PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE
ESCUELA DE INGENIERIA

MEASURING THE IMPACTS OF CHOOSING BY ADVANTAGES AS DECISION-MAKING METHOD FOR BUILDING DESIGN

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Thesis submitted to the Office of Research and Graduate Studies in partial fulfillment of the requirements for the Degree of Master of Science in Engineering

Advisor
PAZ ARROYO

Santiago de Chile, August, 2016

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To my family, for their support. To Amelia and Nicolás, for their time and patience.

ACKNOWLEDGEMENTS

This research was supported in part by the Center for Sustainable Urban Development (CEDEUS) financed by FONDAP N°15110020 and by the UC Timber Innovation Center (Centro UC de Innovación en Madera, CIM UC) of the Pontifical Catholic University of Chile (PUC).

I would like to thank to the AEC practitioners that volunteered in the experiment. To everyone who helped in carrying out the experiment, Daniela Vicente, Camilo Pinto, José Tomás Espinoza and the personnel from MAC (Master in Administration in Construction) from the Pontifical Catholic University of Chile (PUC). Also, thanks to the Chilean company that gave me the opportunity to apply these innovative management techniques for the first time in Chile. In addition, research was supported in part by the UC Timber Innovation Center (Centro UC de Innovación en Madera, CIM UC) of PUC.

Specially, thanks to my advisor, Paz, who helped me all time and gave me the confidence to carry out this research. She gave me many opportunities as a researcher and to attend to conferences.

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RESUMEN

El proceso de diseño de las obras de construcción involucra múltiples decisiones que deben ser tomadas por distintos actores. El diseño final obtenido debe satisfacer los requerimientos de todos los actores involucrados, por lo tanto es relevante que todas las decisiones sean tomadas de manera rigurosa. En la literatura se recomienda un método para tomar decisiones, llamando Choosing by Advantages (CBA), por sobre Weighting, Rating and Calculating (WRC), el cual es el más usado en la práctica. Además, se recomienda usar este método en conjunto con Set-Based Design (SBD) para el diseño de obras de construcción, debido a que SBD incentiva la evaluación de más de una alternativa que resuelve el problema de diseño y CBA ayuda en elegir entre las alternativas evaluadas. Sin embargo, en la literatura no se encuentran medidas de los impactos que genera utilizar estos métodos en el diseño de obras de construcción.

Esta investigación busca llenar el vacío en la literatura, primero, con un experimento controlado para testear dos métodos de toma de decisión, CBA y WRC. Segundo, a través de un caso de estudio, en el cual se utiliza CBA como método de toma de decisión y SBD como estrategia de diseño. El objetivo es determinar los beneficios y limitaciones de utilizar CBA y SBD en el diseño de obras de construcción. Específicamente, cuantificando el tiempo, satisfacción y frustración durante el proceso de toma de decisión y determinando la preferencia del equipo de diseño de usar CBA y SBD para el diseño de obras de construcción, por sobre las prácticas tradicionales. Los resultados muestran una reducción en el tiempo requerido para la toma de decisiones y menores niveles de frustración al usar CBA como método de toma de decisión, cuando se compara con WRC. Además, al usar CBA y SBD aumenta la colaboración entre los involucrados y reduce las iteraciones negativas del proceso, en comparación con las prácticas tradicionales. Futura investigación es necesaria para estudiar otros impactos de utilizar CBA y SBD en el diseño de obras de construcción y para evaluar si estas herramientas son adecuadas en otros contextos y otras industrias.

Palabras Claves: Toma de decisiones, MCDM, CBA, SBD, Diseño de obras.

ABSTRACT

The design process of buildings involves multiple decisions made by several stakeholders. These stakeholders have to get agreement on the final design. In this way, it is relevant that every decision, that shapes the final design, is made rigorously. The literature a recommends the Choosing by Advantages (CBA) method to make decisions, over Weighting, Rating and Calculating (WRC), which is the most used in practice. Some literature recommends CBA to be used in complement with Set-Based Design (SBD), due to SBD forces the development of at least two alternatives that solve the design problem and CBA helps in selecting among alternatives. However, the literature does not provide quantification of the impacts of using CBA and SBD as a decision-making method for building design.

This research fills the literature gap, first, by providing an experiment to test in a controlled environment the application of two decision-making methods, WRC and CBA and second, by conducting a case study that uses CBA as decision-making method complemented with SBD. The objective of this research is to determine the benefits and limitations associated with the application of CBA in building design. Specifically, quantifying time, satisfaction and frustration during the decision-making process and determining the preference of design teams to use CBA and SBD for building design, over traditional practices. The results show a reduction in time required for making decisions and lower levels of frustration when using CBA as decision-making method compared to WRC. Using CBA and SBD increases the collaboration among the stakeholders and reduces the negative iterations of the process compared to traditional practices. Future research is needed to measure other impacts of using CBA and SBD in building design and to evaluate if those methods are suitable for other industries and contexts.

Keywords: Decision-Making, MCDM, CBA, SBD, Building Design.

1. INTRODUCTION

Building design process involves several stakeholders that have to make multiple decisions. Stakeholders are commonly architects, designers, engineers, owners, among others (Pishdad-Bozorgi & Haymaker, 2014). All these decisions have to satisfy the requirements of the client and the design team (Arroyo et al., 2015b; Bucciarelli, 2003; Kpamma et al., 2009). Currently, stakeholders rarely document the design process, which leads to losses of information (Chachere & Haymaker, 2011). This information is the basis to justify the selected choice between the alternatives evaluated; therefore, this information should be available to all the stakeholders, allowing future comprehension of decisions made. Even more, the knowledge generated regarding the situation on which an alternative is preferred and the rationale for a decision, gives information to stakeholders for future decisions considering similar situations.

The lack of documentation can be explained by the traditional practices in building design practices in the Architecture, Engineering and Construction (AEC) industry. According to Arroyo et al. (2012a) "Decision making in the AEC industry appears to often use ‘decide, present, and defend’ approaches" leading to undocumented decisions that are commonly changed later in the design process. Even more, sometimes one specialist, considering only his point of view, makes the decision. Most of the decisions are based on past experience or by intuition, with no structured method for making decisions (Arroyo et al., 2012a).

In the literature, the actual process of building design has been categorized as Point-Based Design (PBD) (Ballard 2000). PBD works with only one alternative, which, from one point of view, is the best one. Then, this alternative is passed to other design specialist, who has to change some attributes of the alternative in order to satisfy the requirements of his/her point of view. This process continues iterating until a last design satisfies all stakeholders’ requirements (Parrish et al., 2007). Those iterations could be on the same subject over and over again without adding value to the design, which are called negative iterations (Ballard, 2000). The opposite of PBD is Set-Based Design

(SBD) in which the design process starts with a set of alternatives that are developed until one alternative is chosen applying must and want criteria. Must criteria are conditions that have to be satisfied with the solution and want criteria are preferences of one or more stakeholders (Parrish, 2009). This process is well explained by Figure 1.1 in which the process ends with the alternative selected that satisfy all must criteria and provides the greatest value for want criteria according to the trade-offs made by the design team. In theory, it is expected that when using SBD, the design outcome is superior than when using PBD, because designers are encouraged to develop and evaluate more alternatives and create new ones bringing together the best attributes of each alternative. In addition, the design process when using SBD is expected to include less negative iterations than when using PBD.

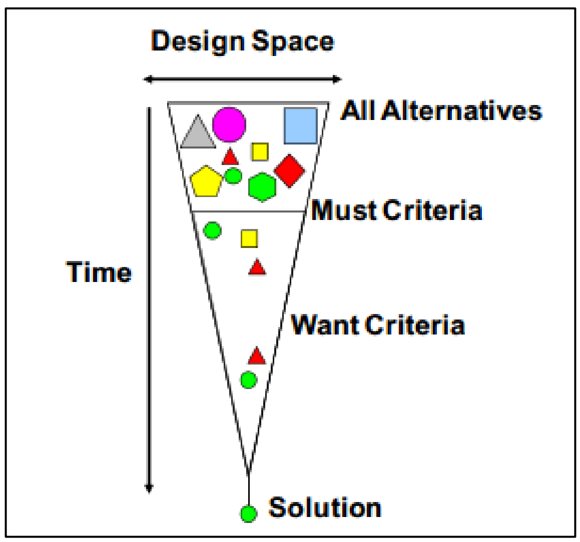

Figure 1.1: Set-Based Design Process (Parrish, 2009)

Even though when stakeholders use SBD, the decision making process is left to the users without much guidelines on which decision-making method to use for a collaborative and effective design process. This research aims to fill the gap in knowledge to recommend decision-making methods that can be used effectively with SBD and measure quantitatively and qualitatively the impacts of using these methods. Next section presents literature review on decision-making methods applicable for building design.

1.1. Literature Review

Some researchers propose using multi-criteria decision making (MCDM) methods to make decisions in the design process (Arroyo et al., 2015b; Sampaio & Neto, 2010). These methods allow deciding between multiple alternatives that have multiple factors, which have to be evaluated before making the decisions. Suhr (1999) highlighted the importance of selecting a sound method for making decisions because of the Cause-Effect model he presented (Figure 1.2). In this model he explained "Our *methods* produce our decisions. Our *decisions* guide our actions. And our actions caused outcomes" therefore, if the outcomes of our actions matter also the method used matters.

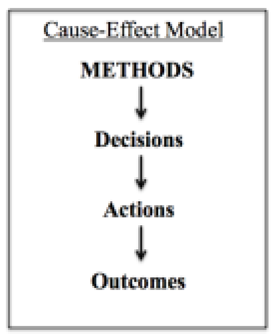

Figure 1.2: Cause-Effect Model (Suhr, 1999)

Multiple MCDM methods exist and are categorized by their approach. Categories presented by Belton and Stewart (2002) are: (1) goal-programming and multi-objective optimization methods, (2) value-based method and (3) Outranking methods. Another method found in the literature is Choosing by Advantages (CBA), proposed in first place by Suhr (1999), which is not within any of the categories listed before.

Arroyo et al. (2012a) showed that the most commonly used method, in the AEC industry, were Analytical Hierarchy Process (AHP) and Weighting, Rating, and Calculating (WRC). These two methods are categorized as value-based methods.

In literature CBA has been poorly studied. From 1999, when Jim Suhr created CBA, to 2016 (June), in google scholar appear about 70 publications regarding "Choosing by Advantages", as a decision-making method. Figure 1.3 shows the evolution in publications in google scholar regarding "Choosing by Advantages", which have significantly increased in the last 5 years. Some of those publications studied applications of CBA in different situations and others compared CBA against other MCDM methods. Many of those studies presents benefits of using CBA and shows the differences between using CBA or other methods.

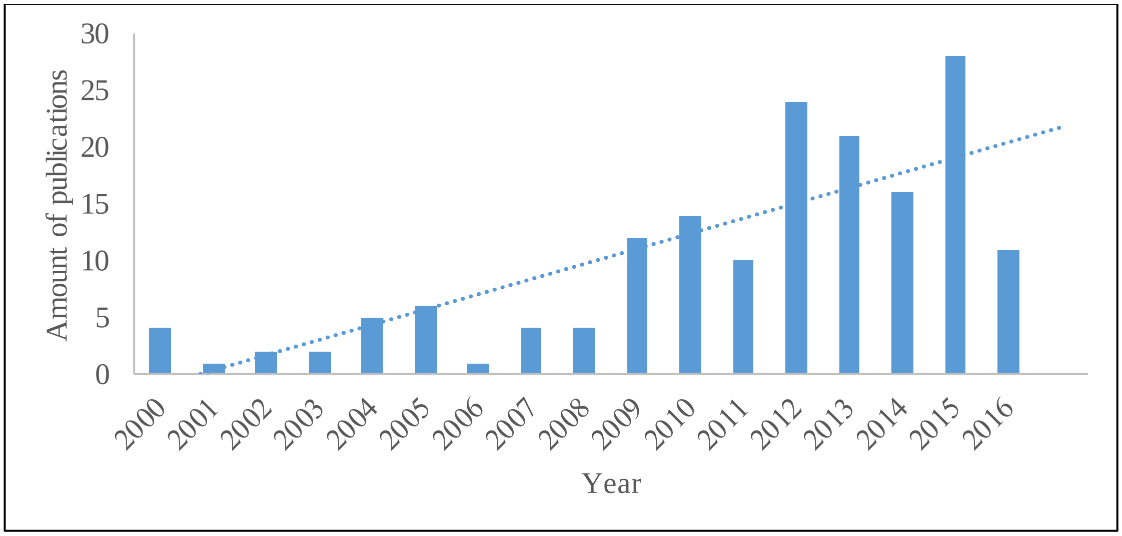

Figure 1.3: Evolution of publications of CBA in google scholar

In sections below a description of WRC and CBA is presented, continued by a literature review about what has been done about both methods. To facilitate this discussion, several definitions are presented on Table 1.1.

Table 1.1: Definitions

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.
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.

1.1.1. Weighting, Rating and Calculating

WRC is a MCDM method categorized as a value-based method. This method bases the decision on ranking factors and attributes independently of each other. In this method, first, stakeholders identify the alternatives; second, stakeholders identify the factors to evaluate the alternatives; third, stakeholders assign a percentage of importance to each factor; forth, stakeholders assign an importance from 0 to 10 (or other scale) to the attributes of each alternative; Fifth, stakeholders calculate a weighted sum with the weights of the factors and the importance of the attributes for each alternative. The result of this calculation gives the selected choice, selecting the one with the greatest score. Figure 1.4 shows the steps of WRC followed in this research. These steps may change in different applications, identifying the factors and assigning weights to them before knowing the alternatives.

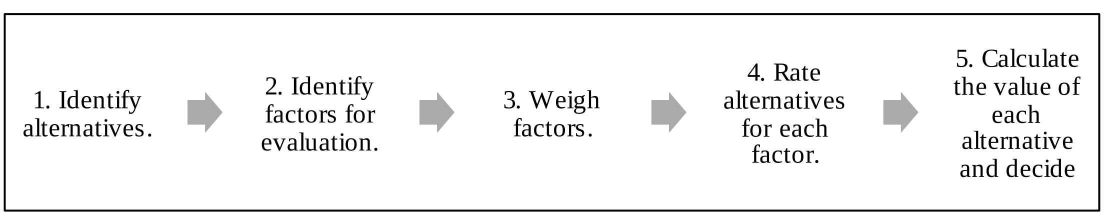

Figure 1.4: Steps of WRC

1.1.2. Choosing by Advantages

CBA is a MCDM method created by Suhr (1999) in which the decision is based on the difference between the attributes of the alternatives. First, the stakeholders identify the alternatives; second, stakeholders define factors; third, stakeholders define the criteria that applies for each factor; forth, stakeholders summarize the attributes for each alternative according to each factor; fifth, stakeholders decide the advantage of each alternative for every factor; sixth, stakeholders decide the importance of each advantage, assigning a score from 0 to 100 (or other scale) scaling the other importance compared with the most relevant one; seventh, stakeholders reach the final decision given by the sum of the importance of the advantages of each alternative, selecting the alternative with the greater score. Figure 1.5 shows the steps of CBA.

