CHOOSING BY ADVANTAGES AND RHETORIC IN BUILDING DESIGN: RELATIONSHIP AND POTENTIAL SYNERGIES

Paz Arroyo[1], Glenn Ballard[2] and Iris D. Tommelein[3]

ABSTRACT

Rhetoric is a natural part of the design process and has caught the interest of researchers in the last 50 years. Indeed, effective rhetoric has been studied and used since the time of the ancient Greeks to persuade and to influence all manner of things. However, little research has been done on rhetoric in design and engineering, specifically during the decision-making portion of the design process. This paper provides examples of how a decision-making method such as Choosing By Advantages (CBA) uses rhetoric during the decision process and explores how the three components of rhetoric (logos, pathos, and ethos) may apply to the decision-making process. The authors argue that understanding rhetoric may provide designers with new means for persuasion, and ultimately, help them make better decisions.

KEYWORDS

Decision-making, Rhetoric, Choosing By Advantages, CBA, Design Management.

INTRODUCTION

Many decisions need to be made in building design. In practice, few decisions are based on a formal and transparent decision-making method, and they are very likely to be influenced by arguments that only a few members of the design team provide. Arguments may sound appealing at the time of the decision. However, often decisions need to be changed later in the design process wasting time and resources. This may be due to, e.g., lack of consensus, failure in considering all relevant perspectives, or because the decisions were made before having relevant data for understanding their impacts.

Choosing By Advantages (CBA) is a decision-making method that helps design teams make collaborative and transparent decisions (Suhr 1999). CBA has been used by the U.S. Forest Service since the 1980s and more recently in Architecture Engineering and Construction (AEC) practice (e.g., Grant 2007, Koga 2012, Nguyen et al. 2009, Parrish and Tommelein 2009). CBA has been shown to be more effective than other methods such as Analytic Hierarchy Process (AHP) or Weighting Rating

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and Calculating (WRC) when choosing one among a set of known and finite alternatives (Arroyo et al. 2014). When applying CBA, the design team must use CBA language in order to provide a common basis for discussion. However, the discussion or argumentation process, especially when deciding the importance of advantages, has not been studied enough. The use of rhetorical tools in CBA, in particular, has not yet been explored.

Rhetoric is the art of discourse, an art that aims to improve the capability of writers or speakers who attempt to inform, persuade, or motivate particular audiences in specific situations (Corbett 1990, Young et al. 1970). In a recent paper Ballard and Koskela (2013) discussed the importance of studying rhetoric in design, claiming that the topic has been addressed in many fields (e.g., Buchanan 1985, Crilly, et al. 2008, Foss 2005) but not much in engineering design. This paper contributes to closing that gap by studying how rhetoric may support the process of decision-making in building related design. Specifically, this paper explores the relationship and potential synergies of the use of rhetorical means of persuasion in the CBA decision-making method.

RESEARCH QUESTIONS AND METHODS

This research explores the following questions:

- Can rhetoric inform or guide the use of CBA decision-making to support the choosing problem in design?
- How can the use of rhetorical tools improve the CBA decision-making process?

In order to answer these questions the authors reviewed the literature on the use of rhetoric in design, rhetorical tools of persuasion, and CBA applications in design decisions in the construction industry. In addition, the authors used a CBA case study to analyse discussions and interactions among design team members, looking for the natural use of rhetoric.

CHOOSING BY ADVANTAGES

Choosing By Advantages (CBA) is a type of multiple-criteria decision-making method developed by Jim Suhr. CBA provides a rich language for argumentation when comparing alternatives (Table 1). The design team is encouraged to base judgements on positive differences among alternatives (advantages), and evaluate their importance relative to the decision context. Examples of CBA applications in the AEC industry can be found in Parrish and Tommelein (2009), Grant (2007), Nguyen et al. (2009), and Arroyo et al. (2013, 2012a and b).

Table 1: CBA Definitions (Modified from Suhr 1999).

Alternatives	Two or more construction methods, materials, building designs, or construction systems, from which one or a combination of them must be chosen.
Factor	An element, part, or component of a decision. When assessing sustainability, factors should represent economic, social, and environmental aspects. It is important to note that CBA considers money (e.g., cost or price) after attributes of alternatives have been evaluated based on factors and criteria.
Criterion	A decision rule or a guideline. A 'must' criterion represents conditions each alternative must satisfy. A 'want' criterion represents preferences of one or multiple decision makers.
Attribute	A characteristic, quality, or consequence of one alternative.
Advantage	A benefit, gain, improvement, or betterment. Specifically, an advantage is a beneficial difference between the attributes of two alternatives.

Suhr developed different CBA methods for different applications. One is the simplified two-list method for simple decisions involving two alternatives of equal cost. Another is the tabular method, appropriate for more complex decisions especially when the decision involves multiple alternatives, too much information is available to judge mentally, large amounts of data have been documented, or a group is involved in the decision making process. This paper will focus on decisions that require the use of the CBA tabular method, which could be described using the following steps.

