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By

John Chachere & John Haymaker

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If you would like to contact the authors, please write to:

c/o CIFE, Civil and Environmental Engineering Dept.,
Stanford University
The Jerry Yang & Akiko Yamazaki Environment & Energy Building
473 Via Ortega, Room 292, Mail Code: 4020
Stanford, CA 94305-4020

Framework for Measuring the Rationale Clarity of AEC Design Decisions

John Marvin Chachere, Ph.D.[1] and John Riker Haymaker, Ph.D., AIA, LEED AP[2]

[1] Consulting Assistant Professor, Center for Integrated Facility Engineering, Department of Civil and Environmental Engineering, Stanford University; Senior Computer Scientist, SGT Inc., NASA Ames Research Center, MS 269-1, Moffett Field, CA 94035 john.chachere@gmail.com

[2] Assistant Professor, Center for Integrated Facility Engineering, Department of Civil and Environmental Engineering, Stanford University, MC:4020 Stanford, CA 94305 johnrhaymaker@gmail.com

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Abstract

Current Architecture, Engineering, and Construction (AEC) design processes often rely on precedent to resolve complex decisions. However, changes to stakeholder concerns, design methods, and building products devalue much of this precedent knowledge. Project teams need to clearly communicate their decision rationale to develop consensus about design decisions. We review a broad range of relevant theory from decision-based design, decision analysis, decision theory, linguistics, logic, organization theory, and social welfare. We define rationale as a set of assertions regarding distinct components (i.e. managers, stakeholders, designers, gatekeepers, goals, constraints, alternatives, and analysis) that support design decisions. We define conditions of clarity (i.e. coherent, concrete, connected, consistent, credible, certain, and correct). We use these definitions to measure the clarity of assertions, components, and the rationale as a whole. Taken together, this Rationale Clarity Framework (RCF) provides a structured view that enables an objective evaluation of design decision methods.

Keywords: design; decisions; rationale; management; project management; clarity; rationale clarity framework; decision making; design rationale

Introduction

The theory and practice of Architecture, Engineering, and Construction (AEC) requires methods to structure rationale information and discern its clarity. This paper proposes a detailed definition of AEC Design Decision Rationale (DDR) and its components, uses these definitions to develop a method to measure the clarity of this rationale, and discusses interdependencies between the DDR components and the conditions of clarity. Together, these definitions form the Rationale Clarity Framework (RCF). Applying the RCF for a specific project consists of reducing project documentation into individual assertions, evaluating their clarity, and reporting the aggregate conditions of clarity in each assertion, component, and the overall rationale.

Supporting every design decision, there are reasons that collectively form a design rationale. Decision-making and organization theory reveals the rationale contains several essential and distinctive parts. These are called components, such as alternatives (e.g., steel or concrete structures), goals (e.g., minimize cost and maximize aesthetics), and constraints (e.g., fire safety codes). Each rationale component, in turn, consists of several individual claims, called assertions, such as "The building could use a steel moment frame for its structure," "Each day's delay is worth $1M to the owner," and "The local fire code requires a window in each bedroom." Since a rationale consists of components, and a component consists of assertions, the clarity of an overall rationale is dependent on the clarity of its weakest assertion.

Clarifying decision rationale faces technical and organizational challenges. But, a standard definition of clarity can facilitate scientific understanding and communication to benefit project and industry. At the level of projects, lack of clarity in rationale often serves participant self-interest at the expense of team and building performance. At the level of industry, rationale clarity is the foundation of well-functioning organization that takes advantage of modern trends such as information technology and globalization.

After reviewing traditional practice and relevant theory, this paper provides a theoretical framework for measuring rationale clarity. The end of the paper provides one example RCF assessment for an AEC project decision, and discusses the implications of clarifying rationale on projects and the industry.

Points of departure

This section identifies a gap in current AEC design practice and theory: Standard, theory-based definitions of design decision rationale and rationale clarity are missing. Such formal definitions can help project managers assess and improve decision-making. Without them, there are no guarantees of success or long-term improvement (March and Olsen 1985). Project teams currently develop a rationale for each decision, often incorporating essential information into a set of inconsistently, or weakly, standardized documents that do not broadly communicate the reasons for a design decision with clarity. Most relevant theories to guide practitioners are fragmented, so that a high-level view of design decision rationale is difficult for management and researchers to grasp.

Practical Points of Departure

On every building and infrastructure project, stakeholders, designers, gatekeepers, and managers collaborate to produce complex decisions while trading off competing priorities. Institutional strengths and weaknesses in this collaboration systematically influence decisions that determine economic, environmental, and social effects.

Traditional Practice

In our field studies, typical AEC practices fail to deliver basic information that project teams need to identify and build consensus on a design (Haymaker et al 2010; Haymaker and Chachere 2006). Figure 1 shows part of a matrix presented by a design team to an owner to build consensus for the selection of a steel structural system. The matrix alone does not provide a clear rationale to support any decision. The identities of stakeholders and gatekeepers involved in the decision are not stated in the matrix. Numerous goals are identified without indicating their relative importance. The options are stated vaguely. The certainty attached to individual analyses is not always communicated. No recommendation or decision is recorded in the matrix. Because of these gaps, this document is open to multiple contradictory interpretations. It needs to be extended with additional material, such as narration, meeting minutes, or 3D models, to convey any substantial, objective meaning. Project teams require a more integrated method for documenting and communicating decision rationale to the project team.

16 May 2007 Structural System Decision Matrix

Score Key: 3 = Much Better, 0 = No Effect, -3 = Much Worse, ? = not enough info to decide

Primary Criteria		Steel		Concrete		General Questions/Comments
	Subcriteria	Comments	Score	Comments	Score	
Minimize First Cost	Structure	+ Garage will be less expensive + Superstructure less cost but Turner should confirm	?	- Probably not enough regularity to make concrete inexpensive?	?	To be confirmed by Turner
	Non-Structural Implications		?		?	Depends on whether steel requires fireproofing.
	Minimize Project Duration	+ Faster to erect	2	- Not enough regularity for fast erection	-1	
Space Needs (cols, floor depth, BF & SW)	Columns	= 12" Deep. If Finishes & Fireproofing is required, 18" total.	0	= 18-24" Exposed, larger under large transfer girders	0	benefit depends on fireproofing.
		+ No wall in E-W direction because of MFs				
	Above Large Classrooms	+ More efficient transfer (e.g. vierendeel truss?)	2	- 48" Deep Transfer Girders	-2	
	Around Openings	- Slightly Deeper Around Perimeter + More flexibility	?	+ Thinner Profiles - less flexibility, beams fly through large openings	?	
	At Exterior Office Bays	- Thicker Exterior Perimeter (18")	-1	+ Thinner Profiles (8")	1	Is this important?
Roof Framing		+ Steel allows much flexibility. All steel roof	?	- Probably will need steel or timber, so new	-1	

Figure 1: Decision matrix on a typical AEC project (Haymaker et al 2010).

