# Success factors for integration of sustainable practices at high performance building processes through AHP-based MCDM

**Molina-Moreno, F. (1) and Yepes, V. (2)**

(1) Universitat Politècnica de València. framomo4@cam.upv.es
(2) Instituto de Ciencia y Tecnología del Hormigón (ICITECH) Universitat Politècnica de València . vyepes@cst.upv.es

Much of the efforts towards low carbon built environment focus on the building energy performance and the relationship between occupant behavior and efficient supply facilities, arguing that impacts are higher during operational stage. However little progression has been The ongoing study aims to provide a simplifed method to decide upon constructive systems for structural slabs based on hierarchical multicriteria weights applied to a set of criteria through a value function: durability, resource depletion, climate impact, investment cost, user comfort and functional desing. The main function of slabs as load distribution layers of the structural frame used to be the solely priority of design practice. Other functions of the building as a dynamic system interact within the environment and occupants along time. Currently dealing with sustainable materials and life cycle inventories we aim to provide with a reproducible method for early election of the type of slab by embedding environmental (resource efficiency) and social (durability and performance) criteria among the design criteria. First, we seek for a way to hierarchically distribute the criteria and sub-criteria among the goals against resource depletion and the diverse alternatives. AHP-based MCDM is chosen to build a multi-level hierarchical structure of objectives, criteria, subcriteria, and alternatives. The analysis outlines the expert preferences for factors of buildability and cost premium of implementation of high environmental value of project design. Further analysis will focus on interrelation among factors.

Keywords: **AHP-based MCDM, value function, environmental impact, construction cost, resource depletion, functionality, construction systems elicitation.**

## 1. Introduction

Much of the efforts towards low carbon built environment focus on the building energy performance and the relationship between occupant behaviour and efficient supply facilities, arguing that impacts are higher during operational stage.

The paper is organised by a first description of successful criteria for contractors, structural engineers and building sustainability assessors according to a literature review. This desk research stablish the basement of a hierarchical structure of assessment criteria. Further analysis of the different groups of expert's preferences will outline how this differ among practitioners, which is the first step to overcome barriers against resource depletion.

### 1.1. High performance building processes

*High performance building processes* are those where a balance of success factors in terms of profitability and project overall benefit meet not only user but stakeholder requirements (1), (2). The user needs considered within social dimension are transferred into a suite of requirements to comply functionality and flexibility of use overtime. This is AS stated in the norm prEN 15643-1 stated by the general framework CEN/TC 350 'Sustainability Assessment of Buildings' (Figure 1). The ongoing research aims to aid the regulation about criteria consensus among stakeholders, including contractors whose major satisfaction is project success.

### 1.2. Success factors in building engineering

We identify two kind of factors:

1. Objective factors, considered as drivers for performance: time, cost, safety. Current measuring lies on:

- Schedule; time overrun, performance rate (gross floor built area per hour).
- Cost (unit cost versus cost overruns)

2. *Subjective* factors; considered as those contributing to social concerns:
   - Quality
   - Professional satisfaction, customers (owner).

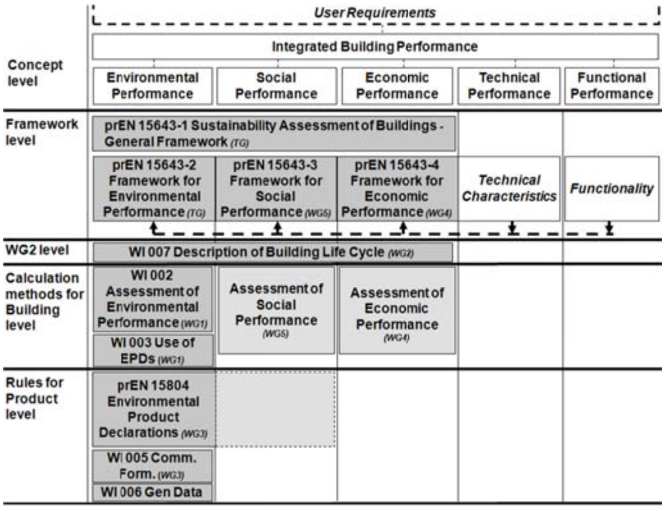


*Figure 1 Framework of CEN/TC 350 for user requirements*

## 2. Framework: Lifetime engineering

In agreement to the lifetime engineering framework (3), (4), other than stability criteria are considered. The availability of building services installation and maintenance becomes a design criteria concerning operational cost. The unplanned *obsolescence concept cited in* CEN/TC-350, (4) concept of building structures differs from the mechanical and degradation limit states. The complex measurement and inclusion of these criteria into the design process makes the need for:

- A decision tree to discard unfeasible design options due to boundary conditions
- A matrix of weighted criteria according to the average values from experts

### 2.1. Limitations of assessment tools implementation

It is well know that application of Life Cycle Analysis (LCA) it is the most accurate way to account environmental impacts but is not as simple to implement in the design procedure so it seems to be a final step of the design process. Checklist and assessment based on awarding points are not getting to the detail in the building processes itself, there is a missing step between the project design (for both design and construction stages) and real impacts' accountability. During design process, contractor's concerns address resource depletion while architects focus on efficiency along lifetime. Integration of both kind of stakeholders in the decision criteria weighting would better shape the real practice of building engineers and contractors to have a balanced decision making procedure (in selection of construction choices) among manufacturing, construction and operational burdens.