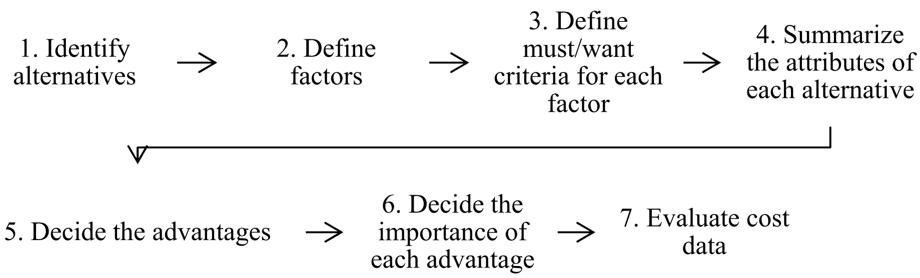

Figure 1: CBA Steps

- In step 1, stakeholders generate alternative designs, or identify alternatives.
- In step 2, they define factors with the purpose of differentiating between alternatives. In CBA, it is important to identify which factors will reveal significant differences among alternatives, not which factor will be more important in the decision.

- In step 3, stakeholders agree on the criteria within each factor. Criteria will be used to evaluate attributes of alternatives. A criterion can be either a desirable (want) or a mandatory (must) decision rule. Alternatives that do not comply with a must criterion are not considered in the following steps.
- In step 4, stakeholders summarize the attributes of each alternative.
- In step 5, they identify the least preferred attribute for each criterion, and then decide on the advantage of every other alternative's attribute relative to the least-preferred one. In CBA, decisions are based solely on the advantages (rather than advantages and disadvantages) thereby avoiding double counting.
- In step 6, they decide on the importance of each advantage (IofA). First they have to select the paramount advantage, which is the most important advantage among all, and use it to assign an IofA scale. Then stakeholders use this scale to weigh other advantages by making comparisons among them. The CBA table gets completed by summing the IofAs for each alternative.
- In step 7, stakeholders finally evaluate cost data (value for money) and select from the alternatives. Once an alternative has been chosen, the group will take time to reconsider their decision as a whole, incorporating a holistic analysis into the decision-making process.

RHETORICAL TOOLS

Aristotle defines rhetoric as "the faculty of observing in any given case the available means of persuasion." (Aristotle 1941). In other words, rhetoric is the art of discovering and delivering all available means of persuasion.

Rhetoric, as understood by Aristotle, involves invention, arrangement, style, memory, and delivery, all of which can be taught. Invention was based on topics, or places from which to launch arguments, such as similarity and difference, better and worse, etc. Arrangement concerned the structure of a speech, style and delivery concerned methods of effective presentation, and memory, obviously restricted to unwritten speeches, concerned aids to memorization.

A speaker knowledgeable in rhetoric supports a message by logical (logos), ethical (ethos), and emotional (pathos) proofs. The use of rhetorical proofs is very common; many would say that some form of logos, ethos, and pathos is present in most public presentations. However, usually few people in design teams use arguments in an appealing manner able to influence decisions. According to Aristotle, the 'art' of rhetoric can and should be taught.

In short, the three different types of rhetorical proof according to Aristotle:

Logos: the use of reasoning, either inductive or deductive, to construct an argument. The term logic evolved from logos. Logos appeals to statistics, mathematics, logic, and objectivity.

Inductive reasoning uses examples (e.g., statistics or historical data) to draw conclusions. Deductive reasoning uses generally accepted propositions to derive desired conclusions. Aristotle emphasized enthymematic reasoning as central to the process of rhetorical invention, though later rhetorical theorists placed much less emphasis on it. Enthymemes are truncated syllogisms, with a missing premise to be provided by the audience. An enthymeme is persuasive because the audience is providing the missing premise. For instance, a manufacturer can make a logical appeal by claiming that their product has 50% more recycled contents than the competition, expecting the 'audience' to supply the missing premise 'More recycled contents are better.'

Ethos: how the character and credibility of a speaker can influence an audience to consider him/her to be believable. This could be any situation in which the speaker is recognized as an expert on the topic. An audience is more likely to be persuaded by a credible source because the source is more reliable. In addition, three qualities contribute to a credible ethos: perceived intelligence, virtuous character, and goodwill. Ethos is also related with 'ethical appeal.' Is the argument ethical?

For instance, if a renowned structural engineer gives his/her opinion about the building design in terms of earthquake performance, it is more likely that the rest of the design team (e.g., owner, architects, MEP, etc.) will accept this opinion. He/she will have a 'strong' credibility because of his/her professional credentials and background.

Pathos: the use of emotional appeals to influence the audience's judgment. This can be done through metaphor, amplification, storytelling, or presenting the topic in a way that evokes strong emotions in the audience. Aristotle used pathos to help the speaker create appeals to emotion in order to motivate decision making. Strong emotions are likely to persuade when there is a connection with the audience. For instance, in building design, architects may evoke the user experience as means of persuasion to incorporate changes in the design.