In this example, the designers simplified the rationale information. Two problems stand out. First, they assumed a shared knowledge of precedents. Second, they invoked trust based on the authority of their professional qualifications. The next section proposes that continuing this common designer practice may not benefit AEC projects or the AEC industry.

Modern Developments

In the last twenty years, the AEC industry has entered a period of turbulence in which many types of previously slow-changing information altered rapidly. Globalization and urbanization have introduced a broader community of stakeholders, designers, and gatekeepers. Information technology has heightened awareness of relevant events. Natural disasters (e.g., Hurricane Katrina), terrorist attacks (e.g., 9/11), and popular films (e.g., An Inconvenient Truth) have heightened stakeholder sensitivities to diverse goals, such as durability, security, and sustainability. In turn, these new goals have led to the development of new options including spatial configurations, structural systems, and energy production schemes. New delivery methods have broadened and better connected communities of stakeholders, designers, and gatekeepers. Information technology has yielded new ways to represent and analyze the performance of different options.

AEC project organizations have not yet developed consistent shared knowledge and authority relationships around this new information. Currently, there are many standards of communication and coordination addressing various components in the design rationale. Some address different components of the design rationale (e.g., building information models (International Alliance for Interoperability 2009), and project delivery models (American Institute of Architects 2008)) and some overlap (e.g., LEED, U.S. Green Building Council 2008; and SPeAR, ARUP 2006). While each of these standards helps to clarify some aspect of design rationale, none addresses the full scope of relevant information with enough clarity to develop and communicate this rationale credibly.

Theoretical Points of Departure

This section reviews research in design decision-making methodologies. Generally, we conclude a model of rationale clarity for the AEC industry has not yet been formulated. However, there is significant related research on the use of Decision Analysis (DA), Decision-Based Design (DBD), Decision Theory (DT), and Decision Rationale (DR). Research on DA and DBD generally focuses on 'optimal' choice and treats clear communication as a valuable but secondary effect. Previous efforts to formalize and communicate DR demonstrated the ability to "record and playback" rhetorical design thinking, but lacked the structure needed to efficiently capture and reuse knowledge, generate new insights, and communicate and develop consensus (Moran and Carroll 1996). As a result, DR methods have not yet had a significant impact in practice.

"Many of the fundamental questions (regarding DR) have barely been raised (Moran and Carroll 1996)." Questions remain about the fundamental components of rationale. How much of the rationale should be made explicit? Who should construct and consume this rationale? What are the likely impacts of clarifying this rationale? The first step toward answering those questions is to formally define rationale and rationale clarity in an AEC design context.

Limits on Rationality

Psychological and organizational limits constrain rational administration on design projects. Many design decisions are too complex for individuals and organizations to address with absolute clarity. This situation results from limited knowledge of options, analyses, and preferences, and a limited ability to process this information (Simon 1977). In general, time and cost pressures present strict limits on the clarity AEC design organizations can achieve. Practitioners understand that rationality is limited, and strive to work around it. During this research, a project manager for a $300M hospital stated to us, "My goal is a significantly better method that's workable, not an ideal method." The optimal degree of rationale clarity for a project to attempt, and the method for attempting it, depends therefore on the resources available. Simplification, including data classification and uncertainty absorption (March and Simon 1958), is a necessary evil; "Simplification may lead to error, but there is no realistic alternative in the face of the limits on human knowledge and reasoning (Simon 1977)."

Increasing project complexity further challenges an AEC team to make rational decisions. Conversely, advancing computer processes and visualizations reshape the boundaries of rationality. Assessing these changes requires measuring and comparing current and ideal practice.

Design as Decisions
Design consists of many interdependent decisions (Lewis et al 2007). These decisions are complex. Each option has associated objectives, constraints, and analyses regarding performance characteristics that may be uncertain. These decisions are also numerous. There are vast numbers of interdependent choices possible, and many of them interact. Since the total complexity of assessing all decisions is unmanageable, project managers divide the problem into manageable portions (Simon 1977). AEC projects can be partitioned so design decisions occur in a sequence of "stages." The sequence starts with fundamental questions (e.g., building location and orientation) and is followed by progressively detailed decisions (e.g., plumbing and lighting fixtures). Project management arranges the work within a stage to assess design decisions and produce a defensible set of choices. Ideally, the product of that stage provides all the information required to make a decision. For example, if a first stage site selection decision culminates in a particular building orientation, then the next stage (which may decide the structural system) will be based on that orientation.

Decision Theory and Decision Analysis
Project management may assess simple decisions formally and guide complex decisions informally using Decision Theory (DT). Classical economics, game theory, and operations research optimization methods use DT's simple, formal basis for making good decisions under uncertainty. DT uses widely accepted axioms to derive a normative rule for rational decision making: the best course of action is the one maximizing expected utility (a personal measure of usefulness) (Ramsey 1931; von Neumann and Morgenstern 1944; Savage 1954; Fishburn 1964; Matheson and Howard 1968). In particular, Decision Analysis (DA) applies DT in the form of "a structured conversation leading to clarity of action" that may be useful for strategic decisions under uncertainty. DA consists of developing a mathematical, probabilistic model of an individual's options, analyzing the possibilities, and assessing the decision maker's preferences regarding the possible outcomes.

The DA framework can provide a structure for communication and reasoning in AEC organizations. Decision analysts have placed increasing emphasis on analyzing and adapting to organization and procedure (Keefer et al 2007). Nevertheless, DA often requires few collaborators and addresses an individual's choice. This practice is unlike building design in which decisions almost invariably require broad collaboration and benefit greatly from consensus.

Decision-Based Design
Decision-Based Design (DBD) applies Design Science and DA methodologies to solve design problems. Moran and Carroll (1996) ask questions such as: "How deeply can we understand design as a generic activity? How can we represent not only the reasons for solutions to sub-problems, but also for the tradeoffs and compromises made to adjudicate between the demands of the different sub-problems?"

