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CRISP AND FUZZY ADVANCED HIERARCHY PROCESS FOR THE DESIGN OF AN INDUSTRIAL BUILDING BASED ON TIMBER AND STEEL ELEMENTS

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Abstract: *Sustainable Development (SD) emerged in the late 90's, as a response to severe environmental problems worldwide and the public pressure they created. SD introduced the notion of environmental and social consequences of anthropogenic activity, affecting the paradigm of 'business as usual' and increasing the complexity of design and implementation of new, environmentally and socially responsible, strategies. Decision making under these new coordinates has to tackle with both quantitative and qualitative information, as well as the relationship between the two. A combination of different knowledge domains, and the different methodological options they introduce, is necessary for tackling complex problems. This research focuses on this (new) challenge, specifically for the construction sector. Two methods, crisp and fuzzy Analytical Hierarchical Process (AHP), are used for the evaluation of the design of a (generic) industrial building. A decision making process is developed, where a problem hierarchy is created, expert knowledge is gathered and evaluated and final priorities of alternative solutions are produced, through a crisp and a fuzzy handling of data. The case study offers a first exploration, indicating the applicability and easy of use of the methods, presenting preliminary results and proposing further research trajectories.*

1 INTRODUCTION

The method of Analytical Hierarchical Process (AHP) is used for the solution of difficult multi-criteria optimization and decision making problems. The optimization problem is splitted in simplest one-by-one comparison questions, which in turn can be resolved from one or more experts. This expert information is used for the evaluation of the various alternative solutions to the problem and the hierarchical evaluation of them. Finally the various alternatives are sorted and the solution is presented to the end-user. Adoption of fuzzy variables and fuzzy inference tools allows us extend the previous method to work with fuzzy variables.

An academic example is solved with details: the design of an industrial building using steel and timber structural components. Timber and steel structures, due to the reusability of the materials, are best solutions from the environmental acceptability point of view.

2 METHODOLOGY

2.1 Multicriteria analysis

Designing and decision making with multiple criteria can be done by one of the three approaches:

- *multicriteria hiearchy of alternatives* which is based on dyadic comparison between the alternatives. It can be used on problems with a finite number of discrete alternatives.
- *multicriteria mathematical programming* which is used on models with infinite alternatives,
- *multicriteria utility theory* which transforms the multicriteria problem into a single-criterion one by using suitable utility (compromise) functions

A number of methods are used for the solution of multicriteria analysis problems, including ELECTRE I, II, PROMETHEE, Compromise programming, Goal programming, Weighting method and Analytic Hierarchy Process.

2.2 Fuzzy logic and systems

In the case that the variables of the system are corrupted with uncertainty, fuzzy variables can be used [1]. All computations arising within the multicriteria problem have to be performed with fuzzy variables calculus. These calculations can be performed with various degrees of accuracy, depending on the application on hand.

2.3 Analytic Hierarchy Process and Fuzzy AHP

The AHP method resolves a complicated decision making problem based on pairwise comparison between various elements and alternatives. The method is composed of the following steps:

1. The hierarchic analysis of the decision making problem into decision elements
2. The collection of preferances from the decision making person, related to the rationale of his/her decision
3. The calculation of partial priorities (weights) for the decision elements
4. The composition of partial priorities into general priorities of the various alternative solutions.

Technical details of the method can be found, among others, in [2], [3]

The usage of fuzzy variables within AHP allows us treat certain objective, uncertain or erroneous data. A simple version of Fuzzy AHP uses triangular fuzzy variables during pairwise comparisons. At the step of final evaluation of the alternatives the fuzzy results before final sorting must be defuzzified. Further information related to Fuzzy AHP can be found in [4]

3 CASE STUDY: DESIGN OF AN INDUSTRIAL BUILDING USING STEEL AND TIMBER ELEMENTS

3.1 Formulation of the problem

Rational evaluation of alternatives in the building sector, taking into account both direct and known costs (materials, labor, construction, transportation) as well as indirect cost and a life cycle analysis (demolition, reusage of materials, environmental and social impact) is a difficult task. From this point of view, timber and steel structures due to the high degree of reusability of the material, are better than the reinforced concrete ones.

As a model application the construction of a small industrial building of general purpose has been considered. The four alternative solutions are:

- **F1** steel frame with high-tech (e.g. composite) panels as walls,
- **F2** steel frame and traditional (e.g. brickwork) walls,
- **F3** Timber panel and traditional walls, and
- **F4** Timber frame and composite panels.

3.2 Hierarchy decision of the problem

The hierarchy with the various criteria involved in the AHP study has the following elements:

- C1 Economic costs
  - WE1 Capital costs
    - W11 Ongoing costs
    - W12 Demolition / end of life
    - W13 Operation
  - WE2 Maintenance
    - W21 Adaptability and flexibility
    - W22 Efficiency and effectiveness
- C2 Environmental aspects
  - WEA1 Resource management
    - WEA11 Managed sources of input materials
    - WEA12 Energy use
  - WEA2 Energy use
    - WEA21 Embodied energy
    - WEA22 Energy demand
  - WEA3 Biodiversity
  - WEA4 Resource extraction
- C3 Social aspects
  - WS1 Environmental profile of materials used
  - WS2 Indoor environmental quality
  - WS3 Ease of removal of hazardous materials
  - WS4 Long term health risks
- C4 Technological aspects
  - WTA1 Maturity and reliability
  - WTA2 Efficiency of contruction methods

3.3 Expert opinion

Experts evaluate every pair of criteria belonging to the same level by using the rating proposed by Saaty:

- 1 for criteria of equal importance
- 3 weak dominance of first criterion w.r.t. the second
- 5 strong dominance
- 7 proven dominance
- 2-8 intermediate values

Members of our research group were asked to fill in questionnaires and acted as experts for the evaluation of the criteria within the limits of the reported study. In the future we plan to support this step with selected experiments or results of numerical models, in order to make the evaluation objective.