CASE STUDY

BACKGROUND AND CBA RESULTS

This case study applied CBA to deciding on ceiling tile alternatives on a Design-Bid-Build (DBB) project in which the client was seeking LEED (Leadership in Energy and Environmental Design) gold certification. The researcher (the first author on this paper) was actively involved in helping the design team apply the CBA method. She obtained access to the project information through an internship and was aware of the background of the decision. The design team was composed of architects, interior designers, an acoustic specialist, and a sustainability specialist. The researcher led a decision session, which was videotaped, so the interaction between the design team could be analysed later. Details of the case study were published in Arroyo et al. (2013).

Tile selections were being made for a number of different office building locations throughout the world. The decision for the San Francisco office considered 3 ceiling tile alternatives evaluated against 6 factors and criteria. Table 2 shows the result of the tabular method.

Table 2: CBA steps (1) to (6).

Factor & Criterion	Optima (Fiberglass)		Ultima (Mineral Fiber)		Optima Plant Based (Fiberglass)	
1. Acoustics Crit.: Higher is better. Minimum 0.7 NRC.	Att: 0.9		Att.: 0.7		Att.: 0.95	
	Adv.: 0.2 Higher noise resistance	Imp.: 100	Adv.:	Imp.: 0	*Adv.: 0.25 Higher noise resistance*	Imp.: 100
2. Anti-microbial Crit.: Higher is better	Att: Inherent		Att.: It has BioBlock+		Att: Inherent	
	Adv.: Better Anti-Microbial	Imp.: 15	Adv.:	Imp.: 0	*Adv.: Better Anti-Microbial*	Imp.: 15
3. Weight Criterion: Lighter is better	Att.: 0.55 (lbs/sqft)		Att.: 1.14 (lbs/sqft)		Att.: 0.55 (lbs/sqft)	
	Adv.: 0.59 (lbs/sqtf) lighter	Imp.: 50	Adv.:	Imp.: 0	Adv.: 0.59 (lbs/sqtf) lighter	Imp.: 50
4.Insulation Value Crit.: Higher is better	Att.: R Factor 4.0 BTU		Att.: R Factor 2.2 BTU		Att.: R Factor 4.0 BTU	
	Adv.: *1.8 BTU higher*	Imp.: 45	Adv.:	Imp.: 0	Adv.: *1.8 BTU higher*	Imp.: 45
5. VOC Formaldehyde Crit.: Lower is better	Att: Low Formaldehyde - less than 13.5 ppb		Att: Free of Formaldehyde		Att: Free of Formaldehyde	
	Adv.:	Imp.:0	Adv.: *Free of Formaldehyde*	Imp.: 90	Adv.: *Free of Formaldehyde.*	Imp.: 90
7. CO_2 Emission SF Crit.: Lower CO_2 emission is better	Att.: 275 t CO_2eq		Att.: 392 t CO_2eq		Att.: 275 t CO_2eq	
	Adv.:117 *t CO_2 less than Ultima*	Imp.: 30	Adv.:	Imp.: 0	Adv.:117 *t CO_2 less than Ultima*	Imp.: 30
Total IofA SF		240		90		330

Figure 2 shows step 7, in which the IofA vs. cost of the alternatives is analysed.

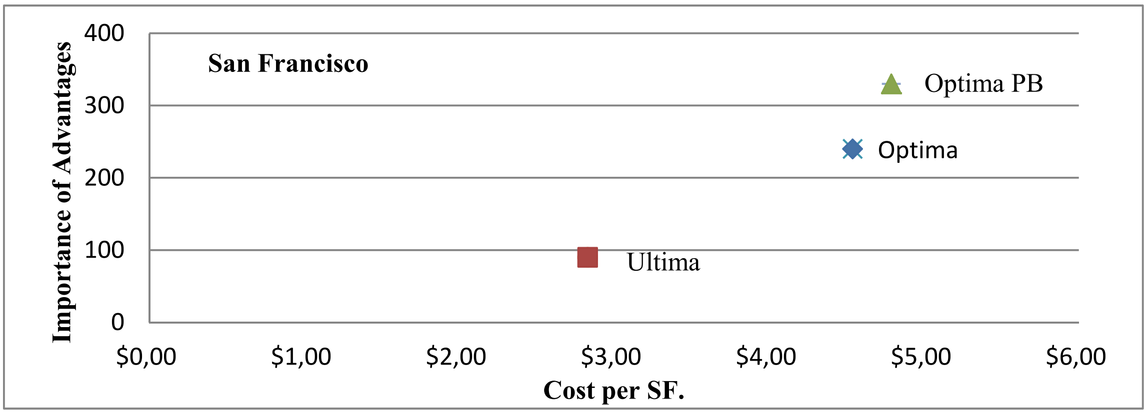

Figure 2: CBA results IoAs vs. first cost

EVIDENCE OF THE USE OF RHETORIC IN CBA

During the application of CBA the researcher could observe the use of rhetorical arguments:

Acoustic performance factor

In the process of summarizing attributes, describing advantages and assigning importance to them, all three types of rhetorical proofs were used:

- An example of logos in CBA is the design team's requirement to assess advantages based on attributes of the alternatives. In other words, design teams describe alternatives using their inherent and quantitative characteristics. For example, the design team can use the advantage that Optima PB has 0.25 higher NRC points for noise resistance than Ultima (Optima PB 0.95 NRC vs. Ultima 0.7 NRC) for arguing in favor of Optima.
- An example of ethos is the design team believing the information provided by the acoustic specialist about the level of acceptable performance for the ceiling tiles. That specialist had the authority and knowledge to influence the decision. In this case, the acoustic consultant recommended using a minimum acceptable value of 0.7 for NRC to be aligned with the rest of the design and the purpose of the building. This information was used for setting the criterion for the factor acoustics.
- An example of pathos was that a designer made an argument appealing to user experience. He argued that the difference in acoustic performance of Optima PB vs. Ultima would affect the users in how they would feel about the space. This argument was enough to convince the rest of the team that the advantage of Optima PB vs. Ultima in acoustic performance was the most important advantage. In this case, he was using empathy with the user in order to convince other decision makers.

A change in perspective from thinking about importance factors to thinking about importance of advantages.

In one instance, a designer disagreed with an IofA score. She argued that the team should assign the highest IofA to the advantage of Optima vs. Ultima in terms of Global Warming Potential (GWP). Her argument was that the GWP factor was the most important to her due to its importance of climate change. The researcher reminded the design team that in CBA decisions are based on the differences between the alternatives instead of the general importance of the factor. When looking at the differences in WGP, the design team realized that the differences between the GWP attributes of the alternatives (275 t CO_2eq vs. 392 t CO_2eq difference between Optima PB and Ultima respectively) were not that significant compared to the paramount advantage (0.95 vs. 0.7 NRC difference between Optima PB vs. Ultima respectively). In order to understand the impact of differences in CO_2 emissions, the design team translated it into taking 18 average U.S. cars off the road for 1 year (logos argument). However, that argument need to be put in perspective, approximately 140,000,000 cars circulate every year in the U.S., the impact of this decision on GWP it is insignificant. By contrast, the building's user will perceive the higher noise resistance over the life of the facility, which in this case is around 50 years. This is an important impact on user experience (pathos argument). Finally, the design team agreed to assign an IofA of 30 to the advantage of Optima vs. Ultima in GWP.

The change of perspective in CBA, in which decision makers analyse the particular advantages instead of the general ideas about the importance of factors, makes the design team more connected with the context. This provides more 'strong' arguments since the decision makers can appeal to data that is relevant to this particular decision instead of data that is abstract or ambiguous.

Deciding the importance of the advantages

The CBA process of deciding the importance of the advantages is highly collaborative and decisions are reached through discussion within the design team. Rhetorical tools are used in many comparisons between advantages including facts (logos), and expert opinion (ethos). The designers often appeal to the client vision or to the user experience (pathos) in order to argue in favour of an advantage. However, not all the members of the design team are aware of the tools they can use to build arguments. A person with better rhetorical skills can dominate the decisions.

DISCUSSION

Even when the design team has no formal training in the use of rhetoric, the use of rhetorical tools appeared naturally during the discussion and argumentation phase of the decision, especially when deciding the IofAs.

As Aristotle thought, designers can improve their rhetorical skills to discover and develop better arguments. We think that the better the arguments that are discovered, the better the design outcome can be. Here are some questions that we thought may contribute to the discovery of new arguments.

Using Logos

In CBA the use of logos is encouraged by requiring the design team to describe the advantages of the alternatives based on their attributes; the design team needs to summarize the attributes of each alternative. These assessments influence the decision.

The design team needs to think of all available arguments which favor a particular alternative, for example:

- What data or facts can support an advantage?
- What other factors may be considered?

Using Ethos

Considering the arguments from people who have authority or relevant knowledge (Superiority).

- Who can speak for making a credible statement about one advantage? Who has relevant knowledge for this decision context?
- The specialist's role in the AEC process, their attitude and words will impact the decision. Have all relevant specialists been given the option to speak?

- A tool for developing a more credible speech is to show a variety of sources. This may be applied by involving all relevant specialists and having the 'right people' in the design room with the authority to judge (the right status).

Using Pathos

Considering arguments that appeal to the people who will be affected by the decision (e.g., users, environment, etc.). (Inferiority)

Designers can appeal to emotion in many ways. Some relevant questions are:

- How will this advantage impact the user experience?
- How will this advantage impact the environment?
- How can previous experiences relevant to this context be used?

CONCLUSIONS

In conclusion, the case study confirmed the use of rhetoric in CBA applications including conscious and unconscious use of rhetoric. The authors provide insights about the use of rhetoric in CBA by providing questions that the design team should ask in discovering new arguments.