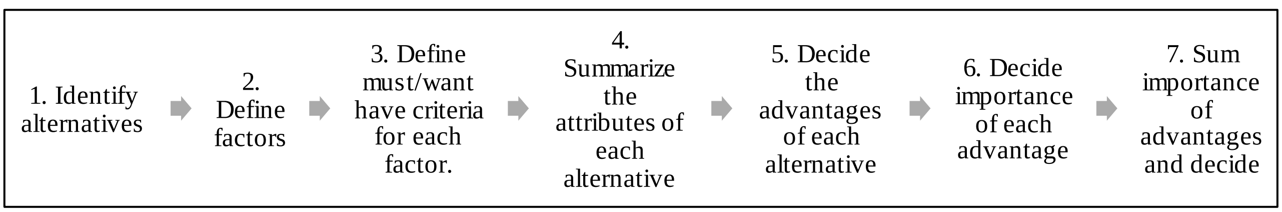

Figure 1.5: Steps of CBA

1.1.3. Literature Review of Choosing by Advantages

Some authors have studied different applications of these MCDM methods highlighting the advantages and disadvantages of their application on examples or case studies. The following paragraphs describe some of these studies and their conclusions in order to review what has been done about CBA.

Some research have been done to prove that CBA is a sound method for making decisions in the AEC industry (Arroyo et al., 2012a; 2012b; Parrish & Tommelein, 2009). Studies show that CBA gives more transparency of the decision making process. This allows future comprehension of the decision made and the rationale for making a decision. This is because CBA shows the objective information that was consider and clearly shows the judgment that leads to the decision (Arroyo et al., 2012b, 2014;

Parrish & Tommelein, 2009; Scöttle et al., 2015). Another characteristic that CBA has, is that when the alternatives have a factor that does not differentiate them, that factor could be eliminated and the alternative chosen will still be the same. This is a shortcoming of WRC and AHP in which if the non-differentiating factor is eliminated the preferences could change (Arroyo et al., 2012b, 2014). Scöttle et al. (2015) uses CBA to select project team in tendering precedure, Parrish & Tommelein (2009) to select reinforcement in a beam column joint, Nguyen et al. (2009) to select the installation of viscous damping wall system.

Arroyo et al. (2015a) compares CBA with AHP in an example of application, founding factors that differentiate them. They conclude that in all of them CBA is superior to AHP when selecting one from a finite amount of alternatives which attributes are known. Other study also compares AHP and CBA concluding that CBA allows stakeholders make decisions minimizing conflict of interests and facilitating collaboration (Arroyo et al., 2012b). A third study (Arroyo et al., 2012b) comparing these methods proposes that a characteristic that disqualifies methods is weighting factors, which is a step in AHP and WRC. This characteristic is important because weighting factors is very subjective and may cause conflict between the participants. They also conclude that CBA facilitate the decision between the alternatives because it bases the decision on relevant facts, considering the advantages of the alternatives to decide. In contrast AHP bases the decision on judgments of the participants about the factors and attributes of each one of the alternatives, which is a subjective activity (Arroyo et al., 2012b). Even though when CBA has also a subjective part when deciding the importance of the advantages, this subjective portion is done at the end of the decision in contrast to WRC.

Arroyo et al. (2014) presents a case study comparing WRC and CBA. They found that CBA helps making decisions more transparently and building consensus among the stakeholders. Another study (Scöttle et al., 2015) that compares WRC, CBA and Best Value Selection (BVS) proposes studying cost and value of the alternatives separately. WRC may include the cost of the alternative as a factor meanwhile CBA and BVS study them separately. However, they propose that CBA gives a clearer perspective, than BVS, about the value of the alternatives and its cost.

1.2. Problem Definition

Some research has been done in order to test different decision making methods in the AEC industry for collaborative design. All the literature shows qualitative analyses, studying the result of the decision that was made and how it changes according to the method used. When searching in google scholar "Choosing by Advantages" about 13 studies (Arroyo et al., 2012a; Arroyo et al., 2013; Ballard and Koskela, 2013; Johnson et al., 2013; Koskela, 2015; Wao, 2015; Kpamma et al., 2016; Arroyo et al., 2015b; Arroyo et al., 2016; Haapasalo et al., 2015; Kpamma et al., 2015; Hickethier et al., 2011; Kreivi, 2014) make an analysis of using CBA to make decisions, presenting benefits of using it and how it helps in decision-making. Another 4 studies (Arroyo et al., 2015a; Arroyo et al., 2012b; Arroyo, 2014; Arroyo et al., 2016) compare different methods for making decisions, giving guidelines to select which method use according to the characteristics of each one and presenting how the method used affect the decision made. Only 1 study (Pishdad-Bozorgi and Haymaker, 2014) presents the impacts of using different decision making methods in terms of the capability of building trust among decision-makers.

Only a few studies have demonstrated the use of SBD and CBA in conjunction (Lee et al., 2010; Parrish, 2009; Parrish and Tommelein, 2009). However, these studies do not measure the impacts in the design process and they do not follow the design team in a complete project with several interrelated decisions.

In literature there was no study which measure the impact of using one method over another in terms of the process of decision-making experienced by decision-makers. This study aims to fill that literature gap by providing quantitative and qualitative analysis of the impacts of using CBA vs WRC in terms of the process experienced by decision-makers. Specifically, the decision-making process in building design from the design team perspective in terms of the satisfaction with the final decision and the suitability of using decision-making methods in building design. In addition, this research measures how CBA method works in conjunction with SBD in a case study for several interrelated decisions, in terms of satisfaction with the design outcome, negative iteration, and collaboration in the design process.

1.3. Objective

The general objective pursued with this study is to identify the impacts of employing CBA with SBD in building design in comparison with traditional practices, i.e. PBD design and no structured method for making decisions. The specific objectives are listed below:

- Objective 1: Quantify the difference when making decisions using CBA or WRC, in terms of time, satisfaction and frustration during the decision-making process.
- Objective 2: Quantify the preference of using CBA or WRC as decision-making method when deciding about building design.
- Objective 3: Quantify the preference of designing with traditional practices or using CBA and SBD in different design situations.
- Objective 4: Analyze qualitatively the process of building design using CBA and SBD in comparison with traditional practices in terms of the satisfaction with the outcome of the project, the negative iterations and how it fosters collaboration.

1.4. Hypothesis

The hypothesis formulated for the present study is that using CBA in building design provides positive impacts, compared with traditional practices. Specifically, on one hand, that the application of CBA provides benefits in comparison to the application of WRC when making decisions, decreasing the time required to make decisions, increasing the satisfaction with the final decision and reducing the frustration of the group during the decision-making process. On the other hand, using CBA complemented with SBD provides advantages in comparison to traditional practices by increasing satisfaction with the outcome of the project, decreasing negative iterations and fostering collaboration between design team members.

1.5. Scope

The scope of the study is to measure the impacts of using CBA as decision making method in building design. Specifically, in conceptual design of commercial and residential buildings. The study was conducted in the Chilean context, between 2014 and 2016. The variables measured were time required to make decisions, satisfaction with the final decision, and individual and group frustration during the decision-making process. A qualitative analysis is made regarding collaboration and negative iterations produced by the design process when using CBA and SBD.

1.6. Methodology

The methodology for this research is presented in figure 1.6. The first activity done was a literature review about decision-making methods and building design. It is relevant to note that literature review has been present during the whole research, providing background and insights to all the research steps.

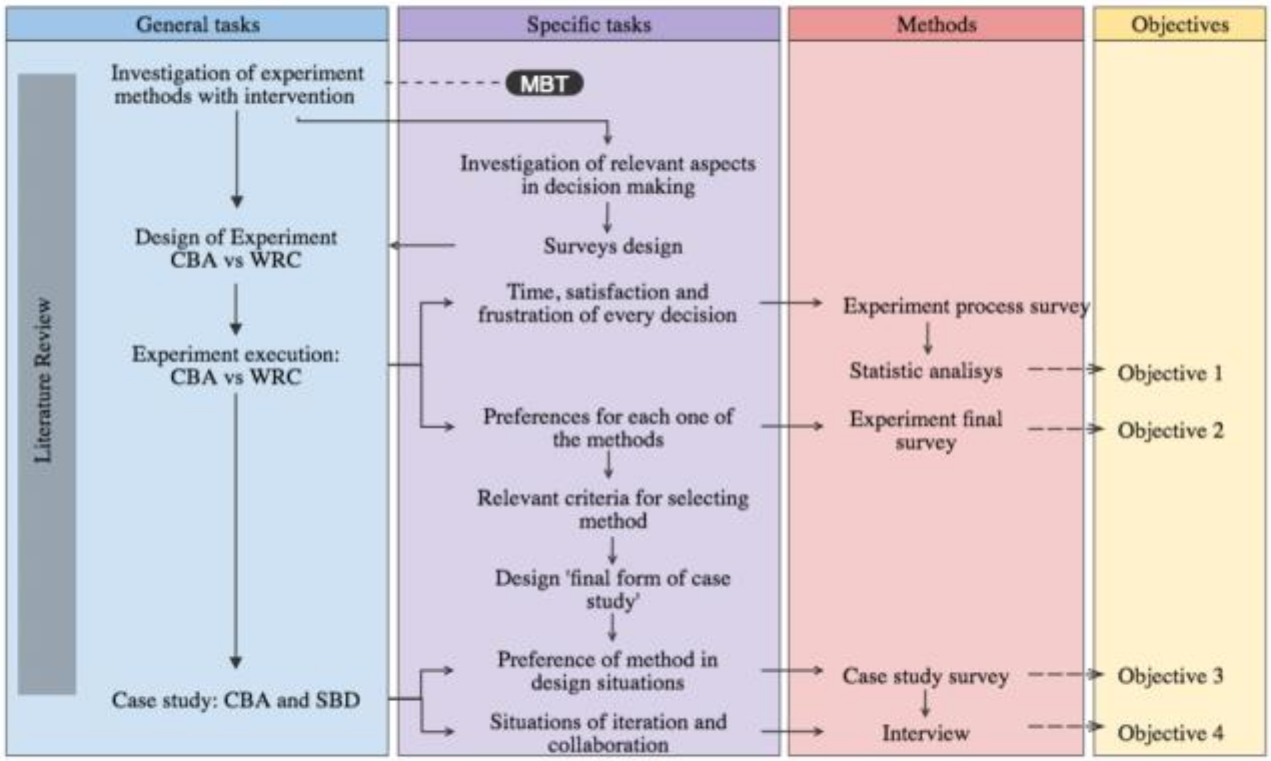

Figure 1.6: Methodology of research

Second, a research was carried out about methods of experimentation with intervention, finding a method called Multiple Baseline Testing (MBT) (Albert et al., 2015). This method comes from pharmaceutical research to prove the effect of a determined intervention. In parallel, relevant aspects that have to be measured during the process of decision-making were investigated. With this information the 'experiment process survey' and the 'experiment final survey' were designed. These two surveys in conjunction with the MBT method allowed the design of the experiment as a whole.

Third, the experiment was carried out in which five groups of three people each had to make twelve decisions. Decision were about design situations, for example, selecting between building materials, HVAC systems, etc. At the beginning of the experiment roles were assigned to participants, in order to have one architect, one owner and one structural engineer per group. Every decision was made first individually and then in group. After every decision, participants completed the 'experiment process survey' in which they filled with the time required to make the decision in group, the satisfaction with the final decision, the frustration experienced during the decision-making process and the frustration perceived of the group during the process, among other things (see Appendix 1 for more details). The responses of the ‘experiment process survey' were analyzed statistically responding to the objective 1, which quantifies the difference of time, satisfaction and frustration during the decision making process between using Weighting, Rating, and Calculating (WRC) and Choosing by Advantages (CBA). After the twelve decisions were made, every participant had to fill the ‘experiment final form’ to choose which method, WRC or CBA, they would use in future applications and to name the advantages of using each one of the methods. The responses of the 'experiment final survey’ determine the preference of one method over another, responding to objective 2. The justification of the choice gives relevant criteria for the participants to take into account when selecting a method for making decisions. These criteria is used to design the 'case study survey'.

Then a case study was conducted in which a design team had to design a project collaboratively using CBA, as decision-making method, and Set-Based Design (SBD). The project consisted in conceptual design of corporate offices for a Chilean company using timber as structural material. At first, the design team, the owner and a specialist in timber building were introduced on CBA and SBD. Then, a planning session was performed to plan the sequence in which decisions have to be made and the commitment dates to deliver the project. At the end of the project design team members were asked to answer a survey in which they have to choose which method they would use in different design situations. One method was designing with traditional practices, i.e. with no structured method for making decision and mostly like Point-Based Design, and the other method was collaborative design, using CBA and SBD. After they have completed the survey, they were interviewed to understand the design process they have experienced and to clarify responses of the survey. To compare their experience, they were asked to think about a project in which the same design team used traditional practice. In reality the same design team used traditional design practices for detail design of social housing project, mandated by Ministerio de Vivienda y Urbanismo

(MINVU, Ministery of housing and urbanism) of Chile. In the interview they were asked to explain the process of design in both projects, give examples of situations of negative iteration and of collaboration. They were also asked to evaluate if they feel satisfy with the outcome of both projects and if, from their own point of view, the owner and future user of both projects were satisfied with the final design. The responses of the survey were analyzed to respond to objective 3 and the interviews were recorded and then analyzed to obtain concrete examples of iterations and collaboration in both project to respond to objective 4.

2. COLLABORATING IN DECISION MAKING OF SUSTAINABLE BUILDING DESIGN: AN EXPERIMENTAL STUDY COMPARING CBA AND WRC METHODS

2.1. Abstract

This study compares Choosing By Advantages (CBA) and Weighting Rating and Calculating (WRC) as Multiple Criteria Decision Making (MCDM) methods in how they support collaboration in groups, particularly pertaining to design decisions involving sustainability factors in architecture, engineering and construction industry.

This study is based on an experiment done with 15 practitioners, where they formed 5 groups of 3 people each. The experiment used Multiple Baseline Testing (MBT) and all groups made 12 decisions. The initial decisions were made using the WRC method and later, in a staggered manner between the fifth and ninth decision, the groups were taught to apply the CBA method. The CBA method is considered to be the intervention in the experimental design. Four dependent variables were analyzed: (1) time to reach consensus, (2) satisfaction with the final decision, (3) personal frustration during the decision, and (4) perceived frustration from others during the decision. The results showed with statistical significance that CBA was faster than WRC for reaching consensus and presents less personal and perceived frustration during the decision. The results do not show statistical support in favour of any method regarding satisfaction with the final decision.

2.2. Introduction

Collaboration in decision making is often required in Architecture, Engineering, and Construction (AEC) design process, especially when multiple competing factors must be considered in concert. For example, collaboration is crucial to decision making surrounding sustainable design of buildings because design alternatives often involve different materials, components, layouts locations, and building systems upon which decision makers must agree. It is also desirable that the design team reach satisfaction rather than frustration with the final design. Multiple-Criteria Decision-Making (MCDM) methods can help AEC practitioners to structure decisions and facilitate collaboration. However, few research studies (Hopfe et al., 2013; Kim and Augenbroe, 2013) have measured the actual impacts of using different MCDM methods on collaboration and decision making.

Arroyo et al. (2014) have retrospectively analyzed a case study to compare the impact on the final decision of two decision-making methods: choosing by advantages (CBA) and weighting, rating, and calculating (WRC). However, to this day, there has been no formal experimental research to test the relative impacts of these methods on collaboration and decision-making. This paper fills that research gap by comparing CBA and WRC using Multiple Baseline Testing (MBT).