### 2.2. Potential benefits for building engineering

To enable clear spaces at high-rise buildings imply length spanning that can be covered by different type of slab elements. Pretension or posttensioned slabs or precast planks are feasible choices whose selection may be done as a result of technical criteria and construction cost. The flexibility of use is a relevant criteria for architects but not among structural engineers or contractors. Building services evolve to accomplish energy efficiency measures and do often interact with the structure and structural slab floors during installation of building services (indoor air comfort).

## 3. Methodology

The wide selection of slab types considered may respond to an interval of feasible solutions different enough so that certain hesitation among options is expected, according to span length and maximum deflection. The rationale of alternatives considered lies on the need to best perform at constructability.

### 3.1. Objectives of the methodology

The overall objective of this research is to support the decision process of building engineers, selection of a structural typology is done early in design but evaluation of sustainability compliance is afterwards done. It is our goal to disclosure the importance of factors which matters to contractors and engineers that fit together with the main environmental concerns in the construction industry; raw material consumption, resource depletion, and emissions (LCA and MFA approaches).

The main objective is to outline subcriteria considered in the literature for each of the wider criteria by involving decision makers and key roles representing stakeholders in the comprehensive of the selection of construction systems, according to consensus in criteria weights in hierarchy. Cost, quality and schedule were traditionally considered hard criteria for engineers and contractors but nowadays it is recommended to introduce the environmental criteria (5).

### 3.2. Rationale for Analytic Hierarchical Process choice

*AHP-based MCDM* is chosen to build a multi-level hierarchical structure of objectives, criteria, subcriteria, and alternatives. The goal is to show successful integration of MCDM for construction success and LCA approach so that contractor interests and user satisfaction (social benefit) meets. The first step is to select criteria so we proceed with a questionnaire through Delphi method.

| ***Specialisation*** | ***Total respondents*** | ***Valid responses*** |
|---|---|---|
| On-site specialisation | 17 | 88% |
| Structural performance | 17 | 82% |
| Environmental impact assessment | 14 | 93% |
| Construction budgeting | 14 | 71% |
| From all disciplines | 9 | 35% |

## 4. Criteria under consideration

Among all domain specific criteria most of them can be grouped in four main groups: Constructability, flexibility and functionality, environmental impacts and initial and long-term costs.

### 4.1. Constructability on site

Several definitions of constructability emphasize that good constructability must facilitate efficient, economical, and safe building process. Some authors work on measuring Success Factors during construction: (6), (7), as proved by current research (8), (9).

Speed of construction is directly related to construction costs. We include both criteria however, through subsequent sensitivity analysis to know the potential consequence of variations; how much the bottlenecks are influential on contractors and its affection to cost and how process can help to waiting times between tasks (casting of the uppermost floor, in case of in situ option, etc.).

### 4.2. Structural efficiency

Also slab thickness and horizontal stiffness are directly related, however they are considered as different sub criteria because their influence affects different aspects: dead loads of the slab and subsequent transfer into foundations and the static behaviour of the slab in terms of impact strength, shear failure and active deflection. The need for shear load connectors and other localized solutions may increase cost and environmental burdens due to process manufacturing.

### 4.3. Environmental impacts over lifecycle

#### 4.3.1. Extraction and manufacturing

Raw materials extraction and manufacture burdens imply considering new variables in the design system: the use of greater amount of concrete on construction do not always imply higher and/or relevant concrete costs, sometimes machinery leasing and set up is the bottleneck for upraising. Therefore contractors would not care about carbon emissions and energy used as one of the priority criteria, as material needed can be the criteria defining impacts flows as a direct data obtained from raw material quantification. As far as there is a need for changing the construction procedure the amount of concrete and steel remains in a secondary level. This criteria aims to account for an objective measurement of environmental burdens.

#### 4.3.2. End of life and demolition

Waste generated by deconstruction or demolition is accounted in volume and weight. While it is hard to predict the time in which those impacts would happen, our data source provide waste generation by construction materials, so we can include it in our impact analysis. However the easefulness for separating layers remains a problematic. Unless there is a separation of plaster from other materials of multi-layered exterior walls or mixed floor slabs are disadvantageous in separation for recycling. Since it is difficult to separate plaster from multi-layered exterior walls demolition. Therefore valorisation of materials becomes a cost-intensive task. Considering demolition stage, single layer exterior walls will be evaluated as low-carbon intensive at demolition stage.