We think that CBA provides the right framework to ask questions and find arguments to influence decisions. The score behind every IofA should be analysed using logos (the facts and differences among the alternatives), ethos (the opinion of the relevant specialists about the impact of the advantage) and pathos (the sense of how this advantage will affect others). In other words, the alternatives should be judged based on how they work, how they are perceived by expert judgement, and how they appeal to the users.

More research in needed in order to understand how best to consciously apply rhetoric in the CBA process and what the benefits are.

ACKNOWLEDGMENTS

Research for this paper was supported in part by the Project Production Systems Laboratory (P2SL). In addition, P. Arroyo is supported by a CONICYT Ph.D. fellowship from the Chilean government and the Pontificia Universidad Católica (PUC) de Chile. All support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of contributors to P2SL, CONICYT or PUC.

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COMPARING WEIGHTING RATING AND CALCULATING VS. CHOOSING BY ADVANTAGES TO MAKE DESIGN CHOICES

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ABSTRACT

Teams engaged in building design are composed of multiple stakeholders, including architects, owners, engineers, and sometimes users. Members of the design team often have different and conflicting interests, especially when considering sustainability issues. For example, issues may include reducing embodied energy while creating an earthquake resistant building at the same time. Practitioners require a decision-making method that allows for creating transparency, building consensus, and continuous learning. Weighting Rating and Calculating (WRC) is a widely used decision-making method. However, it has several shortcomings. Choosing By Advantages (CBA) is a decision-making method that supports the design process by fostering greater transparency.

This paper presents a case study comparing the use of WRC vs. CBA in the selection of a structural system for a campus residential building in Palo Alto, California. The case study found that the same decision resulted from both methods, but the assumptions of the two methods were different, and CBA helped more in creating transparency and building consensus on the decision rationale.

KEYWORDS

Decision-making, Choosing By Advantages, CBA, Sustainability, Design Management.

INTRODUCTION

Creating and building consensus are both desired for the decision-making process in design. The lack of a clear and shared rationale often requires decisions to be changed late in the design process, which results in wasted time and resources. The literature does not provide enough support for practitioners to select a decision-making method in this context. This paper helps in filling that gap by comparing and contrasting the use of Weighting Rating and Calculating (WRC) and Choosing by Advantages (CBA) in choosing a structural system for the Stanford University Green Dorm project. This

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supplements previous work comparing the Analytic Hierarchy Process (AHP) and CBA (Arroyo et al. 2012, Arroyo et al. 2014).

RESEARCH METHODOLOGY AND QUESTIONS

This paper proposes answers to the following questions:

- What are the differences between WRC and CBA?
- What are the impacts of those differences in the decision-making process?

A case-study method was used for answering these questions, following guidelines from Yin (1994). Two structural design alternatives were evaluated by WRC and CBA, and the methods were compared and evaluated. The researchers studied the literature to understand the use of both WRC (e.g., Stanford 2006,Tatum 1984) and CBA (e.g., Parrish and Tommelein 2009, Grant 2007, Nguyen et al. 2009, and Arroyo et al. 2013, 2012a and b).

The researchers used the same information when applying the WRC and CBA methods based on what the design team originally used. The design team used WRC to evaluate 2 alternatives (wood bearing wall structure and a steel frame with metallic deck and concrete topping) considering 11 factors, including cost. The researchers studied how WRC was used to choose between these two alternatives, and then applied CBA to the same choosing problem.

CASE BACKGROUND

The Stanford Green Dorm project, formerly known as the Lotus Living Laboratory at Stanford University, was designed to house students and include a lab targeting high sustainability standards. The initiative began in 2003 and was organized by the Department of Civil and Environmental Engineering (CEE). A design team (i.e., owner, architect, structural engineer, mechanical systems engineers, cost estimator, contractors, and electrical engineer) was selected in August 2005 to spearhead the feasibility study. Since 2006 the project has been on hold due to a lack of funding. However, the decision for selecting the structural system was well documented, which allowed the researchers a good case study for this research.

The building has an area of 21,150 square feet spread over three floors. The schematic design includes 47 student beds, and a building systems laboratory sharing an enlarged ground floor with residential common spaces. Building systems would monitor and measure building performance providing constant feedback to building users. The design team's idea was to use the whole building as a lab. The physical space was designed to enable a program involving innovation, laboratory research, education, and student housing.

STRUCTURAL SYSTEM DECISION

The design team wanted to choose a structural system that reduced impact on the environment, and that conformed to the cost and schedule constraints of the project. The design team analyzed both first cost and life-cycle cost of the alternatives. The intent was to design a structural system with low embodied energy while achieving a good seismic performance for the building lifetime.