The relative impact of MCDM methods is not often understood (Arroyo et al., 2014), it has been proven many times that different MCDM methods may lead to different results (Zavadskas and Turkis, 2011). MCDM methods used in a decision will impact the decision itself, including the consequences of the decision, and also will impact the performance of the team by supporting or not collaboration in terms of reaching consensus, increasing satisfaction, and decreasing frustration among other aspects. This research contributes to the body of knowledge by conducting the first controlled experiment where CBA and WRC are compared. In practice the results will facilitate collaboration when making design decisions.

2.3. Definitions

In order to set a common language to compare WRC and CBA methods we will use the definitions in Table 2.1, which have been modified from Suhr (1999). These operational definitions are important as the lexicon can be used in many ways depending on context.

Table 2.1: Definitions

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.
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.

2.4. Background

This section presents some background information about sustainable design of buildings in the AEC industry, collaboration in-group decision making, and MCDM methods.

2.4.1. Sustainable Design of Buildings

Sustainability is not easy to measure or to define; multiple stakeholders will even have different opinions about the definition of sustainability. The most widespread definition of sustainability can be traced to the Brundtland Report (World Commission on Environment and Development, 1987), presented at the 1987 UN Conference. It defined sustainable developments as those that “meet present needs without compromising the ability of future generations to meet their needs.” The US Environmental Protection Agency (2012) also states that sustainability is important in making sure that we have and will continue to have the water, materials, and resources to protect human health and our environment. An absolute truth about what is and what is not *sustainable* does not exist. Most of the time, buildings designers have to make trade-offs. For example: How much air quality performance are you willing to give up for energy efficiency? Should I prefer a material with low CO_2 emissions but high VOCs? The answers may vary based on the points of view of each member of the design team, and on different contexts (geographic location, culture, etc.).

For many authors sustainability is seen as the only possible direction for the future (e.g., Papamichael, 2000; Yohe et al., 2007; Oehlberg et al., 2009). In particular, building design is now required to account for sustainable outcomes. Traditionally the AEC industry has focused on delivering a project on time, on budget, safely, and with a certain quality. Recently, concerns about impact on the environment and health have become more important and involve considering other types of information in the decision-making process.

2.4.2. Collaboration in Decision Making

Decisions in the AEC industry are usually made without rigorous analysis (Fischer and Adams, 2011). In sustainable design of buildings, multiple stakeholders are involved who have different perspectives and, often, conflicting interests. The current practice for choosing among alternatives can be detrimental for sustainable design of buildings (Ding, 2005). Therefore, projects require a collaborative delivery system. In order to optimize the whole building design, and not just the parts, extensive collaboration is required. Some authors point out the necessity of using a collaborative delivery process (Korkmaz et al., 2009; 2010), an integrated design process (National Institute of Building Sciences, 2005), and an early involvement of key project participants (Riley & Horman, 2005). Russell-Smith et al. (2015) presented a software to help in decision making when considering sustainable factors, to rapidly assess the impact of the entire life cycle of a building when making design decisions. A collaborative delivery system should also include a collaborative decision making process.

Measuring collaboration in a decision-making process is not a simple task. Some studies have analyzed collaboration in terms of group effectiveness, time to reach consensus, satisfaction of participants, among others (Baltes et al., 2002; Jelodar et al., 2014; Tsamboulas et al., 1999).

2.4.3. MCDM Methods

Many MCDM methods exist (Arroyo et al., 2016; Azapagic & Perdan, 2005a, 2005b; Belton & Stewart, 2002; Wang et al, 2009) such as optimization methods, value-based methods (e.g., Analytic Hierarchy Process (AHP) and WRC), outranking methods (e.g., ELECTRE), and CBA. However, more research is needed to evaluate how MCDM methods support AEC group decisions transparently and how they help in building consensus, particularly when decisions consider sustainability issues in building design. In fact, using different decision-making methods with the same information may lead to different outcomes (Arroyo et al., 2016). The selection of a decision-making method is very important; therefore it should not be left to chance. Several sustainable design decisions are made using MCDM methods. For example, Hopfe et al. (2013) select an HVAC system using AHP and Kim & Augenbroe (2013) select a ventilation strategy of a hospital with utility function considering multiple criteria to evaluate.

In our opinion literature does not provide enough support for AEC practitioners to select a decision-making method to choose a sustainable alternative (e.g., a material, a building component, a structural system). Several research studies (Guitoni and Martel, 1998; Zanakis et al., 1998) have compared MCDM methods in other contexts, but none of them are focused in construction industry and none compares CBA. This paper helps to fill that gap by testing the use of two MCDM methods: WRC and CBA.

WRC method is also known as weighted sum, where decision makers have to weigh the factors involved in the decision based on their importance (w_i), then rate the alternatives for each factor (u_i), and finally calculate the weighted sum of each alternative to make a decision ($\sum_i^n w_i * u_i$). WRC is widely used in AEC practice. For example, Sabapathy & Maithel (2013) used WRC to create a ranking to choose walling materials in India; and Tatum (1984) describes WRC in a wide range of decisions.

CBA is a method developed by Suhr (1999). In CBA the decision is not about which factor is more important, but which factor will highlight important differences among alternatives. Decision makers have to decide what are the advantages of each alternative, and then they assess the importance of these advantages by making comparisons among them. By following the CBA method, decisions are anchored to relevant facts, and decisions are particular to a given context. CBA is mostly used within the lean community. For example, Grant and Jones (2008) use CBA to select green roof designs, Nguyen et al., (2009) use CBA to select a wall system; Parrish & Tommelein, (2009) uses CBA for structural design desions; Arroyo et al. 2016 uses CBA to select an HVAC system. This paper supplements previous work comparing AHP and CBA (Arroyo et al., 2012a; 2012b; 2016).

2.5. Research Hypothesis

From previous research (Arroyo et al., 2015a), we have observed that CBA is more helpful in differentiating alternatives than WRC. However, this evidence is based on retrospective analysis and the impact of potentially confounding factors had not been controlled. In order to make the inference that CBA causes a greater increase in collaboration than WRC, a controlled experiment is required. The present study aims to perform a controlled experiment, specifically addressing the following hypotheses, stated in the negative in accordance with scientific convention:

(1) CBA does not decrease the time to reach consensus compared to WRC.

(2) CBA does not increase satisfaction with the final decision compared to WRC.

(3) CBA does not decrease personal frustration during the decision compared to WRC.

(4) CBA does not decrease perceived frustration from others during the decision compared to WRC.

Notice that in order to test these four hypotheses the WRC method is considered to be the baseline, and after an intervention CBA replaces WRC method.

As one will note, the hypotheses above includes causal inferences. That is, we hypothesize that CBA *causes* improvements in collaboration outcomes compared with WRC. Thus, our experimental design involves controlling external factors that may be competing explanations of improved collaboration if they are observed. Such a controlled experiment allows the team to provide undeniable evidence that the dependent variables (e.g., decision time, satisfaction, and frustration) are changing only because of the manipulation of the independent variables (the use of WRC or CBA method). The follow section explains the methodology applied in order to test these four hypotheses.

2.6. Research Methods

Figure 2.1, represents the research method followed to test our hypothesis.

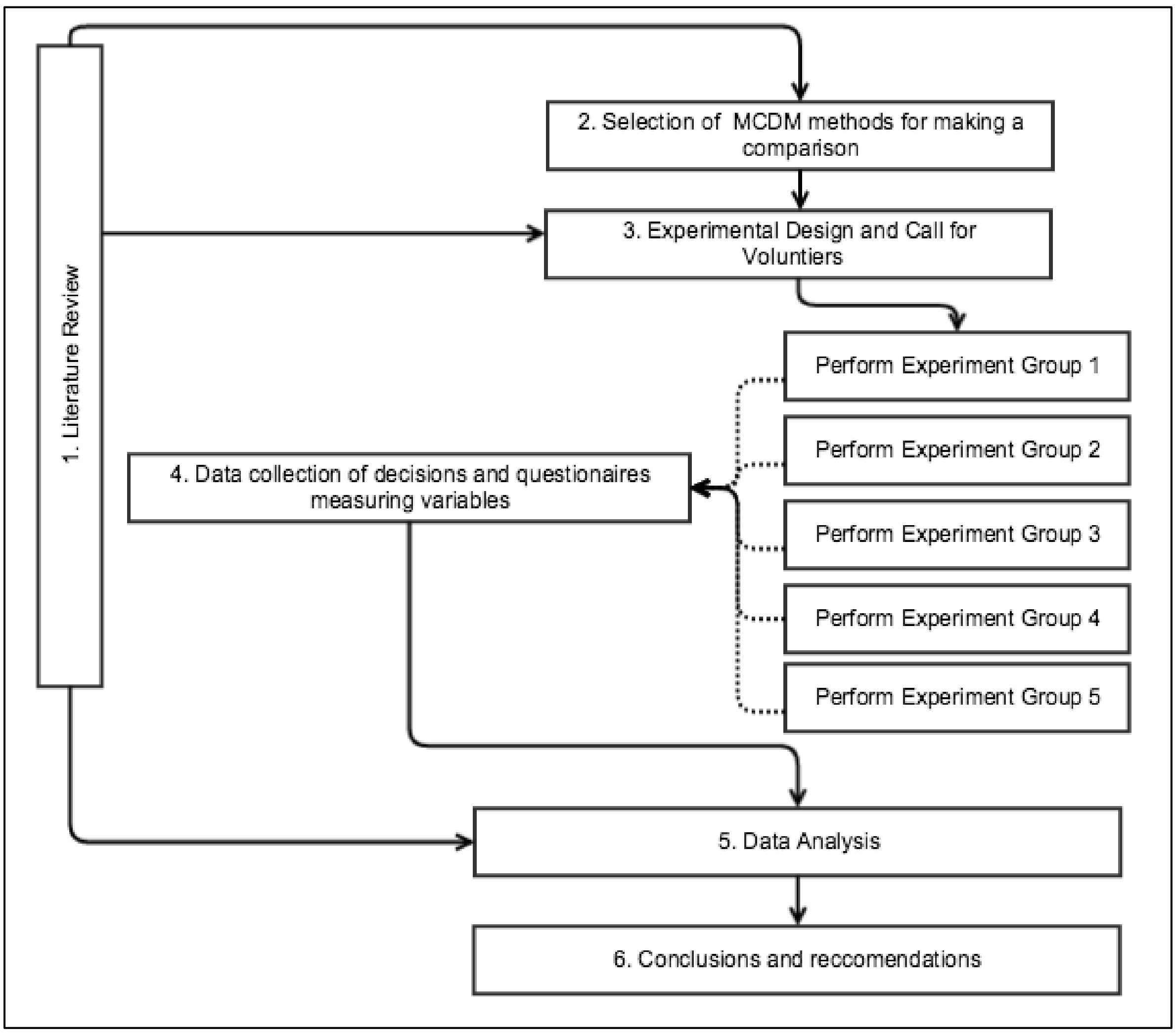

Figure 2.1: Research methodology

First, the researchers studied literature about MCDM methods in AEC industry, for developing an experimental design, and for data collection.

Second, the researchers selected two MCDM methods, in this case WRC and CBA. WRC was selected because is the most used MCDM method in engineering practice and CBA was selected because it presents significant differences with WRC and may provide different results for group decision making collaboration.

Third, in order to test the effects of WRC and CBA on collaboration, the researchers designed a controlled multiple baseline experiment using the protocol described by Albert et al. (2015). The roots of multiple baseline testing (MBT) come from pharmaceutical research where drawing causal inferences in a highly dynamic and complex environment. For example, pharmaceutical researchers must demonstrate, undeniably, that a drug causes specific impacts to the human body before it is approved. In this study we use the same MBT protocol in an effort to test the impact of new decision-making strategies. Because WRC is considered the norm for decision-making in the AEC industry, our protocol involves deciding with WRC as the baseline, and then replacing WRC by CBA after the intervention.

Forth, we developed measured four dependent variables: (1) time to reach consensus, (2) satisfaction with the final decision, (3) personal frustration during the decision, and (4) perceived frustration from others during the decision. We selected these variables due to their importance for collaboration in group decision-making. The variable *time* is a measure of the rate at which consensus was reached in the group discussion, where faster consensus is better. Also we asked the participants about their satisfaction with the final decision in an effort to measure the extent to which they agree with the group decision and the extent to which their personal requirements were satisfied with the selected alternative. We also asked the participants to rate their level of frustration and the perceived frustration of the group. Frustration was understood to be the level of opposition about a subject or disagreement with others opinions. All of these measures give a different perspective on how effective the evaluated methods are for making decisions in groups.

Fifth, we analyzed the data by comparing the measured variables and tested our aforementioned hypotheses.

The experiment was conducted in 2015 with students of the Master in Construction Management in Pontificia Universidad Católica de Chile. They were man and woman between 30 to 45 years old and with 5 to 7 years of professional experience in the AEC industry. They were architects and engineers by profession but in the experiment they were assigned to a role. We tried to assign their roles accordingly with their professions, although it was not possible in all the cases. The participants were arranged in 5 groups of 3 people each. They had to play a role in the decisions as owner, architect, or engineer, i.e. in each group there was one architect, one engineer and one owner. All groups made the same 12 decisions pertaining to choosing alternative materials, components, building systems, building layouts, and building location. Table 2.2 shows a description of the 12 decisions. All decisions considered social, environmental and technical factors. However, cost was not considered as a factor in the decisions, future research could incorporate cost as a constraint. For both methods the practitioners did not considered cost as a constraint; therefore, the analysis is focused in reaching consensus about which is the alternative that provides more value for the project regardless of its cost. This strategy is recommended when incorporating sustainability and technical factors in the decisions such as environmental impacts, social impacts, health impacts, and technical performance. The objective is to understand value of the alternatives first and then assess the cost considering a particular project budget. Otherwise, if alternatives are evaluated merely on cost, sustainability and technical factors may not be addressed properly or left outside of the decision choosing the alternative with the lowest cost. In both methods one could make a cost vs. value analysis to make decisions considering both aspects. Arroyo et al. (2016) presents an example of CBA's importance of advantages scores against first-cost and life-cycle-cost to make a final decision.

The order in which decisions were made was randomized before assigning decisions numbers to them, however, all groups made the decisions in the same order, starting with decision 1 and ending with decision 12, as shown in table 2.2. All decisions have a similar level of difficulty understood as the number of alternatives and factors considered in each one, two to four alternatives, and five to eight factors.

Table 2.2: Decisions

Decision 1: Choosing ceiling tiles for an office renovation.
Decision 2: Choosing materials for exterior wall formwork in office renovation.
Decision 3: Choosing insulation materials for a house
Decision 4: Choosing insulation materials for a hospital.
Decision 5: Choosing construction materials for a house
Decision 6: Choosing light bulbs for a house.
Decision 7: Choosing an HVAC system for a museum.
Decision 8: Choosing the structural system for a house.
Decision 9: Choosing the layout of a library.
Decision 10: Choosing a wall system for a house
Decision 11: Choosing windows for a house
Decision 12: Choosing location for the offices of a company

All groups started making decisions with WRC as the baseline. Later, CBA was introduced to each group as an intervention, which required a 20-minute training session. Following this intervention, the groups started making decisions using CBA. The intervention was made one group at the time in a different room. Group 1 was intervened after decision number 4 using WRC, Group 2 was intervened after decision number 5 using WRC, and so on until Group 5 was intervened after decision number 8 using WRC. After the intervention the groups started making decisions in a third room, so they did not disturb other groups who were still applying WRC. Figure 2.2 summarizes the setting of the experiment based on MBT method, the intervention are represented with a star. Notice that next two decisions after intervention was trial period, therefore studied variables were not analyzed in that period.

