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Application of multi-criteria method to assess the usefulness of a hydrotechnical object for floating housing

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Abstract. This publication presents the analysis of three hydrotechnical objects located in the Municipality of Gdańsk with a view of mooring Floating Houses. The assessment of the adaptation of a hydrotechnical object has been carried out by a multi- criteria method AHP and using the main criteria such as: mooring system, communication with the mainland, availability of the utility networks, waste disposal and location of the parking spaces. The analysis allowed to conclude that there are no hydrotechnical objects in Gdańsk, which would be fully adapted to mooring of Floating Houses without additional infrastructure investments. The most adapted site out of the three ones considered in the Municipality of Gdańsk is location no. 1 – the Rybackie Pobrzeże.

1. Introduction
Both in Western Europe and in the United States of America, the phenomenon of living in Floating Houses has gained popularity at the beginning of the 1980s. It was the reaction to the growth in the wealth of societies whilst rising in the prices of land. The only exception is the Netherlands, where the popularity of Floating Houses has been increasing in the manner forced by nature. About 60% of the land territory of the Netherlands is below sea level [1, 2]. The consequence of the greenhouse effect is the climate change which causes sea level rise and more violent storms. That is precisely why in the Netherlands it has been decided that they will not fight the sea, but use its strength and adjust to it. The Dutch Government has implemented provisions for supporting floating housing.

In Poland floating housing is gradually growing more popular. The first Floating House was located in Wrocław in 2010. Since then, there has been many changes and public awareness has become great enough not only to accept Floating Houses, but to awaken an interest of increasing number of people.

The objective of this work is the answer to the question if the existing hydrotechnical infrastructure in Poland is prepared for the new type of construction, namely Floating Houses. The selection of the location of Floating Houses was considered in terms of the most important criteria for users: mooring system, communication with the mainland, availability of the utility networks (water installation, sewage, electricity), waste disposal and location of the parking spaces. The publication analysis three selected hydrotechnical objects (waterfronts) located in the centre of Gdańsk, applying multi-criteria method AHP (Analytic Hierarchy Process). AHP is one of the multi-criteria decision making technique and is used to solve complex problems in various areas for example in political science, sociology and management process to evaluate multiple types of projects or in complex technical-economic issues. Due to combining the concepts of mathematics and psychology it is also one of the fastest developing

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as well as the most famous methods in the world. One of the advantages of AHP is pairwise comparisons of selected elements and attributing them to a scal [3].

2. The technical parameters and construction of Floating House

The object concerned is the floating dwelling, whereas the construction features described are most commonly found amongst the objects of this type in Poland.

A Floating House is settled on a special floating system, which is based on pantoons with dimensions of 2,5- 3.0 meters in width and 10-12 meters in length, pooled in longitudinal or lateral setup. The frame of "the surface" part is made out of hot tinned steel mouldings, protected by a corrosion- resistant coating as well as impregnated and multilayer glued wood. The hull of the fame building kit can be made out of "aqua panels", DLH laminboard, panels of powder coated aluminium sheets, treated wood or its conglomerate of PCV. The roof was designed as flat, thermally insulated with panels of Styrodur, covered with water insulation. Rainwater from the roof is conveyed to drainpipes hidden in the facade. The door and window carpentry is made of wood or powder coated aluminium profies. Insulating is made of Styrodur, according to the thermal regulations for the residential houses. The board of the floating object is made of tropical wood or wood conglomerate and PCV. The rails protecting against falling overboard are made of stainless steel with wooden or steel handrails. The object is equipped with:

- electrical installation,
- heating,
- water and sewage system [2, 4].

3. The description of the muli-criteria decision method AHP

The method of the hierarchical analysis of a problem (AHP- Analytic Hierarchy Process), developed by Saaty [5-7], is mostly used to support the analysis connected with selecting a decision option. The options could be the physical objects, such as machines, products, as well as some states represented by design or implementation variants leading to achievement of a certain state (quality, safety, risk). By AHP method it is also possible to carry out a diagnostic or comparative assessment of the objects in question, because the assessment of variants constitutes a pre-decision-making stage.

