# AHP MULTI – CRITERIA METHOD FOR SUSTAINABLE DEVELOPMENT IN CONSTRUCTION

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***Summary:*** *The initial assumption is that the sustainable construction is certainly one of the most important parts of sustainable developments. In connection to sustainable development, sustainable construction must also provide durability, quality, financial, economic and environmental acceptability. The construction and the use of buildings have large, direct and indirect impact on the environment. The designers and builders are faced with the challenge to meet the needs of sustainable development. In making important decisions, multi-criteria analysis can be of great importance. Method AHP (Analytical Hierarchy Process), such as mathematical method, is based on the principle of multi-criteria decision-making, where from an existing groups the most favorable alternative is chosen, based on a defined number of criteria for decision making. More attributes have different importance and they are expressed by a variety of scales. The aim of this paper is to provide the AHP method for decision-makers in the construction industry, setting priorities and making the quality decisions, considering both qualitative and quantitative aspects of sustainable development.*

***Keywords*:** *sustainability, construction, mathematics, AHP method*

## 1. INTRODUCTION

In a very complex problems that are found in projects (interests, multiculturalism, multilingualism, multidisciplinary, multi-connection towards a common goal, climatic and working conditions of project performance) countless opportunities are found for an active support to the sustainability of development. Simple, it wouldn't be possible to

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think about quality and positive realization of any project in construction, if the sustainability of development wasn't seriously considered from the very beginning.
For this purpose, AHP process can be of a very great importance and benefit. Construction of the buildings and their use as part of the living environment, significantly affects on the development sustainability.
The big challenge for the constructors is to realize new or renovated projects while preserving the environment. In addition to providing a certain level of conformal living, as one of the basic needs for modern society, in light of the global trend towards sustainable development, it is necessary to meet those needs in a way that energy resources are preserved for the future generations, completely or at least partially. The construction, as an ancient human activity, stemmed out of the human need to protect themselves from the harsh climatic conditions, by controlling their immediate area. Historical construction development was marked by various trends. Science and technology development have brought new challenges in connection with environmental protection, energy saving and the need for sustainable development in the construction industry.
Attention is drawn to a wide range of global, scientific and political public that the concept of the sustainable development is in the top of the priority interests of international, professional and political public, and therefore in the construction industry. Plans for the society development should take care about saving energy in all areas of human activity, as it became clear that the available resources are limited and they indicate equally cautious approach to the design of objects and systems that are used for their heating. Many different methodologies with a holistic approach in assessing the sustainability of buildings have been developed [5], [6].
The complexity of the project selection has its different aspects, because in that choice different criteria are embedded. Until the election, the decision can be reached only through implementation of complex scientific and analytical procedures. The complexity of the problem environment imposes request to the creators of mathematical models and methods in order to help decision maker in the solution analysis and selection, based on multiple criteria that are simultaneously considered [7]. The decision-maker implicitly retains the freedom to adopt, change or reject the solution obtained on the basis of a mathematical model of optimization. Methods that from the very beginning of the establishment of mathematical models, for a specific real problem, take care of multiple targets, simultaneously, develop in the field of MCDA (Multi-Criteria Decision Analysis) [13], [14], [15]. These factors influence the decision and all outcomes that would eventually have possible solution are considered as criteria whose values should be optimal.

## 2. METHOD OF ANALYTIC HIERARCHY PROCESS (AHP)

The method of analytical hierarchy process (AHP) was created to assist in solving complex decision problems [1], [2]. Field of application method is multi-criteria decision-making, where based on a defined set of criteria and attribute values, for each alternative the most acceptable solution is selected, and the complete schedule of the importance of alternatives in the model is displayed. A larger number of decision-makers and larger number of criteria are participating in multiple time periods.

The main feature of multi-criteria methods for decision making (MCDM) is to consider more than one attribute in the decision. They represent a tool for the assessment selection in sustainability. Their main quality lies in the fact that compromise between groups with different interests can be found, giving ranked options as the final result.
Priorities which are given to a certain criteria depend on the interests and needs of different groups and affect the final assessment.

