# Measuring and Improving Rationale Clarity in a University Office Building Design Process

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**Abstract:** This paper measures and improves the clarity of design rationale on an architecture, engineering, and construction (AEC) project and observes the effects. The rationale clarity framework (RCF) defines decisions in terms of components of rationale—managers, stakeholders, designers, gatekeepers, objectives (constraints and goals), alternatives, and analyses (impacts and assessment of stakeholder value). RCF defines relations and conditions of clarity for each component—coherent, concrete, connected, consistent, credible, certain, and correct. Using RCF, the rationale clarity of decisions was observed and documented on an industry case project. A decision-assistance methodology that seeks to clarify rationale, called MACDADI, was then implemented and costs and benefits from each team member's perspective were observed. Future work is identified that can lower costs and increase benefits of clarifying rationale. **DOI: 10.1061/(ASCE)AE.1943-5568.0000041.** 

**CE Database subject headings:** Building design; Decision making; Commercial buildings.

**Author keywords:** Design; Engineering; Rationale; Decisions; Collaboration; Clarity; Ambiguity; Management; Organizations.

## Introduction

This paper presents findings from an ethnographic and action research study on a $300 million university building design project. The study applies organizational, management, design, decision, information technology, and other views of rationale (Moran and Carroll 1996) to measure and understand the effects of rationale clarity (RC) on projects. RC refers to the level of broadly available and understandable reasoning supporting a decision. The rationale clarity framework (RCF) (Chachere and Haymaker 2011) is a method for measuring RC in different components of a decision according to several conditions of clarity. Project managers, designers, and stakeholders were first observed conducting design. Using RCF, the achieved clarity of rationale in each component in the design process was measured. A decision-support system, known as multiattribute, collaborative design, assessment, and decision integration (MACDADI) (Haymaker and Chachere, 2006) was then implemented. MACDADI is a method of structured collaboration with social and technical elements intended to build consensus on AEC decisions by improving transparency, precision, and comprehensiveness of rationale. The MACDADI implementation was found to produce measurably clearer rationale than the observed practice.

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Clarifying rationale involves complex social and technical interactions. Human organizations may at times desire ambiguity (March and Olsen 1985; Perrow 1967). Efforts to clarify rationale on an architecture, engineering, and construction (AEC) design project can be met with acceptance and resistance and can incur benefits and cost. Technical and organizational challenges encountered while developing and measuring RC in the project are detailed in this paper, and future work for increasing benefits and decreasing costs of clarifying rationale is discussed.

### *Motivation*

Integrating information and processes on AEC projects is technically and socially complex. Project teams—consisting of planners, architects, engineers, contractors, regulators, owners, operators, and other stakeholders—have a limited ability to make decisions rationally (Simon 1977). AEC project teams have typically relied on prescriptive and precedent-based design processes that explicitly consider a very small subset of the design space (Watson and Perera 1997; Gane and Haymaker 2010; Clevenger and Haymaker 2010). Several recent developments have significantly complicated design decisions. Expanding and urbanizing populations require increasingly complex buildings, which affect more stakeholders. Stakeholders' views of the built environment also have grown more complex, dynamic, and uncertain. Terrorism and global warming have made security, environmental stewardship, and building durability higher priorities. New building technologies enable designers to propose solutions that were unavailable a few decades ago, and it has become possible to parametrically search through spaces of designs and receive nearly instantaneous feedback on some performance objectives. Understanding and designing for these conditions is critical to AEC project success. Project teams can use new technologies to transition from precedence-based to performance-based processes in which rationale is clearly documented and explicitly considered. However, this transformation requires better methods to develop and communicate design rationale. It also requires better frameworks for measuring the clarity of that rationale to enable comparison and improvement.

Finally, it requires teams to accept the need for and adopt fundamentally different processes that clarify and leverage rationale.

### Rationale Clarity Framework

Rationale clarity framework (RCF) was introduced to address the need to measure how clearly rationale is communicated (Chachere and Haymaker 2011). Fig. 1 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 alternatives to be analyzed, and determines which gatekeepers (e.g., fire marshal 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. RFC designates only direct, required dependencies between components (Haymaker 2006). For example, designers may anticipate goals and constraints when selecting alternatives, but they need not explicitly reference these objectives until performing analyses. Therefore, the figure connects (using an arrow) goals to analyses, but it does not connect goals to alternatives.

In addition to components, RCF defines seven conditions of clarity that apply to each assertion that makes up the design rationale. Of the seven conditions, the rationale observed never explicitly described certainties (limited degrees of belief), and the correctness of assertions (their observed factuality) could not be determined by either project participants or researchers. This paper therefore explicitly assesses only five of the RCF conditions for clarity:

- Coherent (assertion is grammatically complete);
- Concrete (assertion is objectively measurable);
- Connected (assertions use common language and delivery);
- Consistent (assertions are free of logical contradictions); and
- Credible (information source is legitimate—has knowledge and lacks bias).

As with the components, conditions of clarity in RCF are also interdependent. For example, RCF views any assertion that is either inconsistent or vague (not concrete) as unable to impart meaning and therefore not credible, regardless of the assertion's source. RCF defines the clarity of each component to equal the clarity of its weakest assertion.

### Scope of the Research

Researchers employed a combined ethnographic and action research method (Hartmann et al. 2009) to address the three questions addressed in the following sections.

#### How Clearly do AEC Project Teams Communicate Design Rationale Today?

The following section describes observations of a multidisciplinary team, including two project managers, seven stakeholders, an architect, a structural engineer, a mechanical engineer, a researcher embedded with the engineering firm, and a researcher serving on two committees related to the project. The research team iteratively observed and built RCF models that describe and measure the clarity of the project team's documented rationale.

#### How Can Project Teams Communicate and Manage Design Rationale More Clearly?

After that, the subsequent section describes the use of a novel decision-assistance methodology (termed MACDADI) (Haymaker and Chachere 2006) to guide a process for collaboratively constructing design information. Through action research cycles, decision models were developed and shared with the project team. Stakeholders formally defined and assessed goals and preferences, and designers worked to explicitly document the analysis of alternatives. This information was iteratively visualized and improved with the project team, and the clarity of the decision rationale was assessed using RCF.

#### What Are the Costs and Benefits of Clarifying Rationale?

A final section describes the observations of the costs and benefits of clarifying rationale. It is concluded that although the act of clarifying rationale does have the potential to positively impact the process and product, better tools for and justification of the benefits of clarifying rationale are needed before industry is willing to incur the costs.

## Assessing Clarity of Design Rationale on an AEC Project

This section describes observations on a $300 million business school campus design project at a large American university. The discussions detail mechanical (heating ventilating and air

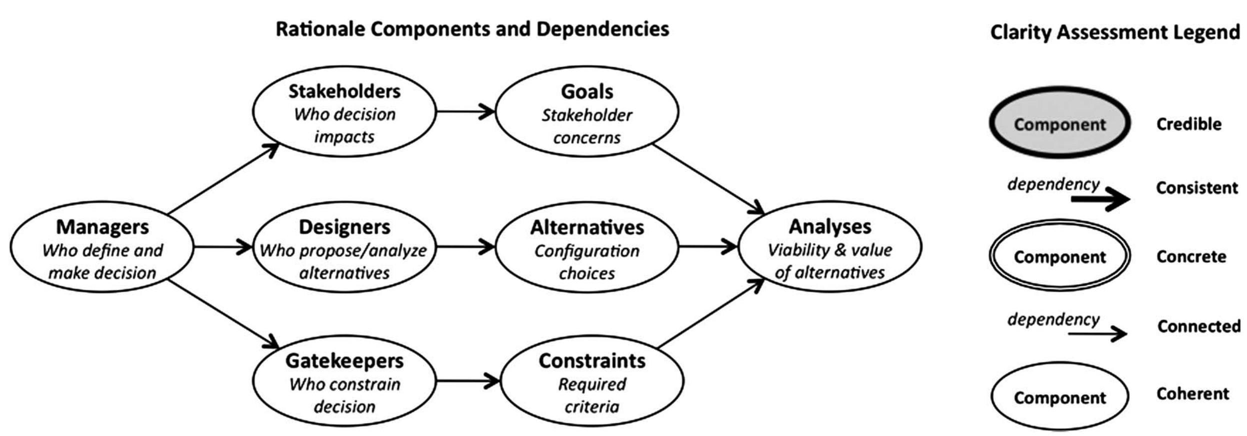


**Fig. 1.** RCF describes AEC decisions in terms of eight components: managers, stakeholders, designers, gatekeepers, goals, alternatives, constraints, and analyses; the definition of each component (except managers) is directly dependent on at least the definition of one other component as shown by the connections; RCF measures the clarity of each component of rationale with respect to seven conditions, five are shown: coherent, concrete, connected, consistent, and credible

conditioning) and structural design decisions regarding only one of the campus' many buildings, the faculty office building. The first subsection explains the typical project delivery processes that owner and design consultants applied on this project. The next subsection describes observations of structural and mechanical systems' design decision-making processes and identifies the conditions of clarity each rationale component achieved.

### General AEC Decision Processes

The AEC industry is experiencing rapid growth of new ways to document different aspects of project rationale. On AEC projects today, organizational charts are common, but formal organizational models that link individual project members to specific design/construction roles, processes, and product models are not routinely used. One framework currently used to support making and managing decisions with regard to sustainable building design goals, Leadership in Energy and Environmental Design (LEED) (U.S. Green Building Council 2008), is gaining widespread use and was implemented on the observed project. LEED defines a set of "credits" to measure the project's effects on site, water, energy, atmosphere, material, indoor environmental quality, and innovation. Early in the design process, teams often assess their project with respect to these credits, and then develop strategies to achieve a threshold number of credits for a desired certification level. LEED is broadly acclaimed as a first step toward environmentally responsible design, but it is criticized for failing to address important differences between projects' priorities.

