DECIDING A SUSTAINABLE ALTERNATIVE BY 'CHOOSING BY ADVANTAGES' IN THE AEC INDUSTRY

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ABSTRACT

When deciding what alternative is more sustainable than others (i.e., selecting materials while considering environmental-, social-, and economic outputs) in the AEC industry, stakeholders need to select a method for their decision-making process. From the literature it appears to be assumed that all multiple criteria decision analysis (MCDA) methods are equal or that the differences between them does not matter, and it is left to the user to select any one. In this study we argue that methods matter. This paper explores what characteristics make a method viable and, correspondingly, what characteristics disqualify methods. We compare and contrast value-based methods versus Choosing By Advantages (CBA). In addition, we explore what characteristics would make a method be aligned with lean thinking. We have found that methods that rank factors or values, such as value-based methods, require a high level abstraction, inducing unanchored conflicting questions. In contrast, CBA methods base judgments on anchoring questions, which are based on valuing the importance of advantages between alternatives. CBA produces fewer conflicting questions and allows stakeholders to discuss what they value in a richer context. We discuss why we think that CBA methods are superior to other methods for making sustainability decisions. In addition, we discuss why CBA is in line with lean thinking.

KEYWORDS

Decision-making methods, sustainability, Lean construction, Choosing By Advantages (CBA), multiple criteria decision analysis (MCDA).

INTRODUCTION

Decision-making lies at the heart of many human endeavors, including designing and constructing. Design teams use decision-making skills for designing products and processes, for developing alternative building systems along the way, and finally shaping construction projects, thereby causing environmental, social, and economic impacts. Unfortunately, a popular belief appears to be that decision-making methods do not matter; the authors believe they do. According to Suhr (1999), decision-

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making methods produce decisions, decisions trigger actions, and finally actions cause outcomes. Consequently, if the outcomes matter then the selection of the decision-making method also matters. Decision methods used for assessing sustainable alternatives are responsible for an important portion of environmental, social and economic impacts.

Our research indicated a lack of sound methods for decision making to choose one- among various sustainable alternatives. Decision making in the AEC industry appears to often use 'decide, present, and defend' approaches; resulting in decisions made without formal discussion, rigorous analysis, nor documentation.

This paper is part of research with the objective of improving the decision-making process of selecting sustainable alternatives in the AEC industry. This paper explores the following questions: (1) What method should support the decision-making process for selecting sustainable alternatives in the AEC industry? (2) What characteristics make a method viable and, correspondingly, what are characteristics that disqualify methods? (3) What characteristics would make a method be aligned with lean thinking?

This paper studies these questions by comparing and contrasting two multiple criteria decision analysis (MCDA) methods. Particularly, we explore value-based methods, widely used in the AEC industry, including the Analytical Hierarchy Process (AHP). In addition, we explore Choosing By Advantages (CBA) methods. Our hypothesis is that CBA is superior to value-based approaches, and we recommend that CBA be incorporated in the lean construction body of knowledge.

BACKGROUND

Construction projects are the result of the decision making process and the methods used. As is known, they have a high impact on sustainability. In fact, EPA (2009) states that in U.S., the environmental impacts of buildings over their life cycle include: 39% of total CO_2 emissions, 72% of total electricity consumption, 38.9% of total primary energy use, 13% of potable water consumption, 2.3 billion acres use, and 40% of landfill material generated (254 million tons annually). Are these outcomes sustainable? In our opinion they are not. Thinking about the Brundtland report (WECD, 1987) and the triple bottom line, we are clearly focusing in meeting our short term social and economic needs without considering the environment, which may affect the ability of future generations to meet their own needs.

Several studies describe how Lean can contribute to obtaining more sustainable outcomes in the AEC industry (e.g., Lapinski and Riley 2006). Lean practices are focused on increasing value to the customer while reducing waste, which helps to achieve better design and construction solutions using fewer resources (materials, labor, time, cost, etc.). Lean means designing product and processes at the same time, providing support not just to define what to achieve, but also how to achieve a sustainable project.