## 2.1 Methodological Basis of the AHP method

Analytic Hierarchy Process (the AHP) belongs to a class method of "soft" optimization. Basically it is a specific tool for the formation and analysis of decision-making hierarchy. Firstly, the AHP enables interactive creation of the hierarchy problems as preparation of decision-making scenarios, and then evaluation in pairs of the hierarchy elements (objectives, criteria, sub-criteria and alternatives) in the *top-down* direction. In the end, the synthesis of all evaluations is done, and under strict determined mathematical model the weight coefficients of all the elements of the hierarchy are established. The sum of weight coefficients of elements at each level of the hierarchy is equal to one (1), which allows decision makers to rank all of the elements in horizontal and vertical sense. The AHP allows interactive analysis of the sensitivity of evaluation process on the final ranks of the hierarchy elements. In addition, in evaluating the elements of the hierarchy, until the end of the procedure and synthesis of results, the consistency of decision-makers' reasoning is checked, and the validity of the obtained rankings of alternatives and criteria is determined, as well as their weight values. Methodologically speaking, the AHP is a multi - criteria technique based on the decomposition of complex problem in the hierarchy. The goal is at the top of the hierarchy, while the criteria, sub-criteria and alternatives are at lower levels.
The AHP is intuitive and relatively easy method whose features can be described through three basic components. Analyticity uses the mathematical and logical reasoning. Hierarchy structure the decision problem into levels: the objectives, criteria, sub-criteria, alternatives (variants). Gradualism - the goal is at the top and cannot be compared to other elements. At level 1, the n criteria that are in pairs are compared each with each. They are compared in relation to the direct parent element at a higher level (here the aim is at the zero level). It takes total n(n-1)/2 comparisons. The same procedure applies on going through the hierarchy to the bottom, until the last level where all alternatives comparisons are completed.
Analytical hierarchy process is flexible because it allows us for complex problems with many criteria and alternative to find relatively easy, relations between the influencing factors; recognize the explicit or relative influence and importance in real conditions and to determine the predominance of one factor over another [12]. The method is based on the fact that even the most complex problem can be decomposed into a hierarchy in such a way that in the further analysis includes both qualitative and quantitative aspects of the problem. AHP keeps all parts of the hierarchy in a relationship, so that it is easy to see how changes in one factor affect other factors. The complexity of the problem increases with the number of criteria and alternatives.
To avoid clutter in AHP diagrams, the lines connecting alternatives and their covering criteria are often omitted or reduced in number (Figure 1). Regardless of any such

simplifications in the diagram, in the actual hierarchy each alternative is connected to every one of its covering criteria.