AEC industry and government bodies are also developing a wide collection of performance targets and criteria by which to design and assess sustainable buildings. Still, the industry rarely quantifies the relative importance of goals, rather tending to generate vaguer goal statements, such as those illustrated by Fig. 2, which was produced by the university to represent the trade-offs that apply to this and all its other campus projects.

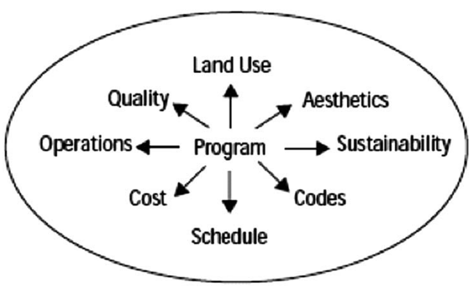


**Fig. 2.** Diagram by a university owner identifying the trade-offs required for the design of its buildings; the relative importance of goals is rarely quantified in AEC projects today (reprinted with permission from Stanford University)

To improve the ability of designers to clearly document and analyze their design alternatives, building information models and model-based analyses are rapidly being implemented in industry (Eastman et al. 2008). Contracts (Lichtig 2005) and design processes (Chachere et al. 2004) are also evolving to encourage more collaborative decision making. However, these improvements for the organization of project teams and their objectives, alternatives, and analyses have not yet been synthesized into a framework that assures a decision rationale is broadly communicated during design processes.

### Owner's General Decision Process

A senior project manager at the university describes their process as relatively unique in the way it focuses on "collaborative and shared risk environment among designers and contractors, and extensive stakeholder involvement…That said, we still deliver the fundamentals of project management—scope, schedule, budget. The basic project management of what we do is the easiest part—defining just what [the university] wants is what is so dynamic."

The university strives to deliver its projects according to the project delivery process (PDP) (Stanford Univ. 2001). The PDP developed by the university describes "the planning, design and construction processes, which are segregated into nine distinct process phases. Each phase requires specific tasks to be performed and deliverables (such as a budget) to be produced prior to obtaining the necessary approvals to move forward. These tasks, deliverables, and approvals combine to create an organized set of process controls." Fig. 3, the first figure to appear in the PDP, is a graphic representation of this process called the "heartbeat."

For example, the heartbeat identifies the schematic design phase, and the PDP further describes tasks such as "identify the project team members, hold structural peer review meeting, determine the project schedule." Subsequent phases, such as design development and construction documentation, involve improving the design decisions made in these early stages. The emphasis in the figure on budget control is noteworthy for its lack of explicit social or environmental objectives. Although several documents other than the PDP, such as guidelines for sustainable buildings, life cost analysis, and seismic engineering (Stanford Univ. 2002, 2003, 2005) guide this process further, the university lacks a comprehensive framework to assure a decision rationale is broadly integrated and communicated during design processes. It is the authors' experience that the owner methods reflect the industry's best practices.

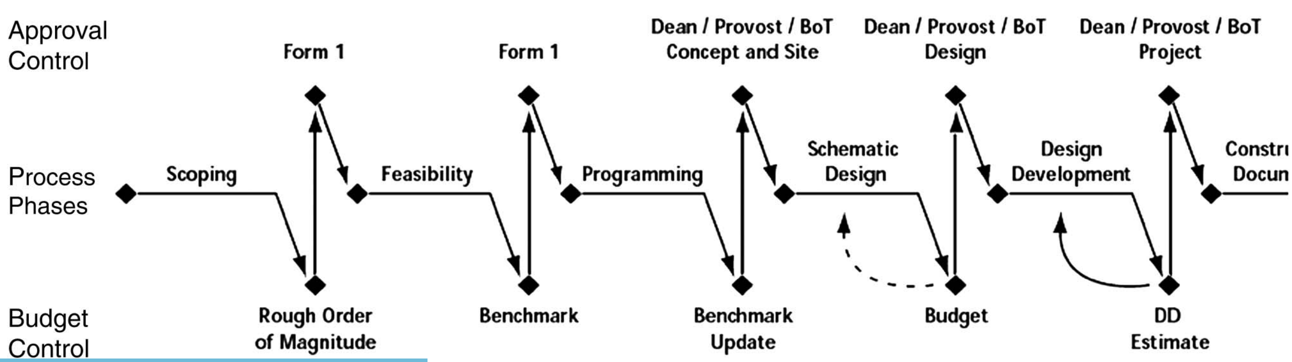


**Fig. 3.** "Heartbeat"—a high-level process map that describes the project delivery process (reprinted with permission from Stanford University)

### *Consultants' General Decision Process*

In a presentation to an engineering class at the university, the architect of the case project explained that her team considers many alternatives, but it documents relatively few of them. The architect characterized their process as generally choosing alternatives that have precedent, based on proven design principles, by creatively "flailing away to find order in chaos" (Vresilovic and Grauman 2007).

The engineering firm on this project provided an integrated set of services, including mechanical and structural. The firm experimented with several ways to formalize and track its decision rationale. For example, they sometimes use SPeAR (McGregor and Roberts 2003), which helps teams state project goals and track the current design with respect to them. Based on contractual relationships, the engineering firm modified its design process and documentation methods to the needs of the client and architect. In this case, formal decision methods were briefly considered by the project team but not pursued because of the perceived cost involved in implementing them.

The following sections describe how these organizations documented their rationale for two of the case project's decisions: the selection of structural and mechanical systems. The researchers' observations began after the programming phases and lasted through the design development phase. RCF assessments of the managers, stakeholders, gatekeepers, and designers had the same levels of clarity for both the structural and mechanical decisions, so these assessments are not discussed separately. In some cases, the level of clarity in the structural and mechanical goals, alternatives, constraints, and analysis differed; therefore, these assessments cases are described separately.

### *Structural Decision Process on Case Project*

The choice of structural system significantly impacts building cost, schedule, environmental footprint, integration with other building systems, and future building flexibility. Fig. 4 shows an abridged version of a table that the design team presented to the owner to build consensus for choosing a steel structural system. Though a rationale exists for the structural system decision, the consultants did not present the entire rationale to the owner. The table alone does not provide a clear rationale to support decision: it is unclear which stakeholders, designers, and gatekeepers should be considered in making the decision; the table identifies numerous goals without indicating their relative importance; and the certainty attached to individual analyses is not communicated. Because of these knowledge gaps, the document is open to multiple and contradictory interpretations. Additional reasons supported some decisions, but these were not broadly available to the project stakeholders.

After reviewing the table, the managers and designers came to a consensus on selecting the steel structural system. Reasons cited verbally included compatibility with program, irregular geometry of the faculty office building, seismic performance, more flexibility for future programming changes, and cost.

### *Mechanical Decision Process on Case Project*

Strategies of heating, ventilation, and air-conditioning systems significantly affect typical objectives including thermal comfort, life-cycle costs, schedule, environmental footprint, and indoor air quality. Fig. 5 shows a decision-making table the designers assembled for heating/cooling in the faculty building. The columns of the table represent different heating/cooling schemes. According to the lead designer, "The matrix was used to make the argument that the 'one size fits all' approach used in past projects is not adequate for a LEED Platinum intention. It helped the designers understand what the owner representatives feel is most important and help the owner understand that all systems have pros/cons and that in general the team and building needed to ensure that overhead VAV [variable air volume] (which scored lowest) could not be applied throughout the design as is historically typical."

The table shows the relative performance of each system with respect to the various goals; some goals are preferred more than others, as data in the importance column indicates. The table demonstrates rigor in decision making not often observed in traditional practice. By looking simply at this table, however, one should assume that natural ventilation would be the best and, therefore, the only system used. The table consolidates a great deal of information, but to the outside observer the metrics are unclear, and it is uncertain whether objectives are based on stakeholder consultation. The table is disconnected from other documents and conversations that considered potential interactive effects of systems working in combination, or particular stakeholders, conditions, or regions in which certain systems are better than others, undermining the table's potential to support a credible design decision rationale.

The lead designer states that clear rationale is not the purpose. "In a creative design process, not all decisions need to be explained retrospectively, rather design options must be presented, discussed, and recorded in a cost effective form that moves the project forward successfully…A more nuanced and sophisticated approach that applies systems to their most appropriate location based on analysis for cost and performance was then used." However, the rationale generated during this phase was not as clearly shared with the researchers as in Fig. 5. Fig. 6 shows one (the chosen) layout alternative with different heating/cooling schemes in different parts of the floor plan.

### *General Assessment of Rationale Clarity on Case Project*

Fig. 7 illustrates the RCF assessment for the structural and mechanical system decisions. The following sections explain the reasoning behind each assessment.

**Manager Clarity Level: Coherent**
Management is the team of decision makers who define and monitor the methods of developing rationale and of commitment to the final decision. The campus and university management created a list of the owner representatives and provided that list to the project team. The list defined roles for each person, but it did not explicitly relate each person to the scope of decisions for which he or she held responsibility. The list assigns people to a coarse product breakdown structure, so it was relatively clear which owner representatives were working on which parts of the project. However, the list did not specify managers' degrees of authority. For instance, a representative working on the parking garage might have final authority, limited authority, or no authority to make garage design decisions. It was concluded that the rationale's management component is coherent but vague (not concrete).