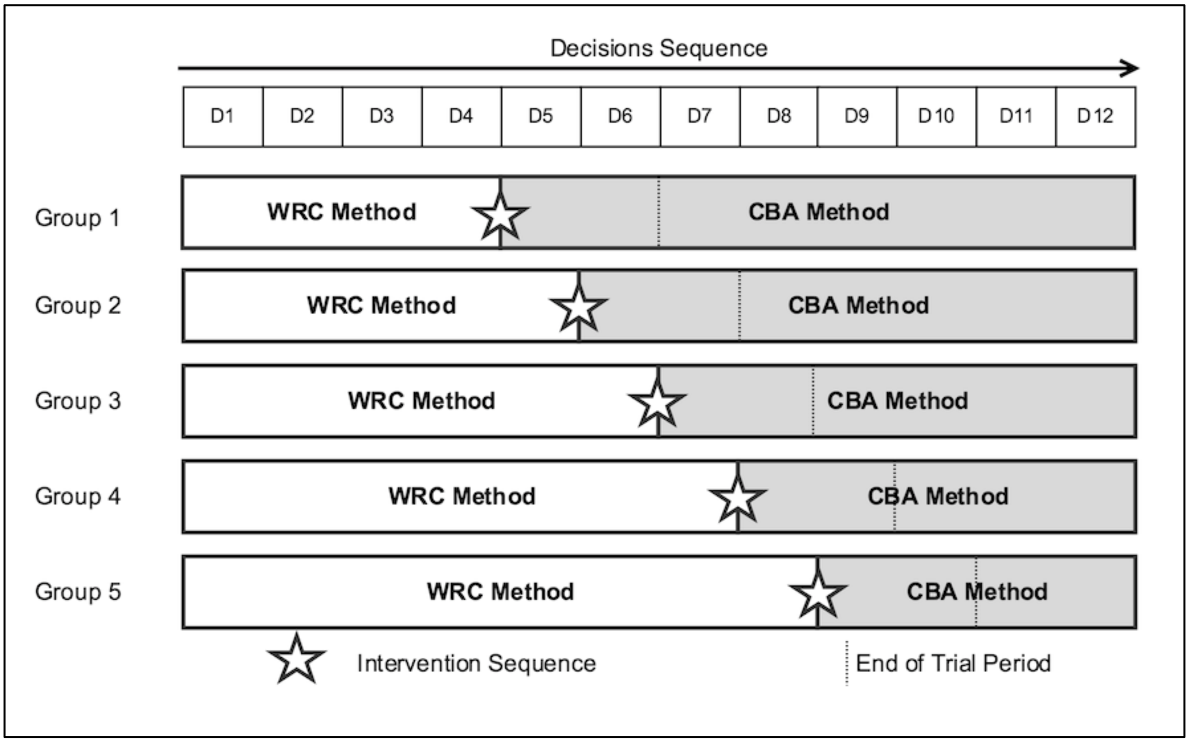

Figure 2.2: Experimental Design

All twelve decisions followed three key steps:

1. Each person makes a decision individually, assigning scores to alternatives into the decision form. The decision form included all relevant information to make the decision including alternatives, factors, and attributes. The decision form had a different table structure for WRC and CBA decisions in order to follow the methods. However, the same information was presented for both methods.
2. The group starts a discussion until they reach consensus to make a group decision, the group fills up the agreed decision form.
3. Each person fills out the evaluation form after the decision. This form includes all four variables (1) time for reaching consensus, measured in step 2; (2) satisfaction with the final decision, measured in a scale from 0 to 20 where a higher scored represented more satisfaction; (3) personal frustration during the decision, measured in a scale from 0 to 20 where a higher scored

represented more frustration; and (4) perceived frustration from others during the decision, measured in the same way than personal frustration.

When the 12 decisions have been made, all the participants answered another form in which they have to indicate which method they would use in future applications and why this selection. Also, they were requested to mention some advantages of using each one of the methods.

2.7. Baseline Method: WRC

In the beginning of the experiment the groups were introduced to the definition of alternative, factor, and attribute and trained in how to apply WRC. The groups used WRC to make their firsts decisions. WRC can be summarized in the following 5 steps (Figure 2.3).

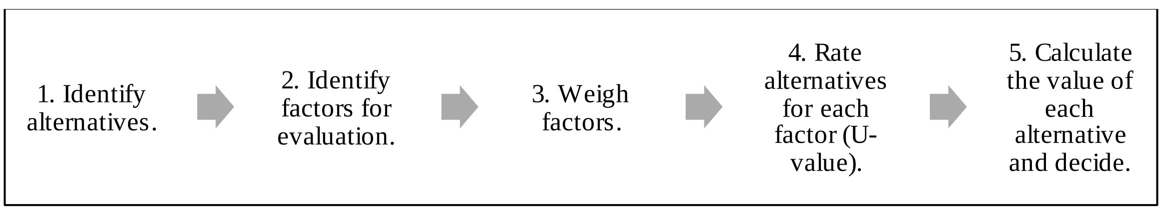

Figure 2.3: WRC steps

For the experiment, we provided the information for steps 1 and 2 (shown in Table 2.3 for decision 1) in order to focus the analysis on reaching consensus and not on gathering data. The practitioners performed steps 3-5 for all of the decisions using WRC, filling the blanks in Table 2.3. First they made the decision individually and then in group, filling the same form in both instances.

Table 2.3: WRC decision forms

Decision 1: Choosing materials for ceiling tiles for office renovation.									
Factor	**Factors Weigth**	**Alternative 1: Optima (fiberglass)**	**U**	**Alternative 2: Ultima (mineral fiber)**	**U**	**Alternative 3: Optima plant Based (fiberglass)**	**U**	**Alternative 4: Optra (fibreglass)**	**U**
Acoustics (NRC)		0.9		0.7		0.95		0.9	

Anti-microbial		Inherent		It has BioBlock+		Inherent		Inherent	
Durability		Scratch resistance, impact resistance		Scratch resistance, impact resistance		Scratch resistance, impact resistance		No Scratch resistance, No impact resistance	
Weight (kg/m^2)		0.023		0.05		0.023		0.02	
Insulation Value (R-Value)		R-value 4.0		R-value 2.2		R-value 4.0		R-value 3.0	
VOC Formaldehyde		Low formaldehyde-less than 13.5 ppb		Free of formaldehyde		Free of formaldehyde		Low formaldehyde-less than 13.5 ppb	
Guaranty (years guarantee)		30		30		30		15	
CO_2 Emissions (t CO_2 eq)		54		70		54		56	
Total									

2.8. Intervention Method: CBA

During the CBA intervention the teams were introduced to the definition of criteria, differentiating criteria from a factor. In addition, they were introduced to the notion of advantage and trained in how to apply CBA.

After the intervention the groups made decisions using CBA. Figure 2.4 presents the CBA steps. Again, we provided the information for steps 1, 2 and 4. Then, the practitioners completed steps 3 and 5-7 using the decision form in Table 2.4 for decision 1.

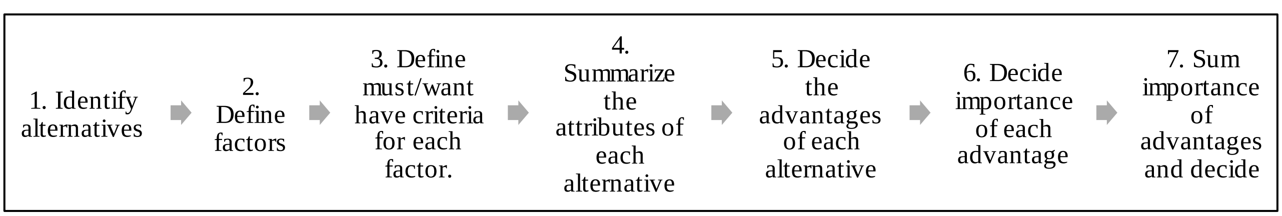

Figure 2.4 CBA steps

Table 2.4: CBA decision forms

Decision 1: Choosing materials for ceiling tiles for office renovation.								
Factor (criterion)	**Alternative 1: Optima (Fiberglass)**		**Alternative 2: Ultima (Mineral Fiber)**		**Alternative 3: Optima plant Based (Fiberglass)**		**Alternative 4: Optra (Fiberglass)**	
Acoustics	Att: NRC 0.9		Att: NRC 0.7		Att: NRC 0.95		Att: NRC 0.9	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
Anti-microbial	Att: Inherent		Att: It has BioBlock+		Att: Inherent		Att: Inherent	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
Durability	Att: Scratch resistance, impact resistance		Att: Scratch resistance, impact resistance		Att: Scratch resistance, impact resistance		Att: No Scratch resistance, impact resistance	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
Weight	Att: 0.023 kg/m^2		Att: 0.05 kg/m^2		Att: 0.023 kg/m^2		Att: 0.02 kg/m^2	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
Insulation Value	Att: R-value 4.0		Att: R-value 2.2		Att: R-value 4.0		Att: R-value 3.0	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
VOC Formaldehyde	Att: Low formaldehyde- less than 13.5 ppb		Att: Free of formaldehyde		Att: Free of formaldehyde		Att: Low formaldehyde- less than 13.5 ppb	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
Guaranty	Att: 30 Year Guarantee		Att: 30 Year Guarantee		Att: 30 Year Guarantee		Att: 15 Year Guarantee	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
CO_2 Emissions	Att: 54 t CO_2 eq		Att: 70 t CO_2 eq		Att: 54 t CO_2 eq		Att: 56 t CO_2 eq	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
Total								

Different from WRC in CBA decisions are based on the importance of the advantages, anchoring decisions on the attributes of the alternatives. For example, for someone the factor emissions of CO_2 could be very important, therefore it would have a high weight in WRC. But if in this factor one alternative emits 100kg of CO2 and the other emits 101kg of CO_2 it could be less important in comparison of the difference in the guaranty factor, in which one alternative has an attribute of 1-year guaranty and the other one 30-years guaranty. In this way CBA compares which difference is more important: the emission of 1 kilogram of CO_2 more or 29 more years of guaranty. However, WRC compares which factor is more important: emissions of CO_2 or the guaranty of the product without considering the differences between the attributes of the alternatives.

2.9. Data Analysis

The research process yielded a large volume of data. Specifically, 50 decisions were made by 5 different groups and data pertaining to 10 variable measures were gathered yielding over 500 data points. As mentioned above, the variable measures for each decision included (1) time to reach consensus (measured as a group); (2) satisfaction levels with the final decision of the decision makers (measured individually); (3) frustration levels of the decision makers during the decision making process (measured individually); and (4) the perceived frustration levels of other decision makers during the decision making process (measured individually). The focus of the data analysis was to compare the impact of introducing CBA as an intervention to replace WRC for decision making.

To estimate the impact of adopting CBA as an intervention, two-sample statistical tests comparing the variable measures in the pre-intervention and post-intervention phase was performed. To improve statistical power for inference, the researchers decided to combine data across groups while making these comparisons. For example, when comparing the amount of time taken for decision making, the pre-intervention data for all groups were combined and compared with the overall performance in the post-intervention phase. Consequently, one two-sample test was performed for each of the variable measures.

To select the most appropriate two-sample statistical test, the normality of the data pertaining to each variable measure was assessed using the Anderson-Darling test. The test results revealed that the data was not normally distributed in most cases. Therefore, assuming each of the decisions were independent, the non-parametric Mann-Whitney U test test was adopted.

For each variable measure, the null hypothesis that was tested is that there was no significant difference in the post-intervention phase compared to the pre-intervention phase. Because there were 4 variables, 4 separate hypotheses were tested. The change in performance (Δ) for each variable measure was assessed as the mean difference between the pre-intervention and post-intervention phase. Based on each statistical test, the standardized effect size *(r)* was computed using Equation 1.

$$r = \frac{z}{\sqrt{n_a + n_b}} \qquad (2.1)$$

Where, r is the standardized effect size, z is the z-score resulting from the statistical test, n_a *is the sample size of the pre-intervention data, and* n_b *is the sample size of the post-intervention data*

The standardized effect sizes (r) for each variable measure was interpreted using the criteria suggested by Cohen (1992). Based on that criteria, the standardized effect size ranging between 0.10 and 0.30 (i.e. explains between 1% and 9% of total variance) is small, between 0.3 and 0.5 (i.e. explains between 9% and 25% of total variance) is medium, and over 0.5 (i.e. explains over 25% of total variance) is large.

2.10. Results and Discussion

In the following sections the results of the analysis is shown for each one of the variables in study.

2.10.1. Time to Reach Consensus

Table 2.5 presents the results comparing the difference in the amount of time taken to finalize the design decisions and reach consensus. As can be seen, on average, Group 1 took 13.95 minutes (i.e. 13 minutes and 57 seconds) while using the WRC method to reach consensus. However, after receiving the intervention, the group only took 7.12 minutes (i.e. 7 minutes and 7 seconds) on average to reach consensus. Therefore, time savings of 6.83 minutes per decision was seen when the group replaced WRC with the CBA method.

Comparing across all groups, the groups took 13.02 minutes on average to reach consensus when WRC was adopted. However, this dramatically reduced to 6.32 minutes when the CBA method was adopted – signifying time savings of over 6 minutes for each decision. Further, the Mann-Whitney U test revealed that the difference in time taken to make decisions between the two methods were statistically significant ($p\text{-}value < 0.01$). The corresponding effect size based on Cohen's criteria is large.

This difference in time to reach consensus between the two methods can have a substantial impact when multiple decisions have to be made. For example, if project participants are tasked with making 10 decisions for a particular project; adopting CBA will reduce the amount of time devoted to decision making by over 60 minutes.

Table 2.5: Time to achieve consensus

Group No.	WRC Mean	CBA Mean	Change (Δ)	Overall WRC Mean	Overall CBA Mean	Overall Change (Δ)	Effect size (r)	p-value
1	13.95	7.12	6.83					
2	12.86	3.90	8.96					
3	11.42	5.06	6.35	13.02	6.32	6.69	0.63	<0.01
4	12.29	5.67	6.62					
5	16.13	13.50	2.63					

This result is consistent with the responses of the final form given by the participants. Most of them highlighted that when using CBA the advantages of the attributes were, most of the time, the same among the group. Therefore, it was easier to agree on the importance of the advantages based on the difference between the alternatives. In that way, less time was used in arguing generalities, such as the weight of factors when using WRC. As an illustration, Figure 2.5 shows the evolution of time to reach consensus reported by the Group 1.

