# ANALYTIC HIERARCHY PROCESS: A USEFUL TOOL FOR ASSESSING SUSTAINABILITY IN THE CONCRETE INDUSTRY

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## 1. Introduction

The importance of sustainability is on the rise within the concrete industry, and with it has come increased consideration of the environmental impact and sustainability of concrete construction practices and materials. This gradual shift in thought is, however, complicated by the diversity of perspectives and lack of specificity on what qualifies as "sustainable" and the broad scope of sustainable development. A variety of guidelines have been developed to assess sustainability, such as the United Nation's sustainability indicator framework, or long-term environmental impact, such as the ISO 14040-series life cycle assessment, but these do not consider the specific conditions and needs of the concrete industry. Concrete-specific standards such as the JSCE "Recommendation of environmental performance verification for concrete structures (draft)" or the ISO sub-committee *Environmental Management for Concrete and Concrete Structures*, which is still under development, will form the basis for improved, environmentally-conscientious practices and materials in the future, but even they neglect a critical aspect underlying sustainability: that it is a human vision with human values [1]. What may be sustainable in one region of the world under a given set of social, economic, and environmental conditions may not be sustainable in a different region of the world under different conditions.

Since concrete construction occurs globally in a diverse number of markets and conditions, assessment systems need to be constructed considering this difference. This will require not only flexibility in considering and balancing a wide variety of needs, but will also necessitate the integration of qualitative perspectives on how sustainability varies from region to region. Therefore, tools which can address these issues should be explored for application in the concrete field.

## 2. Analytic hierarchy process

The Analytic hierarchy process (AHP) is a multi-criteria framework developed by Thomas L. Saaty for making complex decisions. It's been applied to a wide variety of decision-making processes such as quality improvement strategy for computer design, relocation of an earthquake-devastated city, oil platform construction, research project funding allocation, and more. The basic premise of AHP is to model a decision-making problem as a hierarchy composed of quantifiable elements and their relations and alternatives towards a goal [2]. The weight of these elements towards the goal is determined by comparing the elements against each other in pairs using quantitative or qualitative judgment values, which are converted to numerical values that can be used to determine weights for the elements in the hierarchy and allows comparisons between different elements. Weights can be similarly applied to the alternatives for achieving the goal, based upon the weights of the elements of the hierarchy and the characteristics of the alternatives, and a decision for achieving the goal can then be made by analyzing the weights of the different alternatives.

AHP can be applied to the problem of assessing sustainability in the concrete industry in multiple ways [3]. As the concrete industry is made up of a variety of stakeholders, they will necessarily have different value systems and view concrete sustainability from different perspectives. Converting these qualitative perspectives into quantitative values for comparatively assessing the different options – such as alternative material choices, structural systems, project designs, etc. – can provide decision-makers with a numerical means for choosing the most sustainable option. Furthermore, concrete materials possess many different performance characteristics but there is oftentimes a trade-off between different aspects, such as reduced durability when utilizing recycled materials. AHP can also be applied to balance these, particularly considering differing stakeholder values.

## 3. Utilizing AHP to assess material sustainability

To demonstrate the utility of AHP for the concrete industry, an example will be given in which concrete materials utilizing waste and recycled materials with similar strengths but differing environmental impacts and durability are compared and the material with the best "balance" is determined using AHP [4]. The mix properties of the eight materials, which have various combinations of fly ash (FA), blast furnace slag (BS), and recycled aggregate (RA), are summarized in Table 1. All of these materials have strength similar to the "control" mix, which represents normal-use concrete with a water-

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cement ratio of 50 and 28-day strength of roughly 40 MPa. Durability was evaluated using the air permeability coefficient and environmental impact was evaluated using $CO_2$ footprint and volume of raw materials.