The most important decisions on a project are made in the design phase. Lean thinking can offer many tools and techniques to collaborate and find optimal solutions from a whole project perspective, considering sustainability issues. According to lean design management strategies such as Set-Based Design (SBD), the design team should delay decisions in order to allow time to explore and evaluate as many feasible design solutions as possible, and also make sure that all factors and criteria are applied consistently to all alternatives. In contrast, when using point-based design, a single, presumably best design is chosen (from one stakeholder perspective), and possibly proven infeasible later when feedback from other stakeholder is considered (Ward et al. 1995). This strategy results in repeating the process over and over again, generating negative (non-value-adding) design iteration, characterized by last-minute changes, lack of a systematic approach to promote innovative thinking, poor communication, and poor integration of design concepts (Ballard 2000).

In addition, when trying to obtain a sustainable building, additional requirements must be met that differ from those on traditional building projects. Examples are considerations in the delivery process to achieve expected performance goals (Korkmaz et al. 2009); early involvement of "green" concepts in projects and owner's commitment to sustainability (Lapinski et al. 2006); Integrated design process (NIBS, 2005), and Early involvement of key project participants (Riley and Horman, 2005). Therefore, decision-making methods need to account for this additional consideration, allowing stakeholder participation in early stages of the design and allow trade-offs between conflicting sustainable criteria.

METHODOLOGY

The research questions were investigated using various methods. First, a background literature study included a search for decision-making methods (e.g., Belton et al., 2002; Saaty 2008, Suhr 1999) and for sustainability issues in green building design (e.g., Korkmaz 2009, Lapinski and Riley, 2006). In addition, original interviews were conducted with architecture-, engineering-, and construction firms in the US in order to gather real application examples and gain understanding of decision making practices in green building design. The following sections present the literature review on MCDA, illustration of the application of two methods (AHP and CBA) and the findings for the research questions.

MULTIPLE CRITERIA DECISION ANALYSIS

MCDA is defined as: "A collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups to explore decisions that matter" (Belton and Stewart, 2002). In this paper we compare two groups. (1) Value-based approaches, which assume that decision-makers are able to 'quantify' their preferences. This approach use scores and weights to construct a 'model' of a decision-maker's preference in the form of value function. (2) CBA, which also assumes that decision-makers can 'quantify' their preferences. However, CBA requires decision-makers to identify the advantages of alternatives prior to construct their preferences.

VALUE-BASED APPROACHES

Value-based approaches (here value is about defining preferences) are commonly used in sustainability analysis. They include the AHP that has been applied in AEC decision making, e.g., for assessment of concrete structures (Aguado et al. 2012) and for structural materials evaluation (Bakhoum and Brown 2012).

When applying value-based approaches, the following steps must be followed: (1) identifying alternatives, (2) developing sustainability decision criteria (we here use the term 'factors' instead of criteria, and we define criteria differently in Table 1), (3) factor scoring, (4) factor weighting, (5) sensitivity analysis, and dealing with uncertainty. Figure 1 illustrates how these methods use weights on factors.

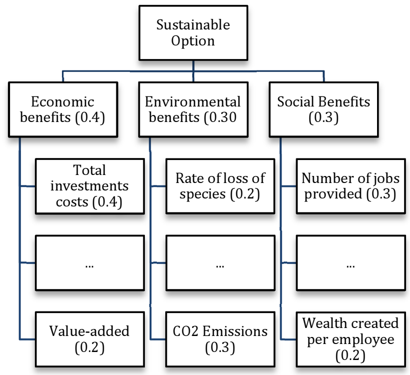

Figure 1: Example of a value-based approaches approach to assess sustainability (Azapagic and Perdan 2005 p. 109)

Analytical Hierarchy Process (AHP)

The procedure for using the AHP can be summarized as (Saaty 2008): (1) Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives. (2) Establish priorities among the Factors by making a series of judgments based on pairwise comparisons of the elements. (3) Synthesize these judgments to yield a set of overall priorities for the hierarchy. (4) Check the consistency of the judgments. (5) Come to a final decision based on the results of this process.

Step (2) measures relative importance of factors and preferences for alternatives through pairwise comparison matrices, which are recombined into an overall rating of alternatives by using eigenvalue method. When weighting factors decision-makers are asked to indicate the strength of their preferences for one factor over another on the following scale: 1 Equally Preferred, 3 Weak Preference, 5 Strong Preference, 7 Demonstrated preference, and 9 Absolute preference.