3.4 AHP computations and calculation of best alternative

By using the algorithm of AHP the following decision table is produced for the four alternatives:

- **F1** 0,4540
- **F2** 0,3339
- **F3** 0,1350
- **F4** 0,0769

It is clear that from the experience of the experts the first solution is better than the second one etc.

3.5 Fuzzy AHP results

The notes proposed by Saaty are extended with triangular fuzzy membership functions to the following fuzzy evaluation notes:

Classical Saaty	description	Fuzzy Saaty			
			m_i	α_i	β_i
1	equal importance	$\bar{1}$	1	1	3
3	weak dominance	$\bar{3}$	3	1	5
5	strong dominance	$\bar{5}$	5	3	7
7	proven dominance	$\bar{7}$	7	5	9
9	intermediate	$\bar{9}$	9	7	9
2	intermediate	$\bar{2}$	2	1	3
4	intermediate	$\bar{4}$	4	3	5
6	intermediate	$\bar{6}$	6	5	7
8	intermediate	$\bar{8}$	8	7	9

After calculations using a simplified calculus of fuzzy variables the fuzzy result is:

Fi	m	α	β
F1	0,392610538	10,25090243	14,52304669
F2	0,298285826	7,536559008	10,21202736
F3	0,113588928	2,682335962	4,207367459
F4	0,070351484	1,471270857	2,271786158

For final ranking (defuzyfication) of the results, the total integral value method is used [5]:

$$I_{(A)} = \frac{1}{2} * [\lambda * \beta + m + (1 - \lambda) * \alpha], \lambda \in [0, 1] \tag{1}$$

For different values of λ the risk policy of the used experts can be taken into account.

For λ = 0, pessimistic vs risk:

I(F1) =	5,321756483
I(F2) =	3,917422417
I(F3) =	1,397962445
I(F4) =	0,770811171

For λ = 0,5, moderate vs risk:

I(F1) =	6,389792548
I(F2) =	4,586289504
I(F3) =	1,779220319
I(F4) =	0,970939996

For λ = 1, optimistic vs risk:

I(F1) =	7,457828612
I(F2) =	5,255156592
I(F3) =	2,160478194
I(F4) =	1,171068821

In this particular example the ranking of the four alternatives does not change for different values of λ.

4 CONCLUSIONS

AHP and Fuzzy AHP are well known decision making methods for the solution of difficult multiobjective problems. First attempts to use these techniques on the optimal choise of engineering alternatives have already been published. Especially when the total cost of a technical work is taken into accoynt, including Life Cycle Analysis (LCA) and environmental impacts. In structures steel and timber elements are most suitable for such a study, due to the high degree of reusability of the two mentioned materials. An academic case study concerning the design of an industrial building has been used to demonstrate the concepts. Technical details of the implementation as well as all calculations can be found in the diploma thesis of the second author.

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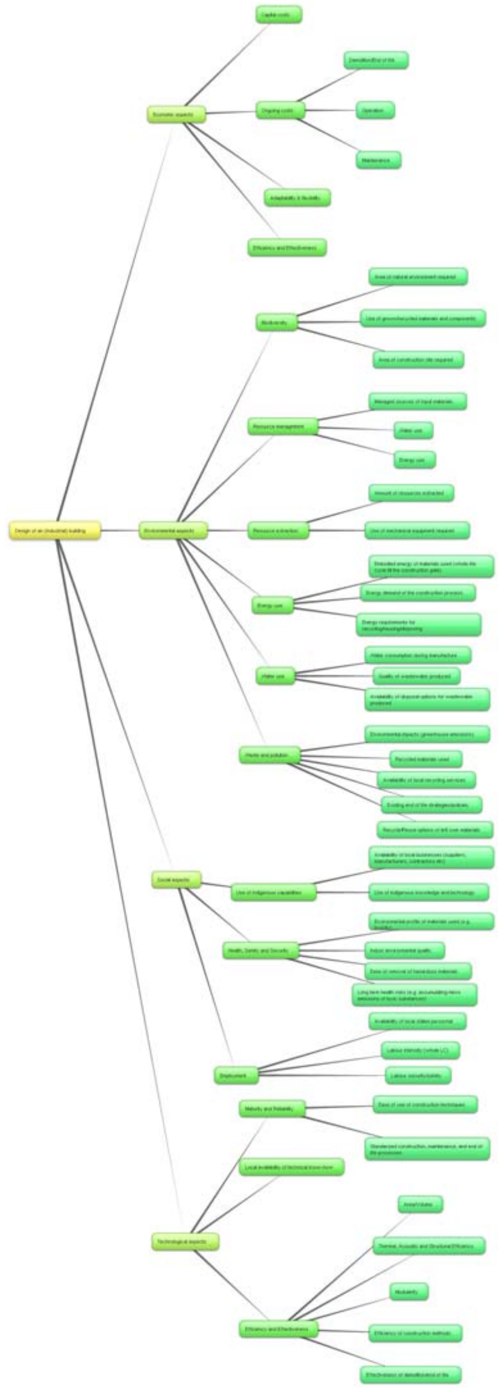

Figure 1: Components of the proposed hierarchy