Thurston (2007a) formulates design as an optimization problem, distinguishing design options, goals, preferences, analyses, and constraints. Research also defined methods to decompose difficult optimization problems into smaller, simpler problems, solve them in a decentralized fashion, and synthesize them into system optimal solutions. Some properties of the hierarchical optimization method match theories of organizational behavior (Burton and Obel 1980). Renaud and Gu (2007) provide a mathematical decision-based collaborative optimization (DBCO) method of making simultaneous design and business decisions. Kumar et al. (2007) provide a hierarchical view with enterprise-level product planning decisions driving engineering-level product design decisions within a mathematical, multi-level optimization. Herrmann and Schmidt (2006) describe design organizations as systems for producing decisions. They point out bounds of rationality in product development decisions: "Viewing a product development organization as a decision-making system leads to a systems-level approach to improving product development." "While efforts should be made to extend the envelope of the rigorous decision theory in the design field, another approach is to adapt the principles of design theory to create practically applicable design methods (Jin and Danesh 2007)."

Design as decision-making and design as process execution are complementary views (Donndelinger 2007). In AEC, DBD methods can help clarify many aspects of AEC design rationale in principle and practice. The formulation matches the high level structure of many design problems. However the need to incorporate diverse stakeholder objectives provides an additional structure that is central to AEC. AEC design decisions rely on clarity and consensus among a wide range of participants who may be unwilling or unable to understand highly technical design documents. Efficient AEC DBD requires evidence of decision quality that is easily communicated to project participants.

Design Rationale
There has been much research on formal models of Design Rationale (DR) but little success institutionalizing them in practice. A DR is a document that provides explicit, logical reasons given intended to justify decisions on the design or features of a building (Moran and Carroll 1996). A DR is a product of reflection on the construction of a design (Schön 1984), and its purpose is to "rationalize discussion" (Fischer et al 1991). Moran and Carroll (1996) ask, "What types of rationale are there?" Next, process-oriented and structure-oriented rationales are discussed. In this paper, we apply a structure-oriented rationale to AEC design.

Process-Oriented Design Rationale
A process-oriented design rationale emphasizes a "history of the design process" that can nevertheless help find design errors (Conklin and Burgess-Yakemovic 1991). The practice relies on rhetoric. "Its qualitative approach avoids the complexities of multi-attribute utility theory…and the quagmires of arbitrary and hair-splitting quantitative judgments." Researchers

began formally modeling design rationale decades ago to deal with "wicked" problems that have many complex interactions but little known structure (Rittel and Webber 1973). The seminal design rationale representation, Issue-Based Information System (IBIS), was built to help designers clarify and communicate design and planning for such problems. IBIS consists of a network of related textual statements: issues, positions regarding issues, and arguments for or against positions. The overall success of semiformal design rationale in industry has been decidedly mixed (Fischer et al. 1991). Research and practice has found IBIS "too simple and homogeneous… to support decision making in the presence of change … (these original methods) tend to ossify and become impossible to revise or extend" (Potts 1995). While explicit design rationale "reduces the chances of missing some important consideration (Fischer et al. 1991)," it also relies upon decision makers to realize the existence and relevance of that information. Without structure, "the (design rationale) document can grow into an unwieldy amount of loosely organized textual information… repeated occurrences of an issue will usually be worded and even conceived of differently (and) the (design rationale) document will grow to contain inconsistent information (Conklin and Burgess-Yakemovic 1991)."

Structure-Oriented Design Rationale

Research has addressed perceived deficiencies in process-oriented design rationale by leveraging knowledge about the structure of design work. For example, some models explicitly articulate design goals (Lee and Lai 1991; McLean et al. 1991), or incorporate industry-specific design methods (Potts 1995). A structure-oriented design rationale "emphasizes the careful construction of (design rationale) as a map of the design space and focuses on a rigorous and logical representation of the rationale. This approach maximizes the payoff of (design rationale) through its reuse and/or through lowering the cost of system maintenance (Conklin and Burgess-Yakemovic 1991)." McLean et al. (1991) provide an example of structure orientation.

Acceptance of design rationale depends upon its match to existing process. However, theory does not yet contain a definition of the components of design rationale, or the clarity of that rationale, suitable to match to AEC processes.

Rationale clarity framework (RCF)

Moran and Carroll (1996) ask, "How far can we characterize the structure of design abstracted from specific domains?" This section builds on decision and organization theories to structure a formal definition of Clarity of AEC Design Decision Rationale. Projects generate numerous materials to support design choices, including rhetorical arguments, references to building codes, and design models. Each of these materials provides numerous individual claims that are relevant to the design rationale, called assertions. This section defines the RCF's two views. The first view is that each assertion addresses one or more of a set of components that span the necessary and sufficient information to explain design decisions. This section explains how these components follow from the organization of AEC design and from theories describing the fundamental requirements of decision-making. The second view is that each assertion in a rationale satisfies conditions of clarity. This section provides a way of describing the project team's achievement of clarity in design rationale by defining and comparing several definitions of clarity from literatures such as linguistics, logic, and organizational theory. For example, the decision matrix presented in Figure 1 encodes assertions such as, "Choosing the steel structure scores a 2, meaning 'much better,' for project duration." The assertion regards the analysis component of a rationale, meaning that it measures the effect of an option on project objectives. In terms of clarity, the example assertion is coherent but vague. This means that it makes grammatical sense, but it is vulnerable to subjective interpretation. The project team needs to determine whether the steel structure's faster erection is worth its potentially higher cost. This requires greater precision than the phrase 'much better'. By contrast, a different assertion such as, "The steel structure will be 4 weeks faster to erect" would provide an analysis that is both coherent and concrete, because it is objectively measurable.

Viewing the DDR documents in terms of components and clarity reveals which portions are clear, and are therefore supportive of a decision. It also reveals which portions are unclear, and are therefore vulnerable to criticism. RCF also dictates how unclear assertions limit overall clarity because of dependencies in the achievable clarity within components. For example, objectives must be coherent before they can be credible because incoherent assertions carry no meaning. There are similar dependencies in the achievable clarity between components. For example, stakeholders must be concrete for the objectives to be concrete. This is because objectives express the preferences of stakeholders.