AHP method recognizes a multi - criteria approach based on compensatory strategy of preferences modelling and on the assumption of variants comparability. Taking into account the preferences of an assessor, which decides about the subjectivity of the assessments, underpins the multi- criteria approach that treats these preferences as a natural phenomenon for the assessments made by a human, in contrast to the measurement which is objective.

AHP method considers the specificity of psychological evaluation processes which have a relational and hierarchical nature. Numerous applications of the method in supporting economical, technical and social decisions confirm its usefulness, especially in the applications where most criteria are qualitative and the experience of an assessor constitutes the main source of the subjective assessments [8].

AHP methods popularity and strong position in the largest international databases of high-scoring peer-reviewed journals, such as, for example, ScienceDirect, Wiley, Scopus. When comparing the frequency of articles on AHP with other decision support methods, it can be concluded that references to the AHP method are most common [9].

4. Modelling using hierarchical method

Analytic Hierarchy Process (AHP) consists of 4 stages:

Step 1. Prioritizing a problem - the aim of this stage is the detailed description of a problem, identification of the participants, defining the main objective and expectations. Thereafter, a decomposition of a problem is undertaken in the form of the primary objective, the main and partial factors and variants considered, which generate some fulfillment of aims function on particular levels of the hierarchical model.

Step 2. The assessment of the criteria by comparison with pairs - it is conducted by a decision- maker, who compares the pairs with each other using the criteria and the criteria in relation to the primary objective on the basis of subjective decision as to which of the criterion and to what extent is more important than the other. The relations between the particular elements are established on the basis of 9- point scale presented in Table 1 [7, 10].

Table 1. Fundamental scale of absolute numbers [11].

Identysity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance order of affirmation
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
1.1-1.9	When activities are very close a decimal is added to 1 to show their difference as appropriate	A better alternative way to assigning the small decimals is to compare two close activities with other widely contrasting ones, favouring the larger one as needed a little value over the smaller one using the 1-9 values.
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A logical assumption
Measurements from ratio scales		When it is desired to use such numbers in physical applications. Alternatively, often one estimates the ratios of such magnitudes by using judgment

To make pair comparison of the selected criterions it is essential to put them in the diagonal matrix type (n x n). The comparison is made by identifying the impact of the element on the left side of the matrix to the elements at the top of the matrix. Below the main diagonal there are the inverse of the pairwise comparisons, the formula of matrix A [3]:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & 1 \end{bmatrix}, \tag{1}$$

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Due to the inverse of the pairwise comparisons, the i-th row is the inverse of the i-th column, so there is a relation:

$$Aw = nw \tag{2}$$

where:

w – vector of weights $w_1, w_2, \ldots, w_n$

Elements of the vector of weights *w* are priorities vector of the various criteria because of the overall goal:

$$w = \sum_{j=1}^{n} w_j a_{ij} \tag{3}$$

Step 3. Defining mutual preferences (scales) with respect to criteria and decisional variants- having built the matrix, the calculations of criteria scales are made. The standardized rows of matrix are aggregated and the proprietary vector of matrix is calculated:

$$\lambda_{max} = \frac{1}{w_i} \sum_{j=1}^{n} a_{ij}\, w_j \tag{4}$$

A is consistent if and only if [3, 12]. The second factor necessary to obtain the AHP method is the CI (Consistency Index). It is the negative average of the other roots of the characteristic polynomial of A:

$$CI = \frac{\lambda_{max} - n}{n-1} < 0{,}10 \tag{5}$$

The last factor is CR (Consistency Ratio). If the ratio of CI is significantly small, the estimate of w can be accepted. CR is determined by the formula:

$$CR = \frac{CI}{RI} \tag{6}$$

where:
RI- random index [3, 8, 13].

In the case where λ max = n and CI = 0, CI index is calculated with regard to random index RI, which is the average value of CI for a large number of random generated matrix of comparisons. The value of RI is provided in the tabulated form [7, 10].