Figure 1 shows the relationship between the environmental impacts and durability. It can be clearly seen that no single mix stands out as having the best balance of all three criteria. To determine the best balance, a hierarchy for assessing these materials was constructed as shown in Figure 2, with "sustainable concrete" given as the goal, the environmental impacts and durability as the evaluation elements, and the eight materials as the alternatives. For the analysis, equal importance was given to all three criteria. The comparative weights of materials was calculated using the AHP methodology and are given in Figure 3, and from this result a single material can be identified as the best alternative. Varying the weights of the criteria – for example, placing more importance on durability over environmental aspects – can accommodate and identify which alternative best meets the needs of differing perspectives. Furthermore, comparing the weights of the alternatives to that of the control can verify that the selected material is more sustainable than the current normal-use material.

Table 1 Mix properties of concrete materials

| Variable | Values |
|---|---|
| Water-binder ratio | 30, 37.5, 45 |
| Binder content | 50% C – 50% FA<br>50% C – 25% FA – 25% BS |
| Recycled aggregate replacement ratio | 0%, 50%, 100% |

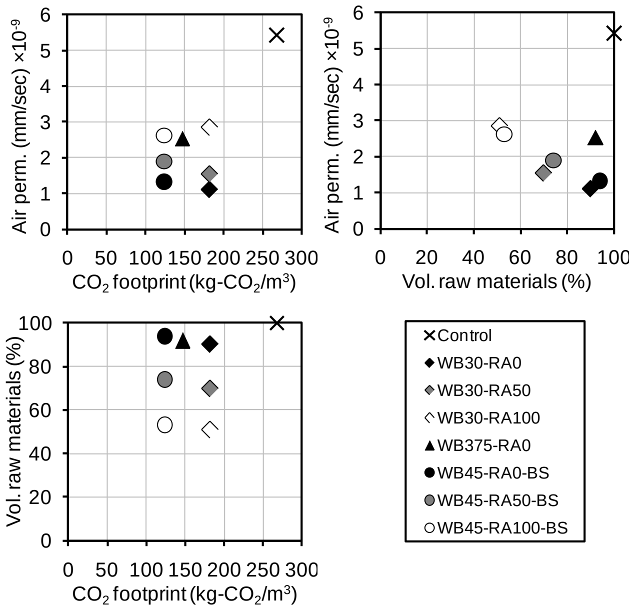

Figure 1 Relationship between different environmental impacts and durability

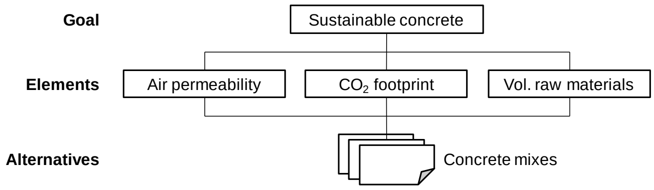

Figure 2 Analysis hierarchy with assessment criteria and alternative materials

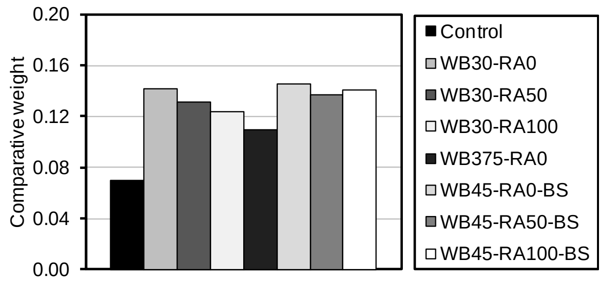

Figure 3 AHP calculation results when applying equal importance to the three performance aspects

**4. Flexibility of AHP for addressing different issues**

AHP can consider different value systems not only by varying the importance of the criteria, but also by including different criteria or by restructuring the analysis hierarchy. In the previous example, the materials were only evaluated considering three criteria, and the relative value of the actual materials themselves was not considered. However, in Japan blast furnace slag is more widely used than fly ash, and thus the utilization of blast furnace slag should be given more value as its usage better serves industrial ecology in Japan. This illustrates another important aspect of the flexibility of AHP, in that varying the criteria weights or restructuring the hierarchy can be used to reflect different regional conditions. As this is a fundamental aspect of sustainability, as discussed at the beginning of this paper, the value of AHP for assessing sustainability in the concrete industry is clear.

**References**

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