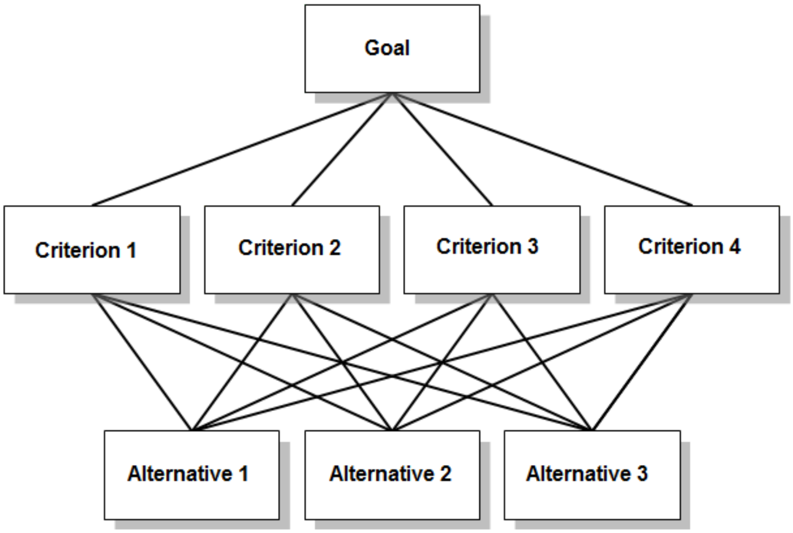


*Figure 1: A simple AHP hierarchy*

## 2.2 The mathematical concept of the AHP method

AHP method is based on the following axioms:
Reciprocity axiom: If the element A is n times more significant than the element B, then element B is 1/n times more significant than the element A;
Homogeneity axiom: Comparison only makes sense if the elements are comparable;
Dependency axiom: Allows the comparison among the group of elements of one level in relation to the element of a higher level, i.e. comparisons at lower levels depend on the elements of a higher level;
Axiom of expectations: Any change in the structure of the hierarchy requires recalculating priorities in the new hierarchy.
The problem structure consists of disassembling particular complex decision problems into a series of hierarchy, where each level represents smaller number of the managed attributes.
Phase two of AHP begins with collection of data and their measurement. Decision maker assigns relative marks to couples of attributes of one hierarchical level, and that for all levels of the entire hierarchy. Thereby, the presented evaluation scale is used (Table 1).
The result is a corresponding matrix of pairwise comparisons that are appropriate for each level of the hierarchy.
The third phase of the AHP application is estimation of the relative weights. Matrix of comparisons will be 'translated' per couples into problems of determining their

eigenvalues in order to obtain normalized and unique eigenvectors, as well as the weight of all the attributes on each level of the hierarchy $A_1$, $A_2$ ,..., $A_n$, with the weight vector $t=(t_1,t_2,...,t_n)$.

The overall synthesis of the problem is carried out in the following way: participation of each alternative is multiplied by the weight of the observed criterion, and then these values are summed up for each alternative separately. The resulting information is the weight of the observed alternative in the model. In the same way, the weight is determined for all other alternatives, after which the final order of alternatives in the model can be determined. Any comparison between two elements (models) of hierarchy is made using Saaty's Scale [4], [10], [11]

$$S = \left\{\frac{1}{9},\frac{1}{8},\frac{1}{7},\frac{1}{6},\frac{1}{5},\frac{1}{4},\frac{1}{3},\frac{1}{2},1,2,3,4,5,6,7,8,9\right\} \tag{1}$$

The priority, which one alternative has in relation to other, is expressed with descriptive values.

*Table 1. AHP pairwise comparison scale adopted from Saaty*

| **Intensity of importance** | **Definition** | **Explanation** |
|---|---|---|
| **1** | Equal importance | Two activities contribute equally to the objective |
| **3** | Moderate importance | Experience and judgement slightly favor one activity over another |
| **5** | Strong importance | Experience and judgement strongly favor one activity over another |
| **7** | Very strong or demonstrated importance | An activity is favored very strongly over another, its dominance demonstrated in practice |
| **9** | Extreme importance | The evidence favoring one activity over another is of the highest possible order of affirmation |
| **2,4,6,8** | Intermediate values | Requires compromise or further division |
| **Reciprocals of above** | If factor i has one of the above numbers assigned to it when compared to factor j, then j has the reciprocal value when compared with i | A reasonable assumption |

## 2.3 Consistency

AHP method belongs to the group of popular methods, because it has the capability to identify and analyze the consistency of decision-makers in the process of comparing elements of the hierarchy. Since the comparison of alternatives is based on a subjective

assessment by the decision makers, there is need for constant monitoring, in order to provide the necessary accuracy [3].
AHP method enables monitoring the consistency of assessments at any time in the process of comparing pairs of alternatives. Using index consistency:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

where $\lambda_{max}$ is the maximum eigenvalue of the matrix comparisons, the ratio of consistency $CR = CI/RI$ is calculated, where $RI$ is a random index, (consistency index of the matrix dimensions $nxn$, randomly generated pair comparisons), for which we use Table 2 (with theoretical values):

*Table 2. Random index for each matrix size (adopted from Saaty 1982)*

| Matrix size (n) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Random index (RI) | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 |

Thereby $\lambda_{max} \geq n$, and the difference $\lambda_{max} - n$ is used in measuring the consistency of assessment. If $\lambda_{max}$ is closer to $n$ value, assessment is consistent. If for the comparison matrix applies $CR<0.10$ , assessment of the relative importance of the criteria (alternative priorities) are counted as acceptable. Otherwise, the reasons for that unacceptably high inconsistency assessment need to be found.