Table 2. Value of index RI [8, 10].

n	2	3	4	5	6	7	8
RI	0	0,52	0,89	1,12	1,25	1,40	1,45

Step 4. The analysis of the selected results – choosing the best variant, which would address the main objective.

5. Selection criteria for the hydrotechnical objects

The hydrotechnical objects appointed for further analysis using AHP method were selected based on three key criteria, which are as follows:

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- the mooring zone- the object should be situated in the living area,
- the owner of the hydrotechnical object- it is recommended that the owner is a municipal or state entity,
- the access to a floating object from land- there should be easy and unrestricted access provided to an object.

In the light of the criteria stated above, three locations were selected:
- location no. 1 - The Rybackie Pobrzeże,
- location no. 2 - Stara Motława,
- location no. 3 - Nowa Motława.

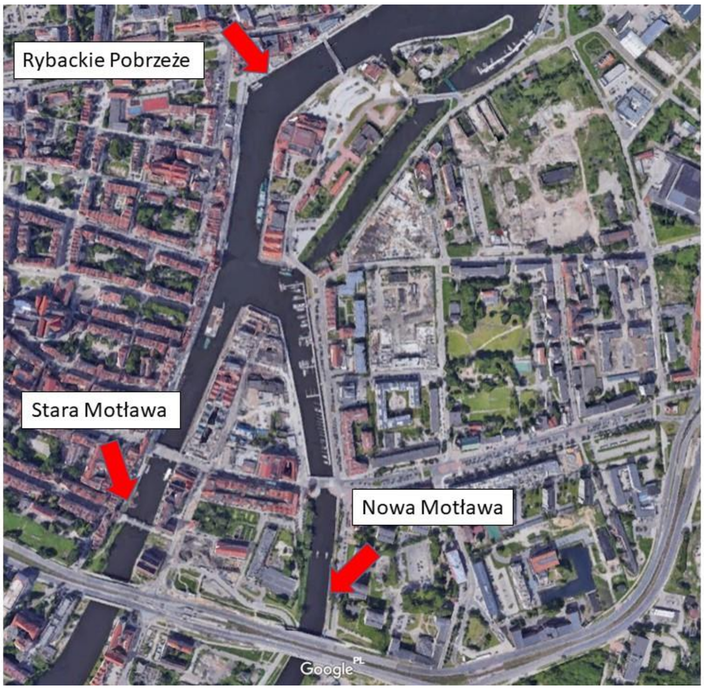

Figure 1. Map of the location options [14].

The locations presented in Figure 1 are situated in the city center, in the living area. In all three cases, a municipal or state entity is the owner of the quay.

The Rybackie Pobrzeże is located by Targ Rybny in Gdańsk, on the left bank of the river Motława Gdańsk. It has a plate construction set up on the sheet piling type Larssen II and a mooring trestle made of prefabricated piles. It is equipped with moorage piles, electrical and water installations, however, there are no installation of sewage collection from a floating object. The quay is sited by a frequented fairway and is used as a boulevard by the inhabitants. It is a densely urbanized area under protection of the conservator of monuments [2].

Stara Motława is positioned on the waterfront, between Most Krowi and Most Zielony on the left bank of the river Stara Motława, which has been made navigable again since 2012. The girt structure quay of 99 meters in length. The upper edge of the quay is covered with a steel angle. The quay is equipped with a steel railing, a discharge pipe probably used as rainwater drainage system, continuous wooden buffer lin and two falls in the quay, one of which was used for mooring of a water tram stop. The site is not developed with any utility networks, it only holds some moorage piles [2].

Nowa Motława is a quay located between Podwale Przedmiejskie Street and Strągiewna Street, along Szopy Street. It is the girt structure quay, which is not equipped with any installation. In the quay there is a fall equipped with the moorage piles and protective railings, which hinder free communication with the mainland [2].