The problem with these methods is that the process of weighting factors is subjective. When using these methods stakeholders need to decide what is more important: economic, social, or environmental aspect of sustainability. This leads to conflicting questions, such as: what is more important when choosing a material: impacts in human health, embodied energy, or life-cycle cost? This question has a high level of abstraction; it does not have a particular meaning for a given decision context. By using this approach the differences between the alternatives are not highlighted, and therefore decisions are not anchored to relevant facts.

Choosing By Advantages (CBA)

CBA is a sound system to make decisions using well-defined vocabulary to ensure clarity and transparency in the decision-making process (Parrish and Tommelein, 2009). According to this system, it is important to identify which factors will reveal significant differences among alternatives, not about what factor will be important in the decision. Examples of CBA applications in the AEC industry are: for design and construction decision-making (Parrish and Tommelein 2009), for selecting a green roof (Grant 2007), for analyzing a viscous damping wall system (Nguyen et al. 2009).

In order to describe how to use CBA for selecting a sustainable alternative in the AEC industry; we use terms from Suhr's book (1999)(Table 1).

Table 1: CBA definitions

Term	Definition
Alternatives	Two or more construction methods, materials, building design, or construction systems, from which one must be chosen.
Attribute	A characteristic, quality, or consequence of one alternative (construction methods, materials, etc.).
Advantage	A benefit, gain, improvement, or betterment. Specifically, an advantage is a beneficial difference between the attributes of two alternatives.
Factor	An element, part or component of a decision. For assessing sustainability factors should represent economic, social and environmental aspects. It is important to notice that CBA considers money separately from other factors.
Criterion	A decision rule, or a guideline-usually. A 'must' criterion representing conditions each alternative must satisfy, or a 'want' criterion, representing preferences of one or multiple decision makers.

The CBA system has four principles: (1) decision makers must learn and skilfully use sound methods of decision making; (2) decisions must be based in the importance of the advantage; (3) decisions must be anchored to the relevant facts; (4) different types of decisions call for different sound methods of decision making.

According to principle (2) of CBA, decisions are based on advantages of alternatives, not advantages and disadvantages, avoiding double counting of factors. Once the advantages of each alternative are found, CBA assess the importance of these advantages making comparisons among them. The weighting process should be only on the advantages, not criteria, attributes, or other types of data (Suhr 1999, p.80). In addition, CBA anchors decisions to relevant facts (principle 4) and postpones value judgment about alternatives as long as possible.

CBA Tabular method for moderately complex decisions comprises five phases: (1) the Stage-Setting Phase, (2) the Innovation Phase, (3) the Decision-making Phase, (4) the Reconsideration Phase, and (5) the Implementation Phase.

The focus of this paper is on phase 3, which comprises four steps: (1) Summarize the attributes of each alternative, (2) Decide the advantages of each alternative, (3) Decide the importance of each advantage, and (4) If cost is equal for all alternatives, choose the alternative with the greatest total importance of advantages.

It is also important to highlight that the Reconsideration Phase (4) gives the opportunity to exanimate the chosen alternative as a whole, incorporating a holistic analysis into the sustainability decision-making process. This stage raises questions such as: are there any additional alternatives that should be considered? Do the importance score accurately represent the viewpoint of the stakeholders?

APPLICATION EXAMPLE

An example compares different exterior wall assemblies for a residential building in California. For simplicity we are comparing two alternatives: (1) standard wall construction (Figure 1), and (2) double stud wall construction (Figure 2). Building Science Corporation (2009) presents the main advantages of each alternative.

