P_j}
\]

**Land-use coefficient** is used to present the gross surface area of the building plan in relation to the surface area of the parcel, and it can be defined as a number which represents the ratio between the sum of all gross surface areas of the building floors and the sum of the parcel surface areas, or surface area of an appropriate complex.

By multiplying the land-use coefficient \((K)\) with the net residential building area \((P_n)\), we obtain the overall surface area of the floors \((P_e)\) of all residential buildings at a certain building surface.

\[
P_e = K \times P_n
\]

The basic expression has to contain a correction factor, obtained upon modeling, where \(V\) is percentage (%) of water surface, which can range from 3.66% to 25.81%. This represents an optimum sustainable percentage of water share in relation to total city area subject to transformation. (Fig. 12)

\[
P_{v'} = \frac{P_o \times 100}{P_f}
\]

This means that the combination of the model samples, on which transformation of land occurred thanks to the presence of water, should be carried out by using a new, modified formula, as it follows below:
\[ P_{VM} \times \frac{PM}{P_M} \rightarrow P_{VG} = \frac{P_{VM} \times P_{VM}}{100} \rightarrow P_{VG} = \frac{P_{VM} \times 100}{P_{VM}} \]

\( P_G \) – surface area of the selected city determined approximately in accordance with the
given surface model

\( P_{VG} \) – surface water model of the selected city

\( P_M \) – given surface model

\( P_{VM} \) – water surface on the given surface model

\( P_{PVG} \) – percentage of water presence on the given surface model

\( P_{VG} \) – percentage of water in the selected city

New optimum indicator of water percentage for every particular city compared with
appropriate urban structure matrices on a given surface model is considered an instruction
for future planning and designing of urban morphology transformations.

4. Model matrix

The model matrix of water influence on a city is obtained by analyzing random sam-

ples, which can be seen as occurrences in cities:

Fig. 3 Synthesis review of several examples and water presence within urban structures
4.1. Proposal for defining a space model for matrix modeling

$L_0$ – basic view of the natural position of water (black) in relation to a city and its primary structure of the built space with usual positions and space ratios ($l_a$, $l_b$, $c_1$, $c_2$, $c_3$, $g_1$, $h_1$, $i_1$, and $k_1$);

$L_1$ – water as an expansion and transformation factor of the inner-structure forms of a city; influential expansion course of inner structures which are complementary and parallel in relation to a river; here a river is taken – water as an existential phenomenon, which represents the expansion corridor, dual or restricted to only one side ($l_{1a}$, $l_{1b}$, $l_{1c}$, $l_{1d}$);

$L_2$ – spatio-functional expansion models in which river – water is a generator of space transformations;

$L_3$ – position of the river – water in relation to city center in variations $L$ ($l_{3a}$, $l_{3b}$, $l_{3c}$, $l_{3d}$ and $l_{3e}$);

4.2. Elementary types of city expansions conditioned by water presence

$L_a$ – water showing the longitudinal direction of city expansion, with a coast on one or both sides;

$L_b$ – water tangentially influences the city expansion; provided that the city structure's principal direction of expansion is radial or tangentially-longitudinal on its outline;

$L_c$ – variation of conditions similar to $L_b$ with difference in strict radial solutions of the city street system;

$L_d$ – diagonal position of the water flow in relation to the available city territory enables radial approach to water or expansion on both sides (which is often the case), as well as longitudinal expansion;

$L_e$ – cities on estuary of two rivers represent a special phenomenon, which the urban planners should take into particular consideration; the water integrated within the urban landscape enables aesthetic shaping of its coastal areas and formation of particularities which are later considered as city's "spirit";

$L_f$ – developed river estuary factor is very rare, but quite exceptional; this factor is often seen as generative element of transformations within the context of radial expansion of a city – phenomenon often seen throughout the history;

$L_g$ – lake and sea coasts provide linear expansion of streets with tangential and radial exits to the coasts; this type requires planning of walking zones, promenades, lookouts commanding a wide view and formation of pedestrian and other attractions by using the so called *lungo mare* concept;
Lb – variation of conditions similar to Lg; longitudinal expansion along coasts;
Li – indigenously developed structure and future river flow from its spring;
Lj – indentedness of the indigenous river flow from its spring and formation of settlements;
Lk – settlements in form of an island – water completely affects the settlement structure;
this type can be relevant for analysis of structures of medieval island cities;
Ru – river with tributaries – estuary – attractive for city development;
Ru1 – penetration of water into the city structure;
Ru2 – coastal indentedness – penetration of structure into the water matrix;
R2a – structure penetrating the water (natural or artificial);
R2b – water penetrating the structure (natural or artificial);

4.3. Expansion types of the urban matrix inner structures

L1a – water by means of centripetal force concentrates the expansion and planning concepts around its matrix, which cause transformation of the built space, and accentuate transformability of non-built spaces;
L1b – developed form L1a, with presence of centrifugal forces, whereby the urbanization of transformed structures is balanced and harmonized;
L1c – encouraging development of the existing center to expand to the opposite side;
L1d – parallel expansion of two centers ("dual" cities phenomenon);
L3a – river provides longitudinal expansion of city center and its development to the other side;
L3b – river "opens up" a longitudinal expansion direction for the structures, connects future facilities with bridges and encourages expansion of the city;
L3c – optimum natural "cooperation" of river banks with the centers, which encourages phenomena similar to L3b;
L3d – river flows diagonally through the matrix structure;
L3e – river – barrier; center is one side, river influence is minimum;

