# VALUE BY DESIGN - SYSTEMATIC DESIGN DECISION MAKING IN THE ARCHITECTURAL DESIGN PROCESS

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ABSTRACT: The authors survey design decision making in architecture and related design professions, setting forth normative practices and identifying important proposals for innovative methods to navigate the complex constraints of design problems. First the authors set forth conventional decision making methodology in the engineering and architecture design process. Then the authors survey typical decision making processes in related design fields such as industrial design, engineering design, and product design and identity their different approaches. The paper compares decision making strategies in engineering and architecture design. The authors conclude by analyzing strengths and gaps of systematic decision making methods in the context of architectural design. This literature review will lay the theoretical foundation for researchers in the area of architectural decision-making and evaluation. The authors will apply these findings to their study that proposes and tests an innovative design decision-making methodology that systematizes a process for evaluating early design proposals against client criteria.

KEYWORDS: design decision making, process, methodology

## 1.0 INTRODUCTION – DECISION THEORY AND METHODS IN DESIGN

Architectural design is the process by which the designer applies intellect, creativity, and knowledge to resolve a complex array of constraints into a solution that balances the Vitruvian ideals of firmness, commodity, and delight. The traditional design approach is characterized by deterministic problem solving, generally a loosely structured, open-ended activity that includes problem definition, representation, performance evaluation, and decision-making. A number of systematic approaches have been proposed to organize, guide, and facilitate the architectural design process. The main objective of these design thinking research studies is to discover a logical and rigorous path to a design that is acceptable to the architect, satisfies the client, and serves the needs of users. All approaches focus heavily on decision making, which is integral to the process, and an important element of nearly all design phases. In fact, the center of all architectural design approaches is decision making. However, architects and engineers typically do not consciously integrate decision analysis (modeling real-life choices involving uncertainties) and modeling strategic interactions into their design processes. But, strategic interaction among multiple stakeholders with uncertainty is critical in the architectural and engineering design cycle. In fact, systematic design decision making in architectural design process has been unclear, hard to understand, and therefore difficult to teach in architecture school. This paper will provide a foundational platform to understand how architects and related design professionals make decisions and to identify strengths and weaknesses in the process.

Design is a process involving constant decision-making. The decision process is influenced by sets of conditions or contexts; some are controllable, such as the business context, and some are uncontrollable, such as the market and economic conditions. The business context represents the long-term view of the developer/owner and is in general largely in the control of the developer/owner. Decisions such as project capital investments, real estate profit margin and future building upgrades, and sales marketing strategy are determined by the developer/owner. However, some aspects of business contexts, such as market share (which is influenced by competing design products), are somewhat uncontrollable. In addition, the state of the economy and market demands are not controlled by the developer/owner. Correctly assessing the context for making a decision is important because it dictates the level of effort and long-term impact. Decisions with long-term impacts are often irreversible after implementation; therefore, the decision-maker must seriously analyze the context and impact of alternatives before arriving at a decision. Whether the conditions are controllable or not, there is always uncertainty involved in decision-making. For example, in the field of product design, the uncertainty largely comes from the inputs, such as the completeness of and variation in product requirements and constraints established by the customers.
In general, in design development in the architectural context, the product could be a single building or multiple buildings; decisions are made at different levels under different types of scenarios. At a high level, decisions are made for scenarios such as team organization, product cost, work breakdown, and suppliers. At the mid-level, a decision involves issues such as design requirements, material selection, subsystems and components, and the manufacturing and fabrication process. At a low level, a designer determines the design objectives, forms and dimensions of the individual components, and so forth. There are many methods that aid in decision-making. Some of these methods developed

decades ago are more ad hoc and incorporate relatively high levels of subjective judgment, such as decision matrix, in which weighting factors that significantly affect the decision are assigned by the designer. When these methods are used, they are generally applied to support more significant project decision-making at a high level. Methods developed more recently involve rigorous theory and mathematical frameworks in decision-making, such as utility theory and game theory.