CASE-STUDY PROTOCOL

The steps that the researchers followed were: (1) Conduct an interview with the structural engineer to understand how WRC was applied in this project. (2) Obtain public data to understand the project background and the interrelation between the different building systems. This information included reports that explained the rationale behind the WRC method (Stanford 2006). (3) Identify attributes for applying CBA between two alternatives, wood and steel. (4) Develop an example of a CBA application, and compare it with WRC application.

WRC APPLICATION

The design team used WRC to make their decision. WRC is a value-based method. It is significant that the feasibility report did not mention the name of the method, and that the interviewee was not aware of the method's name or its theoretical foundations. Application of the WRC method followed these steps:

STEP 1: IDENTIFY ALTERNATIVES

The design team analyzed two alternatives in depth. (1) Wood bearing wall and (2) Steel frame/Metallic deck/Concrete Topping

STEP 2: IDENTIFY FACTORS AND CRITERIA FOR EVALUATION

The design team used 11 factors that they considered relevant to differentiate between alternatives. The 11 factors included cost, which is not a factor in CBA. They divided the factors in three categories as follows:

Life cycle cost factors:

1. First Cost: measures the cost of designing and constructing the building.
2. Construction Speed: measures the speed of construction of the different structural systems.
3. Earthquake Losses: measures the future earthquake (EQ) losses, which are comprised of architectural damage, structural damage, content damage and loss of use—all caused by building drift (the measure of lateral distortion between floors) and accelerations.
4. Maintenance/Durability: measures the impacts from maintaining the building over its lifetime. Building maintenance activities like cleaning and repairs often cause complaints from building occupants. Therefore, maintenance requirements should be minimized.

Environmental (CO2 impacts) factors:

5. Embodied Energy. measures the carbon load on the environment needed to produce the building. For example, the carbon impact of a unit volume of concrete used can be measured as the sum of CO_2 produced in making and transporting the cement and other ingredients.
6. Thermal Mass: measures the thermal mass created for the structure. This is important in order to reduce energy during building use.

7. Insulation: measures the insulation capacity of the structure. It also contributes to the net carbon impact, since greater insulation capacity reduces the energy required to operate the building, and hence the carbon quantities produced from operations over the building's lifetime.

Other factors:

8. Research Value: measures the research potential of the design, the construction and the use phase (performance monitoring) of the structure itself by faculty and students in the CEE Department.
9. Thermal Comfort: measures the qualitative benefit to students of the building's mass moderating the effects on overheating. This factor is also influenced by other systems and decisions.
10. Deconstructability: measures how easy it is to deconstruct the structure after its use has come to an end.
11. Flexibility: measures how flexible the structure is with respect to future changes. This includes internal spaces and the installation of new building systems.

STEP 3: ESTIMATE THE RELATIVE IMPORTANCE OF THE FACTORS

The design team weighted the factors by assigning them a number from 1 to 5 (where 1 is the least important and 5 is the most important), in order to represent relative importance within the factors (factor weights in Table 1) considering the design team members' values. According to the structural engineer, the weighting of factors was done based on project context, including the building location, earthquake probabilities and weather characteristics among others. The factors' weights were agreed upon among the stakeholder. Table 1 shows the results.

Table 1: Choosing a structural system with WRC (Stanford 2006).

Structural System Stanford Green Dorm	**Life Cycle Cost Factors (10 points)**				**Environmental Factors (5 points)**			**Other Factors (9 points)**				**Total (Weighted)**	**Total Life Cycle Cost Factors**	**Total Environmental Factors**
	First Cost	**Construction Speed**	**Earthquake Losses**	**Maintenance/Durability**	**Embodied Energy**	**Mass**	**Insulation**	**Research Value**	**Thermal Comfort**	**Deconstructability**	**Flexibility**			
Factors weight (1-5)	5	1	3	1	3	1	1	4	2	1	1			
1. Wood bearing wall	5	3	1	3	5	2	3	1	3	3	2	69	34	20
2. Steel frame/Metallic deck/ Concrete Topping	3	5	4	5	2	4	3	4	4	4	5	83	37	13

The Stanford University (2006) feasibility report gave the following rationale for the weights of factors:

- Life cycle factors: "the weighting was greatest for the factor 'first cost' with 5 on a 1-5 scale, this reflects the cost constraints of the project. 'Earthquake losses' had the next largest weight with 3, which is relatively high compared with the rest of the factors. This was justified by the fact that the effects of local seismicity are clearly an issue in the Bay Area. 'Construction speed' was given a weight of 1. 'Maintenance/durability' was given a weight of 1. These four factors together accounted for the building's life cycle cost, with an overall effective weight of 10."
- Environmental factors: "recognizing the environmental impact of constructing the dorm and lab, 'embodied energy' has a relatively large weight of 3. 'Mass' and 'insulation' were given a weight of 1 each. These relatively low values reflect the minor beneficial impact that added mass and insulation have on the operating costs of the project in light of California's mild climate. The cumulative carbon impact weight, made up of these three factors, is 5."
- Other factors: "The factor 'research value' had a weight of 4, reflecting the priorities of the Civil Engineering Department. 'Thermal comfort' was assigned a weight of 2, representing the qualitative benefit for students due to the building's mass moderating the effects of overheating. 'Flexibility' and 'deconstructability' were each given a low weight of 1, since both are benefits that can be realized only in the distant future."