**Stakeholder Clarity Level: Coherent**
Stakeholders are defined as individuals or entities selected by managers as the ones whose goals matter when making decisions about the building. The university distributes a diagram that specifies a communication link between the designers, occupants, and the facility operators. Although this diagram was constructed for the overall project and was not specialized to the specific decision, it was relatively complete in terms of who was relevant to the design decision. However, while coherent, the specific user groups were neither defined concretely nor linked to specific goals or decisions.

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

| Primary Criteria | Subcriteria | Steel Comments | Steel Score | Concrete Comments | Concrete Score |
|---|---|---|---|---|---|
| Minimize First Cost | Structure | + Garage will be less expensive<br>+ Superstructure less cost but Turner should confirm | ? | - Probably not enough regularity to make concrete inexpensive? | ? |
| | Non-Structural Implications | | ? | | ? |
| | 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 |
| | | + 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<br>+ More flexibility | ? | + Thinner Profiles<br>- less flexibility, beams fly through large openings | ? |
| | At Exterior Office Bays | - Thicker Exterior Perimeter (18") | -1 | + Thinner Profiles (8") | 1 |
| Service Integration | | + easier to poke through steel beams and around braces<br>- but more beams in the way horizontally.<br>+ more flexibility for floor openings | ? | - Small services (conduits, sprinklers, etc.) can't pass through beams.<br>- Services through walls takes more coordination<br>+ Easier to pass services in exterior bays,<br>- Less flexibility at transfer girders.<br>- large floor openings difficult to accommodate | ? |
| Improve Seismic Performance | | + more ductile before damage occurs<br>+ easier to control damage to gravity system<br>+ lighter | 1 | - less ductile<br>- many large monolithic transfer girders<br>- heavier. | -1 |
| Use Materials Responsibly | | To Be Confirmed | ? | To Be Confirmed, info needed from Turner on fly ash and slag availability, material sources. | ? |
| Aesthetics & Finishes (ceiling, firing) | | - Columns and primary girders need fireproofing | 0 | + If exposed, minimal firing. | 0 |

| Additional Criteria To Be Considered | | | | | |
|---|---|---|---|---|---|
| Provide Acoustic Performance | | probably little difference | 0 | probably little difference, concrete may be better at roof | 0 |
| Provide Good Light | | Even steel is still thin at exterior. Ceiling space will not as broken up at interior and transfer girders | 0 | Even thinner at exterior, if ceiling is exposed, beams may break up light | 0 |
| Provide Good Indoor Air Quality | | no significant difference | 0 | no significant difference | 0 |
| Limit Vibration | | | 0 | perhaps less vibration at interior spaces | 0 |
| Durability | | Not as durable if finishes are used. Probably will require replacement throughout building life | 0 | Exposed concrete requires no refurbishment. | 0 |

**Fig. 4.** Decision matrix the engineering consultant used to communicate the design trade-offs to the owner; although supplemented with other information, the decision matrix alone does not provide rationale clarity (Arup, with permission)

### Designer Clarity Level: Credible

Designers are defined as individuals or entities selected by managers to propose and analyze alternatives. Fig. 8 presents an organizational model generated by the engineering consultant listing the responsibilities of all senior designers for the project. The model did not contain detail about the junior engineers; however, junior engineers generally switched roles frequently and relied on the legitimacy of senior members to present alternatives to owners or stakeholders. Consequently, the definition of the designers is both concrete and consistent. Management directly delegated to designers the authority to propose alternatives, so the designer component of rationale is credible.

### Gatekeeper Clarity Level: Incoherent

Gatekeepers can suspend a project or decision by enforcing constraints. For example, the fire marshal is a gatekeeper with the authority to prevent buildings going forward if they do not meet the constraints established by fire code. Managers occasionally choose a gatekeeper, but in most cases the gatekeeper is imposed upon the manager. It was observed that the project team did not clearly understand who all of the gatekeepers were. For example, some professors were assumed to be stakeholders only, but they in fact had sufficient political power to block project progress. The inner workings of the owner organization were not made explicit to the design team and sometimes appeared unknown to project

| | | | Overhead VAV (Baseline) | | Underfloor Air Distribution | | Chilled Beams | | Radiant Ceiling | | Radiant Floor | | Displacement Ventilation | | Natural Ventilation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Importance | Rating | Score | Rating | Score | Rating | Score | Rating | Score | Rating | Score | Rating | Score | Rating | Score |
| Energy & IEQ | Energy Efficiency | 4 | 2 | 8 | 4 | 16 | 4 | 16 | 5 | 20 | 5 | 20 | 4 | 16 | 6 | 24 |
| | Local Controllability | 3 | 2 | 6 | 5 | 15 | 4 | 12 | 4 | 12 | 2 | 6 | 3 | 9 | 5 | 15 |
| | Thermal Comfort | 3 | 2 | 6 | 4 | 12 | 3 | 9 | 4 | 12 | 4 | 12 | 3 | 9 | 3 | 9 |
| | Acoustics | 3 | 3 | 9 | 3 | 9 | 3 | 9 | 3 | 9 | 2 | 6 | 3 | 9 | 2 | 6 |
| | Indoor Air Quality | 2 | 2 | 4 | 4 | 8 | 3 | 6 | 3 | 6 | 2 | 4 | 4 | 8 | 3 | 6 |
| | *Category Sub-total* | | *44%* | *33* | *80%* | *60* | *69%* | *52* | *79%* | *59* | *64%* | *48* | *68%* | *51* | *80%* | *60* |
| Architecture | Ceiling Height | 2 | 3 | 6 | 3 | 6 | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 | 5 | 10 |
| | Clean Ceiling | 2 | 2 | 4 | 5 | 10 | 3 | 6 | 4 | 8 | 4 | 8 | 4 | 8 | 5 | 10 |
| | Façade Load Handling | 2 | 4 | 8 | 3 | 6 | 4 | 8 | 2 | 4 | 2 | 4 | 3 | 6 | 2 | 4 |
| | *Category Sub-total* | | *60%* | *18* | *73%* | *22* | *73%* | *22* | *67%* | *20* | *67%* | *20* | *73%* | *22* | *80%* | *24* |
| Space & Equipment | Simplicity & Robustness | 2 | 3 | 6 | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 | 4 | 8 |
| | Equip. Space | 4 | 2 | 8 | 3 | 12 | 4 | 16 | 4 | 16 | 4 | 16 | 3 | 12 | 5 | 20 |
| | Riser Space | 2 | 2 | 4 | 3 | 6 | 4 | 8 | 4 | 8 | 4 | 8 | 3 | 6 | 5 | 10 |
| | Ease of Maintenance | 3 | 2 | 6 | 2 | 6 | 3 | 9 | 4 | 12 | 4 | 12 | 2 | 6 | 4 | 12 |
| | Equipment Lifespan | 2 | 2 | 4 | 2 | 4 | 3 | 6 | 3 | 6 | 3 | 6 | 2 | 4 | 4 | 8 |
| | *Category Sub-total* | | *43%* | *28* | *55%* | *36* | *72%* | *47* | *77%* | *50* | *77%* | *50* | *55%* | *36* | *89%* | *58* |
| Cost & Flexibility | Market Familiarity | 2 | 5 | 10 | 4 | 8 | 2 | 4 | 2 | 4 | 3 | 6 | 3 | 6 | 3 | 6 |
| | Capacity Adaptability | 2 | 3 | 6 | 3 | 6 | 3 | 6 | 4 | 8 | 4 | 8 | 3 | 6 | 2 | 4 |
| | Short Term Flexibility (Churn) | 4 | 2 | 8 | 5 | 20 | 2 | 8 | 2 | 8 | 2 | 8 | 2 | 8 | 2 | 8 |
| | Long Term Flexibility (Adaptive Reuse) | 3 | 3 | 9 | 4 | 12 | 3 | 9 | 3 | 9 | 3 | 9 | 3 | 9 | 3 | 9 |
| | First Cost | 2 | 4 | 8 | 4 | 8 | 3 | 6 | 2 | 4 | 4 | 8 | 3 | 6 | 5 | 10 |
| | *Category Sub-total* | | *63%* | *41* | *83%* | *54* | *51%* | *33* | *51%* | *33* | *60%* | *39* | *54%* | *35* | *57%* | *37* |
| | *Total Score* | | | 120 | | 172 | | 154 | | 162 | | 157 | | 144 | | 179 |

**Fig. 5.** Decision table used to assist the decision for mechanical systems on the project; the table lists goals in the left columns and priorities (under the heading "Importance"); remaining columns identify seven alternatives, and indicate their analyses (under "Rating", which is the analysis without accounting for priorities, and "Score," which equals the goal's importance times the alternative's rating); although supplemented with other information, the decision matrix alone does not provide rationale clarity (Arup, with permission)

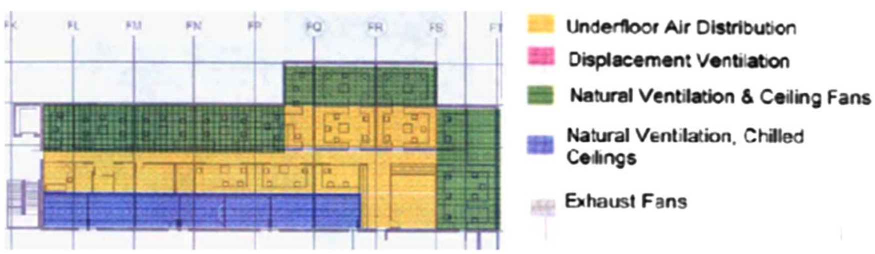


**Fig. 6.** Drawing by the designers illustrates the selected mechanical system alternative and indicates that management selected three different systems for the different spaces; this distinction between spaces is commonplace, but it is inconsistent with the supporting analysis in Fig. 5, which scores alternatives without regard to location (Arup, with permission)