6. Preliminary assumptions and description of the criteria

In order to compare the assessment criteria of the examined hydrotechnical objects, the main criteria had been selected, then they were divided into partial criteria [5]. The main criteria were demonstrated based on the technical solutions and the expectations of a Floating House user. These are as follows:
- the mooring system
- communication with the mainland
- availability of utility networks
- the place for municipal waste disposal
- a parking space [2].

The first main criterion is safe mooring, that is mounting a vessel or other floating object to the mooring devices of hydrotechnical objects by means of a mooring line. There are various mooring systems available, these are:
- mooring to steel piles, which are driven into the seabed,
- mooring using mooring booms, that is special beams, which hold the house in the safe distance from the shore,
- system of anchors Seaflex allows the mooring of a floating object by placing four concrete blocks around a Floating House on the bottom of the reservoir. They are connected with a floating platform using a system of resilient ties, which limit the impact on wave motion and hold the object in a stable position in relation to the shore or a mooring pier [2].

Another important criterion is communication between the users of a vessel and the mainland. Communication with the land is secured through:
- additional devices, for example a gangway used if the distance from a vessel to the edge of the quay is significant or if the difference between the level of the quay and the deck of a Floating House prevents independent communication with the mainland,
- falls in the quay, applied in a case of the mooring to “high quay”, where the difference between the level of the deck and the edge of the quay is significant, in addition the construction of a hydrotechnical object has a special decrease in the construction in order to allow the mooring of the smaller vessels,
- supplementary devices or the decrease in the quay- used when a decrease in a quay does not ensure free and safe communication with the mainland,
- without the decrease in the construction of a quay and additional devices.

Providing users with the access to utility networks, satisfying their basic needs such as, access to electricity, heating, water and sewage disposal is vital and should be guaranteed in the place of permanent residence.

Therefore, a hydrotechnical object ought to be equipped with:
- electrical installation- a possibility of connecting to the network
- water and sewage system- on floating objects water and sewage system is treated separately as water intake and sewage discharge. Whilst during the summer season water intake does not raise any difficulties, in wintertime most water installations are emptied for technical reasons, so that freezing water does not destroy them. In such cases a user should have an opportunity of water supply delivered by the water trucks. Sewage can be disposed of via a special installation at quays or by storing waste in containers on a vessel and collecting it by a slurry spreader when the containers are filled.

Each household regardless its location, size or number of people, generates municipal waste. It is required by law to sign an agreement concerning waste disposal. A user of a floating house should have an opportunity to select a waste collection point to service the collection of municipal waste.

Currently, in every flat/house there is a minimum of one car and the inhabitants of floating objects have the need to use and own such means of transport too. It is not essential for functioning to ensure a parking space nearby a vessel, but it significantly improves the comfort of life [2].

7. Hierarchical model

The analysis using AHP method was conducted in Excel spreadsheet.

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7.1. Prioritisation of a problem

A decision- making problem in AHP method is presented in a hierarchical way, which illustrates grouping all the criteria into the main and the partial ones. The following table presents 5 main and 15 partial criteria for the analysed issue.

Table 3. A summary of main and partial criteria.

1.	The mooring system
1.1.	Mooring Piles
1.2.	Mooring Booms
1.3.	Seaflex anchors
2.	Communication with mainland
2.1.	Using auxiliary devices
2.2.	Decrease in the construction of a quay, configuration with or without a gangway
2.3.	Decrease in the construction of a quay, configuration with or without a gangway, with an obstacle in a form of a railing
3.	Utility networks
3.1.	Water installation
3.2.	Sewage
3.3.	Electricity
4.	A waste collection point
4.1.	An agreement combined with a nearby property
4.2.	Necessity to provide underground rubbish bins
4.3.	Opening an individual waste collection point
5.	Parking spaces
5.1.	Free public car park
5.2.	Paid public car park
5.3.	No car park in close vicinity to the quay

7.2. The assessment of criteria by comparison using pairs

The matrices of pairwise comparisons of the criteria given by the specialists of floating objects construction, sailors and users of floating houses is shown in Table 4 [5], and for the matrix for level 1 is shown in Table 5 [5].