Overview of the Rationale Clarify Framework

Figure 2 illustrates the main components and dependencies in RCF. A Manager (e.g., school dean) initiates the design decision, determines which Stakeholders (e.g., students, faculty, and staff) can provide Goals for the Analyses, determines which Designers (e.g., Engineering Firm A and Architect B) can propose design Alternatives to be analyzed, and determines which Gatekeepers (e.g., Fire Marshall and County Supervisors) provide Constraints for the Analyses. Finally, the project assembles the Goals, Constraints, and Alternatives, and performs Analyses to select the best design. RCF designates only direct, required dependencies between components. For example, Designers may anticipate Goals and Constraints when selecting Alternatives, but need not explicitly reference these Objectives until performing Analyses. Therefore, the figure connects (using an arrow) Goals to Analyses, but does not connect Goals to Alternatives.

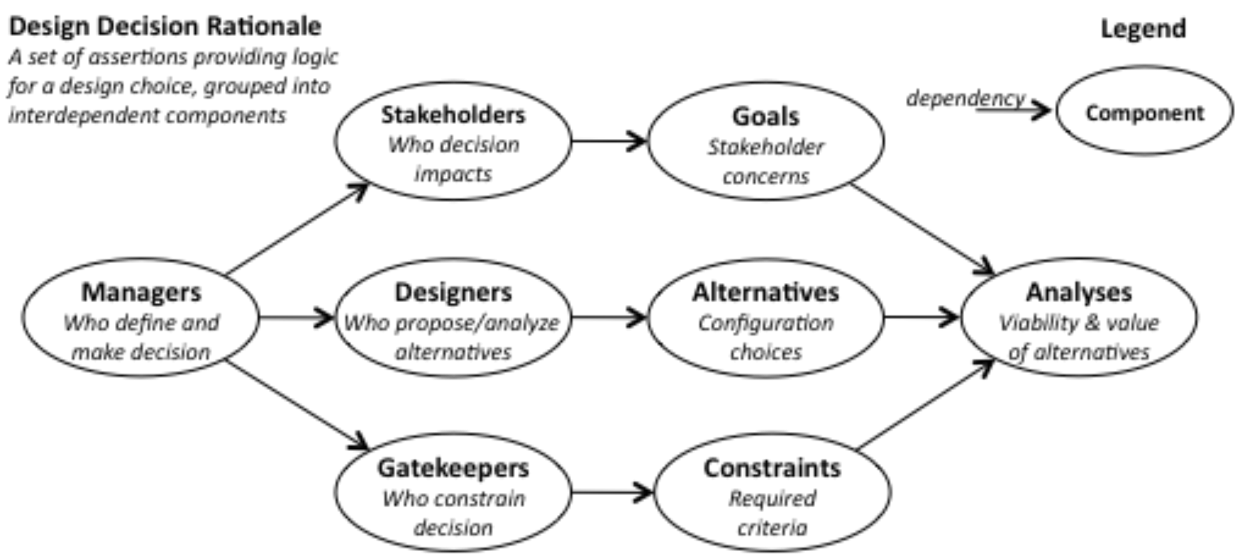

Figure 2**:** RCF describes AEC decisions in terms of eight components.

The definition of each component (except Managers) is directly dependent on at least the definition of one other component as shown by the connections. RCF measures the clarity of each component of rationale with respect to seven conditions, illustrated in Figure 3.

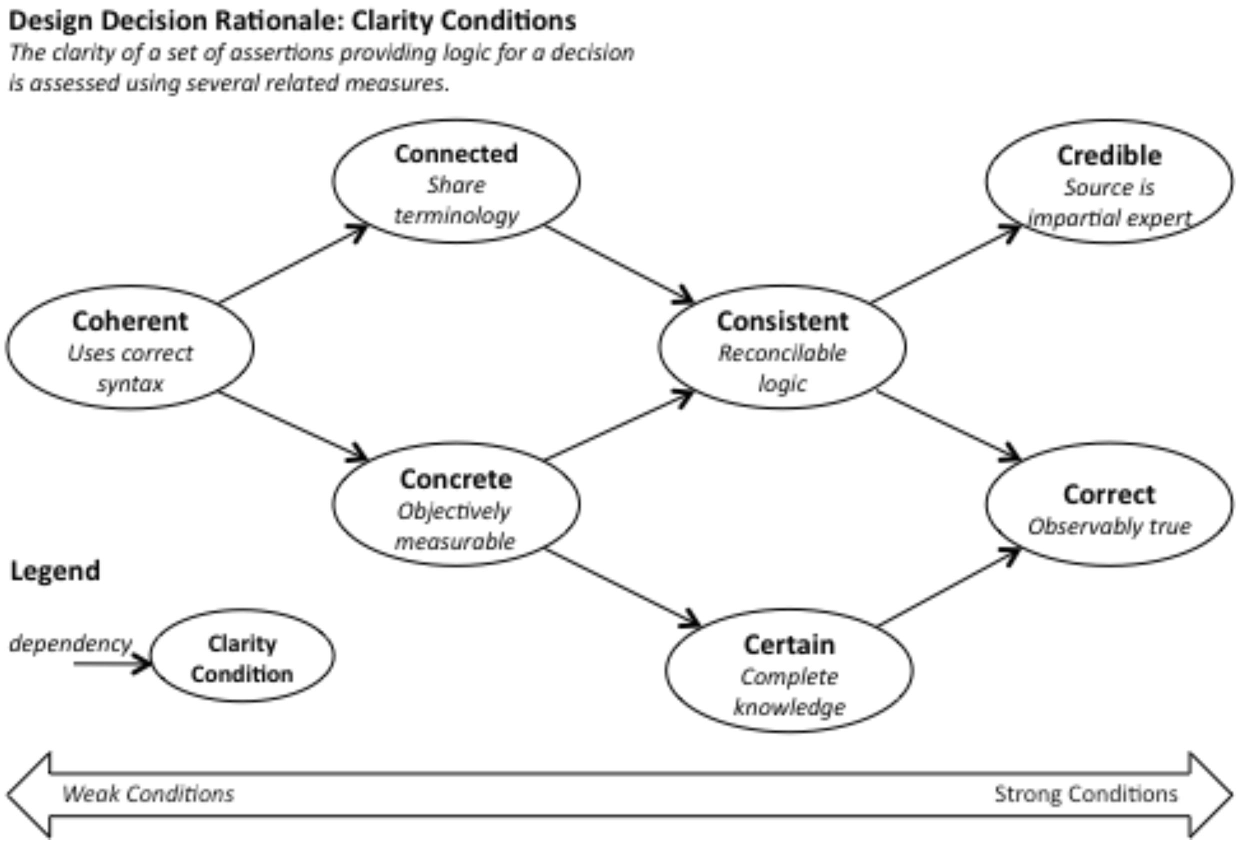

Figure 3: Conditions of Rationale Clarity - Definitions and Dependencies

Rationale Components

Howard (Howard 1988; 2007; Howard and Matheson 1983) provides a set of criteria for judging decision quality to guide attention toward weaknesses in the application of DA. This section builds upon Howard's work by providing definitions and conditions of clarity for each DDR component.