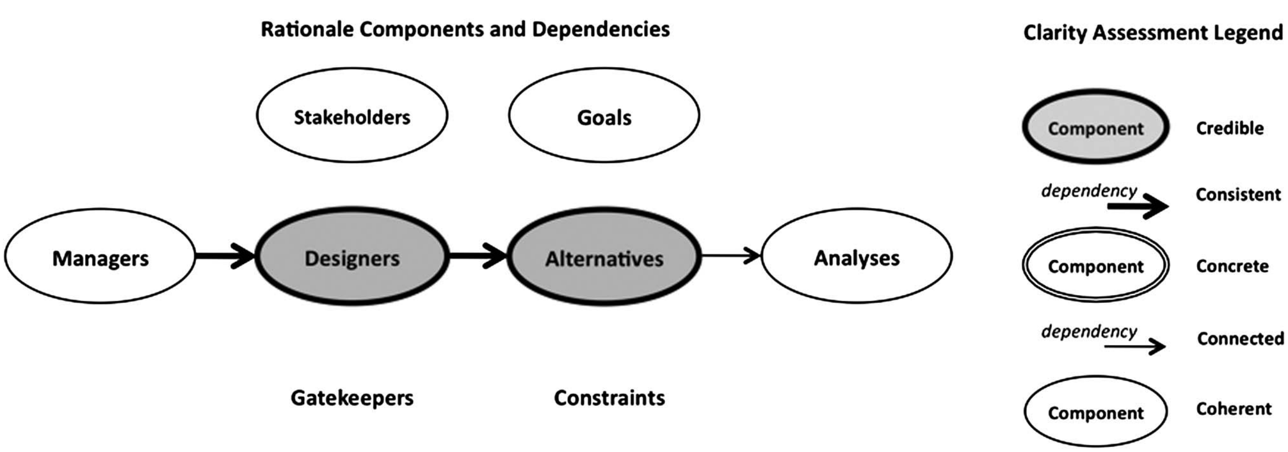


**Fig. 7.** Assessment of clarity of decision rationale constructed for structural and mechanical decisions on the case project; the diagram shows the gatekeepers and constraints were not communicated coherently by showing no circle on these components; managers, stakeholders, goals, and analyses, were coherently, but not concretely or credibly communicated; designers and alternatives were communicated credibly

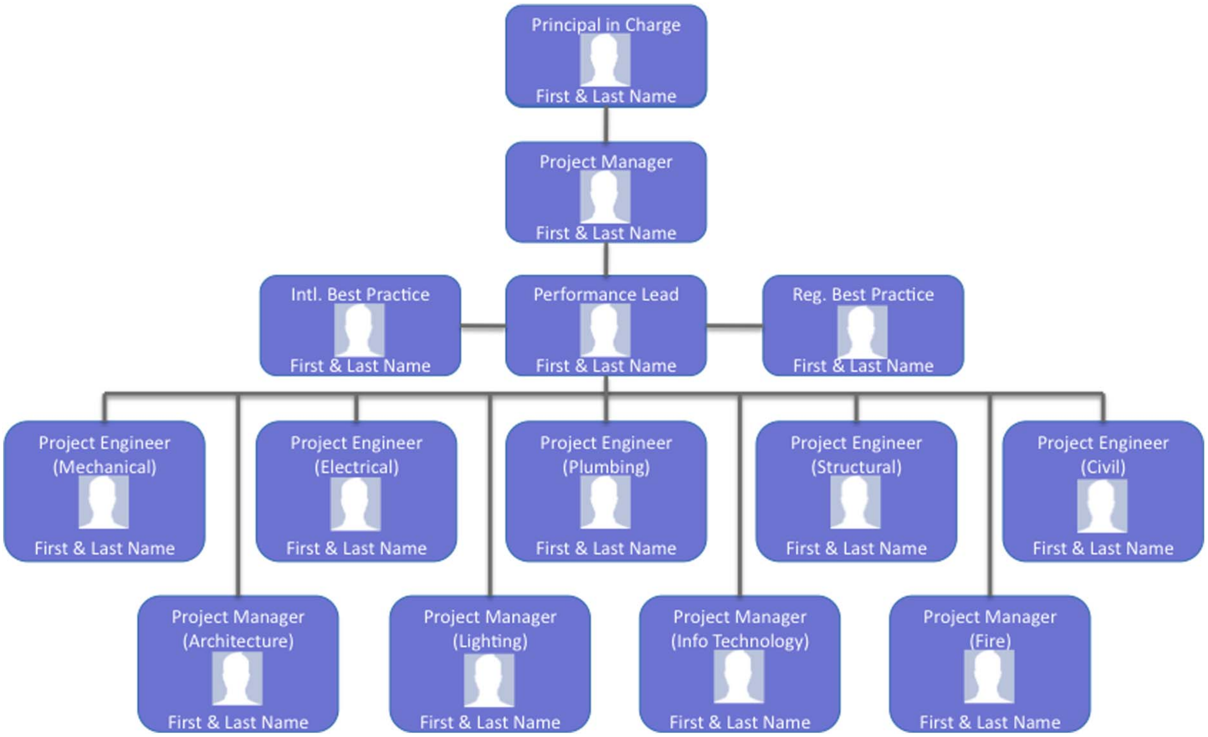


**Fig. 8.** Engineers' organization model, which was supplemented with a list of responsibilities (adapted from Arup)

management. Therefore, the Gatekeeper component was judged as incoherent and disconnected from the manager.

### Constraint Clarity Level: Incoherent

Constraints must be achieved for an alternative to be viable. For instance, choosing a wall material that violates a fire code constraint would result in the fire marshal gatekeeper prohibiting construction. Numerous documented constraints apply to the project. These include government-imposed constraints (e.g., the California Building Code) and owner constraints (e.g., budgets and life-cycle cost policy and programmatic requirements). The design team documented most of the constraints in project narratives. Others are published in building codes and university guidelines. These constraints were widely available to the project team and analyses often but did not always reference them. The team tried to make the constraints as concrete as possible; however, some constraints were vulnerable to the subjective interpretation of gatekeepers. In some cases, different gatekeepers defined inconsistent constraints. For example, at the outset there were constraints requiring a minimum number of parking spaces and requiring a maximum budget. Early analysis showed, however, that satisfying the parking constraints prevented achieving the budget constraints. Management deemed budget to be more important than parking, in this case, and replaced the parking constraints with a goal to maximize parking spaces. Explicitly connecting the constraints with the responsible gatekeepers was often impossible because the list of gatekeepers was ill-defined and incoherent. Therefore, this component was judged to be incoherent.

### Goal Clarity Level: Coherent

Goals define stakeholder desires for the project and their relative importance. The university's website explained the guiding principles of the project as "promote academic excellence," "sustain the environment," and "be economically responsible." However, the managers lacked formal methods to define and weigh goals. As a result, the designers asked the managers about their goals. In addition to documenting these goals, the designers provided supplemental goals when and if they felt goals had been omitted or insufficiently represented by the managers. Designers aggregated these goals to propose and analyze building alternatives. The supporting documentation for the structural decision identifies a list of primary criteria and additional criteria to be considered. The structural engineer used his judgment to quantitatively weigh the importance of each goal, but these goals were not connected to stakeholders. The mechanical engineers also defined supplemental goals for the mechanical systems. Similar to the structural system, the origins of the goals were not explicitly connected to stakeholders. The mechanical team communicated each goal to the project team, so they were coherent. They were provided numerical scores, but those scored were not defined in objectively observable terms, and so the metrics and therefore the goals are not concrete.

### Alternatives Clarity Level: Credible

Alternatives, such as a steel or wood structure, are designs that management will choose from. The team described many of the alternative structures concretely [by using three-dimensional (3D) models, such as Fig. 9], consistently (properly aligned with other design documents) and credibly (sourced by the design team).

The mechanical schemes (such as chilled beams and radiant flooring) are listed in the top row of Fig. 5 and mapped onto the floor plans as shown (for one wing) in Fig. 6. A few different plans with different mechanical configurations (alternatives) were presented to the project managers. The alternatives were coherent because the designers clearly indicated which mechanical system would be applied to which area for each alternative. The definitions of the systems themselves were communicated to the managers in a way that they could understand without prior knowledge of the various systems, insofar as the names for each system are standard in the industry and managers can easily find working definitions.

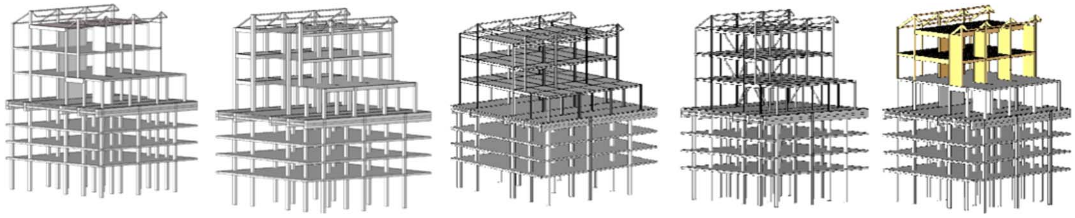

**Fig. 9.** Alternatives—designers provided 3D models of typical bays for five design alternatives (from left to right: concrete shear wall, concrete moment frame, steel braced frame, steel moment frame, and wood above concrete); the structural alternatives were very clear (Arup, with permission)

Therefore, the alternatives were judged to be concrete. The alternatives are identified as coming from the designers, so they are connected, consistent, and credible.