7.3. The analysis of the selected results

As demonstrated by the results of the AHP analysis, it has been proven that The Rybackie Pobrzeże-location no. 1 is the most usefulness of a hydrotechnical object for floating housing. The judges pointed out that the most important criterion in the order are: utility networks, the mooring system and communication with mainland. Criteries like parking spaces and a waste collection point has the least effect.

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Table 4. Comparision matrices and local priorities – level 2 [5].

The mooring system	1.	2.	3.	Priority vector	Communication with mainland	1.	2.	3.	Priority vector
1.	1	7	4	0.69552	1.	1	$\frac{1}{6}$	$\frac{1}{5}$	0.07796
2.	$\frac{1}{7}$	1	$\frac{1}{4}$	0.07543	2.	6	1	3	0.63484.
3.	$\frac{1}{4}$	4	1	0.22905	3.	5	$\frac{1}{3}$	1	0.28720
λ_{max}=3.07642, CI=0.0382, CR=0.07348					λ_{max}=3.09402, CI=0.0470, CR=0.09040				
Utility networks	1.	2.	3.	Priority vector	A waste collection point	1.	2.	3.	Priority vector
1.	1	8	6	0.76116	1.	1	$\frac{1}{4}$	3	0.21092
2.	$\frac{1}{8}$	1	$\frac{1}{3}$	0.07261	2.	4	1	7	0.70494
3.	$\frac{1}{6}$	3	1	0.16623	3.	$\frac{1}{3}$	$\frac{1}{7}$	1	0.08414
λ_{max}=3.0735, CI=0.0368, CR=0.07069					λ_{max}=3.0324, CI=0.0162, CR=0.03112,				
Parking spaces	1.	2.	3.	Priority vector					
1.	1	$\frac{1}{3}$	$\frac{1}{7}$	0.08096					
2.	3	1	$\frac{1}{5}$	0.18839					
3.	7	5	1	0.73064					
λ_{max}=3.0626, CI=0.0313,CR=0.06024									

Table 5. Pairwise comparison for level 1 [5].

	1. The mooring system	2. Communication with mainland	3. Utility networks	4. A waste collection point	5. Parking spaces	Priority vector
1.	1	3	$\frac{1}{2}$	5	8	0.3034
2.	$\frac{1}{3}$	1	$\frac{1}{4}$	3	5	0.1413
3.	2	4	1	6	9	0.4534
4.	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{6}$	1	3	0.0683
5.	$\frac{1}{8}$	$\frac{1}{5}$	$\frac{1}{9}$	$\frac{1}{3}$	1	0.0335
λ_{max}=5.155098, CI=0.0388,CR=0.03462						

8. Summary

The AHP method although time - consuming is the most popular tool for the analysis of muli-criteria issues [3]. Its advantages such as flexibility, easiness of use, objectivity of variant selection, comparison of both - qualitative and quantitative factors [10], outweigh the disadvantages which are reflection of reality through the hierarchical model, relativity of experts' opinions and problems with application of 9 - point scale of Satty.

This publication analysed three hydrotechnical objects located in the Municipality of Gdańsk. The main criteria adopted for the analysis by a multi- criteria method AHP were: mooring system, communication with the mainland, availability of the utility networks, waste disposal and location of the parking spaces. The locations were selected based on a location in the urban zone, the owner of a public or municipal institution and easy access to the quay. The assessment was carried out in relation to the technical solutions and the expectations of the user. The above analysis demonstrated that in the area of the Municipality of Gdańsk concerned, there are no hydrotechnical objects which would be fully adapted to mooring of Floating Houses without additional infrastructure investments. Out of the main criteria, the most relevant was utility networks, and the least important was parking spaces. As a result, it has shown that the Rybackie Pobrzeże is the most adapted site for mooring Floating Houses out of the three ones considered in the Municipality of Gdańsk.

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