## 2.0. CONVENTIONAL DECISION MAKING THEORY IN DESIGN

Two primary methods developed decades ago are commonly employed to aid design decision-making: programmatic decision-making approach versus instinct-driven approach. The two approaches present an iconic dichotomy existing in all different decision-making in design process. Within the programmatic approach, various methods are commonly used to aid designers in decision-making, such as a decision matrix (Shafer 1976), a decision tree (Shamim et al.2010), quality function deployment (Akao 1994), and so forth. These methods are generally ad hoc and incorporate relatively high levels of subjective judgement, or so-called "designer's intuition." An additional set of methods addresses variability, quality, and uncertainty in the design process, such as the Taguchi method (Otto et al. 1993), Six Sigma (Linderman et al 2003), and so on. These tools are more analytical and are typically coupled to the processes used to produce products. Design theories also exist, such as Suh's axiomatic design (Albano and Suh 1994), that are less widely used but offer more rigorous analytical bases. Finally, certain other methods are used primarily in the fields of management science and economics, such as utility theory and game theory, which are explored in the current research for feasibility and applicability to support decision-making in design, mostly engineering and product design. Traditionally, architectural design has been viewed as an intuitive or subconscious thinking process.

### 2.1. Programmatic decision-making approach

### 2.10. Decision matrix method

Decision matrix techniques invented by Stuart Pugh (Pugh 1991) are used to define attributes, weigh them, and appropriately sum the weighted attributes to find a relative ranking among design alternatives. Note that, in practice, attributes are weighted as numeric figures based on a prescribed ranking system for individual design alternatives. In some contexts, such as design optimization, attributes are also called design objectives, which are to be maximized or minimized, or constraint functions, which must be kept within limits. In general, attributes are also referred to as design criteria or decision criteria. A basic decision matrix consists of a set of criteria options that are scored and summed to gain a total score, which can then be ranked. Importantly, it is not weighted to allow a quick selection process. An example of decision making with the design matrix is a case in which the design team needs to choose between two sites, A and B. in this case, there are nine attributes to be considered: visibility, accessibility, setting, environmental impact, neighbors, size, cost, schedule, and operation. Each attribute has a different weight in the value. The team will first score the two sites and then multiply by the weight to get the overall score, and the overall score could provide guidance for the team to make a decision.

**Table 1:** Decision-making Matrix (by authors)

| Issue | | Site A | | Site B | |
|---|---|---|---|---|---|
| | *Weight Value* | *Score* | *Total* | *Value* | *Total* |
| Visibility | 3 | 1 | 3 | 3 | 9 |
| Accessibility | 2 | 3 | 6 | 2 | 4 |
| Setting | 1 | 2 | 3 | 2 | 2 |
| Environmental Impact | 1 | 3 | 3 | 2 | 2 |
| Neighbors | 3 | 3 | 9 | 2 | 6 |
| Size | 2 | 2 | 4 | 1 | 2 |
| Cost | 3 | 2 | 6 | 2 | 6 |
| Schedule | 1 | 1 | 1 | 2 | 2 |
| Operation | 2 | 1 | 2 | 1 | 2 |
| TOTALS | | | 37 | | 35 |

**2.12. Decision tree method**

The decision tree method is another way to evaluate different alternatives. This method is often used in evaluating business investment decisions, considering the outcomes of possible future decisions, including the effect of uncertainties. The strength of the method is that it allows an evaluation of the benefits of present and future profits against the investment. It is a useful technique when a series of decisions must be made in succession into the future. Every decision tree is a collection of branches connected to each other by nodes. A tree is constructed from the left starting with a decision node, and branches emanating from a decision node represent individual options. The right end of each branch must terminate in one of three types of nodes: decision, event (or chance), or payoff. Note that the event is also called the state of nature, which is in general out of the control of a designer. To illustrate the method, we consider the decision tree shown in Figure 1, which is concerned with deciding whether an architectural firm should carry out research and development for new life cycle assessment (LCA) software or a tool that can be quickly integrated into the design process and generate relatively reliable results to capture a potential market niche in the next 10-15 years. The firm has extensive experience in developing software. However, the firm has no direct experience with LCA tools, which could dramatically increase the firm's competitive edge. With preliminary research completed, it was found that a \$4.0k investment is required upfront to develop new software. However, a \$1.5K investment is needed to improve the current design process. The primary decision selection criterion for the firm is the front cost, so based on this decision tree diagram, the final decision the firm should make is to do nothing.

