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.

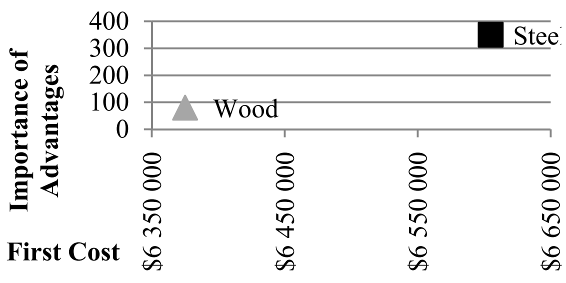

Figure 1: IofA vs. first cost.

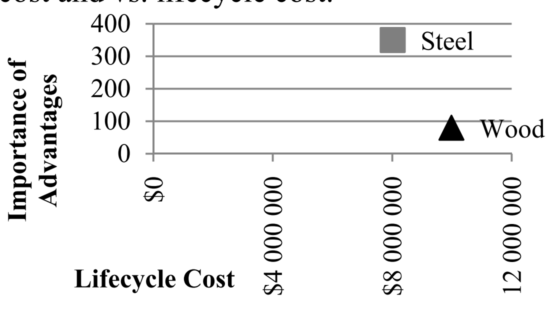

Figure 2: IofA vs. lifecycle cost.

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 richer opportunities for research than the wood structure, (2) significantly less EQ losses than the wood wall, and (3) considerable more flexibility than the wood structure. Figure 2 shows that in the long term the steel structure is better with regards to cost and importance of advantages. Therefore, if affordable, it should be selected.

DISCUSSION

WRC and CBA have important differences in the way information is presented and summarized, even when the final decision in this case seems to be obvious and is the same using either method. Some differences are presented next.

DIFFERENCE 1: DOUBLE COUNTING COST

WRC allows mixing cost with 'value' of the alternatives. In this case cost was incorporated as a factor with all the others. In contrast, CBA treats cost as a constraint. In this way the design team can describe the advantages of the alternatives and the 'value' they provide (Figures 1 and 2), and then evaluate if they have sufficient money or if they need to seek more.

DIFFERENCE 2: WEIGHTING FACTORS AND ATTRIBUTES VS. WEIGHTING ADVANTAGES

Figures 3 and 4 illustrate WRC and CBA. In WRC decision makers had to debate the general importance of factors. For example, deciding if 'research value' is more important than 'thermal mass' and then assigning a weight to the attributes in order to calculate and overall score. In contrast, in CBA decision makers need to discuss the relative importance of specific advantages.

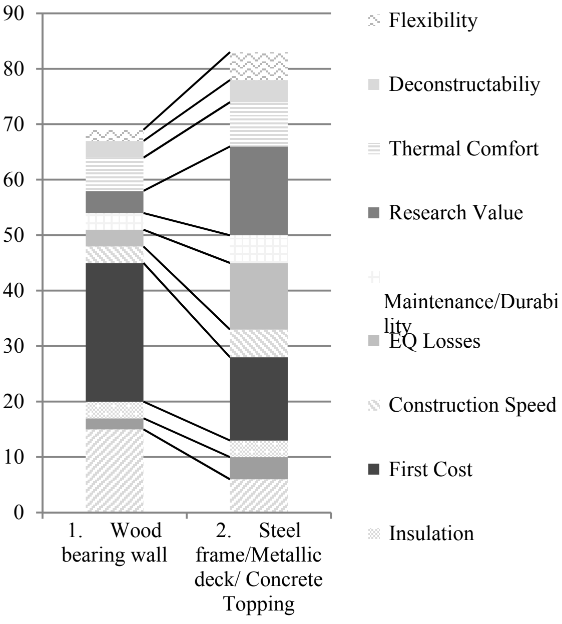

Figure 3: WRC scores.

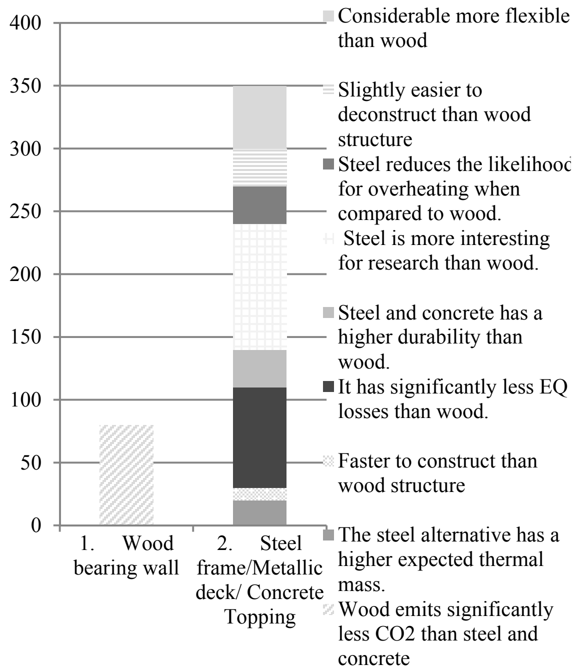

Figure 4: CBA IofAs.