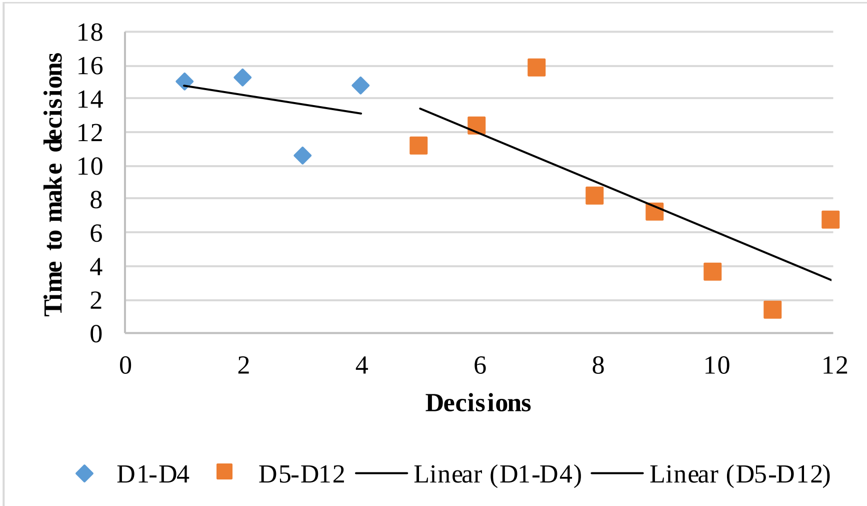

Figure 2.5: Variable time for group 1

2.10.2. Satisfaction with Final Decision

Following the same procedure as with the time to reach consensus, the satisfaction levels of the decision makers were assessed. Table 2.6 presents the results comparing the decision maker's satisfaction level before and after the intervention was introduced. As can be seen, decision makers from Group 1 expressed high levels of satisfaction with the final decision (Mean = 19.33). Similarly, there was also high levels of satisfaction when the CBA decision process was adopted (Mean = 19.33).

Comparing across groups, the average satisfaction level was 17.48 before CBA was introduced as an intervention; and slightly increased to 17.62 after the intervention. The corresponding effect size was 0.004 suggesting that less than 1% of the total variance was explained by the decision-making method used. Not surprisingly, the Mann-Whitney U test revealed that the difference in satisfaction levels between the two phases was not statistically significant. Given that, the maximum possible satisfaction level was 20; the results suggests that there was generally very high satisfaction levels with both decision-making methods. Therefore, both methods can be expected to yield approximately equivalent levels of satisfaction during decision making.

Table 2.6: Stakeholder satisfaction level

Group No.	WRC Mean	CBA Mean	Change (Δ)	Overall WRC Mean	Overall CBA Mean	Change (Δ)	Effect size (r)	p-value
1	19.33	19.33	0.00					
2	17.07	16.33	0.73					
3	17.39	16.50	0.89	17.48	17.62	0.14	0.004	0.97
4	15.24	16.56	1.32					
5	18.81	19.50	0.69					

In the final form, most of the participants notice that using any of both methods gives benefits compared to an unstructured decision-making process. They say that quantifying preferences using a structured method makes easier the process, especially when many stakeholders are participating in a decision where everyone tries to agree on a final decision. We believe that practitioners were satisfied using a method in which rules were clear and every participant could take part in the decision, which is not what happens in everyday work. As an illustration, Figure 2.6 shows the evolution of the level of satisfaction with the final decision reported by the engineer of Group 4.

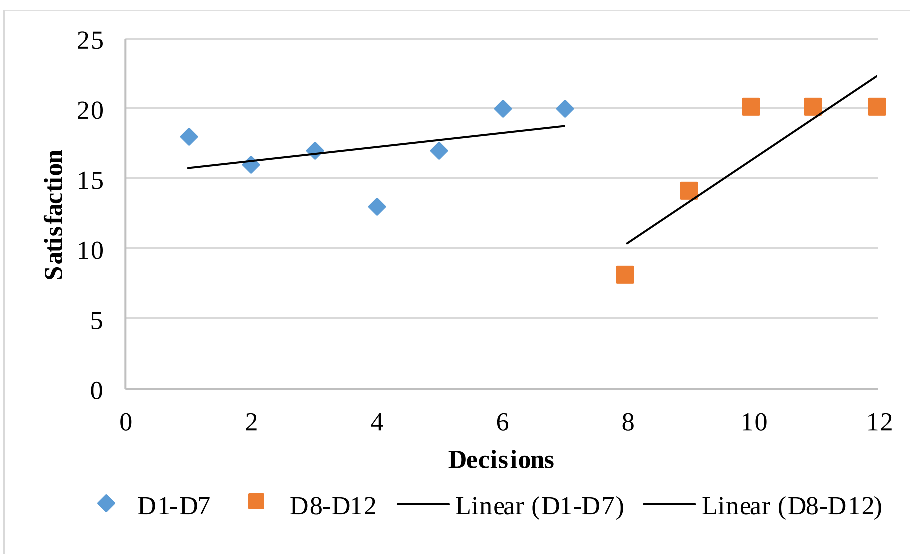

Figure 2.6: Variable satisfaction for the Engineer of group 4

2.10.3. Personal Frustration During the Decision Process

Table 2.7 presents the results comparing the frustration levels during the decision making process between the two decision making methods. As can be seen, the mean frustration level for Group 1 when the WRC was adopted was 4.58. However, when CBA was adopted, the frustration levels reduced to 3.28 signifying a reduction of 1.31. Comparing across all groups, the frustration level when WRC was adopted was 5.49. The overall frustration level reduced by 2.36 to 3.13 after CBA was introduced as the intervention. Moreover, this reduction in frustration levels was statistically significant with the p-value less than 0.05. The corresponding effect size for the change was 0.346 suggesting a medium effect. Based on the results, lower frustration levels among decision makers can be expected when CBA is adopted as the decision making method.

Table 2.7: Stakeholder frustration levels

Group No.	WRC Mean	CBA Mean	Change (Δ)	Overall WRC Mean	Overall CBA Mean	Change (Δ)	Effect size (r)	p-value
1	4.58	3.28	-1.31					
2	5.33	2.63	-2.70					
3	5.72	1.17	-4.56	5.49	3.13	2.36	0.34	<0.05
4	9.29	8.22	-1.06					
5	2.54	0.17	-2.38					

This result can be interpreted with the answers in the final form filled by the participants in which they consider that the great advantage of using CBA was that it was easier to compare between the alternatives having clearly highlighted the differences between them. Many of the participants notice that, since the difference between the alternatives were objective, most of the time the entire group agreed in the final decision. They emphasized that CBA was more consistent with their intuition, helping them aligning criteria, advantages, and the final decision. As an illustration, Figure 2.7 shows the evolution of the level of frustration with the final decision reported by the owner of Group 2.

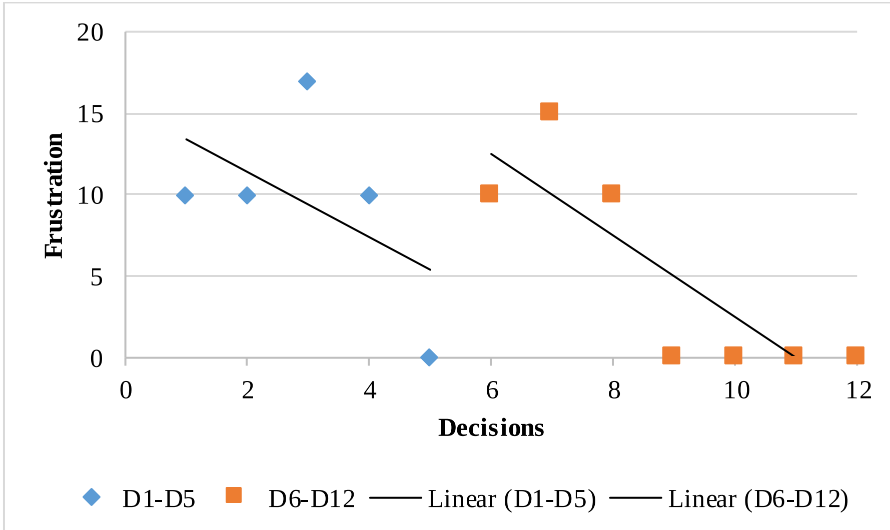

Figure 2.7: Variable frustration for the Owner of group 2

2.10.4. Perceived Frustration Level Among Decision Makers

The results comparing the perceived frustration level among decision makers with the two decision-making methods is presented in Table 2.8. Members of Group 1, on average, perceived that the frustration level of other members of the group was 5.08 when WRC was adopted. The perceived frustration level reduced to 3.56 after CBA was introduced as an intervention.

Group No.	WRC Mean	CBA Mean	Change (Δ)	Overall WRC Mean	Overall CBA Mean	Change (Δ)	Effect size ®	p-value
1	5.08	3.56	-1.53					
2	6.07	2.63	-3.43					
3	6.61	2.75	-3.86	5.74	3.48	2.27	0.3084	<0.05
4	9.05	7.89	-1.16					
5	2.33	0.17	-2.17					

Table 2.8: Perceived frustration levels among stakeholders

Across all groups, the perceived frustration level was 5.74 when using WRC and 3.48 using CBA. Further, this change is statistically significant with a medium effect size based on Cohen's criteria. Therefore, lower perceived frustration is another advantage of choosing CBA over WRC.

Similar to frustration during decision making, we believe that these results, regarding the perceived frustration level among decision makers, are due to the fact that when using CBA practitioners could easily reach agreement on which alternatives had advantages, considering a particular context, as participants stated in the final form. As an illustration, Figure 2.8 shows the evolution of the level of perceived frustration level among decision makers reported by the architect of Group 4.

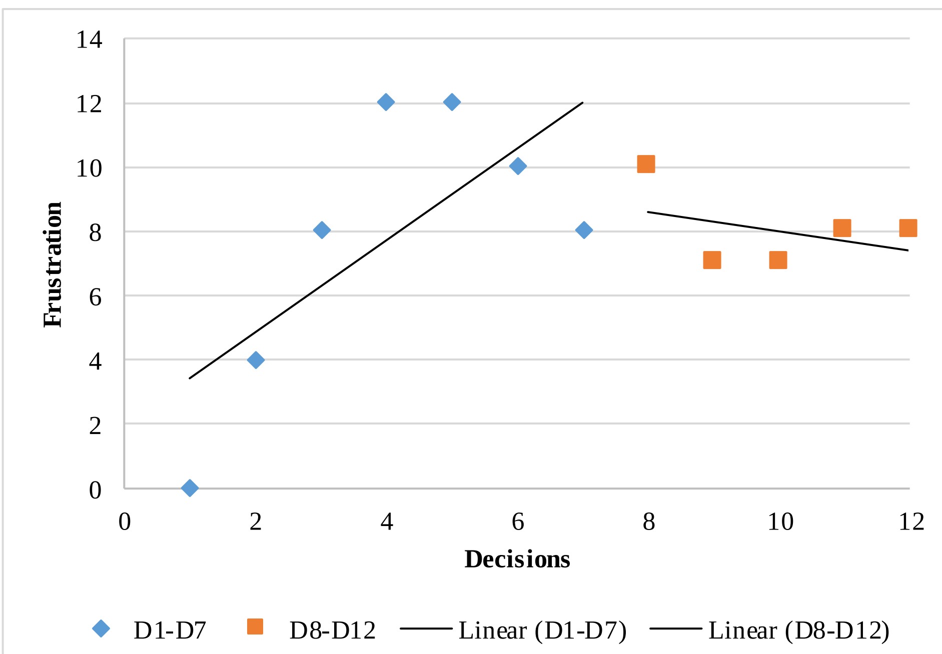

Figure 2.8: Variable perceived frustration by the Architect of group 4.

2.10.5. Final Preference of the Practitioners

The results from the form taken at the end of the experiment shows that 86% of all participants choose CBA rather than WRC for future application in decision-making. The main reason given by the respondents was that CBA makes decisions more objectively and reduces the conflict among the participants, because the individual decisions, most of the time, coincide among all. They highlighted that CBA provides more transparency in identifying the differences between the alternatives, allowing the decision maker base their decision on those differences and not on subjective assessments as WRC does.

2.10.6. Implications for Sustainable Decisions in AEC

As Wang et al. (2009) states MCDM methods have become increasingly popular in decision-making for sustainability because of the multi-dimensionality of the sustainability goal and the complexity of socio-economic and biophysical systems. This trend may also apply for the AEC industry where more complex decisions are required when including sustainable factors. Therefore, this study presents relevant results for AEC practitioners in order to select a MCDM method for sustainable building design. Using the CBA method practitioners should require less time for reaching consensus, and be less frustrated during the decision-making process. These reductions in time and frustration may lead to better collaboration in the design process and eventually lead to better buildings.

2.11. Limitations of the Study

There were several limitations associated with our study that must be recognized. Some of these limitations are inherent to the method and the problem. Others may be addressed by follow-up research. The limitations are as follows:

- We did not considered cost as factors of the decision to make the comparison fear between the two methods.
- The 12 decisions were made continually in one session, so we could have the same teams making decisions, otherwise; if we made two or more sessions we would risk not having the exact same teams. However, the participant of the experiment could be exhausted at the end of the session.

- The 12 decisions were based on real case studies, and the attributes used were real. However, a controlled experiment will never be the same than studying actual decisions in going on projects in terms of the care that practitioners would have with the design decisions of a building. This fact makes case studies a more in depth tool to understand decision-making process in building design. Moreover, this experiment complements previous case study research.
- In repeated decisions, when using WRC, assigning weight to factors can be made one time and then use the same weights in future decisions. This scenario is not considered in this research and could be studied in the future to demonstrate the impact on the studied variables.

2.12. Conclusion

This study contributes to the body of knowledge by testing WRC and CBA in a controlled experiment, showing with statistical significance that CBA was faster than WRC for reaching consensus, and presents less personal and perceived frustration during the decision. In addition, overall practitioners preferred CBA as a decision-making method for future design decisions considering multiple and conflicting sustainable factors, such as CO_2 emissions, air quality, acoustics, VOC emissions, site location, etc. The results showed in the experiment are coherent with previous research (Arroyo et al., 2012a and 2014) which shows that the nature of the CBA method, allows practitioners to highlight the advantages of each alternative, and focus more on relevant facts rather than preconceived judgments to weight factors, such as in WRC.

Surprisingly, the results do not show statistical support in favor of any method regarding satisfaction with the final decision. According to our findings practitioners where not used to make decisions with any structured method. Therefore, they valued the support of both methods in terms of satisfaction with the final decision.

More research is required to fully understand the impacts of using different MCDM methods, and to measure other variables, such as consistency, transparency, and long-term satisfaction with the final decision.

Finally, the researchers recommend the use of CBA method in the AEC industry instead of WRC for sustainable building design, due to the fact that the CBA method will help practitioners make decisions in less time and with a less frustration than WRC, and will probably make the design process more transparent and collaborative. This is relevant in sustainable building design, where hundreds of decisions are made by the design team, considering social, environmental, technical, economic factors.