Moran and Carroll (1996) ask "Who will create the rationale?" Organization is central to the formation of DDR. Contemporary design integration in the Architecture, Engineering, and Construction (AEC) industry is socially complex. Participants (e.g., planners, architects, engineers, and contractors) design, construct, and operate the buildings and infrastructure that help sustain human life and society. The organization of these projects influences views of their decision-making. Descriptively, "organizations will have structure… insofar as there are boundaries of rationality (March and Simon 1958)." Normatively, "An organization using Decision Analysis (DA) agrees to act as if it were a single entity using the logic of a person. Separate groups might have the assignment of creating the frame and the elements of the decision basis (Howard 2007)." The general rational framework (March 1994) views decision making in terms of both organization and decision components and this view provides a structure that assists describing and comparing both traditional practices and theoretical improvements to practice.

In these projects, knowledge regarding decision rationale is generally distributed among four role types: Managers know process and organization; Stakeholders know goals and preferences; Gatekeepers know constraints limiting the project; and Designers know alternatives and analyses.

Managers

A DDR should state who supervised the project organization, process, and technology. It should also provide administration of the design reasoning, judged by Howard (1988) as "logical integration and evaluation," to define how decision data determine the choice that is made.

Managers provide expertise and leadership regarding process (stages and gates) and organization (stakeholders, designers, and gatekeepers). They use formal and informal processes to integrate the decisions of many individuals into a set of collective, rational design decisions. "The problem is one of organizing the entire system of decision-making and information flow (Hermann and Schmidt 2006)."

A principal management role is assigning resources (such as time and money) and establishing procedures to guide the broadest possible range of creative ideas through the most rigorously critical evaluation. The manager therefore identifies the designers who can propose and analyze options, the gatekeepers who can prohibit construction of options, and the stakeholders whose objectives the building might affect.

Stakeholders

A DDR should state what groups of people the design might affect. This is fundamental to addressing Moran and Carroll's (1996) question, "How can rationale methods and tools be used to expand the role and voice of various stakeholders in a participatory design process?"

A stakeholder is a person or organization that the decision may affect. In theory and in practice, we have often observed this role confused with the role of Decision Makers or Designers. For example, Howard (2007) states, "It is useful to define a stakeholder in a decision as 'someone who can affect or will be affected by the decision." Stakeholder groups that we have often encountered for building projects include Maintenance Staff, Faculty, Students, Residents, and Neighbors.

Goals

A DDR should state the project goals, which are the set of attributes that the building design may affect and that stakeholders may care about. According to Howard (1988) "clear values," indicate which possible outcomes are preferred, and by how much. Typically, a building owner values some of these objectives directly (such as first cost) and some indirectly (such as project duration, which affects cost by delaying revenue-generating occupancy). A metric and description is associated with each objective. Explicit objectives enable tradeoffs in decision-making methods in both traditional practice and in Decision Theory and Decision Analysis.

A DDR should also state how much different stakeholders care about each goal. However, none of the consultants we ethnographically observed used quantitative stakeholder objective valuation. Instead, engineers either relied on professional judgment (updated informally, if at all, based on perceived changes in demand) or inferred preferences from ordinal or rhetorical descriptions. Keeney and von Winterfeldt (2007) propose the notion of a practical value model based on decision context. “On any major decision, it is worthwhile to initially think of objectives from the viewpoint of various stakeholders concerned about a decision …Analysts can help by combining values expressed throughout the organization and by improving the communication of values within the organization.”

Value-focused thinking (Keeney 1992) provides a method of using goals as primary drivers of problem structuring, such as the generation of alternatives, which has been applied broadly in recent years. Nevertheless, challenges remain: “In architectural design and planning, due to broad social participation, design goals are many and often represent inconsistent and even conflicting desires and concerns. It is often difficult to clarify and understand the concerns of different parties, not to mention aggregating them into a single decisive option (Cao and Protzen 1999).”

Altruistic preferences regard satisfaction of other stakeholders, rather than direct building effects. “Even when the decision maker is one person, that person may consider the consequences of the decision on other people (Howard 2007).” As an important example, the building owner’s wish to satisfy investors, residents, community, and other stakeholders may be the principal determinant in the final design choice. Unfortunately, “It is not possible to construct the definitive, normative group utility function…No methods exist for accurately comparing subjective preferences between individuals (Thurston 2007b).” Furthermore, “When one attempts to make the distribution of welfare (or level of satisfaction) among individuals more even or “fair,” then one must sacrifice total group welfare (or in the case of design, overall design worth)”. In spite of the difficulties, design decisions require developing a model of altruistic and direct goals for all stakeholders and integrating those models into a single view of social welfare.

Designers
A DDR should indicate who the designers are to establish their legitimacy. Designers define building options and analyze those options regarding stakeholder objectives and gatekeeper constraints. Examples of building Designers that we have often encountered for building projects include Architects, Structural and Mechanical Engineers and Contractors among others.

Alternatives
A DDR should describe the investigated options and alternatives. Alternatives include potentials building sites, viable building orientations, possible building and subsystem technologies, and the available structural materials. Emerging computational design methods such as parametric modeling (Kolarevic 2003) are helping designers generate these Alternatives quickly, and Building Information Modeling (Eastman et al. 2008) is assisting them to represent them clearly.

Gatekeepers
A DDR should state the project's gatekeepers, which are individuals and teams with the power to constrain the range of viable options. Moran and Carroll (1996) ask, "How can we keep track of the assumptions made during the design process, many of which are implicit?" In particular, experienced teams share numerous assumptions regarding which options are viable. Documenting an explicit list of gatekeepers is fundamental in explaining the rationale for a building design. AEC design decisions are subject to many gatekeepers. These gatekeepers, alone or in combination, have the power to prevent a building project from going forward based on certain criteria. They can also act without trading off stakeholder preference in a utilitarian manner. Typical Gatekeepers we've encountered on building projects include the building department, the fire marshal, and particularly powerful stakeholders who possess the power to control the process unilaterally.