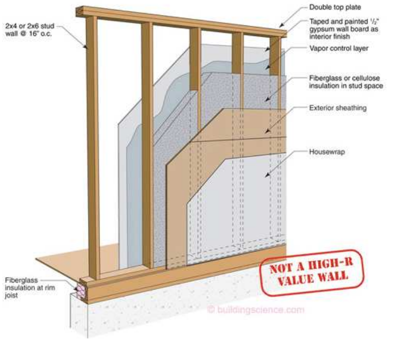

Figure 2: Standard wall construction
(Source: Building Science, 2009)

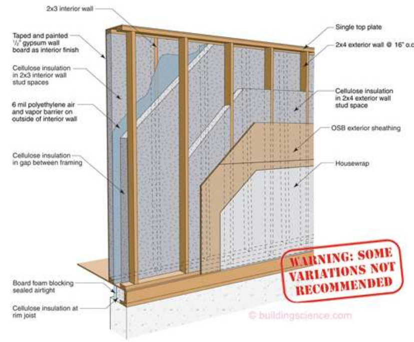

Figure 3: Double-stud wall construction
(Source: Building Science, 2009)

In this example we considered the following factors and criteria: (1) Thermal Control relates to the amount of energy that the building needs to maintain in order to achieve a thermal comfort level for their occupants. This is expressed in a characteristic measured through the R-value of the whole-wall system. The criterion for selection is 'the higher R-value the better' as this means higher insulation properties. (2) Durability relates to how long the building will last, and depends on the ability of the wall to stop rain, moisture, and air leakage. The criterion for selection is 'the building must last 50 years.' (3) Buildability refers to how easy it is to build the wall assembly considering the current available knowledge in the AEC industry in U.S. The criterion for selection is 'the easier to build, the better.' (4) Material use refers to the quantity of material used for wall assembly, and it is related with the embodied energy of the wall, which certainly also depend on the type of material used for insulation. The criterion for selection is 'the less material used the better.'

AHP

Here we present step (2) factor weighting of the AHP method. Table 2 presents the matrix of value judgment for the factors. The meanings of this numbers are the value preferences of the factors expressed as a ratio. For example, number 3 in the second column and first row of the matrix mean that thermal control has a weak preference over durability, and correspondingly the first column second row has a value of 1/3.

Table 2: AHP (step 2)

Factors:	1	2	3	4
1- Thermal Control	1	3	1/3	1/5
2- Durability	1/3	1	3	3
3- Buildability	3	1/3	1	1/5
4- Material use	5	1/3	5	1

This process requires high level of abstraction. The questions here are: What is more important buildability or material use?, thermal comfort or durability?, etc. It is hard to defend that thermal control is more important than durability without considering what are the relevant differences of the alternatives. Finally, when the eingenvalue of this matrix is calculated, it provides the factors weight, which is assuming linear trade-offs between performances of the alternatives. That is not always true, for example stakeholders may not want the building last more than 50 years, and if an alternative present a durability higher than that, stakeholders may not be willing to have a worse performance in buildability for example.

CBA

Here we present step (1) and step (2), of the Decision-making Phase of CBA tabular method. Steps (3) and (4), are discussed but not developed because they require a subjective value judgment that will depend on the stakeholders involved in the decision-making process and the context of a particular building. Summary of the attributes of each alternative (step 1) are presented in Table 3.

Table 3: Summarize the attributes of each alternative (step 1)

Factors & Criteria	Attributes of standard wall construction	Attributes of double stud wall Construction
Thermal Control (The higher R value the better)	R-10. (2x4 wall with R-13 stud space insulation)	R15 (2x4 wall with fiberglass batt)
Durability (It must last 50 years)	Depend on exterior barrier	Depend on exterior barrier
Buildability (The easy the better)	Easy to construct. Designers, trades and SC are use to it	Not very complicated, but It requires custom frames for penetrations.
Material use (The less the better)	Framing lumber could be minimized further if advanced framing was used.	Wall framing material is increased significantly due to secondary interior wall.

According to CBA tabular method the advantages of each alternative must be highlighted (step 2), which is what is considered the relevant facts for decision-making. The advantages and not advantages and disadvantages are decided. Table 4 presents the advantages of each alternative relative to the least-preferred one.

Table 4: Decide the advantages of each alternative (step 2)

Factors (Criteria)	Attributes of standard wall construction	Attributes of double stud wall construction
Thermal Control (The higher R value the better)	-	R value is higher by 5 than standard wall
Durability (It must last 50 years)	-	-
Buildability (The easier to build, the better)	Easier to construct than double stud	-
Material use (The less the better)	It uses less material than double stud	-

Now, it can be seen that step (1) and (2) of the CBA Decision Making Phase are objective and easy to agree with. However Stakeholders need to agree on criteria, which will depend on climate conditions, building orientation, building type, who uses the building, etc. Once the advantages are decided, CBA leads to subjective questions anchored to the relevant facts such as: what is more important: the advantage in buildability and material use of the standard wall construction or the advantage in thermal control of Double Stud Wall Construction? It is important to notice that the factor durability has not relevance in the decision due to there is no advantage of one alternative over another.