**Analyses Clarity Level: Coherent and Connected (Incoherent if Accounting for Constraints)**

Analyses identify each design alternative's valuation (impact on stakeholders' goals and preferences) and viability (satisfaction of gatekeepers' constraints). The clarity of analyses was different for different goals and for different alternatives. The structural system analysis included a cost estimate for the steel alternative but no analysis for the concrete alternative, and a detailed environmental impact analysis of the concrete versus steel alternatives was not performed. For example, because the designers agreed that the concrete alternative would be significantly more expensive than the steel system, the team decided to go ahead with the steel alternative because they felt a more precise cost analysis would not affect the decision. The cost analysis is coherent, but not concrete because cost is a goal, and the cost difference was not determined. Similarly, even though the client stated "material responsibility" as a goal, the design's performance regarding this goal was not documented. Those analyses that were performed were connected to the goals, alternatives, and constraints. Because a highly regarded engineering firm performed the analyses, they are credible. As a whole, the structural analysis is judged coherent (but not connected) based on its weakest assertions.

The mechanical system analysis shown in Fig. 5 used scores to assess the performance of each scheme in a coherent manner. However, each goal's score is not related to any metric, so the meaning of the score is not concrete. Although the scores come from the design team, RCF states that assertions that are not concrete cannot be credible because there is no goal meaning established. The analysis directly accounts for the goals, so it is connected. The analysis in Fig. 5 suggests only one mechanical system should be chosen because the table does not reflect that some systems are better in particular areas of the building. Thus, although the floor plan diagrams in Fig. 5 are connected to the table, they are not consistent. According to RCF, an inconsistent component cannot be judged wholly credible (despite the designers' broadly perceived legitimacy to conduct analysis).

## Clarifying Design Rationale Using MACDADI

This section describes the application of a decision-assistance model called MACDADI to the same case project and the results of applying the RCF method for measuring rationale clarity after the new method was applied.

### *MACDADI: Method for Clarifying Decision Rationale*

The MACDADI process was prototyped to help design teams make integrated collaborative decisions. MACDADI helps the team to define the stakeholders and designers. The stakeholders and designers determine, synthesize, and hierarchically organize the project goals and establish preferences with respect to these goals. The design team proposes alternatives that respond to these goals and preferences and then performs analyses of the design alternatives with respect to the goals. The project team visualizes the relationship between goals, preferences, alternatives, and analyses to assess value and make a decision. MACDADI relies on simple linear utility functions for the assessment of preference and for the calculation of value. Fig. 10 illustrates the MACDADI process constructed for the structural system decision. The researchers performed a similar process for the mechanical system. The following sections describe the information constructed, and the RCF assessments of clarity, which Fig. 11 summarizes.

### *Assessment of Decision Rationale Clarity with MACDADI*

**Manager Clarity Level: Credible**

MACDADI explicitly defines the decision process and organizations, including a mechanism for assigning a manager to a specific decision. Based on these observations, the rationale's management component was judged to be credible.

**Stakeholder Clarity Level: Credible**

Management established consensus on a set of stakeholders associated with six groups: staff, businesses, alumni, university community, students, and faculty. The stakeholder model was concrete because it clearly identified the individuals and was credible because it clearly identified and linked to role-specific credentials (membership in a stakeholder group or position in a design firm). The information was judged connected and consistent because the managers chose the stakeholders they wanted to consider.

**Designers Clarity Level: Credible**

The model of designers was not improved upon, so the clarity of this component does not change from its previous presentation.

**Gatekeeper Clarity Level: Incoherent**

A new model of the gatekeepers was not built, so the clarity of this component does not change from its previous presentation.

**Constraint Clarity Level: Incoherent**

A new model of the constraints was not built, consequently the clarity of this component does not change from its previous presentation.

**Goal Clarity Level: Credible**

A series of brainstorming sessions were held with stakeholders, such as staff, faculty, and students, to assess and document their goals. These goals were then synthesized into the tree in Fig. 12 to illustrate their dependencies. A description was developed for each goal and a metric and process for its evaluation. For example, Fig. 13 shows a description of the "use materials responsibly" goal and a quantitative method of measuring an alternative with respect to this goal.

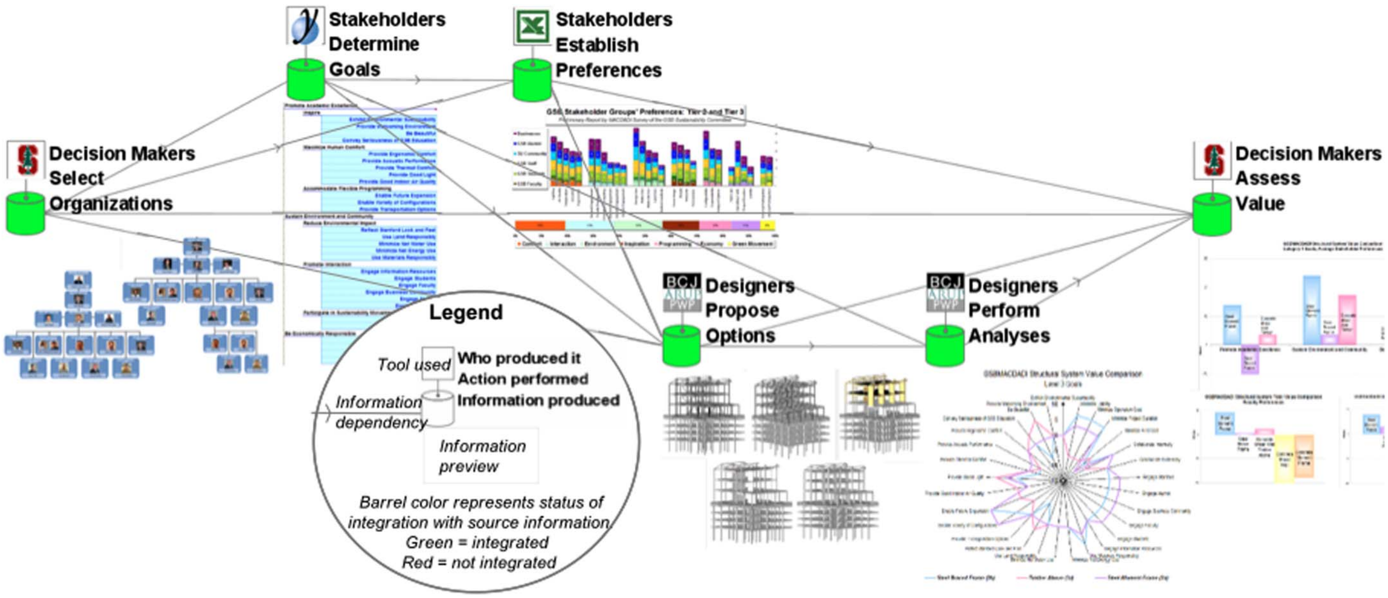


**Fig. 10.** MACDADI overview—a process diagram illustrating how decision makers, designers, and stakeholders interact through models of the organizations, objectives (goals and preferences), alternatives, analyses, and value to assist in a systematic and transparent decision-making process

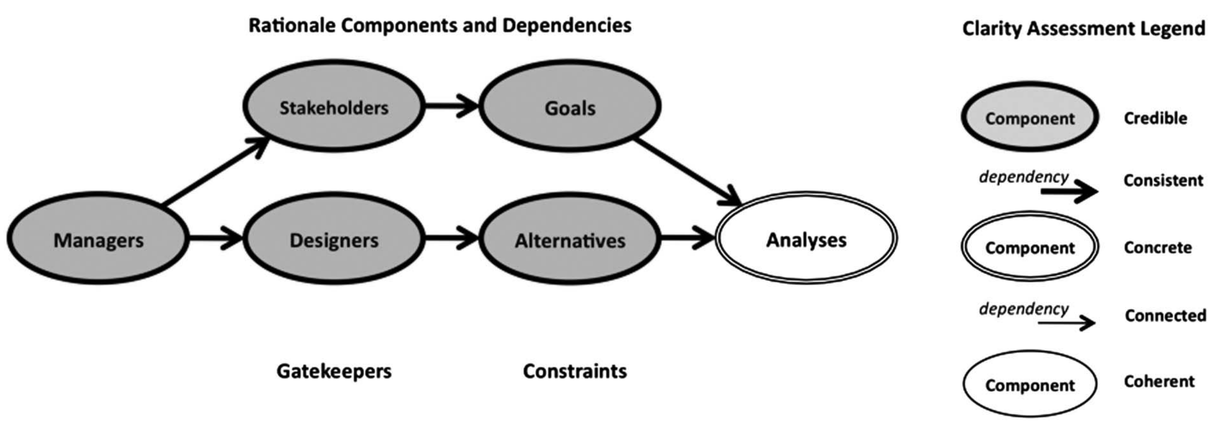


**Fig. 11.** Assessment of the rationale clarity of a MACDADI-enabled process; the diagram shows clarity for all components except gatekeepers and constraints; in this implementation of MACDADI, gatekeepers and constraints were not coherently communicated so their components are not circled; analyses are therefore not assessed as credible because they lacked analyses for constraints; analyses were assessed as concrete for the goals that were defined and analyzed; by comparing this assessment to Fig. 7, it was concluded that the MACDADI process improves rationale clarity relative to current practice

Preferences define how different levels of goal achievement affect each stakeholder. The stakeholders were given a survey that allowed them to distribute 100 preference points over the "leaf" goals of the tree in Fig. 12. Fig. 14 shows the aggregated preferences of these stakeholders. The product of goals and preferences, as well as any assessment of the relative importance of the various stakeholders, equates to the goals in RCF. Consequently, goals are coherent, concrete, and credible.