3. TESTING SBD AND CBA DURING CONCEPTUAL DESIGN: A CASE STUDY ON TIMBER BUILDINGS IN CHILE

3.1. Abstract

Early collaboration during conceptual design is expected to provide benefits relating efficiency during the design process. It can also improve the quality of the design outcome, in terms of creating new design alternatives. This study compares collaborative design method against traditional practices in real-life setting, to test the impacts of using collaborative design techniques. This research followed the design process of an architectural practice which included the use of Set-Based Design (SBD) and Choosing by Advantages (CBA), two techniques for collaborative design applied during conceptual design for corporate office buildings in Chile. In this specific context, the researchers provided training activities on collaborative design methods, CBA and SBD, to the design team and client. A final measure technique assessed the benefits and limitations of those methods through a survey and interview to the design team, taking in consideration criteria relating to the quality of the process itself and quality of final design outcome. These results are compared to another project performed by the same design team in which traditional methods were employed, like Point Based Design (PBD) and no-structured method for making decisions

The results showed that collaborative design methods, SBD and CBA, are preferred for future design situations when comparing with traditional practices. Also, benefits in terms of increasing satisfaction with the final design by stakeholders, a reduction in negative iterations of the design process and fostering collaboration among participants are encountered when using collaborative design methods against traditional practices. Future work is needed to evaluate the quality of the design outcome, in terms of innovation, when using collaborative methods or traditional practices.

3.2. Introduction

Collaboration in early stages is key to sustainable building design. Brunsgaard et al. (2014) describes the necessity of more integrated and cross-disciplinary approaches to building design through state-of-the-art of the building sector and education. Traditional practice in building design is based on design silos, where each specialty, like architecture, structural, mechanical, construction, among others, works separately (Arroyo et al., 2012a). Design decisions are made independently and shared once they have been made by one of the designers, usually the architect. In most cases, this approach generates waste and rework to make the design compatible with the requirements of the others stakeholders, such as structural or constructive issues.

Traditional practice has been documented as Point-Based Design (PBD) in literature (Ballard, 2000). PBD starts the design process with only one alternative, which from one point of view is the best one. Then, this design is continuously modified by the stakeholders until a last design satisfies everyone’s requirements (Ballard, 2000). The opposite of PBD is Set-Based Design (SBD) in which design starts with a set of alternatives that solve the design problem. Those alternatives are further developed until selecting one alternative that better solves the design problem. In literature it was found a recommended method to choose between the alternatives called Choosing By Advantages (CBA) (Lee et al., 2010; Suhr, 1999).

Even though these design tools and methods are used in the AEC industry, few cases are documented and only a few studies have attempted to study the impacts of using lean practices for collaborative design, such as CBA and SBD (Arroyo et al., 2012b; 2015a; 2015b; 2016; Grant, 2007; Lee 2010; Nguyen et al., 2009; Parrish et al., 2007; 2008; Parrish and Tommelein, 2009). This study fills that gap by documenting a case study which uses SBD and CBA compared to another project, designed by the same team, using non-collaborative methods.

3.3. Background

This section presents in more detail the differences between Set-Based Design (SBD) and Choosing by Advantages (CBA) methods when comparing with traditional practices, e.g. Point Based Design (PBD) and no structured method for making decisions.

3.3.1. SBD and CBA vs Traditional Practices

When using Set-Based Design (SBD) designers are encouraged to explore alternatives collaboratively and keep them open until the last responsible moment. This means keeping all alternative paths open until the choice of an alternative path can be made with enough confidence (Parrish et al., 2007). In SBD, the generation of alternatives, or exploration, starts from the owner's needs. The design team should delay decisions in order to allow time to explore and evaluate as many feasible design solutions as possible (Singer et al. 2009), and also make sure that all factors and criteria are applied consistently to all alternatives. Designers need to understand the presumed outcomes of each alternative before making a decision. Then, the exploration of new alternatives begins again. SBD proposes that multiple alternatives have to be evaluated in order to avoid "Design Fixation", and sometimes to create a new alternative that contains the better attributes of each alternative to take advantage of the most valued aspects (Singer et al., 2009). In the opposite, PBD works with one alternative selected earlier in the design process and then, presented to the next design specialist to further development. The first design specialist chooses a single, presumably best design from his own point of view, which may later prove to be infeasible when other designers' views are considered (Ward et al. 1995). PBD results in repeating the process over and over again, generating negative (non-value-adding) design iteration, which is characterized by last-minute changes, lack of a systematic approach to promote innovative thinking, poor communication, and poor integration of design concepts (Ballard 2000).

CBA is a decision-making method, aligned with SBD, that allows for flexibility in the design, facilitating the incorporation of new design alternatives, and supporting the creation of new alternatives. CBA complement the dynamic SBD method throughout its different stages (Parrish et al., 2009; Thanopoulos, 2012) since CBA postpones 'value' judgment about alternatives as long as possible. In contrast, when using a non-collaborative method to make decisions, designers just pick an alternative and do not share or document their rationale for decisions. CBA is centred on understanding 'value' of the alternatives since it bases the decision on differences between alternatives. CBA clearly separates 'value' from cost of the alternatives to understand the value of the alternative and make a decision based on that. Traditional practice did not use structured methods for making decisions. Most of the time decisions are made considering only one point of view of the design problem and not documenting the rationale employed. Table 3.1 shows a comparison between collaborative design, CBA and SBD, and traditional practices, PBD and no- structured method for making decisions.

Table 3.1: Comparison between traditional practices and collaborative design

Aspect	Traditional practices	Collaborative design
Stakeholders participation	The decision is made in a closed circle. Each design specialist optimizes his or her part (Arroyo et al., 2012a)	Early involvement and collaboration among stakeholders. Holistic approach. Optimize the whole, not the parts. (Arroyo et al., 2012a).
Exploration of alternatives	Explore alternatives within a discipline, select one, and then pass it to the next discipline. Repeat the process one discipline at a time (Arroyo et al., 2012a). Iterate an existing idea by modifying it to achieve objectives and improve performance (Singer et al., 2009).	Explore alternatives in multidisciplinary teams, but delay design decisions to evaluate as many feasible alternatives as possible (Arroyo et al., 2012a).

Communication of alternatives	Communicate the best alternative (Singer et al., 2009).	Communicate sets of alternatives that are not Pareto dominated (Singer et al., 2009).
Decision –making	Formal schemes for selecting the best alternative (Singer et al., 2009). No-structured method for making decisions. Decisions are based on past experience and intuition (Arroyo et al., 2012a).	Consistent factors and criteria applied for every alternative evaluated (Arroyo et al., 2012a). It does not consider the use of any specific decision-making method.
Display of information	Does not explicitly show everyone's choices (Arroyo et al., 2012a).	Visualization while eliciting preferences helps to build consensus among stakeholders (Arroyo et al., 2012a).
Documentation	Little or no documentation is used. (Arroyo et al., 2012a).	Small reports are used to clearly state problem, include key information and recommendations. This document is distributed to relevant stakeholders (Arroyo et al., 2012a).

Managing the timing of the interrelated decisions is key to make the design process efficient. Traditionally, design teams are not clear in the order in which design decisions are made. By contrast, when applying SBD with CBA, decisions can be scheduled and documented, allowing the team for exploring alternatives until the 'last responsible moment', which may help the design team avoiding unnecessary iterations. Documenting the decisions helps in creating knowledge to use in future applications. Working with more than one alternative could cause extra cost to the design phase of the project, because of the time required to develop them, however there has been no formal research to test it.

3.4. Research Question

The main research question is: Which are the impacts of using to incorporate Choosing By Advantages (CBA) Set–Based Design (SBD) in early design stages, in comparison to traditional practices, i.e. Point-Based Design and no structured method for making decisions? The analytical framework to answer such enquiry is based on the following criteria:

- Participant's preference to design using CBA and SBD or traditional practices in different design situations.
- Participant's level of satisfaction with the design outcome.
- Documented negative iterations.
- Documented collaboration experienced during design process.

3.5. Research Methodology

A case study is conducted to answer the research question. Case-study methodology is recommended following Yin (1994). Is understood as "an empirical inquiry that investigates a contemporary phenomenon within real-life context, especially when the boundaries between the phenomenon and context are not clearly evident" (Yin 1994). The case study methodology is used because the objective is to describe a situation that happens in a particular case and to use it to facilitate the interpretation of the results. Flyvbjerg (2006) states that case study produces concrete knowledge to understand a specific case which is not for proving statistical tendency. In this case, analysis will be conducted from a design team that uses collaborative design method for conceptual design on a real-setting commission. To document the preferences of the design team on using traditional practices or Choosing By Advantages and Set-Based Design, participants were asked to complete a survey in which they had to select which design method they would use in different design situations. To analyze the process experienced by the design team, an in depth interview was conducted with every participant to understand the design process using collaborative methods. To compare their experience with traditional practice they were asked to think about a project in which the same team had designed a project using traditional practices. In this survey they were asked about the satisfaction with the outcome of both projects, about negative iterations in the design process and situations of collaboration among participants in both projects.

3.6. Case Study Protocol

The following protocol describes the steps the researchers followed when conducting the case study about collaborative design.

1. Selected the case study. One researcher was invited to participate in the design process of corporate offices building for a Chilean company with participation of the UC Timber Innovation Center (Centro UC de Innovación en Madera, CIM UC)
2. Understood the context on which the project is being developed. The general context about the company, the specific needs for this project in particular and the stakeholders involved in the design process.
3. The researcher suggested to the client the use of collaborative design methods to develop the project, specifically to use Choosing by Advantages (CBA) and Set-Based Design (SBD) methods. The client approved using those methods for designing the project.
4. Conducted a training session in the use of CBA and SBD to the design team and the client. This session lasted about one hour.
5. Set weekly meetings for collaborative work.
6. Made a plan of the decisions that have to be made and the sequence of them.
7. Documented every decision at the moment they are being made.
8. Designed a survey of different design situations to choose between traditional practices and collaborative design methods, i.e. CBA and SBD.
9. Applied the survey to the design team and the owners.

10. Designed an interview to understand the design process experienced using traditional practices and collaborative methods. Specifically, to ask about the satisfaction with the final outcome of the project and to get examples of negative iterations and situations of collaboration during the design process. Also, to understand the responses of the survey of each participant.
11. Applied the interview to the design team and the owners.
12. Analyzed the results of the surveys and interviews of the participants.

3.7. Case Study Background

The case study presented is part of a new trend towards the use of timber building systems at the Chilean building industry, which have heavily relied on concrete and steel. Therefore, is a relevant experience as it could become one of the first buildings which uses engineered timber products, like Cross-Laminated Timber (CLT), in this country. The researchers have identified a need for providing a collaborative design strategy for CIM UC in order to cope with interdisciplinary decisions and uncertainty while designing timber buildings.

The study is based on a real commission between September 2014 and July 2015. The design team was integrated by professionals from UC Timber Innovation Center (*Centro UC de Innovación en Madera, CIM UC*), through its Technological Transfer (TT) Unit, specialized in timber architecture and innovation[1] (Figure 1). TT team included graduate architects supported by a team of specialists on timber technologies, structural design and environmental design. The client was a large Chilean private company producer of paper and cardboard products. They hired CIM UC for the conceptual design of their new headquarters. An expert in collaborative design worked with both, the client and design team, who had no previous experience on collaborative methods. The expert in

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[1] CIM UC is structured in two main areas: Technology Transfer (TT) and Research. TT works as a consultancy on three main areas: architectural and urban design, training and technological adaptation and development.

collaborative design was incorporated from the beginning of the activities as part of the commission contract

The project with non-collaborative method involved the architectural design for an Eco-sustainable neighborhood in Chañaral, a northern Chile location, commissioned by the Chilean Government, the Ministery of Housing and Urbanism (MINVU, Ministerio de Vivienda y Urbanismo). It included the architectural design of housing units, urban infrastructure and specialist's projects, such as environmental design, structure design, and landscape, among others. The design team included the same professionals from previous commission (Figure 3.1), with the addition of urban specialists. The design process itself relied on non-collaborative methods, like Point-Based Design and no-structured method for making decisions. .

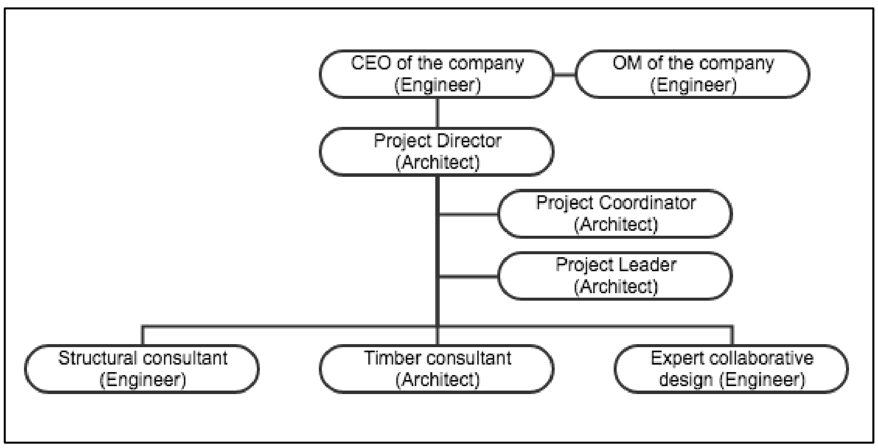

Figure 3.1: CIM UC Team structure

3.8. Design Process

The design process for the new headquarters building commission started by defining that all participants of the design team would have to agree on the decisions made, and the timing in which they are made. This initial planning stage is an essential step in collaborative methods since it determines the last responsible moment and allows that all team members agree on the process that is going to be followed. Planning stage started by setting the submission date of the project to set milestones backwards, considering the duration of each activity and the time required to develop the alternative that was going to be evaluated. Figure 3.2 shows the sequence of the decisions made. In every one of them the client, architects, structural specialist, and timber specialist were involved. In this case the building material cost is not considered, as it was a conceptual design commission.

The design process involved the generation of design alternatives for each one of the pre-set decisions. According to SBD, the team have to create at least three alternatives per each decision within the planning stage. As Figure 3.2 shows, this goal was partially achieved, since Decision 1 has three alternatives, Decision 2 has four alternatives, Decision 3 two alternatives and Decision 4 two alternatives.

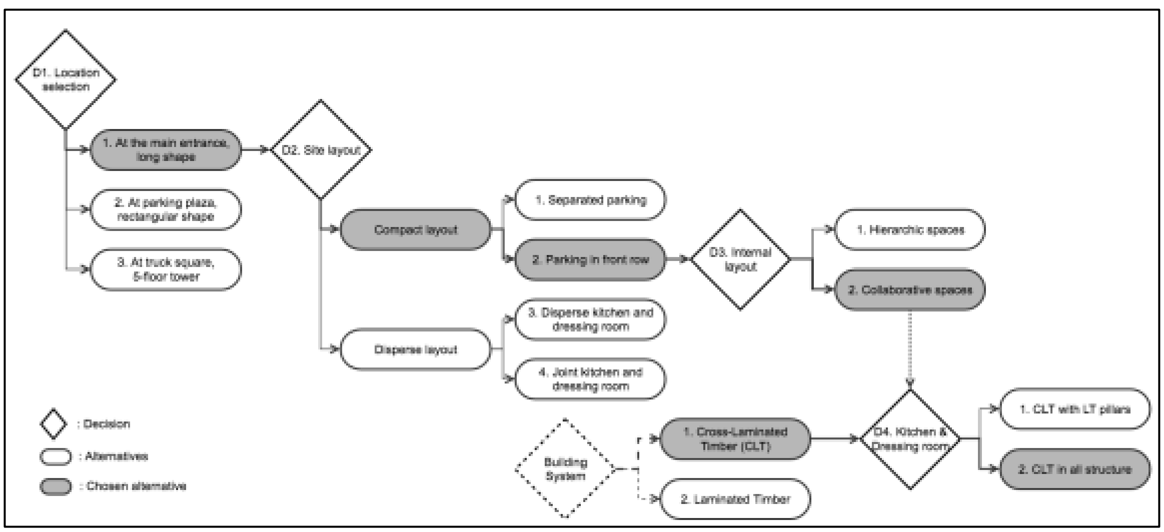

Figure 3.2: Design process and alternatives

The plan made for the decisions sequence consider the decision on the building system collaboratively. Contrarily, the design team never executed such decision and they assumed that the client would not be willing to innovate on the building's structural system, e.g. Cross-Laminated Timber (CLT), since it may be considered risky and expensive. When working towards Decision 3, the client proposed CLT as building system because it wanted to innovate and become the first building built in CLT in the country. As consequence the building decision appears like dot line in figure 3.2, as it was not adopted at the planning stage and it was only raised following the client's recommendation to take into account that particular building system.