Constraints
A DDR should state constraints. These are known conditions that are required for a design option to be selected and built. Hazelrigg (1996) defined constraints as higher-level design decisions that simplify decisions but actually serve as higher-level proxies for system-level objectives. "(There is a) range beyond which the decision-maker is no longer able and willing to make trade-offs (Thurston 2007b)." "(In design rationale,) a feature of a good design space analysis is that it clarifies the boundaries of a given possibility space (Haymaker 2006)." Formally, a constraint is a logical statement that must hold for each option, but that does not affect valuation. Often models will include both a constraint and a goal regarding the same objective. For example, owners prefer to minimize cost, which is an objective, but are constrained to keep cost below the limited available budget.

Gatekeepers contribute information about constraints, and therefore constraints can be defined no more clearly than the gatekeepers are defined. A DDR should provide clear definitions of gatekeepers and their constraints as to frame "the right challenge," as motivated by Howard (2007), and restrict attention based on the decision context. The constraints limit attention to the actionable set of decisions. They can establish higher-level choices (made in an earlier stage), forestall lower-level decisions (made in a later stage), and specify pragmatic, political, or legal requirements.

Analyses
A DDR should provide Analysis, judged by Howard as "informational excellence," that identifies the implications of choosing each possible design Alternative. An analysis is an assertion about the consequences of a particular building choice. An analysis relates an organizational actor providing the source of data (the designer), an option that the analysis regards, a goal according to which the analysis is performed, and the result of the analysis. The Analysis provides a designer's assertion of how choosing an Alternative will impact a previously identified Goal.

A DDR's analysis also includes each Alternative's viability, which is whether the Alternative satisfies the design Constraints. Alternatives are viable if and only if they do not violate Constraints. A design rationale should also analyze each option's valuation, which is how the option would affect stakeholders. The combination of analyses and objectives determines valuation. Each option is valued according to how much stakeholders prefer the results that corresponding analysis predicts, and how much that stakeholder's utility is valued by the decision maker.

Analyses contribute information about how options relate to constraints and objectives. Therefore, analyses can be defined no more clearly than the constraints, options, and objectives are defined.

Rationale Clarity

Moran and Carroll (1996) ask, "How much design rationale should be made explicit?" A DDR should provide sufficient clarity to motivate adopting the choice of consensus, judged by Howard (2007) as "commitment to action." Teams need to know what clarity is, and where it is required. This clarity will help them develop consensus and broadly communicate the reasons behind any decision.

Teams vary in their ability and motivation to clarify rationale components. As a result, projects achieve different conditions of clarity in their components. In order to compare the project rationales developed by these projects, participants require a language for describing the conditions of clarity they achieve in each component.

For example, design teams who specialize in analyzing building performance using computer models can achieve clear analysis of building options. However, such a team may achieve less clarity in stating objectives, and present only a partial list of performance targets. Clearly understanding the details of building performance, without clearly grasping their significance regarding objectives, results in an unclear overall rationale to support building decisions. The assertion with the least clarity determines the overall clarity of a Design Decision Rationale (DDR).

Definitions of Clarity of a Rationale

The notion of clarity measures the information conveyed in atomic portions of DDR called assertions. An assertion is an indivisible part of a rationale that some member of the project presents. Each assertion contains information regarding a DDR component, such as constraints, analyses, and objectives. Each assertion typically achieves some, but not all, definitions of clarity. For example, a structural analysis may contain the assertion, "The steel structure will cost less than $10M to build." The assertion is clear about the amount of money, and clear about the option being analyzed. However, it is unclear about who is providing the cost analysis. Therefore, the assertion is not credible, and may be incorrect.

Figure 3 introduces RCF's conditions of clarity, their summary definitions, and dependencies between the conditions. This section defines several clarity conditions that design rationale assertions can achieve: coherent, concrete, connected, consistent, credible, certain, and correct. Ideally, teams would develop DDRs meeting all these criteria, in all rationale components, to collaboratively produce a design decision. However, since teams have limited knowledge and time, the assertions comprising their DDR typically do not achieve all conditions of clarity. Generally, a team should be able to produce a credible rationale. However, most teams fall short of that target because their assertions are unclear or absent from key rationale components.

To introduce the conditions of clarity, consider the following assertion by a structural contractor regarding the structural decision rationale's analysis component: "The modeled steel structure's materials will cost $10M."

1. *Is the assertion coherent?* Yes, it is *coherent* because it is grammatically correct. By contrast, the assertion "Will cost $10M" does not indicate the assertion's subject and is therefore *incoherent.*
2. *Is it the assertion concrete?* Yes, it is *concrete* because it identifies the exact structure and dollar amount. Merely stating that the structure will be "expensive" would be *vague.*
3. *Is the assertion connected?* Yes, it is *connected* because it relates to an existing model of the steel structure. If there were no modeled steel structure, the above assertion would be *disconnected.*
4. *Is the assertion consistent?* Yes, it is *consistent* because this is the only assertion relating structural costs. A second assertion that the total structural cost will cost $9M would render the above assertion *inconsistent*.
5. *Is the assertion credible?* Yes, it is *credible* because it comes from a reliable expert on the subject. If it had come from an electrical contractor, the claim about structural costs would be *not credible.*
6. *Is the assertion certain?* Yes, it is *certain* because it represents the utmost confidence regarding the cost. Stating that the steel price is equally likely to be $9M or $10M, based on market price fluctuations, would be *uncertain*.
7. *Is the assertion correct?* Yes, it is *correct* because it turns out the materials cost $10M. If the steel cost totaled $11M, the above assertion would be *incorrect***.**

Although each clarity condition measures a different criterion, failing to meet some criteria renders assessing other criteria impossible. For example, assertions must be coherent to meet any other criteria, and they must be both concrete and connected to be evaluated for consistency. The following sections detail each clarity condition, explaining definitions, dependencies, and examples.

Coherent/Incoherent
Coherent assertions obey the most basic rules that communications media require to convey meaning. For example, coherent rhetorical statements obey the grammar of a natural language, coherent mathematical formulas are well-formed, and coherent computer algorithms are syntactically correct (i.e., they compile).

In practice, incoherent assertions commonly result from assuming readers possess and will apply specific background knowledge. For example, we often observe blank spaces in analysis matrices such as Figure 1. Unless there is an accompanying explanation, this practice is equivalent to stating, "The option's effect on the goal is." Readers can interpret these blank spaces to mean the corresponding analysis was not conducted, was not applicable, resulted in a prediction of an option having zero effect on a building, or was erroneously omitted.