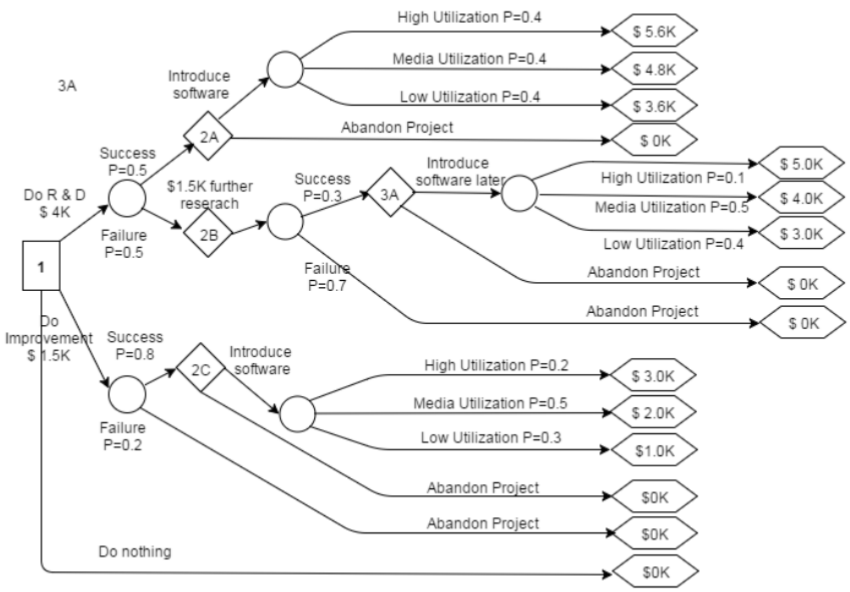


**Figure 1:** Design Tree for R & D project. Source: (Author 2017)

**2.2. Instinct-driven approach**

Creativity is the core of design as each architecture design proposal is uniquely tailored to meet a set of unique requirements, while in other domains, problem solvers seek solutions based on reason and evidence with an analytic approach. The relentless practice of this form of reason could trap us in the reason and cause the loss of creativity. This has become the main worry and mental block for architects to pursue the programmatic approach to design. Researchers have attempted to study the source of creativity to find out how creativity arises in many different situations: a solid and novel proof of a mathematical theorem comes from a mathematician's creativity; a beautiful painting or wonderful music comes from an artist's creativity; an innovative electronic gadget comes from an engineer's creativity, and a profitable stock trade comes from an investor's creativity. In the context of architectural design, we define creativity as an act of discovering design alternatives with components that meet objectives in ways previously unseen or creating new value with a new use of existing components. As Robert Clemen and Terence Reilly pointed out: "From a decision-making perspective, we need not be stuck with the alternatives that present themselves to us; in fact, good decision making includes active creation of new and useful alternatives. Moreover, the very process of decision analysis - especially the specification of objectives - provides an excellent basis for developing creative new alternatives" (Clemen and Reilly 2001).

In architectural design, alternatives are often generated through design iteration and "gut" feeling. Former general electric CEO Jack Welch describes "gut" as emotional response (Harvard Business Review 2014). "Gut" is relative to human feeling and associated response; "gut-decision" makers do not always make high quality decisions, however, trusting intuition does have a certain place in creative activities. A cognitive approach suggests that creativity arises from a capability for making unusual and new mental associations of ordinary objects or concepts. Campbell suggests that more creative people are better at generating multiple alternatives (Campbell 1960). In architectural design concepts, the alternatives are design proposals. In Clemen and Reilly's book, they described the commonly used phases of the creative process as: preparation, incubation, illumination, and verification, which could be translated into the traditional architecture design process: conceptual design, schematic design, design development, and construction documentation. Clemen and Reilly's different creativity techniques include fluent and flexible thinking and idea checklist. Fluency is the ability to come up with many new ideas quickly. Flexibility, on the other hand, stimulates variety among these new ideas (Linderman et al 2003). And together they could be rooted in "guts."