3.8.1. Making Decisions Using CBA

The planned decisions were made using CBA. A first meeting of the design team consisted in a training session that included the owner, the architects and consultants with the expert in collaborative design, which introduced the use of CBA as a decision-making method. In this session the team explored with the definition of alternatives, attributes, advantages, factors and criteria to use a common language when using CBA (Arroyo, 2013). After the training session the group made decisions using CBA in a pre-defined sequence. The researchers provided the first steps (1) Identify alternatives, (2) Define factors and (4) Summarize the attributes of each alternative. The design team performed step (3) Define the must/want criteria for each factor, (5) Decide the advantages of each alternative, (6) Decide importance of each advantage, and (7) Aggregating the importance of each advantages and make a decision.

In each decision, participants had to make the decision individually and then, as a group. While making the decision they have to fill the tabular form of CBA to document their preference. Table 3.2 shows the tabular form used to make Decision 1, in which first column are the factors and the criteria used to evaluate the factor (criteria is in blank because it had to be filled by the participants). In second, third and fourth column are the alternatives with their attributes, and below each attribute participants have to fill the advantage and the importance of the advantage of each alternative in the corresponding factor. In the last row the participants have to fill with the sum of the importance of the advantages for each alternative.

Table 3.2: Tabular form of CBA for Decision 1

Factor (criteria)	**Alternative 1: At the main entrance**		**Alternative 2: At parking plaza**		**Alternative 3: At the truck square**	
1. Ground floor interaction. (More interaction between level is prefereable)	Attr: New offices proximity with existent premises.		Attr: Greater proximity between new and old offices.		Attr: Proximity to new plant addition.	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
2. Exhibition space. (More visibility of the built form is prefereable.)	Attr: High potential to reconfigure main access and corporate image towards the street		Attr: Opens possibility to be visualised from train line.		Attr:Potential visibility of the building at the interior of the site.	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
3. Internal collaboration. (More collaboration is prefereable.)	Attr: Allows collaboration as the building has less levels and also allows articulation with other buildings.		Attr: Potential to consolidate a high density node for staff, workers and visitors to the site.		Attr: Thinner building mass. Vertical collaboration.	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
4. Dismanteling condition. (More easily to dismantle and transport is prefereable.)	Attr: Partially portable due to pre-existent building		Attr: Greater factibility for dismanteing.		Attr: Higher dismanteling factor.	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
5. Parking space. (Safer parking space is prefereable.)	Attr: Limits to parking space.		Attr: Underground parking.		Attr: Significatelly increase the number of parking spaces.	
	Adv:	Imp:	Adv:	Imp:	Adv:	Imp:
Total Imp						

Decision 1, on location selection, considered alternative scenarios to allocate the building mass, a challenging effort since the available space at the site was limited. Figure 3.3 shows the alternatives for Decision 1, in which red blocks are the location of new offices in the plant and the orange block are for parking. Alternative 1 was based on locating the offices at the main entrance of the plant by expanding an existing building on two floors and two underground levels for parking on one side. Alternative 2 was related to locate the offices at the parking plaza and configuring a new building of four floors and two underground levels for parking. Alternative 3 proposed the location of the offices at the truck parking in a five-floor building with parking on the surface of one side.

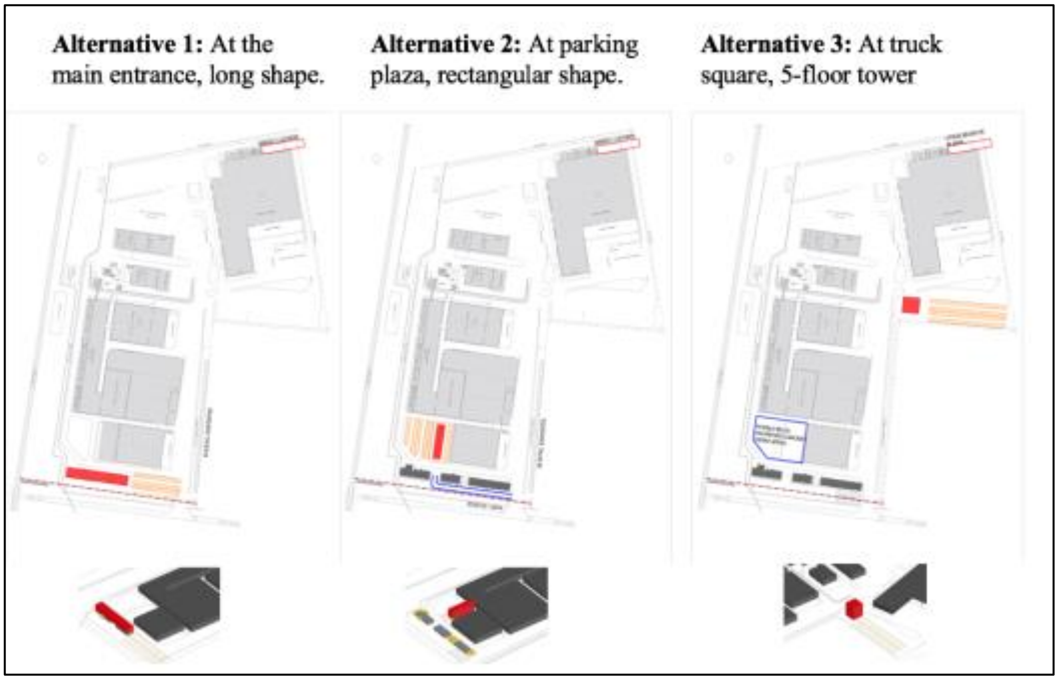

Figure 3.3: Alternatives for Decision 1

Table 3.3 shows the scores assigned by every participant and the score agreed by the group when making Decision 1. It is relevant to note that the alternative chosen by the group was not the same to the one individually selected in some cases. For example, the project director selected individually alternative 3, but when making the decision in group the alternative selected was alternative 1. When making the decision, the participants had to agree on the importance of the advantages on each factor. In the factor 'ground floor interaction' participants misunderstood which alternative had the worst attribute. Four participants believed that alternative 1 was the alternative with the worst attribute and the other four members believed that was alternative 3. In this way, the participants who in first place thought that the best alternative for factor 'ground floor interaction' was alternative 3, received concrete reasons that made them change their judgement and to keep feeling satisfied with the selected alternative by properly understanding the rationale made by the others members.

Table 3.3: Scores for Decision 1

Factor	Participant	Alternative 1	Alternative 2	Alternative 3
1. Ground floor interaction. More interaction between level is prefereable.	Project leader	100	80	0
	Coordinator	100	80	0
	Project director	0	40	60
	Operation manager of the company	0	60	70
	CEO of the companuy	0	30	40
	Structural consultant	70	60	0
	Expert in collaborative design	100	90	0
	Group	0	30	30
2. Exhibition space. More visibility of the built form is prefereable.	Project leader	80	60	0
	Coordinator	40	0	30
	Project director	80	0	80
	Operation manager of the company	100	90	70
	CEO of the companuy	70	50	0
	Structural consultant	100	0	80
	Expert in collaborative design	50	40	0
	Group	70	0	20
3. Internal collaboration. More collaboration is prefereable.	Project leader	70	50	0
	Coordinator	80	0	40
	Project director	100	0	0
	Operation manager of the company	90	70	0
	CEO of the companuy	100	70	0
	Structural consultant	70	90	0
	Expert in collaborative design	60	60	0
	Group	100	30	0
4. Dismanteling condition. A more easily to dismantle and transport building structure is prefereable.	Project leader	50	0	60
	Coordinator	0	60	20
	Project director	0	40	30
	Operation manager of the company	0	40	50
	CEO of the companuy	0	50	60
	Structural consultant	0	80	90
	Expert in collaborative design	0	30	30
	Group	0	10	10
5. Parking space. Safer parking space is prefereable.	Project leader	40	0	50
	Coordinator	0	40	60
	Project director	0	20	30
	Operation manager of the company	50	0	60
	CEO of the companuy	0	40	80
	Structural consultant	40	50	0
	Expert in collaborative design	0	30	20
	Group	20	0	10
TOTAL	Project leader	**340**	190	110
	Coordinator	**220**	180	150
	Project director	180	100	**200**
	Operation manager of the company	240	**260**	250
	CEO of the companuy	170	**240**	180
	Structural consultant	**280**	**280**	170
	Expert in collaborative design	210	**250**	50
	Group	**190**	70	70

3.8.2. Final Design

The outcome of the design process was locating the new office building at the main entrance in a compact layout with parking in front row. When the owner proposed using CLT as building system, all the design team agreed that was the best building system, therefore it was selected as the building system for the project and subsequently they make a decision to use it throughout the structure.

3.9. Survey Application and Results

A survey was conducted to respond to the first criteria of the research question. The survey consisted of 14 scenarios with repetition to test the consistency of the responses of the participants. Each scenario exacerbated one of the following aspects: (1) decisions that consider different disciplines, (2) decisions with clear amount of alternatives, between two and five alternatives were evaluated, (3) decisions that consider many stakeholders to take into account, and (4) decisions that have to be made quickly. We could only get four responses of the survey from members of the design team. We could not get responses from the owners and structural consultant. The results are shown in table 3.4, like a sum of the responses of participants.

Table 3.4: Results of the survey

Design situation	Collaborative design	Traditional Practices	Aspect measured
1	0	4	Quick decision (4)
2	4	0	Interdisciplinary (1)
3	3	1	Amount of alternatives (2)
4	2	2	Interdisciplinary (1)
5	3	1	Stakeholders (3)
6	4	0	Interdisciplinary (1)
7	1	3	Interdisciplinary (1)
8	3	1	Amount of alternatives (2)
9	1	3	Interdisciplinary (1)
10	0	4	Stakeholders (3)
11	4	0	Stakeholders (3)
12	4	0	Interdisciplinary (1)

13	4	0	Interdisciplinary (1)
14	3	1	Stakeholders (3)
Total	36	20	

In relation to the interdisciplinary of the design, in 71% of the situations participants would use collaborative methods, because there are many factors that have to be considered and it is relevant to include a specialist view on each subject, with the expert with more knowledge about it. In this way, collaborative methods allow to include everyone's perspective and to decide based on it. Also, they mentioned using collaborative methods when the design includes some issue out of their area of expertise. When the amount of alternatives for evaluation was expressed in the situations, in 75% of them participants selected collaborative methods. However, they did not mention that it was related to the amount of alternatives that they selected collaborative methods, but they related their decision on the interdisciplinary nature of the decision to make, and the multiple aspects that have to be considered. In 63% of the situations where several stakeholders were involved in the design process, participants would use collaborative methods. They expressed that when using collaborative methods, it would be easier to incorporate other people's point of view earlier and to reach agreement with everyone. However, practitioners choose traditional method when deciding about a single aspect that could be made by the owner or the architect by his own, justifying that could be a matter of tastes in relation to what the owner or the architect wanted. Regarding the immediacy of the decision, participants would use traditional practices in 100% of the cases when decisions have to be made quickly. Another perspective given by practitioners, was about selecting collaborative methods when the project is transcendent, because it gives them the confidence that the design considers all aspects and it will deliver the most efficient design.

3.10. Interview Results

The interview made to the participants gave us different perspectives about the process they have experienced comparing the project for corporate offices (collaborative methods) and the project for social housing (traditional method). We could only get four interviews from members of the design team and from the expert in collaborative design. We could not get responses from the owners and structural consultant. The results include the perspective of every interviewed practitioner. We cluster the comments of the practitioners to show evidence of the three measured variables of the design process.

3.10.1. Satisfaction with the Final Outcome

The three respondents were satisfied with the outcome of the project for corporate offices, but only one of them feels satisfied with the outcome of the project for social housing. The other two feel dissatisfied because they consider that was a very complicated project, in which the final design was not efficient, because they proposed an original design which then was losing parts in order to meet the budget and the constraints of the general contractor. The most important issue considered by them was that the objectives of the social housing project were not clear and the design was not made to fulfil those unclear objectives. At the end of the project they understood that the objectives were to design houses that have to be constructed as quickly as possible, in an area with scarcity of workforce and limited availability of materials, and these constraints were not foreseen in the design.

In relation to the satisfaction with the final design perceived from the other stakeholders, the design team believes that for the project for corporate offices the owner felt satisfied, because they solved many concerns he had about design issues. In the project for social housing the owner was MINVU- a government housing agency- and the end users were going to be the community of Chañaral. According to the design team's perspective the satisfaction with the final outcome of the project from MINVU and the community is not as high as in the project for corporate offices. They believed that the standard and quality of the houses were satisfactory, but there was a key issue that the design could never include. The community of Chañaral wanted isolated houses, which could have never been reached according to the space and resources available for the project. The team thinks that this was an issue that kept frustrated the community, thus getting lower levels of satisfaction with the outcome.

3.10.2. Negative Iterations

In the project for social housing the design team perceived that half of the time available they were iterating the same aspect in order to include the general contractor’s perspective. Since they were not part of the process of the original design, the requirements of efficiency, productivity and industrialization that the general contractor was seeking were not considered in the original design. The size of the house had to be modified in order to include those perspectives in the design. The preliminary design was losing parts in order to meet the budget, but it was not intended as a whole. Moreover, the community of Chañaral requested changes to the design in order to meet their needs and the design team had to re-design the project over and over again to meet the suggestions made by the future users. A specific example of iterating was related to the sanitary system when the specialist decided the type of sewerage. Then, when the specialist in soil mechanics knew about that decision, it contradicted the specialist in sanitary systems because of soil configuration. It caused changing the first decision made, loosing time and re-doing work because it changed the project for the sanitary system and the budget of the project.

In the project for corporate offices the design team think that they iterated in one single aspect about the building system, because the decision was scheduled but it was never made rigorously with CBA, and they assumed that the owner would not like the CLT system, but then when making the decision about the internal layout the owner proposed using CLT, and the design team agreed on using it. This change delayed the delivery of the project because they have to change to the CLT system. The design team characterized this process as more efficient, because when they make decisions those aspects did not appear again, and everyone agreed on the decided issues. However, the project for corporate offices did not include a general contractor in the design, therefore the design team thought that was not as complex as the social housing project, because the budget issue was not considered and when including the general contractor in the process this issue always arise.