Concrete/Vague
Assertions that are coherent may be concrete enough to convey objective meaning, or may be open to subjective interpretation. Concrete assertions state data in explicit terms requiring no additional project knowledge to understand. Exactly those distinctions meeting the "clarity test" from decision analysis meet this definition of concreteness (Howard 2007). By contrast, assertions that (to the source) seem conventionally understood but have no concrete definition allow for misinterpretation. Only coherent data can be defined as either concrete or vague; in a sense, incoherent assertions are objectively identifiable as a complete failure to communicate, whereas vague assertions do carry information that is are vulnerable to subjective interpretation. As an example, the assertion, "The steel structure's materials cost $10M" is concrete because the exact cost of materials can be objectively determined and compared with $10M. In contrast, the assertion, "the steel structure's materials are expensive" is vague because people may view the materials as expensive when comparing to the building's other structural option, but as inexpensive when comparing to steel used for another building.

Connected/Disjoint
Multiple coherent assertions that share common terms and presentation are termed connected. Connected assertions relate data directly and meaningfully to other assertions, without requiring additional analysis, insight, or expertise. Typical design documents contain many connected assertions in rhetorical, tabular, or visual formats. Assertions from multiple components are more often disjointed.

The definition of rationale clarity includes a notion of connectedness between data because decision-making requires assertions' synthesis. Making implicit knowledge explicit is necessary for integrating multiple perspectives into a single decision basis. Narratives (Haymaker 2006) provide one generic means for representing the connections between multiple sets of information.

Consistent/Contradictory
Any set of connected, concrete assertions can be evaluated for consistency. Consistent assertions are mutually compatible; no reasonable interpretation can support contradictory assertions. For example, the assertions, "The Master Suite will be on the second story" and, "The residence will have only one story" are contradictory.

Only connected data can be considered consistent. Disjointed data cannot be compared to ascertain where any contradictions may lie. Additionally, only concrete data can be consistent or inconsistent. To the extent that an assertion is vague, it carries no objective meaning that relates to other assertions. For example, the assertion, "The steel structure's materials cost $10M. Labor raises the total cost of the steel structure to $8M" is contradictory because $8M is less than $10M. In contrast, the assertion, "The steel structure's materials cost $10M. Labor raises the total cost of the steel structure to $18M" is consistent for labor costs of $8M.

Credible/Dubious
Assertions that are both concrete and consistent may be credible, in the sense that they depend on a notion of legitimacy. For an assertion to be credible, it must come from a source with broadly acceptable evidence of the subject's expertise. The source must also be trusted to formulate and deliver assertions free from bias. Only consistent assertions can be stated credibly because it is illogical to believe in both sides of an unresolved debate.

Credible assertions reflect the highest degree of belief achievable without experimentation. Credible assertions are those management views as legitimate, typically because they have been confirmed by people or organizations broadly viewed as experts in that particular domain. Typically, management-designated designers provide credible options, management-designated stakeholders (or their elected representatives) provide credible objectives, and gatekeepers responsible for enforcing constraints provide credible constraints.

Each assertion has a source who is an organizational actor. That actor may be an individual or a team, and includes associated facilities or information technologies. The logic provided here does not distinguish between actors who are individuals speaking for themselves or teams speaking based on the authority for their organization. However, extending the logic to support additional reasoning is straightforward.

Certain/Uncertain
Assertions that are coherent may report facts using certain terms, such as “the soil is sandy,” or using uncertain terms, such as “an earthquake might strike.” Furthermore, assertions that are concrete can usefully convey uncertainties concretely with Bayesian probabilities; “Assigning probabilities to distinctions that (are vague) is an exercise in futility (Howard 2007).” Uncertain assertions express a limited amount of knowledge regarding events’ likelihood. Whereas credible assertions reflect the greatest practically achievable degree of belief, certain assertions claim absolute knowledge of whether an attribute holds or whether an event will occur (or has occurred).

The first type of uncertainty, known as aleatory, regards facts that are unknowable due to fundamentally random processes. For example, “There is a 10% chance that a magnitude 8.5 earthquake or larger will strike the building within the next 30 years” is a concrete assertion that communicates an aleatory uncertainty. In the case of aleatory uncertainties, methods including experimentation and consultation with additional experts may reduce, but cannot eliminate, uncertainty. Therefore correctness, as defined below, may not be achievable. For example, assessing a coin flip that has not yet occurred may be defined as reaching the highest achievable level of confidence, if stated with equal chances of heads or tails, rather than as the uncertain prediction of heads (or of tails), because the future result of a coin flip is unknowable.

The second type of uncertainty, known as epistemic, regards matters of fact about which we have limited knowledge. For example, “There is a 10% chance the soil at the building site is sandy” is a concrete assertion that communicates an epistemic uncertainty. In the case of epistemic uncertainties, methods including experimentation (such as geologic testing) and consultation with additional experts may reduce or even eliminate uncertainty (therefore enabling correctness, as defined below).

Assertions that include uncertainties are not considered contradictory simply because they result in unlikely conclusions. For example, "There is only a 0.1% chance of an 8.5+ magnitude quake this year," does not contradict "a 9.0 magnitude quake occurred this year" because there is an interpretation that supports both assertions (namely, that an unlikely but possible event has occurred).

Correct/Incorrect
Assertions that are both consistent and certain may be either correct or incorrect. Correct assertions are true in an absolute sense, meaning they are consistent with all other correct assertions; Contradictory data must contain at least one incorrect assertion. Although correctness is often difficult to assess, developing a rationale involves attempting to increase the degree of correctness by checking assertions' consistency against other certain assertions.
Under this definition, all correct data is also certain. Fundamentally random (aleatory) uncertainties, like coin flip outcomes, can eventually be determined correct or incorrect. However, a probability distribution on outcomes cannot be determined correct or incorrect. For example, the occurrence of an 8.5 magnitude quake neither confirms nor negates the uncertain assertion "30% chance of magnitude 8+ quake within 20 years." This definition of correctness agrees with the view of classical statistics (although not with views of quantum physics). Even aleatory uncertainties, like coin flip outcomes, are simple facts that can eventually be learned.
Incorrect assertions can be credible if presented by a legitimated authority. Similarly, correct assertions may be viewed as dubious if they presented by an authority that lacks legitimacy.