## 3.0. MODERN DECISION MAKING THEORY IN ARCHITECTURE DESIGN

Decision theory provides a rational framework for choosing between alternative courses of action when the consequences resulting from this choice are imperfectly known. Decision theory has been applied more to business management situations than to engineering or architectural design decisions.

The literature on design theory of architecture is diverse. Some studies discuss the design of games. M. Montola (Montola et al 2009) explores the aspects that concern game designers and provides a philosophical, solid theoretical, and aesthetic understanding of the genre. S. P. Walz (Walz 2010) analyses and designs games from an architectural standpoint, and this contribution could be particularly applied to an era when games extend into physical, designed space. Architectural design must include various attributes. O. Ma studies the relation between the architecture of platform manipulators and the accuracy of a manipulator and introduces various performance indices that would explicitly or implicitly affect the accuracy. These indices are considered functions during the configuration [ Ma and Angeles 1991]. All existing studies use architectural design as a platform or infrastructure, but little research has examined the decision-making theory and mechanism in architectural design.

The design theory we have discussed so far has focused on a situation in which a single decision-maker needs to find the best possible decision among alternatives. A decision needs to be made by one decision-maker to produce maximum payoffs in a single or multiple attributes (or criteria) under a set of constraints. This one decision-maker could be a group of people. In many situations, however, the payoff of a decision made by an individual depends not only on what he or she does but also on the outcome of the decisions or choices that other individuals make. In architectural design, design decisions are often not made by a single designer or a single design team. Instead, multiple designers or design teams work on the design and are involved in design decision-making, with each designer or team being responsible for one or more design objectives and/or sub-systems. The design team could include architects, engineers, manufacturers, and clients. For example, an architectural design may focus on maximizing the view and solar shading co-efficiency of a window/wall system, while the goal of window manufacturing is to produce the component with the least cost in shortest time. Design decisions made by the architect in determining the geometric shape of the window wall of a curtain wall system may affect the cost and time of manufacturing the component and vice versa.
In practice, some design decisions are made simultaneously at a specific time in a design phase, and some occur in sequence throughout the design process. With several designers (or design teams), each with his or her own objectives, the nature of the design decision can take several paths, and the resulting overall design may not be desired. This is because a single designer or team can theoretically do better and his or her decision could dominate, hence largely determining the performance of the overall product, which may or may not be desired.

Traditionally, architectural design decision-making and practice is learned through a project-based 'studio' approach. Designers explore design alternatives and their consequences through the linked activities of sketching, modelling, and discussion. Visual learning and decision-making based on visual analogies is an essential tool for designers and architects. Alexander proposed that analysis and synthesis are important steps to reach a design decision and need to be taken in that order [Alexander 1964 ]. On the contrary, Rittel and Webber thought that design problems cannot be fully described and are therefore not easy to analyze at the beginning (Rittel and Webber 1973). This could result in an architecture-specific design methodology that does not depend on the completeness of problem analysis before the design reaches a decision. This seems like design decision-making method practiced in real scenarios.