Another perspective was about the time available in both projects. On one hand, the project for corporate offices had two months to think about the design, which allowed the project team to have more instances for collaboration. On the other hand, the project for social housing had three months to design the project considering the building and the economic feasibility, which left no time to think about the efficiency of the design.

3.10.3. Collaboration Among Participants

In the project for social housing, at first, the community and regional authorities thought that the original project does not fit their needs. On one hand, they presented a project with town-houses but the community wanted isolated houses with garden around the perimeter. On the other hand, they presented a project to be built in timber, but the local authorities felt that the timber was exogenous from their region, because it is a desert region in which everything is built on concrete. The design team highlighted that the process of receiving suggestions and changing the project according to them, was made in a non-systemic way, causing wastes of time and re-work.

The design team realized that when using collaborative design techniques, everyone perspectives' can be included, allowing to understand more about the context of the decision that have to be made. Specifically, they highlight that many times they had to change their selected alternative for the selected by the group, because they got an another perspective about the problem. A concrete example about this happened to the expert in collaborative design when making the decision about location. She thought that the view of the plant would be better from the train, but everyone's opinion was different from hers. She then realized that she was making the decisions with a prejudice about and alternative that was not founded. Then, the other design team members explain her the reasons and she could understand and change her perspective about the best alternative. The same experience happened to the project coordinator about dispersing the program, to the project director about the layout of the plant and to the leader of the project when deciding about the location of the offices in the plant.

The design team think that when using collaborative design, you are able to reach a more efficient solution, because the CBA method allows you to understand the strengths and weaknesses of every alternative. In the process of design, the corporate offices they notice that the chosen alternative was weak in the security factor, and it allows them to keep with the selected alternatives, but only if the security factor was enhanced.

The design team expressed that they have learnt with the collaborative process they have experienced, specially to meet the expectations of the stakeholder earlier and to develop a project with their needs as foundation. They thought that getting in touch with the people in the industry, where the project is going to be sold, is a very fertile field, in which conversations happens that could not happen in other contexts. They express that the collaborative design methodology makes the architects work on different alternatives, which they are not used to. Nevertheless, the design team highlight that the methodology has to be well planned in order to make fundamental decisions collaboratively and with the right people, who has some point of view about the issue that is going to be decided. They also think that when using a structured method for making decisions it allows to know that every point of view is going to be taken into account. When there is no such method, in meetings everyone goes to fight for their opinions and make the others listen to them.

3.11. Limitations of the Study

- In the project for social housing the general contractor perspective gives a restriction to the design problem about the budget of the project. In the project for corporate offices costs were not considered as restrictions.
- We consider only the point of view of the architectural team of the project and of the expert in collaborative design, because we could not get a survey response or an interview with other stakeholders of the project, such as the owner, the engineers or other specialists involved.
- The differences about the commission, since one was to make a detail design and the other a conceptual design. It causes differences between the projects about

the quantity of stakeholders involved and the efforts required to complete the projects.

3.12. Conclusion

When using collaborative method, the decision-makers could get more satisfied with the final outcome of the project. CBA and SBD allows the design team to produce more efficient designs considering the point of view of everyone involved. Specially, CBA fosters the collaboration among the members of the design team, creating instances to share the thoughts of everyone and to reach agreement on the final design. It is important that when using CBA and SBD the design team with the owner and other stakeholders, make a planning in which decisions have to be made, the sequence of them and detailing who has to be in which meeting. In order to create an efficient process in which everyone involved in a decision could give their point of view. An important learning outcome from this experience is the role of the expert in collaborative design during design meetings, which allows to keep consistency and data collection during design meetings.

4. RESULTS

The following paragraphs presents the results of the study. First, the results of the experiment and then the results of the case study.

The results of the experiment show with statistical significance a reduction in time when using Choosing by Advantages (CBA). This result is consistent with the responses of the participants of the experiment, because they highlight that most of the time the advantages of the alternatives for factors were the same between the team members. Therefore, it was easier to reach consensus when assigning the importance of the advantages when making the decision in groups.

It was also found that there was no statistical difference in satisfaction with the final decision when using CBA or WRC. It could be interpreted by the responses of the participants, because they notice that using a structured method for making decision, it was easier to listen to everyone point of view. Thus, participants feel equally satisfied when using one method or another because they feel that their opinion was being considered to make the final decision.

About the frustration felt by decision-makers it was found with statistical significance a reduction in frustration when making decisions using CBA. The participants in the ‘experiment finals survey’ mentioned that the great advantage of using CBA was that was easier to compare between the alternatives, because the differences among them were objectives and sometimes the entire group agreed in the final decision. They emphasized that CBA was more consistent with their intuition, helping them aligning criteria, advantages, and the final decision.

Similar to personal frustration, with statistical significance the levels of perceived frustration were lower when using CBA. This result could be explained by the same reasons for personal frustration, since when using CBA, it was easier to agree on the importance of the advantages avoiding conflicts generated when assigning weights in WRC.

About the responses of 'experiment final survey' in which participants have to select which methods they would use in future applications, 86% of participants select using CBA. The main reason given was that CBA makes decisions more objectively, facilitating the agreement between decision-makers, reducing conflict when subjective issues have to be agreed.

From the case study survey, it was obtained that they would use collaborative methods in 71% of the situations in which interdisciplinary issues have to be considered. The main reason was that many factors have to be considered and it is relevant to include the perspective of other specialists who can give another point of view. It was also mentioned that when designers have to consider some issue out of their area of expertise they would use collaborative methods, rather than traditional practices. In 75% of situations in which the amount of the alternatives to be considered was clear, participants chose collaborative methods. However, the reason of their selection was not based on the number of alternatives, but based on the interdisciplinary of the decision and the multiple aspects that have to be considered. In situations where many stakeholders were involved, participants select using collaborative methods in 64% of the cases. The reasons were that when using collaborative methods it would be easier to include another perspective in the same issue. However, participants would use traditional methods when deciding about a single aspect that could be chosen by the owner or the architect, because it could be a matter of tastes.

Regarding the interview conducted to the design team members, it was obtained that every participant feels satisfied with the outcome of the project for corporate offices. By contrast, in the project for social housing two of three participants stated feeling dissatisfied with the outcome. Even though they feel dissatisfied with the outcome, they consider that the owner and the future users could probably be satisfied. Many issues were change from the first design in order to meet their requirements. There was one issue, that kept frustrated the future users of the project. They wanted isolated houses, and because of the available project' budget that could never be incorporated in the design.

In the social housing project, the design team perceived that half of the time they were iterating on many issues at the same time in order to include the community and the local authorities' perspective. They feel that they have reached an inefficient project, since the original design was losing parts, reaching a design not well thought as a whole. By contrast, in the project for corporate offices, the design team consider that they have iterated on one single aspect in the whole project. It was because they did not evaluate an alternative for building system since they assume that the owner would not want it. Further in the design process the owner proposes using the building system they rejected having to re-make work to adapt for the new design.

The design team members highlighted that a benefit of using collaborative design was that they could include other perspectives earlier in the project and to make decisions considering them. When using traditional practices, they get committed with an alternative before incorporating everyone's perspective, having to make re-work and obtaining solutions below the optimal. The design team expressed that when designing collaboratively they have the chance of talking with everyone involved in the design and to listen about their perspective allowing for a better design. The design team experienced many situations in which the final decision made by the group was not the same made individually in the project for corporate offices. But since they were working collaboratively, they had arguments that changed their perspective making them agree on the final decision. This research documented four situations in which they have changed their minds because of the explanations from the other members of the group. In addition, new design alternatives were created using the knowledge from comparing a set of alternatives collaboratively.

5. CONCLUSION

In conclusion, from this research positive impacts of using CBA as decision making methods in building design are achieved, compared with traditional practices. The general objective is achieved, confirming the hypothesis formulated in this research. Specifically, the results of the experiment show that when using Choosing by Advantages (CBA) as decision-making method less time is required to make a decision and lower levels of frustration are experienced by decision-makers compared when using WRC. Also, CBA is preferred over WRC to be used in future applications. According to the case study results, when using CBA for building design in conjunction with Set-Based Design (SBD), design team members feels more satisfied with the outcome of the project than when designing with traditional practices. It was also found that using CBA and SBD in design fosters collaboration among stakeholders, allowing them to exchange their points of view, and reaching better designs. Sharing their sights of the same problem earlier in the project allow them to reduce negative iterations causing less re-work and wastes of time. In building design, where multiple decisions have to be made by several stakeholders, these advantages of using CBA and SBD are expected to be even greater. According to this research the implementation of CBA and SBD should lead to (1) better design outcomes in terms of all stakeholder's satisfaction and (2) better experience in the design process for the design team.

6. FUTURE WORK

About decision-making methods, more research is needed to evaluate other variables to compare Choosing By Advantages (CBA) and Weighting, Rating and Calculating (WRC), such as the deviation produced between the individual and the group decision. In addition, in WRC the weight of the factors could be used in more than one application. Future research is also needed to understand how impacts this characteristic of WRC in final decisions and if this issue is an advantage of WRC above CBA.

In building design, more research is needed about the impacts of using CBA and Set-Based Design (SBD). Other variables have to be measured to demonstrate other benefits and limitations of using them. For example, if those methods promote more innovative designs, compared with the ones reached with traditional practices.

Future work is needed to evaluate if CBA and SBD presents the same benefits in other contexts and other cultures. This study was limited to the Chilean context and only about building design. The same need could be present in other industries or other countries, and it have to be evaluated if using CBA and SBD presents the same benefits encountered in this study.

More research is needed to understand how to better implement CBA and SBD in other projects and to provide guidelines to ensure the success of projects.

7. DEFINITIONS

- Factors: "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" (Arroyo et al., 2012a).
- Alternatives: "Two or more construction methods, materials, building design, or construction systems, from which one must be chosen" (Arroyo et al., 2012a).
- Attributes: "A characteristic, quality, or consequence of one alternative (construction methods, materials, etc.)" (Arroyo et al., 2012a)
- Advantages: "A benefit, gain, improvement, or betterment. Specifically, an advantage is a beneficial difference between the attributes of two alternatives" (Arroyo et al., 2012a).
- Choosing by advantages: a decision-making system that supports sound decision-making using specific comparisons of advantages of alternatives. (Suhr, 1999)
- Weighting, rating and calculating: is a decision-making method in which factors and attributes of alternatives are weighted generating a weighted sum that gives the result of the decision. The cost may be incorporated as a factor. (Arroyo et al., 2014)
- Analytical hierarchy process: is a decision-making method in which factors and the attributes of alternatives are weighted generating a matrix to compare the alternatives. The cost may be incorporated as a factor. (Saaty, 2008)
- Set Based Design: A process that manages alternatives of design considering all the alternatives until the last responsible moment. (Lee et al., 2010)
- Point based design: is the process of design starting with one alternative and making changes to this alternative iteratively reaching the requirements of all stakeholders involved in the design process. Is commonly related to iterations that not generate value. (Lee et al., 2010)

- Best Value Selection: A decision-making method in which the alternatives are compared according to its value. This method considers cost separately. (Scöttle et al., 2015)
- Value: are the attributes of the product that are pursued by the client. It is what satisfies the consumer requirements.
- Cost: it is the monetary cost of implementing the alternative.
- Multi-criteria decision making method: are methods that support the evaluation of multiple alternatives that include multiple factors that have to be evaluated.

8. GLOSSARY OF TERMS

- CBA: Choosing by Advantages
- SBD: Set-Based Design
- PBD: Point-Based Design
- BVS: Best Value Selection
- MCDM: Multi-criteria decision making
- AHP: Analytical Hierarchy Process
- WRC: Waiting, Rating and Calculating
- MBT: Multiple Baseline Testing

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A P P E N D I X

APPENDIX A: EXPERIMENT PROCESS SURVEY

TALLER MÉTODOS DE TOMA DE DECISIÓN MULTI-CRITERIO EN LA CONSTRUCCIÓN

Decisión __

Tu rol: ____________________

1. Tiempo en toma de decisión: [   ] min.
   El mismo tiempo para todo el grupo

2. Valore de 0 a 10 su satisfacción con la decisión final

Muy insatisfecho										Muy satisfecho
0	1	2	3	4	5	6	7	8	9	10

Explique por qué la alternativa seleccionada es la mejor

[   ]

3. Participación Activa
   Distribuir 100% de acuerdo a la participación de cada actor en la decisión

Arquitecto	Ingeniero estructural	Ingeniero de gestión de la construcción	Ingeniero de obra/operación	Mandante

4. Frustración

	Muy relajado									Muy frustrado/ tensionado
Cómo fue el peor momento por el que pasaste durante la decisión	0	1	2	3	4	5	6	7	8	9	10
Cómo fue el peor momento por el que paso el grupo durante la decisión	0	1	2	3	4	5	6	7	8	9	10

Cuéntanos de el/los momento/s que te sentiste tensionado o hubo tensión en el grupo. Mencione en lo que más les costó ponerse de acuerdo.

[   ]

APPENDIX B: EXPERIMENT FINAL SURVEY

TALLER MÉTODOS DE TOMA DE DECISIÓN MULTI-CRITERIO EN LA CONSTRUCCIÓN

Evaluación final

- ¿Cuál de los dos métodos de toma de decisión utilizarías? ¿Por qué?

- Nombra las ventajas de cada método

WRC	CBA

APPENDIX C: CASE STUDY SURVEY

Name: **Role:**

Definitions

Traditional way of designing

The design starts with one alternative proposed by one of the stakeholders. This alternative is modified iteratively until reach every stakeholder satisfaction with the final decision. If in the beginning more than one alternative is presented, one stakeholder evaluates them selecting one to be presented to the rest of the team. The decisions are taken spontaneously, without a defined method. Many times the decisions are made by only one stakeholder, which decides considering only his requirements.

Design method using CBA and SBD

Multiple alternatives that solve the problem are evaluated. These alternatives are analyzed until the last responsible minute, in which not making the decision discard one of the alternatives in consideration. All the group of stakeholders makes decisions using CBA as decision-making method.

In the scenarios presented below choose the method you would use in that specific situation and give the reasons that support you decision.

	Situation	CBA and SBD	Traditional
1	If you have to make an immediate decision about demolishing a damaged wall or to repair it.		
	Reasons:		
2	If you have to select an HVAC system for a hospital.		
	Reasons:		
3	If you have to decide between three types of construction materials for a school.		
	Reasons:		
4	If you want to design a building with the objective of maximum reduction of energy consumption during the operation of the building.		
	Reasons:		
5	If you have to make decisions of the number of floors for an office building, considering that the client lives in another city.		
	Reasons:		
6	If you have to decide about the location of a cement plant.		

	Reasons:		
7	If you have to decide the disposition of the windows in a hospital.		
	Reasons:		
8	If you have to decide between four ways for installing doors in a jail.		
	Reasons:		
9	If you have to design a house with the target of minimizing energy consumption with the use of solar panels.		
	Reasons:		
10	If you have to decide between two floor types for a house.		
	Reasons:		
11	If you have to design a hospital, in which 35 people have to agree with the alternative selected.		
	Reasons:		
12	If you have to design a social housing which will be reproduced in the future.		
	Reasons:		
13	If you have to design a water reuse system for a plan that generates toxic waste.		
	Reasons:		
14	If you have to decide which material is going to be used for sewer pipes and you have to explain you choice to 15 specialists of different areas.		
	Reasons:		