According to the Stanford University feasibility report (2006), the weighting of factors can be subject to further discussion and adjustment as needed.

STEP 4: ESTIMATE THE PERFORMANCE OF EACH ALTERNATIVE

The design team estimated the performance of each alternative considering those factors and then rated the alternatives for each factor. In this case they also used a scale from 1-5 as shown in Table 1. For example, for the factor 'embodied energy', the wood bearing wall was assigned an attribute weight of 5, and the steel frame a 2, since the wood alternative has less embodied energy, and is therefore more desirable from an environmental perspective. The scale of the numbers is based on calculations done by the design team, especially the structural engineer and faculty and students in the CEE department.

The researcher did not have access to all the calculations. However, the data included in the Stanford (2006) report showed models for estimating the earthquake performance, materials properties, and cost of the alternatives, among other analyses.

STEP 5: CALCULATE THE VALUE OF EACH ALTERNATIVE AND COME TO A FINAL DECISION

The design team calculated an overall value of each alternative by multiplying the alternative's rating by the factors' weight. Table 1 shows that the wood bearing wall system had a score of 69, and the steel structure system a score of 83. Therefore, the steel structure system was chosen for the project.

The design team quantified the effects of local seismicity using a life cycle cost analysis. The initial structural performance investment, or cost premium, of the steel alternative over the wood alternative was $230,000. However, the savings of the steel alternative over the wood alternative was $1,964,869 based on the site-specific earthquake hazards, performance-based design of the structure, and loss estimation tools developed by the CEE faculty.

The analysis performed by the design team found the steel structure to be much more durable and cost effective. Its long-term benefits outweighed the higher initial dollar and embodied energy costs.

CBA APPLICATION

The following sections present how the design team might have conducted their analysis by applying Choosing by Advantages to this problem.

STEP 1: IDENTIFY ALTERNATIVES

Same as in WRC.

STEP 2: DEFINE FACTORS

Table 2 shows the factors that are the same as originally used, except for cost. Cost will be analyzed in step 7 as in CBA it is treated as a constraint for the project. The factors and criteria will judge the hypothetical attributes of the alternatives since the design details of the 2 alternatives were not included in the studies the researchers had access to.

STEP 3: DEFINE THE 'MUST'/'WANT TO HAVE' CRITERIA FOR EACH FACTOR

Table 2 summarizes factors and criteria, which were derived from the report. In CBA criteria for evaluation need to be explicitly presented in each factor.

STEP 4: SUMMARIZE THE ATTRIBUTES OF EACH ALTERNATIVE

Table 2 presents the attributes of the alternatives, according to the information provided by the feasibility report.

STEP 5: DECIDE THE ADVANTAGES OF EACH ALTERNATIVE

The design team obtains the advantages by applying the criteria and comparing the attributes of the alternatives. The underlined attributes are the least preferred. Table 2 describes the advantages. In this case the steel structure alternative has advantages in every factor except for embodied energy and insulation.

STEP 6: DECIDE THE IMPORTANCE OF EACH ADVANTAGE

In CBA the members of the design team need to weight advantages and not factors as in WRC. Table 2 presents the Importance of Advantages (IofA) (in this paper they were assigned by the researcher for the purpose of illustrating CBA). The rationale for weighting IofA are as follows:

- It appears that the most important advantage (paramount advantage) is that the steel structure presents much richer opportunities for research than the wood structure. As specified by the CEE Department, this was one of the goals of the building. Accordingly, the researcher assigned 100 IofAs.

Table 2: CBA steps 1 to 6.