It is important to notice that money (whether it is cost or price) is not a factor nor a criterion. Money is treated separately in CBA decision-making analysis as a constraint. Consider the estimated first cost for the standard wall construction to be about $50/m2 and for the double stud wall construction to be about $80/m2. for this example. When considering cost, the relevant question is: if stakeholders value more the advantage in thermal control, do stakeholders want to pay $30 more per m^2? Do stakeholders have the financial power to pay in the short term for that higher first cost?

CBA has the flexibility to add more factors or alternatives with no impact on the previous assessment of alternatives. In contrast to value-based approaches, in which the score and weighting of factors must be recalculated any time a new factor is added to the decision. Some factors that can be added to the analysis are: embodied energy of materials, aesthetics, etc. In addition, other alternatives may be Structured Insulated Panel Systems (SIPs), truss wall, etc.

DISCUSSION

In order to illustrate why CBA should be part of the Lean Construction body of knowledge, Lean vs. not Lean Decision making approaches are described in Table 5.

Table 5: Decision Making Approaches

	Not Lean	Lean
Outcomes	Short term thinking	Long term thinking
Stakeholders participation	The decision is made in a closed circle. Decide-present-defend approach.	Early involvement and collaboration among stakeholders.
Stakeholders Coordination	Divide and conquer approach. Each stakeholder optimizes his/her part.	Holistic approach. Optimize the whole, not the parts.
Generation of Alternatives and decision timing	Point-based design. Explore alternatives within a discipline, select one, and then pass it to the next discipline. Repeat the process one discipline at a time.	Set-based design. Explore alternatives in multidisciplinary teams, but delay design decisions until the last responsible moment to evaluate as many feasible alternatives as possible using consistent factors and criteria for all.
Management of subjectivity	Subjective weighting of factors is made early on the decisions-making process, and is based on general categorization.	Subjective decisions are based on anchored questions and are postponed until the last phase of the decisions-making process.
Display of information	Do not explicitly show everyone choices. Some applications weight the "stakeholder's importance".	Visualization while eliciting preferences help to reach consensus among stakeholders.
Understanding final decision	Weighting factors makes hard to know what was the most important fact in the decision.	Transparent process. The advantages of alternatives are discussed and agreed among stakeholders. Clearly states the paramount advantage.
Documentation	Decisions are based on past experience and intuition; little or no documentation is used.	A3 reports are used to clearly state problem, include key information and recommendations.

The following are desired characteristics of decision-making methods that are to support sustainable building design: allow group decision-making and encourage design integration; help stakeholders to collaborate and reach consensus; look at sustainability issues holistically, considering the triple bottom line; provide a clear vocabulary; help in developing preferences along the design process; make judgments based on anchored relevant facts; and, avoid assuming linear trade-offs.

Here we demonstrate that AHP method does not comply with make judgments based on anchored relevant facts. In addition, AHP assume linear trade-offs between alternative performances. In contrast, CBA comply with all this requirements.

CONCLUSIONS

CBA methods are superior to value-based method when selecting a sustainable alternative in the AEC industry. CBA helps stakeholders to make decisions based on relevant facts minimising conflict. In contrast, value-based methods, which ask stakeholders to weigh factors, may not focus to the same extent on the importances of the advantages between attributes of alternatives, and therefore stakeholders may have difficulties in resolving conflicting interests and collaborating. Methods that weight factors are not taking decisions based on the relevant facts, therefore they should be more likely to produce wrong decisions. Consequently causing worse environmental, social and economic impacts of the AEC industry.

In addition CBA should be part of the Lean Construction body of knowledge because its core is centred on deliver value to the stakeholders while reducing uncertainty in the decision making process, which will reduce the amount of waste generated by unsound decisions. In addition, CBA complements lean practices such as set based design and early collaboration.

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