### 4.4. Life time overall Costs

Construction cost used to be by far the most considered criterion when choosing a construction typology. It is directly attached to structural performance as regards materials However, the relative importance of costs attains uncertainty in early stages, resulting a limitation to tackle with in our research. Construction costs are directly related to stability and functional requirements. While the construction schedule and task are planned under cost optimality, so maintenance, repair and rehabilitation costs may be hindered by early decision makers. Repair costs are uncertain both in quantity and as regards occurrence time, so decision makers –consultants-, focus on construction costs. The concept of obsolescence in buildings is of interest for medium life construction elements (10-15 years), such as cladding, roof, walls and sealing joints. Long-life building elements –frame structure and foundations, slab floors-, require higher lifetime so durability gets importance factor for measurement and assessment. Such would be an indicator of social sustainability since repair costs are afforded by the building property or lifetime occupants.

## 5. Criteria structure for the model

### 5.1. Buildability criteria selected

- Setting time between construction of the uppermost concrete slab floors
- Complexity of the working site programming

### 5.2. Structural efficiency criteria selected

#### 5.2.1. Structural performance

- Load bearing capacity (related to length span) and structural stiffness
- Limit states: Stability (USL, SSL)
- Limit states: Durability (risk informed decision making?)

#### 5.2.2. Flexibility and Functional design

- Slab floor thickness including floor ceiling (cm)
- Degree of stiffness; active deflection (cm)
- Flexibility for building services commissioning, maintenance and dismantling.

#### 5.2.3. Cost Estimation

Cost is, by far, the most considered criterion chosen while selecting a slab solution. However, this has changed during recent years due to increasing interest on lifetime (10) and environmental costs (11). Several construction costs are directly related to stability during construction and functional requirements. Focus on construction schedule planning, safety and construction costs may hinder maintenance, repair and rehabilitation costs. Those costs triggered by obsolescence of the structures (12), these are of major interest for the building property and users.

The need for specialised labour forces and specialised machinery will certainly increase costs. This will be measured according to a national construction costs database both for construction and demolition stages.

#### 5.2.4. Social criteria

Several criteria known as social are not considered in the decision process because remain out of the system boundaries. The following are a matter of additional research:

- User comfort: noise reduction (due to impact.
- Safety and Security: Fire safety in terms of time.
- Adaptability: flexibility to change of use within and beyond design lifetime, in terms of reduction of obsolescence coefficients.

#### 5.2.5. Construction stage

The need for fast erection flooring in multistorey buildings need to widely consider factors as buildability (site accessibility and schedule). In the case of cast-in-place multistorey buildings the highest constraint for erection is the waiting time before one slab is ready to sustain formwork boards of the uppermost slab. Also safety reasons require minimise setting times of shoring and striking as ongoing efforts to optimize the process.

### *1. Weaknesses and measurement limitation*

Therefore precast solutions are known for as optimal in terms of construction costs. However emissions due to transportation are not quite considered early in the design process, meaning a misleading of the concept.

### Final remark

Early preview interdependencies among subcriteria, in that case ANP becomes crucial for next steps; it can handle dependencies among subcriteria which AHP cannot.

## 6. Final draft hierarchical tree

The reviewed criteria can be gathered into four main groups:

1. *Constructability and performance;*
2. *Structural efficiency functional design;*
3. *Environmental impacts;*
4. *Overall lifetime costs.*

| Criteria Requirements | | Subcriteria | Subcriteria considers |
|---|---|---|---|
| CONSTRUCTABILITY ON SITE | 1 | Complexity of site programming. Transport planning to site, special material and stock allocation in site | Waiting times for transport authorizations. Dependence on third parties Early implication of manufacturer |
| | 2 | Delay until operative uppermost slab is operative to build on it. In situ working time versus precaster plant | On site material assembling, casing auxiliaries concrete dumping, vibration, compaction, curing and hardening, shoring and striking, |
| STRUCTURAL EFFICIENCY | 3 | Slab overall thickness (affects clearance height space and overall building heights) | Pronounced overhangs of girders, floor ceiling and abacus hinder passage facilities. |
| | 4 | Stiffness (as the difference between limited and estimated active bending) | Affection on non-structural elements, sound insulation (acoustics) and undesired vibrations |
| IMPACTS DURING LIFECYCLE | 6 | Primary Embodied Energy in manufacturing and construction | Embodied Primary Energy |
| | 7 | Resource depletion - Raw material (%) | Raw material Extraction - Recycling content |
| | 8 | Potential for reuse and recycling (Material Flow Analysis) | Recyclable Content (%) - post consumption |
| | 9 | Contribution to global warming | Atmospheric CO2 emissions |
| LIFECYCLE COSTS | 10 | ∑ Construction costs (material, transport) | Includes specialized labor and transportation costs |
| | 11 | ∑ Estimated operational costs on life time | Refurbishment and maintenance estimation. Deterioration processes under uncertainties |

*Figure 2 Hierarchy of requirements and subcriteria proposed*

### 6.1. Decision method

Analytical Hierarchical Process, AHP henceforth, a consensus methodology (14) to select the best choice according to a set of criteria and subcriteria.

### 6.2. Further analysis

Pair-wise comparisons are gathered at the moment of this submission, results are expected to enlighten a reliable criteria weighting set. Because of different professional profiles and experience results are expected to respond to different interests. Concluding remarks highlight that the relevance on construction costs while long term would remain in a secondary level.

## 7. References

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