## 3. EXAMPLE OF AHP ANALYSIS - CASE STUDY

The aim of this paper, based on the evaluation and comparison of proposed alternatives in the construction industry, is to make the selection of projects whose implementation will have the most significant impact on the sustainable development and the reduction of energy consumption [8], [9]. Until the election, the decision maker can reach only through implementation of complex scientific and analytical procedures. For this purpose, AHP method is formed [1], [2].
By application of AHP analysis, the criteria for selection of the best construction solutions for the sustainable development were established. In this case, three project implementations A, B, C, based on the 5 criteria, are estimated. For the selection criteria, the following characteristics were taken into account:

1) Sustainable location (construction based on pollution prevention, the impact on the development of the building place, transport alternatives, management, planning and development)

2) Energy and atmosphere (commissioning, optimization of the complete building consumption, cooling system management, the use of renewable energy sources, measurement and certification)

3) The efficiency of water consumption (reduction of water consumption in the area, reducing water consumption in the facility and strategies related to waste water)

4) Materials and resources (recycling location, re-use of buildings, waste management, buying materials produced in the region, materials with recycled content, rapidly renewable materials, unprocessed materials and sustainable materials made of wood)

5) The quality of the interior space (cigarette smoke control, outdoor air quality, ventilation, indoor air quality, the use of materials with low emissions, the control of heating and lighting), functionality and durability.

6) Financial, social and economic aspects
The following tags are introduced:
E – Energy and atmosphere, efficiency of water consumption
M – Materials and resources
K – The quality of the interior space, functionality and durability
L – The choice of location, planning and development,
F – Financial, social and economic aspects
T – Weight coefficients

Hence, we need to find the best solution after all simultaneously considered criteria, although some of them are partially or totally conflicted. For this purpose, AHP method is formed. Based on the evaluation criteria, the matrix of comparisons is formed.

*Table 3. Attribute comparison on the first level (decision criteria)*

| | E | M | K | L | F | T |
|---|---|---|---|---|---|---|
| E | 1 | 2 | 3 | 5 | 8 | 0.435 |
| M | 1/2 | 1 | 2 | 4 | 7 | 0.281 |
| K | 1/3 | 1/2 | 1 | 2 | 5 | 0.159 |
| L | 1/5 | 1/4 | 1/2 | 1 | 3 | 0.086 |
| F | 1/8 | 1/7 | 1/5 | 1/3 | 1 | 0.038 |

$$\lambda_{max} = 5.076, \quad CI = 0.019, \quad CR = 0.017 < 0.10 \tag{3}$$

*Table 4. Matrix of relevant importance of alternative in relation to the attribute E (energy and atmosphere, efficiency of water consumption)*

| E | A | B | C | T |
|---|---|---|---|---|
| A | 1 | 6 | 8 | 0.769 |
| B | 1/6 | 1 | 2 | 0.147 |
| C | 1/8 | 1/2 | 1 | 0.084 |

$$\lambda_{max} = 3.018, \quad CI = 0.009, \quad CR = 0.015 < 0.10 \tag{4}$$

*Table 5. Matrix of relevant importance of alternative in relation to the attribute M (materials and springs)*

| M | A | B | C | T |
|---|---|---|---|---|
| A | 1 | 1/4 | 6 | 0.243 |
| B | 4 | 1 | 9 | 0.701 |
| C | 1/6 | 1/9 | 1 | 0.056 |

$$\lambda_{max} = 3.108, \quad CI = 0.054, \quad CR = 0.093 < 0.10 \tag{5}$$

*Table 6. Matrix of relevant importance of alternative in relation to the attribute K (the quality of the interior space, functionality and durability)*