Establishing clear goals is particularly challenging. Considering stakeholders to be credible about their own goals was controversial within the project. For example, the researchers observed that stakeholders' preferences gradually changed, and researchers were not able to adjust the preferences to reflect the shifting political power of the stakeholders. For example, the preferences suggest that energy is very important, but when choosing the structural system, project managers placed almost all of their political capital on reducing costs first, suggesting that the objectives actually applied were different than the goals developed by the stakeholders—or at least that the importance of various stakeholders was different than those professed by the managers.

**Alternatives Clarity Level: Credible**

For the structural system, the application of MACDADI did not change the alternatives generated, so the clarity is the same. For the mechanical system, the application of MACDADI highlighted and addressed the need to score heating/cooling schemes with respect to the floor plans; therefore, the decision assistance model enhanced the alternatives' consistency.

**Analyses Clarity Level: Consistent (Incoherent if Accounting for Constraints)**

MACDADI states that each alternative should be measured with respect to each goal. Fig. 15 shows the analyses of structural systems. The designers analyzed each alternative and assigned a value between +3 and −3 for each goal, depending on the extent to which the alternative positively or negatively impacted each goal.

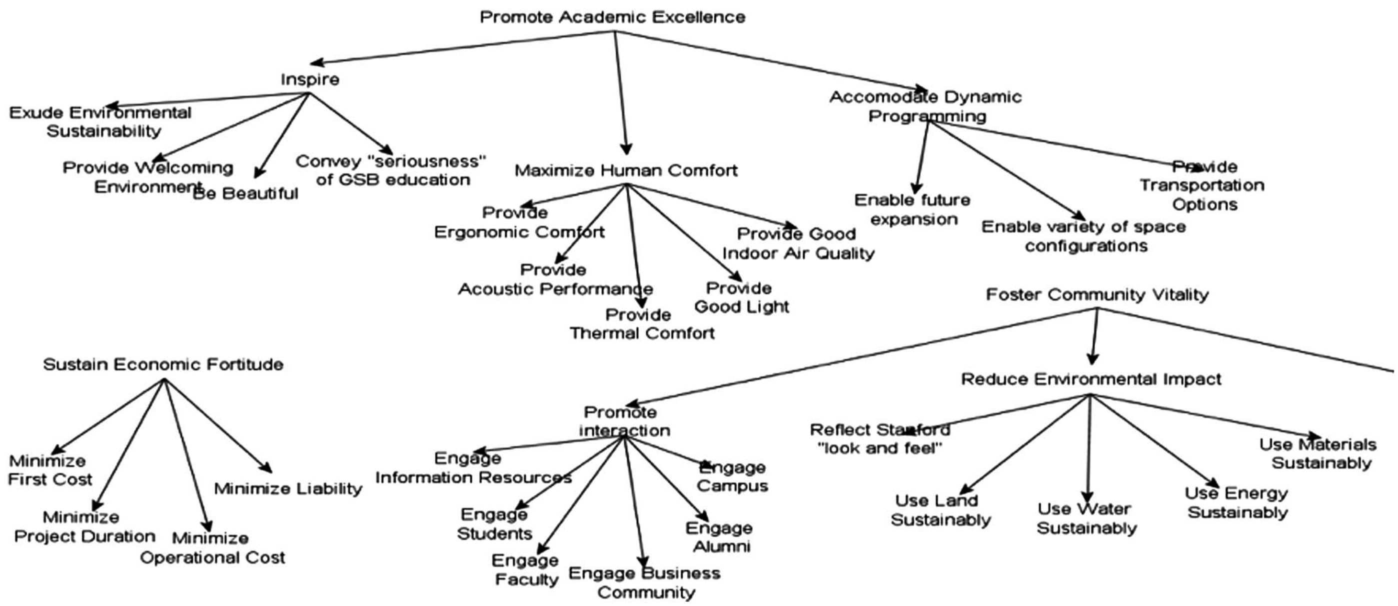


**Fig. 12.** Goals—stakeholder groups develop a goal tree through collaborative brainstorming; the aim is to arrive at a mutually embraced or at least understood set of goals; the case project included high-level goals, e.g., "foster community vitality," midlevel goals, e.g., "reduce environmental impact," and low-level goals, e.g., "use materials sustainably;" each goal links to a description, metric, and measurement process; for example, Fig. 13 shows the description and metric for the "use materials responsibly" goal

Use Materials Responsibly

Description

The campus should use materials with an understanding of their impacts on water, air, and resource availability. Campus should use recycled and reused materials, and use local materials both during its construction and operation phases. Campus should make an effort to avoid waste as much as possible, reduce the existing waste creation, divert the existing waste stream from landfill and ensure provisions to carefully handle hazardous waste. We use the model-based Life Cycle Assesmnent method from LCA Design to measure options for their environmental impact, and compare them to scores from a "baseline" structure.

Metric

| Score | Criteria |
| --- | --- |
| 3 | Beyond Best Practice: ecoProfile score is 50 % below baseline Structure |
| 2 | EcoProfile score is 25 % below baseline Structure |
| 1 | EcoProfile score is 10 % below baseline Structure |
| 0 | Good Practice: ecoProfile score is equivelant to Structure |
| -1 | EcoProfile score is 10 % above baseline Structure |
| -2 | EcoProfile score is 50 % above baseline Structure |
| -3 | Worst Case |

**Fig. 13.** Each goal included a description, a metric, and a process with which to measure a design alternative

Fig. 16(a) shows the analyses of three structural alternatives graphically displayed for comparison. Fig. 16(b) shows these goals aggregated to higher levels of detail to show that one alternative might perform the best in terms of economic goals, but when social and environmental goals are considered, another alternative may provide the most value. Fig. 16(c) shows that these graphs can all be weighted by stakeholder preferences to approximate value for particular stakeholder groups.

## Effects of Clarifying Rationale

This section describes the project team's and the authors' observations of the effect increased clarity had on the design process. First, the experiences of project managers, stakeholders, and designers are summarize (the study omitted gatekeepers). Next, the observed and theoretical affects on objectives, alternatives, and analyses are described. Finally, future work aimed at lowering costs and raising benefits is discussed.

### *Managers Lose Control*

Management verbally expressed support for implementing MACDADI as a side project, and their support helped make this research possible. Management declined, however, to provide the new method with funding or an explicit role in decision making. Management stated that "industry experience, university

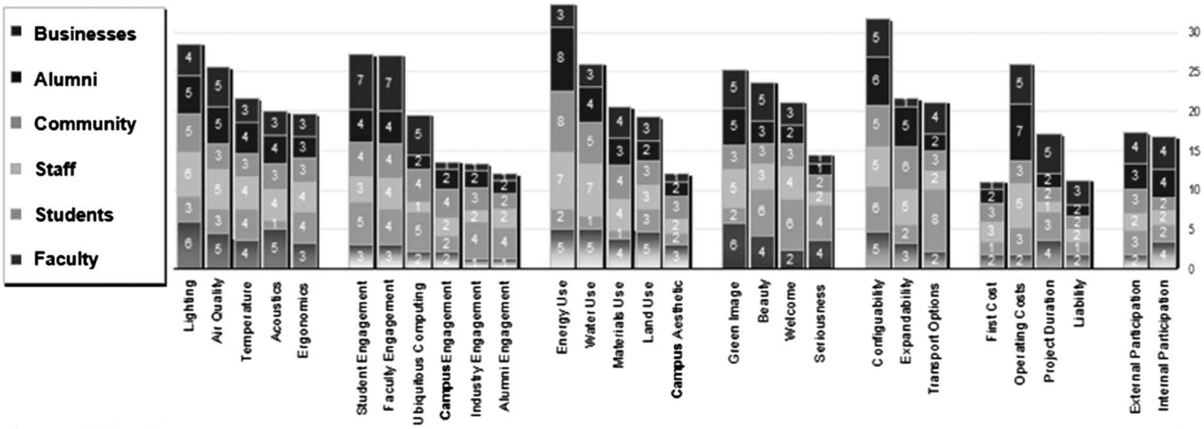


**Fig. 14.** Preferences—stakeholders were given a survey (not shown) that enabled them to weigh goals by distributing 100 points over the goals; this diagram shows the results of the survey, adding up the preferences of all stakeholders; the stakeholders claim energy use is approximately twice as important as maintaining the "Stanford aesthetic," but both are important; the diagram also shows that lighting is approximately twice as important to faculty as students