## 4.0. COMPARISON BETWEEN ARCHITECTURAL DESIGN DECISION MAKING AND OTHER DISCIPLINES

### 4.1 Decision-making in Engineering Design

"Design is decision-making," according to S. Sivaloganathan [ Sivaloganathan 2000]. Engineers are the decision-makers; the design process is important to make sure that newly designed products have improved quality, and more importantly, the design decisions will affect the environment and the safety of the society (Fathianathan and Panchal 2009, Hazelrigg 2012). Some studies in the literature have emphasized that decisions play an important role in concurrent engineering and that engineering design presents a utility-based decision support method for selecting an engineering design. A cooperative enterprise selection mechanism is designed and implemented in an allied concurrent engineering environment (Hatamura 2006). Hatamura points out that decision-making in engineering design is a mental process of design (Sivaloganathan and Andrews 2000). The design decisions are important because they impact the product quality and environment/safety of the society (Fathianathan and Panchal 2009) (Fernández et al 2005) (Hatamura 2006). Hazelrigg claims that decisions play an important role in concurrent engineering and engineering design, and presents a utility-based decision support method for design selection. Chen and research team (Chen et al 00) designs and implements a cooperative enterprise selection mechanism for an allied concurrent engineering environment. In the cooperative enterprise selection process, engineering activities and resources from different enterprises (stakeholders) are integrated through some alliances. Hatamura (Sivaloganathan 2000) points out that decision making in the engineering design is a mental process of design. A variety of researchers (Dixon 1966) (Ertas and Jones 1996) (Jackson 2014) analyze incentives for decision making in engineering design process. Brickley and his team (Brickley et al 2003) studies decision-making and its application within the structure of an organization.

Many decision-making methods have been utilized in engineering design. *The Journal of Decision Making in Engineering Design* (Lewis  2006) provides insights on modeling preference, uncertainties, and validation, and illustrates examples of effective application of decision-based design. Vadde and colleagues (Vadde and Mistree 1994) use Bayesian statistics to model uncertainties for multilevel design. The principles of probability and statistics in realistic engineering problems are studied by two research teams. (Ang and Tang 2006) and (Bandte  2000) study probabilistic multi-criteria decision making (Tzeng  and Huang 2001) in aerospace design. Multiple criteria decision support in engineering design has also been studied in by Sen and Yang, (Sen and Yang  1998) who developed an integrated multiple criteria decision support system with user interface and interactive decision making. Sen and Yang develop an optimization software to assist in engineering design making. Fathianathan and colleagues and Ross (Fathianathan and Panchal 2009) (Ross 2003) propose that collaboration decisions should form a critical component in the modeling of collaborative design processes. Vanderplaats (Vanderplaats 2001) studies numerical optimization techniques in the process of engineering design, such as unconstrained/constrained functions, linear/discrete variable optimization, and structural optimization. The response surface methodology is studied in Unal and his team's work (Unal et al  1996) as an approach to design optimization. This proposal uniquely aims to integrate concepts from both descriptive and normative decision models in engineering design while developing a framework to incentivize the decision makers towards strategic value optimization.

**4.2 Decision-making in Architecture Design**

While decision making has been intensively studied in engineering in the last decades, it has not been exhaustively studied in architectural design. (Lawson 1997) (Yi-Luen et al 1997) This might be due to the complexity of architectural design; unlike engineering design or product design in which the scope and risk are well defined, there is more uncertainty and risk associated with architectural decision-making. Ralph Keeney identified twelve factors contributing to the complexity of decision-making which are adaptable to the architectural design context. The factors are: multiple objectives; difficulty of identifying good alternatives; intangibles; long-time horizons; many impacted groups; risk and uncertainty; risk to life and limb; interdisciplinary substance; several decision makers; value tradeoffs; risk attitude; sequential nature of decisions. (Keeney  1982) Those factors all exist in architectural design and cause complexity. Compared to engineering design, architectural design has overall high stakes, complicated structure and no overall experts, and the need to constant justify decisions. A small amount of critical decisions in an early design stage might result in severe environmental damage. For instance, the decision between building a project in a dense urban area or suburban site might be made by clients with early input from architect and planner, prioritizing infrastructure cost, resulting in tremendous and irreversible environmental consequences.

## CONCLUSION

Conventional design approaches heavily involve decision making, which is integral to the architectural design process and an important element in nearly all phases of design. To the best of our knowledge, this paper is the first to formally provide an overview of decision making theory in architectural and engineering design, a necessary first step in an ongoing research project aimed at proposing an effective decision-making process for architecture.