DIFFERENCE 3: REMOVING NON-DIFFERENTIATING FACTORS

In this case the factor ‘insulation’ does not differentiate between the steel and wood alternatives. The effect of removing that factor from the decision has different consequences in WRC and CBA. In CBA the decision remains the same if ‘insulation’ is removed because (none of alternatives have an advantage). In contrast, in WRC the final decision does not change, but the intensity of the preferences does change. If ‘insulation’ is removed from the list of factors, steel would have 80 points and wood 66 points (case II in Table 4), in comparison with 83 vs. 69 in the original case (case I in Table 4). As Table 4 shows, the percentage between the preferences of the alternatives changes slightly. This may not be relevant for this decision, but stakeholders may have done that to other factors with high scores in WRC and the difference would have been bigger and at some point large enough to change the decision.

Table 4: Differences in final preferences when removing factor insulation in WRC

	Case I	%	Case II	%
Wood	69	45.4%	66	45.2%
Steel	83	54.6%	80	54.8%

Table 5 summarizes the differences between WRC and CBA. Factors 1-5 relate to creating transparency and factors 6-8 to building consensus in the decision making process.

Table 5: Differences between WRC and CBA.

Factor (Criterion) for MCDM methods	Weighting Rating and Calculating	Choosing By Advantages
1. Transparency on trade-offs inside a factor (Must not assume that attributes can be weighted)	WRC assumes that all increments in attribute performance are equally valuable.	CBA does not assume that attribute scales have an inherent value.
2. Transparency on trade-offs between factors (Must not assume linear trade-offs between factors)	WRC may assume that trade-offs between sustainability factors are linear functions.	CBA makes clear what the trade-offs between advantages are, and there is no assumed trade-off function.
3. Focus on differentiating alternatives (Must help differentiate the alternatives)	WRC May not help in differentiating alternatives because it is not based on differences of attributes.	CBA bases judgments on advantages.
4. Analyzing Cost (Must be treated separately from value)	Cost can be a factor and be mixed with the intrinsic value of the alternative.	Cost is not a factor. It is treated separately from value.
5. Consistency (The result must not change when removing non-differentiating factors)	In WRC the intensity of the preferences changes when irrelevant factors are removed. If factors must add up to a given total, then rank order may be	In CBA the decision does not change if irrelevant factors are removed.

	reversed when irrelevant factors are removed.	
6. Collaboration (Must avoid conflicting trade-offs between high-order of abstraction concepts)	WRC requires weighting factors, which are high-order of abstraction concepts, possibly hard to agree upon because of their abstraction.	CBA requires agreement on (more objective) advantages and postpones value judgment until later, which may minimize conflict.
7. Context specific (Must consider a specific context for all judgments)	WRC lacks context specificity when weighting factors.	CBA judges the importance of the advantages, which exist only in a given context.
8. Subjectivity (Must do the more objective part first and then the more subjective part)	WRC asks stakeholders to make explicit which factors are more important (a more subjective task first), without considering relevant differences between alternatives (a more objective task). In group decision making, this may lead to premature argument about value judgments.	CBA highlights the difference between the alternatives first (a more objective tasks) and then decide what advantages (positive differences) are more important (a more subjective task).

CONCLUSIONS

In conclusion, CBA helps more in creating transparency than WRC because (1) CBA does not assume that every increment in performance within a factor is equally valuable as WRC may assume; (2) CBA does not assume linear trade-offs between factors as WRC may assume; (3) CBA focuses on differentiating between alternatives more than WRC; (4) CBA does not mix 'value' and cost as WRC does; and (5) CBA does not change the intensity of preferences if irrelevant factors are removed from the decision as WRC does. In addition, CBA helps more in building consensus than WRC because (6) CBA avoids conflicting trade-offs between high-order of abstraction concepts and WRC does not; (7) CBA is more closely linked to the context than WRC; and (8) CBA first considers objective facts before moving on to more subjective discussion in contrast to WRC.

The researchers acknowledge that no decision-making method is entirely objective and both require subjective trade-offs (e.g., CBA among Advantages and WRC among factors). More research is needed to fully understand the extent to which the CBA process is superior to WRC, and the reasons and conditions in which that superiority is obtained.

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