5. SELECTION AND ANALYSIS OF PARTICULAR OR EXTREME POSITIONS OF WATER/RIVER/LAKE/SEA

The elements of local geographical conditions for city formation along certain form of water are very different, and so the selection is carried out according to the following elements:

- River/water elongated direction of the city,
- Meander watercourse through a settlement or city, meander "negative" of the land image inverted in the sea,
- Peripheral position as a coastal type,
- Cities on water (Venice, Amsterdam, Stockholm, Sankt Petersburg) and
5.1. Overview of the basic indicators of water presence in selected samples

Fig. 4 Venice; City formed as a result of water influence on the possibilities required for a specific survival

Fig. 5 Amsterdam; City emerged as a result of human "taming" of the nature in constant struggle for survival

Fig. 6 Stockholm; Specific penetration of water into city structure

Fig. 7 Sankt Petersburg; River estuary as a generator of formation and development of the city
According to the analysis carried out and explained with respect to the functionality and form phenomena of the presented samples of randomly chosen cities compared with appropriate matrix models, it is possible to obtain their theoretical classification:

- Elementary model of settlements located along water – river – linear expansion: river and the surrounding physical space make one unit;
- Variations of the elementary model of settlements along water: river/lake/sea and spatial units – water articulates the transformation of the built space, but constitutes a barrier for expansion;
- Stretched settlements along certain water form: river as an intersection of stylized space units – concentric city;

6. MODELING AND INTERPRETATION OF THE CRITERIA BY A THEORETICAL TYPOLOGICAL SAMPLE

Modeling refers to graphical interpretation and comparison with selected samples taken from the model matrix, which best reflect the water phenomenon within urban structures (Fig. 11).
6.1. Numeric and tabular interpretation of the indicators

The method for determining the value of water influence on the urban morphology transformation is defined by comparing the model samples on which land and water surfaces are particularly implemented.

There are two sub-phases in the graphic modeling. The samples of water presence from M₁ to M₇ are selected from the Model matrix (Fig. 3).

Comparison of the model samples on the same, randomly selected modeling surface with selected cities gives the values for orientation purposes only regarding the percentage of water presence (%) in the relevant city. It is proportionate to the selected surface model, on the actual example, and it is derived by using the expression for calculation of water presence percentage in a city:

\[
V_{ig} \times 100 = P_{ig} \times 100
\]

According to the analysis regarding the water presence and urban structure on the surface model (using the new, modified formula), it is evident that the model samples M₂ and M₇ constitute optimum indicators, which should be illustrated by every urban structure, besides the presence of water. It is believed that certain extreme cases – attractive and phenomenal – are model samples referred to under M₃, M₄, M₅ and M₆. The cities selected here point to such cases, as it follows below (Table 1. and Fig. 12):

Table 1. Analysis of the water presence and urban structure on the surface model

<table>
<thead>
<tr>
<th>M₀ – modeling surface</th>
<th>M₁ – entire surface model is surrounded by water within minimum limits ranging from</th>
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Fig. 12 Table review of the analyses on water percentages in urban structures on the relevant surface
Throughout his long history, man has been in constant contact with the nature in order to satisfy his existential needs. Those contacts have left a mark, which now constitutes a particularity of a given space and temporal distance.

The connections, which have marked the human movements within space, constitute elementary factors of development of the existential space caused by human activities. The connections are paths, "symbols of time", which respect the original codes of watercourses. By their intersection, the paths form a system, which, besides the linear connections, provide turnings as well, thus making the system more complex. Within such context, watercourses can be crucial in formation of city types following the consequences caused to the urban morphology and its transformation.

Urban planning actively integrates water into the morphological structures, especially when it its presence is strongly imposed.

Graph-analytical interpretation of the samples, selection of models, selection of sign symbols and numeric calculation, contributed to accepting the working percentage model (%) of water presence in the selected cities, and in cities in general, as orientation for future transformations of specific urban morphologies. The selected criteria were used as an auxiliary means for valorization of the city types. The obtained result showed that randomly selected cities in the world (which have only one thing in common – presence of some kind of water) usually belong to $R_u$ and $L_g$, with elaborated sign symbols from the Model matrix.

Overall results of the performed analyses discussed in this paper (theoretical and graphical) define the natural phenomena of water presence within urban structures and its influence on urban morphology transformations. Furthermore, they represent instructions for future transformations (of greater quality) of urban structures encouraged by the presence of water phenomenon.

REFERENCES

FENOMEN VODA – TRANSFORMACIJA URBANOG MORFOSA

Jasenka Čakarić

Istraživanje u radu usmjereno je prema iznalaženju međuvisnosti fenomena vode i urbanog morfosa. Voda je bazični predmet analiza, kao osnovi egzistencijalno-vitalni generator nastanka, opstanka i transformaciju više tipova gradova. Činjenice o vodi iznene su sa aspekta elementarnih kriterija generativnih pokazatelja tipizacije gradova i odnosa urbanog prostora prema prisustvu vode.

Integrisanjem poznatih urbanističko-tehničkih pokazatelja sa vodnim prisustvom na modelskoj površini, proizašli su optimalni pokazatelji procenata učešća vode u gradu.

Ukupni rezultati istraživanja predstavljaju uputu budućim transformacijama urbanih struktura potaknutih vodnim prisustvom.

Key words: fenomen voda, grad, urbana transformacija, urbani morfos, oblik i forma grada, urbana matrica.