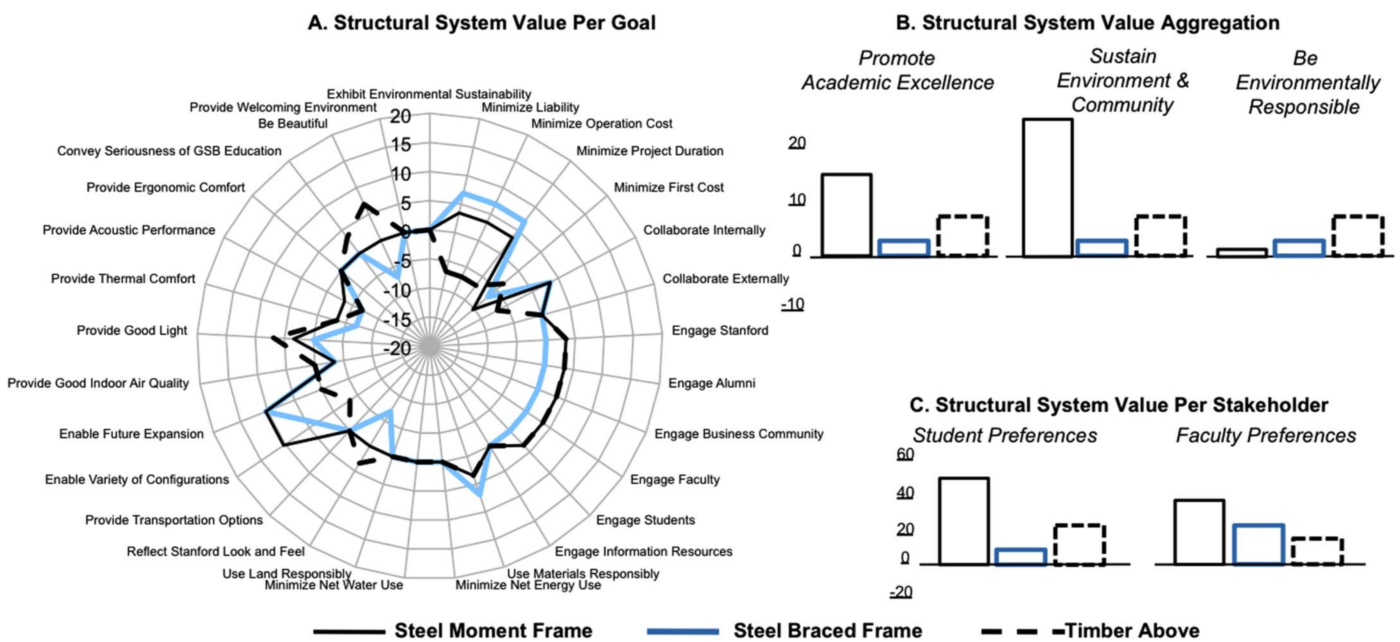


**Fig. 15.** Analyses—after generating the alternatives, the designers make quality assessments with respect to each design goal; they rate the performance based on a +3 to −3 scale: +3 = great and positive effect on the achievement of the Goal, and −3 = great and negative effect on the achievement of the goal; different designers are responsible for different assessments, which can be based on automated model-based analysis or qualitative feedback from stakeholders

experience, and construction expertise are really critical to realizing goals and should be weighted accordingly."

Some resistance to MACDADI resulted from the difficult and political nature of clarifying certain aspects of rationale, such as weighting stakeholder importance. One manager expressed concern over asking stakeholder opinions at all when the managers were not sure they would satisfy those opinions. Many said that they should not ask about objectives, and thereby open themselves up to criticism over contradicting them. Explicit representation of clear rationale disrupts traditional hierarchies. Managers can lose control. The team was concerned that the MACDADI process would compromise power and overburden and distort decision-making logic. One designer commented that they are "a technical consultancy, and the architects are not necessarily interested in the details of the analyses. They want to see the executive summary; the critical variables. MACDADI with its all-inclusive approach presents too much data and does not necessarily refine it."

Other resistance came from limitations or unfamiliarity with the MACDADI toolset. For example, a manager stated, "The model doesn't really account for knowledge base and professional experience—it assumes stakeholders are all equal in knowledge." In fact, RC does define a level called "credible" that requires the information to be from a knowledgeable source, and MACDADI managers can give specific stakeholders more weight in a decision. MACDADI tries to be precise about all the kinds of information involved in the decision, assigning it to a legitimate actor. MACDADI assumes stakeholder's are experts in objectives and designers are experts in alternatives and analyses. That designers may be more expert in stakeholder preferences than stakeholders themselves is an understandable proposition. It is possible to allow designers or managers to enter objectives and preferences. Successful clarification of rationale requires a sophisticated synthesis of tools and teams into a collaborative process that is hard to achieve. Finally, some resistence may have arisen because of the specific decisions selected for modeling. A manager stated, "The hardest part of the decision-making process is determining 'what do we want?' I can see the real need for a MACDADI-type system for the user group to provide this type of direction, much less so for the design elements such as structural, mechanical, etc."

In this case, the professional process adopted by management failed to adequately support the demanding project scope. Shortly after the intervention and observations concluded, management replaced the architectural firm for failing to adequately address their objectives. This outcome is consistent with the theory and evidence that recent industry-wide changes may have reduced the effectiveness of AEC's craft organizations (Stinchcombe 1959). Management's decision is also consistent with the institutional theory of "mimetic isomorphism," a form of organizational inertia motivating actors to mimic what others do (in this case, what other building owners and the industry at large do) rather than to risk too much novelty (DiMaggio and Powell 1991).

### Stakeholders Appreciate Clarity

A group of stakeholder representatives that management directed to establish sustainability goals chose to explore the MACDADI method based on positive references on a previous, well-documented application with similarly complex goals (Haymaker and Chachere 2006). The stakeholders initially expressed reservations over whether the method's technical and organizational details would support this particular application [see Keeney and von Winterfeldt (2007), Keeney and Raiffa 1976), and Edwards et al. (2007) for discussion of similar challenges]. For example, stakeholders expressed concern that an inability to quantify some goals, such as aesthetics, would hinder the method. Stakeholders were satisfied, however, with the explanation that analyses using imperfect measures can be clearer than using no measures at all. In the example, MACDADI could use the architect's ranking of aesthetic appeal, which is credible, rather than the views of individual stakeholders, which are typically vague and not credible. Through iterative use and discussion of the method with researchers, the stakeholders developed confidence in the MACDADI application.

Stakeholder representatives required the MACDADI goal survey to be short and professional in quality to conserve stakeholder attention and bolster their own legitimacy as representatives. After reviewing the goals survey results, the stakeholder representatives generally expressed that MACDADI helped them to refine and communicate their goals. The stakeholder representatives presented management with results from the MACDADI goals survey (Fig. 12) along with a request to seek LEED Platinum—the U.S. Green Building Council's highest sustainability rating. The goals survey provides clear evidence of a broad goal among stakeholders to focus on minimizing energy use rather than minimizing cost on this project. The research made several observations indicating people derive greater satisfaction from a process with greater clarity. One stakeholder remarked, "This is a great exercise—I really enjoyed it. I hope we can circulate [MACDADI] to a wider group—perhaps a subset of students, staff, alumni and faculty—that we think would give us good feedback."

### Designers Skeptical of Application

Designers expressed that MACDADI might make decision making more efficient by helping the team to focus on what was most important and to prevent them from revisiting old issues. One designer commented that a clear rationale is not required, only a clear definition of project goals; that the most valuable part of MACDADI is to "remind us what is important…MACDADI's role as a recorder and reminder of stakeholder goals, that can be returned to throughout the project…is a significant benefit." During observations of current practice in one meeting, the team spent a lot of time discussing durability of concrete versus steel; however, durability had not previously been discussed as an objective. Revisiting MACDADI's goals might have caused the team to reconsider spending time on the subject or to determine that a durability goal is important and should be added and analyzed. Several designer remarks from observing the MACDADI intervention were encouraging or instructive. For example, regarding the visualization of analyses presented for the structural systems shown in Fig. 16, the mechanical engineer stated, "The radar charts for different structural systems are great." Designers saw benefit in MACDADI's ability to record and communicate the rationale.

Designers generally were more outspoken regarding the new method's drawbacks than regarding its benefits, however. The designer commented that MACDADI "ought to be considered an information tool rather than a decision tool. It cannot define, but it can record the decision." Design teams expressed belief that their experiences were valid and felt that clarifying rationale more than traditionally done would incur more cost than benefit. Designers expressed the view that MACDADI goals were insufficient to assist in evaluating real trade-offs between design decisions. One designer commented, "The factors that impacted the parking lot decision were water table, cost, construction time, column spacing, and beam depth only." Designers expressed the belief that as experts in the field they were more aware of stakeholder goals than the stakeholders themselves. Designers appeared to have a limited belief that changes in objectives, building technologies, and collaboration methods cast doubt on the lessons of experience.

The view that designers are "stakeholder experts" is compelling, widely held, and limited. For instance, the designers' legitimacy to express goals based on skill relies in part on knowledge of other people, on other projects, at other times; however, the people, projects, technologies, and times are changing rapidly. Also, the designers' legitimacy to express goals is vulnerable to bias; designers entrusted with defining goals can more easily steer design decisions to favor their own self interest. Finally, designers themselves may benefit from increased clarity helping them distinguish between goal and technology. MACDADI encouraged the use of direct goals, which seek fundamental needs such as health and wealth (Keeney and von Winterfeldt 2007; Keeney and Raiffa 1976). Indirect goals, such as "column spacing," which might affect health (ergonomic comfort) or wealth (cost), are more amenable to design expert analysis, whereas the fundamental goals and their priorities are the domain of the stakeholder.

Combined with management's decision to replace the architect, these results suggest AEC is entering a period of turbulence in which current methods fail to meet contemporary needs. These observations can be explained by organizational inertia theories that indicate organizations tend to overlook the advantages of new methods (Pfeffer and Salancik 2003).