Factor (Criterion)	**Alternative 1: Wood Bearing Wall Structure**		**Alternative 2: Steel frame /Metallic Deck/Concrete Topping**	
1. Construction Speed	Att.: Slow when constructed on site.		Att.: Fast to construct.	
(The faster, the better)	Adv.:	Imp.:	Adv.: *Faster to construct than wood structure*	Imp.: 10
2. Earthquake Losses	Att.: May result in significant architectural, structural, and content damage.		Att.: May result in moderate architectural, structural, and content damage.	
(The lower EQ losses, the better)	Adv.:	Imp.:	Adv.: *It has significantly less EQ losses than wood.*	Imp.: 80
3. Maintenance/ Durability	Att.: Requires frequent cleaning and repairs.		Att.: Requires sporadic cleaning and repairs.	
(The less maintenance required, the better)	Adv.:	Imp.:	Adv.: *Steel frame is easier to maintain than wood.*	Imp.: 30
4. CO_2 Emissions - Embodied energy.	Att.: Wood stores carbon and has a low embodied energy, and it is light.		Att.: Steel and concrete have high embodied carbon.	
(The less CO_2 emissions, the better)	Adv.: *Wood emits significantly less CO_2 than steel and concrete.*	Imp.: 80	Adv.:	Imp.:
5. Thermal Mass	Att.: Has only thin concrete or gypcrete topping slabs on the floors providing little thermal mass.		Att.: Exposed concrete over metal deck and floors provides thermal mass.	
(The more thermal mass, the better)	Adv.:	Imp.:	Adv.: *The steel alternative has a higher expected thermal mass.*	Imp.: 20
6. Insulation	Att.: Good insulation material		Att.: Good insulation material	
Criterion: The higher insulation, the better	Adv.: -	Imp.:	Adv.: -	Imp.:
7. Research value	Att.: Not so valuable for research.		Att.: Very interesting for research.	
(The more interesting for research, the better)	Adv.:	Imp.:	Adv.: *Steel is more interesting for research than wood.*	Imp.: 100
8. Thermal Comfort	Att.: Low thermal mass, which is less effective in reducing overheating.		Att.: High thermal mass, which reduces the likelihood for overheating.	
(The higher thermal mass, the better)	Adv.:	Imp.:	Adv.: *Steel reduces the likelihood for overheating when compared to wood.*	Imp.: 30
9. Deconstructability	Att.: Difficult to deconstruct because of all the nailing.		Att.: Bolted beams and columns are easy to disassemble. Concrete over metal deck requires down cycling.	
(The easer to deconstruct, the better)	Adv.:	Imp.:	Adv.: *Slightly easier to deconstruct than wood structure.*	Imp.: 30
10. Flexibility	Att.: Relatively inflexible. Most room walls are bearing walls. This means that any future alterations would be difficult and expensive.		Att.: Has a post and beam system that is extremely flexible. It has a widely spaced grid. It can easily accommodate future reconfiguration.	
(The more flexible, the better)	Adv.:	Imp.:	Adv.: *Considerably more flexible than wood.*	Imp.: 50
Total IofAs		80		350

- The advantage of wood having a significantly lower embodied energy than steel and concrete seems slightly less important than the paramount advantage. It also seems an equally important advantage that the steel structure has significantly less EQ losses than the wood structure. The researcher assigned 80 IofAs to both advantages.
- The advantage of the steel structure being considerably more flexible than the wood structure seems to be of medium importance compared to the paramount advantage. Therefore, the researcher assigned it 50 points.
- The advantages of steel and concrete having a higher durability than wood, reducing the likelihood for overheating when compared to wood, and being somewhat easier to deconstruct than a wood structure, seem to be on the same level of importance. While these advantages provide a gain in value, they are not as important as the paramount advantage, and thus the researcher assigned 30 points to each of these advantages.
- The advantage of the steel structure having a higher expected thermal mass than wood is not that important since it does not provide a huge difference in terms of energy saving as explained in the project feasibility report. Therefore, the researcher assigned it 20 points. The advantage of the steel and concrete wall being faster to construct than a wood wall, does not seem to be important for the overall goal of the project. Therefore, the researcher assigned only 10 points to this advantage.
- No alternative has an advantage over the other with regard to insulation value.

Finally, the total IofA for alternative 1 is 80 and for alternative 2 is 380. The process of deciding the importance of advantages is subjective. However, CBA provides a clear guide to make trade-offs using the attributes of the alternatives in the context of the decision. In a real application of CBA, the design team would need to agree on the IofAs.

STEP 7: EVALUATE COST DATA

Decision makers can compare IofA vs. first cost and vs. lifecycle cost.

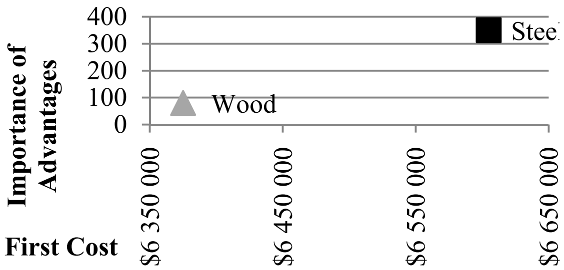

Figure 1: IofA vs. first cost.

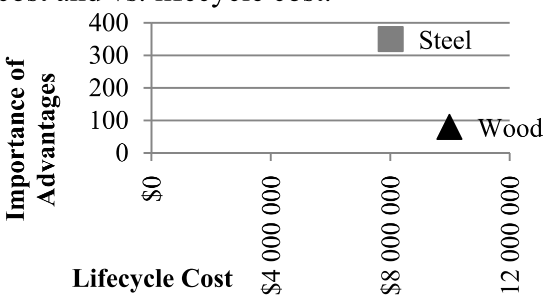

Figure 2: IofA vs. lifecycle cost.

Based on Figure 1 the design team should ask if it is worth paying $230,000 ($6,605,000 – $6,375,000) for obtaining 350 instead of 80 IofAs. It is evident that by choosing the wood-bearing wall the design team will be sacrificing important advantages. The three most important advantages of steel structure are: (1) much