The critical question is what values and preferences the design is based upon. Multiple stakeholders are involved in the architecture cycle, including designers, consultants, developers, regulators, project managers, contractors, manufacturers, and end users. Although those decision influencers may have different (and often conflicting) perspectives, values, and resources, they often jointly and subconsciously determine the effectiveness and success of the design process through discussion, negotiation, and contracts. We acknowledge that through those interaction processes, the stakeholders' preferences and frames of understanding (Goffman  1974) could be altered or transformed. Architectural designers could use decision analysis to evaluate design options and make decisions. The methodologies of decision analysis have been intensely studied; Grayson (Grayson 1960), Allison (Allison 1971), Moore and Thomas (Moore et al 1976), Kaufman and Thomas (Kaufman and Thomas 1977), Keeney (Keeney 1982), Howard and Matheson (Howard and Matheson 1984) provided wide evidence on various aspects of decision analysis methodologies.

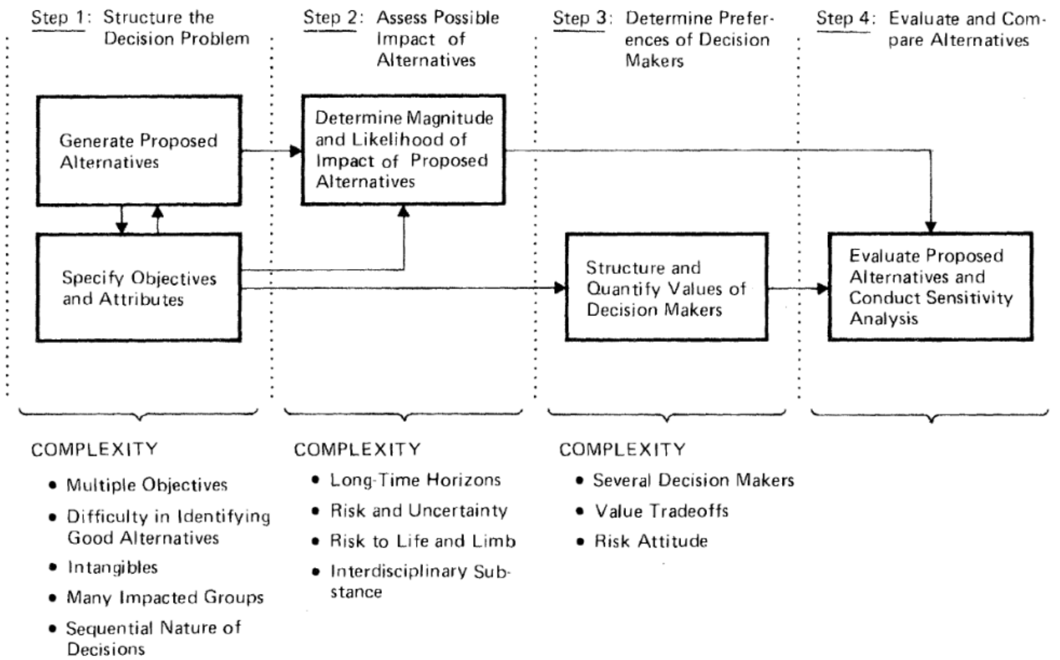


**Figure 2:** schematic representation of steps of decision analysis [36]

Unlike engineering designers, architectural designers have not consciously integrated decision analysis (modeling real-life choices involving uncertainties) as a tool in design process. The largely intuition-based and creativity-driven approach is certainly critical in architecture design, where it does not conflict with a factors-driven programmatic approach. We could model real-life choices involving uncertainties based on decision analysis and modern decision theory that have been adopted in other disciplines. The dichotomy of brain versus gut is largely false; few decision makers ignore good information when they can get it. [Harvard Business Review 2014 ] The reason some decision makers need to reply on their intuition is either the relevant information is largely not available or they have not been trained to consciously use decision making tools following decision analysis methodologies. Since architectural design is composed of many decision making steps, teaching decision making methods and intentionally integrating decision making skills into the architectural curriculum could be critical in educating next generation design professionals.

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