### Clear Objectives

MACDADI assisted the team to be as precise as they could be about all the rationale (qualitative and quantitative) involved in

| GSBMACDADI Structural System Value Assessment | Edited: 04.17.2007 | Promote Academic Excellence | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Goals | Inspire | | | | Maximize Human Comfort | | | | | Accommodate Dynamic Programming | | |
| | | Exhibit Environmental Sustainability | Provide Welcoming Environment | Be Beautiful | Convey Seriousness of GSB Education | Provide Ergonomic Comfort | Provide Acoustic Performance | Provide Thermal Comfort | Provide Good Light | Provide Good Indoor Air Quality | Enable Future Expansion | Enable Variety of Configurations | Provide Transportation Options |
| | Preference Weight | 4.24 | 3.47 | 3.58 | 2.26 | 3.27 | 3.48 | 3.71 | 4.97 | 4.31 | 4.179 | 5.36 | 3.111 |
| All Concrete | Concrete Shear Wall (1a) | 0 | 0 | -2 | 0 | 0 | 1 | 2 | -1 | -2 | -2 | -3 | 0 |
| | Concrete Moment Frame (1b) | 0 | 0 | -1 | 0 | 0 | 0 | 1 | -2 | 0 | -2 | -2 | 0 |
| All Steel | Steel Moment Frame (2a) | 0 | 0 | 0 | 0 | 0 | -1 | -1 | 1 | -1 | 3 | 3 | 0 |
| | Steel Braced Frame (2b) | 0 | 0 | -2 | 0 | 0 | -2 | -2 | 0 | -1 | 3 | 1 | 0 |
| Concrete Shear Wall First Floor | Timber Above (3a) | 0 | 0 | 2 | 1 | 0 | -2 | -1 | 2 | 0 | 0 | -1 | 0 |

| GSBMACDADI Structural System Value Assessment | Edited: 04.17.2007 | Sustain Environment and Community | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Goals | Reduce Environmental Impact | | | | | Promote Interaction | | | | | | Participate in Sustainability Movement | |
| | | Reflect Stanford Look and Feel | Use Land Responsibly | Minimize Net Water Use | Minimize Net Energy Use | Use Materials Responsibly | Engage Information Resources | Engage Students | Engage Faculty | Engage Business Community | Engage Alumni | Engage Stanford | Collaborate Externally | Collaborate Internally |
| | Preference Weight | 2.08 | 3.09 | 4.79 | 6.4 | 3.5 | 2.78 | 4.18 | 4.24 | 2.24 | 2.07 | 2.44 | 2.7808 | 2.6329 |
| All Concrete | Concrete Shear Wall (1a) | 0 | -1 | 0 | 0 | -1 | 0 | -3 | -3 | -3 | -3 | -3 | 0 | 1 |
| | Concrete Moment Frame (1b) | -1 | -1 | 0 | 0 | -2 | 0 | -2 | -2 | -2 | -2 | -2 | 0 | 1 |
| All Steel | Steel Moment Frame (2a) | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| | Steel Braced Frame (2b) | -2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Concrete Shear Wall First Floor | Timber Above (3a) | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | -2 |

| GSBMACDADI Structural System Value Assessment | Edited: 04.17.2007 | Be Economically Responsible | | | |
| --- | --- | --- | --- | --- | --- |
| | Goals | | | | |
| | | Minimize First Cost | Minimize Project Duration | Minimize Operation Cost | Minimize Liability |
| | Preference Weight | 2.01 | 2.34 | 4.74 | 1.73 |
| All Concrete | Concrete Shear Wall (1a) | 0 | -3 | -1 | -1 |
| | Concrete Moment Frame (1b) | -1 | -1 | -3 | -3 |
| All Steel | Steel Moment Frame (2a) | -3 | 1 | 1 | 1 |
| | Steel Braced Frame (2b) | -2 | 2 | 2 | 2 |
| Concrete Shear Wall First Floor | Timber Above (3a) | -1 | -2 | -2 | -2 |

**Fig. 16.** Visualizing analyses and value—analyses, weighted by the stakeholder preferences on goals, approximate the value of an alternative: (a) performance impacts of three structural alternatives with respect to all low-level goals; (b) value trade-offs of higher-level goals approximated by aggregating performance on lower-level goals; (c) different stakeholder goal preferences are reflected in value; although stakeholders agree on the first choice, MACDADI illustrates that the concrete and wood alternative provides the second-highest value to the faculty, whereas the steel braced frame provides the second-highest value to the students

the decision by assigning each component to a credible actor. The team expressed concern with how qualitative goals are addressed. One university decision maker said, "So much of design and what makes a 'successful' building is subjective—analytical measurement of subjective criteria seems tough." A designer stated, "Engineering and design is art, which implies that we have to be cognizant of how to deal with intangibles. MACDADI might have the tendency to oversimplify some qualitative measures." The designer felt that stressing the importance of clarity can overemphasize quantitative defined goals, whereas ambiguous goals such as "be beautiful" may attract less attention despite being highly valued. Regardless of how hard objectives are to define, or who should define them, the process of defining, communicating, and managing objectives affects the number and quality of those objectives and the process that follows from them.

### Connected Alternatives

No increase in the number of alternatives was observed. Engineers feared that the cost of clarifying rationale would reduce the number of alternatives generated. In some cases, the cost of explicitly documenting alternatives may lead to the exploration of fewer alternatives. Having fewer alternatives can benefit a decision maker by allowing greater satisfaction with decisions when time is limited (Iyengar and Lepper 2000). However, limiting the solution space leads to nonoptimal designs. However, this is countered by a trend to increase alternatives enabled by collaboratively documenting alternatives—leading to brainstorming or to computational generation of large numbers of alternatives through parametric exploration. However, in the MACDADI process, there were many more documented relationships among alternatives and their analyses and values, resulting in clearer rationale for the decision.

### Comprehensive Analyses

MACDADI encouraged designers to provide more analyses. For example, currently designers often conflate "no effect" with "no analysis." They would express that because some stakeholder-identified goals seemed irrelevant to the decisions at hand, analyzing them wasted time. MACDADI requires analyzing all alternatives with respect to all direct, project-wide goals [as motivated by Keeney and von Winterfeldt (2007 and Keeney and Raiffa 1976)]. Without a rationale distinguishing where effects do or do not occur, there is no means to identify novel but important analyses that designers have overlooked. For example, columns placed too near parking stalls can make it difficult for visitors to enter and exit their vehicles comfortably. Therefore, omitting the analysis of ergonomic comfort would disconnect the design results from stakeholder goals that seem relevant. The failure to properly distinguish between no effect and no analysis is consistent with the organizational inertia theory of blind spots (Pfeffer and Salancik 2003). This theory indicates actors accustomed to an existing process will tend to overlook the existence or implications of changing circumstances and the advantages of new process. MACDADI also encouraged designers to provide more clear analyses. When considering the mechanical system, project managers asked the designers for more rationale to support the mechanical decision. "They need stronger justification; they need a comfort analysis that is not just an ASHRAE [American Society of Heating, Refrigerating American Society of Heating, Refrigerating] range." MACDADI stated and connected the rationale consistently from stakeholder objectives through analysis results, giving the managers more information required to support a decision. Designers expressed concern that participants would mistake the precision MACDADI requires for certainty in areas in which actual knowledge was uncertain. Other designers felt preferences were imprecise, for example, overstating the importance of the "provide ergonomic comfort" goal. Methods that allow teams to define preferences and certainty information in project-specific ways are needed.

### Clear Decision Rationale

Regarding the steel versus concrete matrix not including a complete rationale, the designer replied, "It never should. The owner wants us to filter our decisions into a 1 h summary, but there is still a role for documenting every consideration for the design team's benefit." These remarks point out the need for, and difficulty of, managing the rationale's complexity. Designers questioned the benefit of clear rationale based on the view that clarifying rationale would not have changed their decisions. A designer observed, "The 'timber above' alternative has been eliminated quickly, primarily due to an architect's request." In the subsequent MACDADI analysis, other structural alternatives indeed outscored the wood alternative. Duplicating the architect's finding weakens MACDADI's justification as a parallel method because spending resources on clarifying rationale failed to improve the design. At the same time, the analysis strengthens MACDADI's validation and justification as an independent method because the new method's result matches a professional architect's intuition but with greater clarity. It was observed that captured rationale produced benefits and suggested potential additional benefits that could be enabled by more structure.

### Procedural Structure Decreases Cost, Increases Benefits

Prior to MACDADI, numerous assertions were disconnected. MACDADI analysis requires designers to assess each alternative regarding each stakeholder-identified goal. Gathering rationale from a distributed team of stakeholders and designers proved cumbersome. Designers, required to rationalize their decisions, produced the information requested as long as it matched organizational incentives and there were appropriate structures to minimize the cost of recording such rationale. Web-based tools that distribute responsibilities to specific team members promise to decrease the cost of capturing and clarifying rationale, and organizational incentives can encourage rationale clarity. For example, stakeholder preferences were visualized to identify potential conflicts and synergies between groups. Processes involving collaborative rationale clarification may enable new alternatives and decisions that diverged from designer intuition. Future work may leverage this structure to automatically suggest objectives, generate alternatives, and construct analyses through data mining of previous projects and design automation.

## Conclusions

This paper applies the RCF method for measuring rationale clarity on the structural and mechanical design decisions in a university campus design project. Using RCF, a current practice was observed developing rationale that was unclear in many areas, particularly in the gatekeeper, stakeholder, goal, and analysis components. The project team was introduced to a decision assistance model, called MACDADI, and applied MACDADI to the previously observed decisions. RCF enabled determination that the design process with MACDADI produced clearer rationale than current processes without MACDADI. Implementing MACDADI improved rationale clarity, particularly in stakeholder and goal components and in their consistency with the analysis of alternatives.

Most team members did not perceive that benefits outweighed costs of clarifying rationale. Team acceptance of MACDADI as a means of enforcing a fair process was juxtaposed with individual resistance where it required yielding power or excess work. Although the costs of clarifying rationale were perceived to outweigh the benefits in this case, it is important to understand how the gap between cost and benefit can be reduced and reversed. Improving theories such as RCF can give project teams more precise lenses with which to understand where to improve rationale clarity and the potential impact of doing so. Developing methods such as MACDADI and integrating them with other emerging tools like building information modeling (BIM) and model-based analyses can give the teams more effective ways to generate, organize, and communicate rationale more clearly. Training design teams to use these tools and theories to produce and interpret clear rationale more efficiently will help them break free from entrenched precedent-based design processes to more systematically search through design spaces. When these theoretical, technical, and organizational challenges can be overcome, a new, performance-based design paradigm based on clear and deliberate construction of rationale becomes possible.

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