| K | A | B | C | T |
|---|---|---|---|---|
| A | 1 | 1/8 | 1/4 | 0.070 |
| B | 8 | 1 | 4 | 0.707 |
| C | 4 | 1/4 | 1 | 0.223 |

$$\lambda_{max} = 3.054, \quad CI = 0.027, \quad CR = 0.047 < 0.10 \tag{6}$$

*Table 7. Matrix of relevant importance of alternative in relation to the attribute L (selection of location, planning and development)*

| L | A | B | C | T |
|---|---|---|---|---|
| A | 1 | 2 | 1/6 | 0.147 |
| B | 1/2 | 1 | 1/8 | 0.084 |
| C | 6 | 8 | 1 | 0.769 |

$$\lambda_{max} = 3.018, \quad CI = 0.009, \quad CR = 0.015 < 0.10 \tag{7}$$

*Table 8. Matrix of relevant importance of alternative in relation to the attribute F (Financial, social and economic aspects)*

| F | A | B | C | T |
|---|---|---|---|---|
| A | 1 | 1/4 | 1/8 | 0.070 |
| B | 4 | 1 | 1/4 | 0.223 |
| C | 8 | 4 | 1 | 0.707 |

*Table 9. Synthesized table for selection of the optimal alternative*

$$\lambda_{max} = 3.054, \quad CI = 0.027, \quad CR = 0.046 < 0.10 \tag{8}$$

| Weight criteria | A | criteria x A | B | criteria x B | C | criteria x C |
|---|---|---|---|---|---|---|
| 0.435 | 0.769 | 0.335 | 0.147 | 0.064 | 0.084 | 0.037 |
| 0.281 | 0.243 | 0.068 | 0.701 | 0.197 | 0.056 | 0.016 |
| 0.159 | 0.070 | 0.011 | 0.707 | 0.112 | 0.223 | 0.035 |
| 0.086 | 0.147 | 0.013 | 0.084 | 0.007 | 0.769 | 0.067 |
| 0.038 | 0.070 | 0.003 | 0.223 | 0.008 | 0.707 | 0.027 |
| | | 0.430 | | 0.388 | | 0.182 |

## 4. CONCLUSION

The maximal eigenvalues $\lambda_{max}$ and weights are obtained in software packet Mathematica. By using the AHP analysis the best alternative (optimal solution) is selected. With precise implementation procedure in applying AHP method is obtained that the first alternative A has the highest total value 0.430, which is the best alternative in the selection of construction project from the perspective of the sustainable development. Proposed AHP method can be successfully applied in decision-making in different segments of civil engineering. The mathematical and in that way the objective methods that support the decision making process in construction, undoubtedly help in daily construction work. Method AHP provides the optimal solution between the defined alternative.

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# ВИШЕКРИТЕРИЈУМСКА АХП МЕТОДА ЗА ОДРЖИВ РАЗВОЈ У ГРАЂЕВИНАРСТВУ

***Резиме:*** *Полазна претпоставка је да је одржива градња свакако један од значајнијих делова одрживог развоја. У вези са одрживим развојем, одржива градња мора осигурати трајност, квалитет, финансијску, економску и еколошку прихватљивост. Изградња и употреба објеката имају велики, директан и индиректан утицај на животно окружење. Конструктори и градитељи се суочавају са изазовом да задовоље потребе одрживог развоја. У доношењу важних одлука, вишекритеријумска анализа може бити од великог значаја. Метода АХП аналитичких хијерархијских процеса, као математичка метода, заснива се на принципима вишекритеријумског одлучивања, где се из једне расположиве групе алтернативно бира најповољнија, а на основу дефинисаног броја критеријума за одлучивање. Више атрибута имају различиту важност и изражавају се помоћу различитих скала. Циљ овог рада је да се АХП методом омогући доносиоцима одлуке у грађевинарству да поставе приоритете и донесу квалитетну одлуку, узевши у обзир и квалитативне и квантитативне аспекте за одрживост развоја.*

***Кључне речи:*** *одрживост, грађевинарство, математика, АХП метод*