Discussion

Design rationale is complex and fragile, and is typically understood and managed poorly in practice. This paper reviewed existing literature relevant to the measurement of clarity in AEC Design Decision Rationale, and found no existing definition could portray the clarity of, and dependencies between, organizational actors and decision basis elements. The paper provided such a definition, the Rationale Clarity Framework (RCF) that views each relevant design assertion in two ways. First, the component of the rationale the assertion addresses, such as objectives, constraints, or options. Second, the conditions of clarity the assertion sustains, such as coherence, concreteness, and credibility. A complete rationale includes assertions addressing each component, and a clear rationale includes assertions that meet the conditions.

We have found that conceptualizing project information using RCF exposes the contributions and deficiencies of existing decision documentation methods. It creates a unified view suitable for developing organizational consensus within AEC organizations to improved process and product performance. RCF has implications for research and practice.

Implications for Research

A standard definition of rationale clarity can improve the ability of researchers to compare theories and methods, and enable the formulation of testable propositions regarding the effects of increasing clarity on AEC projects and industry.

Chachere (2008a) uses the RCF to explore the manifold and subtle causes and effects of clarity on project performance. Managing consensus on novel building design processes is difficult because industry tradition engenders self-interested behavior by project participants and discourages designs deviating significantly from precedents. Whereas a traditional decision analysis provides a structured conversation leading to clarity of action, we have observed that the system of checks and balances in AEC design projects requires a structured collaboration leading to consensus of action. The paper presents a set of propositions about the potential effects that using a clear rationale may have on the project and industry. The paper uses theories of organization, social psychology, management, and management science to form a theoretical argument that building and maintaining consensus in AEC design using an explicit, socially constructed design rationale is possible and can affect outcomes. The paper concludes with a discussion of findings from several ethnographic and intervention studies. These findings support the hypothesis that improvements to the exploration and evaluation of design spaces, and to consensus management, justify socially constructing clear, decision-based design rationale models in AEC.

Chachere (2008b) uses the RCF to explore the manifold and subtle causes and effects of clarity in the AEC industry. In recent years, stakeholder concerns, building codes, and building products have become more dynamic than historically, tracking (for example) increased attention to sustainability, security, extreme weather, information technology, and globalization. The paper describes how these issues have undermined projects' once-valid justification for professionalization, creating an opportunity for disruption by alternate methods of rational administration. In particular, bureaucratizing AEC projects becomes more compelling with the availability of methods that assess novel conceptual designs more clearly and rationally. These observations and existing theories suggest that a combination of contemporary industry challenges (such as supply-chains and competition, new building technologies, and rapidly dynamic project goals) will lead to a period of turbulence and the need for re-organization. The paper argues that the US industry needs to adopt methods of clarifying rationale to assess and adapt to changes in product, organization, process, and technology.

Haymaker et al (2010) provide a case study that uses the RCF to measure current practice and assess the effects of implementing a formal decision support method. Figure 4 shows our evaluation of rationale clarity in current practice using RCF. Marking field observations at their corresponding locations in a visual representation of rationale clarity helped identify and explain weaknesses in the project's development. The research also used RCF to guide construction of and measure a new model that attempts to clarify rationale for the same design decisions. Of the seven conditions, the rationale observed never explicitly described uncertainties (limited degrees of belief), and the correctness of assertions (their observed factuality) could not be determined by either project participants or researchers. The paper therefore assesses only five of the RCF conditions for clarity. Lack of outline around Gatekeeper and Constraint, and lack of arrow between them, means that these components were neither stated coherently nor connected. The paper concludes with a discussion of observed and potential implications for design decision-making processes.

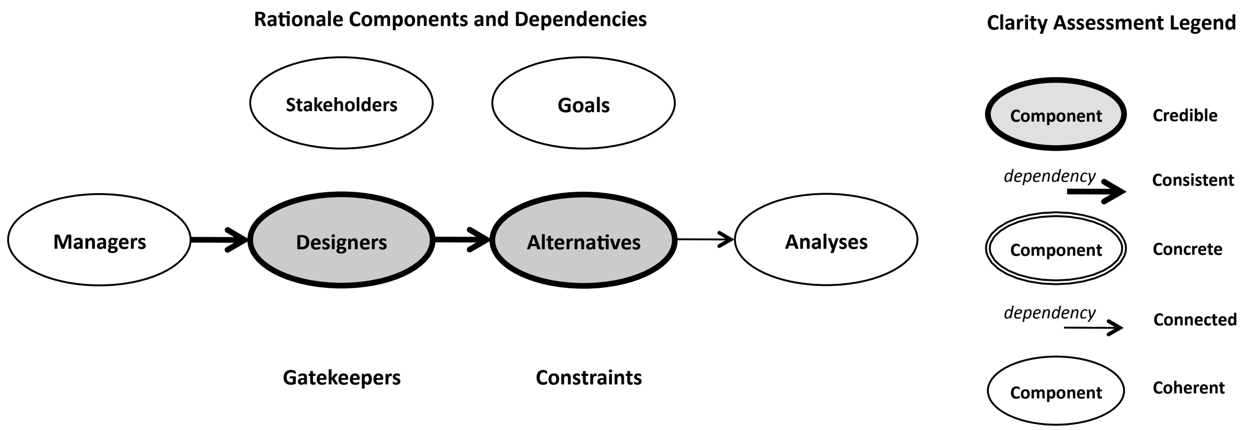

Figure 4: Assessment of Rationale Clarity in a Contemporary Project (Haymaker et al, 2010).

Implications for Practice

Perhaps developing a perfectly clear design rationale is neither possible nor desirable (Fischer at al. 1991). However, RCF identifies some serious gaps in rationale clarity in current practice. Projects typically adopt a wide range of methods to clarify different components to varying degrees. The RCF system of measurements could facilitate theory-based analyses, such as for the assertion that to achieve clarity in analysis, projects ought to spend their limited resources in a balanced fashion, advancing each of the components to an equally high level of clarity. A decision-based design rationale should provide efficiency in the use of decision resources, judged by Howard (2007) as "balance of basis," and similarly, we define the design decision rationale's strength equals the strength of its weakest link. For example, an analysis cannot be credible if the set of objectives are not credible, or if any of the elements are inconsistent.

Deeply understanding the state of rationale development can be difficult because each project's wide array of assertions incorporates myriad ambiguities. However, formal definitions of rationale components and clarity can enable automated construction and management of DDR that can keep pace with and support fast-paced projects. Clear DDR will also enable comparing individual project maps with maps of organizational theory and strategy to facilitate awareness across projects and the industry. Navigating contemporary turbulence in AEC information may require this increased clarity about the clarity of project rationale.

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