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Coordinating goals, preferences, options, and analyses for the Stanford Living Laboratory feasibility study

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Abstract. This paper describes an initial application of Multi-Attribute Collective Decision Analysis for a Design Initiative (MACDADI) on the feasibility study of a mixed-use facility. First, observations of the difficulties the design team experienced communicating their goals, preferences, options, and analyses are presented. Next, the paper describes a formal intervention by the authors, integrating survey, interview, and analytic methods. The project team collected, synthesized, and hierarchically organized their goals; stakeholders' established their relative preferences with respect to these goals; the design team formally rated the design options with respect to the goals; the project team then visualized and assessed the goals, options, preferences, and analyses to assist in a transparent and formal decision making process. A discussion of some of the strengths and weaknesses of the MACDADI process is presented and opportunities for future improvement are identified.

Introduction

To achieve multidisciplinary designs, Architecture, Engineering, and Construction (AEC) professionals need to manage and communicate a great deal of information and processes. They need to define goals, propose options, analyze these options with respect to the goals, and make decisions [1]. This is a social process [2]; they need to coordinate these processes and information amongst a wide range of team members and stakeholders. AEC professionals have difficulty doing this today.

This paper describes observations of these processes on the feasibility study for the Living Laboratory project: a new student dormitory and research facility being planned for the Stanford University campus. It describes the ways in which goals were defined, options were proposed and analyzed, and decisions were made. It also describes some of the difficulty the team had communicating and coordinating these processes and information.

The paper then describes a process called MACDADI: a Multi-Attribute Collective Decision Analysis for the Design Initiative. The authors designed and implemented MACDADI with the help of the design team towards the end of the feasibility stage. The authors and project team collected, synthesized and hierarchically organized the project goals; the stakeholders established their relative preference with respect to these goals; the authors collected and aggregated these preferences; the design team analyzed the design options with respect to the goals; and the design team, stakeholders, and authors visualized and assessed these goals, options, preferences, and analyses to assist in a transparent and formal decision making process. The methods of Decision Analysis [3], including adaptations for group decision-making and multi-attribute decisions [4], inspired our analysis but we did not adhere strictly to those methods. Finally, we discuss some of the strengths and weaknesses of the implemented MACDADI process, and we identify opportunities for future improvement.

Observations on the Living Laboratory Feasibility Study

During the fall of 2005, Stanford University hired a design team consisting of architects, structural, mechanical, electrical, and civil engineers, and construction consultants to perform a feasibility study for a mixed use dormitory and research facility on campus. The Stanford stakeholder constituency consisted of project managers, housing representatives, a cost engineer, the University architects, an energy manager, student representatives, and several professors and researchers with interests ranging from innovative water treatment, to renewable energy strategies, to innovative structural solutions, to design process modeling. This section describes the processes this project team used to define their goals, propose options, analyze these options with respect to their goals, and make decisions. It also describes some of the difficulties they had communicating and coordinating these processes.

Goals: From the moment the dorm was first proposed, stakeholders began defining and refining project goals. A class focused on the project and issued a statement of goals as a final report, a presentation to the Provost to get funding for the project contained additional goals, and the request for proposals to design teams contained another collection of project goals. As the feasibility stage progressed goals were further proposed and refined through meetings and e-mail exchanges. However, as the feasibility stage neared its conclusion, these goals remained distributed throughout the project team and in several documents. A definitive and comprehensive set of goals had not been collected and made public for the design team and stakeholder to collectively assess and share, and the relative preferences amongst goals had not been established. For example, there remained doubt amongst the stakeholders as to whether the project was intended to demonstrate the financial viability of building sustainably, thereby emphasizing first and lifecycle cost, or whether the project should emphasize other goals, and let these project costs fall where they may.

Options: Throughout the process, the design team proposed many design options. For example, the design team proposed options for energy reduction (i.e., passive ventilation, high performance fixtures, daylighting solutions, and light dimming) and energy production (i.e., photovoltaic panels, heat recovery from water, a fuel cell, and even methane gas from a membrane bioreactor). As the design progressed, the design team aggregated several of these options into two alternatives: a baseline green alternative, and a living laboratory alternative. Although the alternatives were intended to only give a sense of the feasibility of the project, several other options and alternatives that were discussed were omitted and not formally documented. For example a well, which would both close the water loop and serve as a source of heat and cooling for the dorm, was not mentioned in the draft of the report, even though several project stakeholders felt this option still had merit.

Analyses: In some cases the design team performed formal and explicit analyses of options and alternatives, such as for the carbon emissions of the different energy sources they were investigating. In other cases the analyses were less formal, albeit explicit. For example, Figure 1 shows a matrix the design team constructed to help them perform and communicate the analysis of room types with respect to a collection of goals they deemed relevant. In other cases the analyses were neither formal nor explicit, such as for the analysis of the roof deck for its impact on the social life of the dorm. In this case, the roof deck was generally determined to be desirable, without explicit analyses as to why this was the case.

ROOM TYPE	NSF / BED (& FACTOR)	EFFICIENCY (& SUSTAIN-ABILITY)	SOCIAL INTERACTION	FUTURE FLEXIBILITY	POPULARITY	FIT W/CAMPUS HOUSING PLAN
SINGLES	110 (1.0)	2	3	2	4	?
DOUBLES	100 (1.1)	4	5	5	3	?
DIVIDED DOUBLES	110 (1.0)	2	3	2	4	?
TRIPLES	95 (1.16)	4	1	5	1	?
QUADS	90 (1.22)	4	3	5	1	?
SUITES	135 (0.82)	1	1	1	5	?
MIX	110?	?	?	?	?	?

1 = WORST
5 = BEST

Figure 1: An analysis of room types.

Decisions: As the design progressed the project team made many decisions, and recorded these in the meeting minutes. However, many other decisions, such as the choice of which room types to pursue, or whether to include the well, were not explicitly recorded or accessible to the stakeholders as the design progressed, but rather most decisions and their rationale were stored in the heads of the participants. The design team did not have a consistent, formal means to record decisions in a way that described how the decision helped address project goals.

The MACDADI process

As the feasibility study drew to a close, the authors saw that a more collective and explicit coordination of goals, preferences, options, and analyses may help the team arrive at consensus and better communicate their rationale. This section describes the MACDADI process that the authors designed and implemented for the project. Figure 2 diagrams the process, and the subsequent text describes each step.

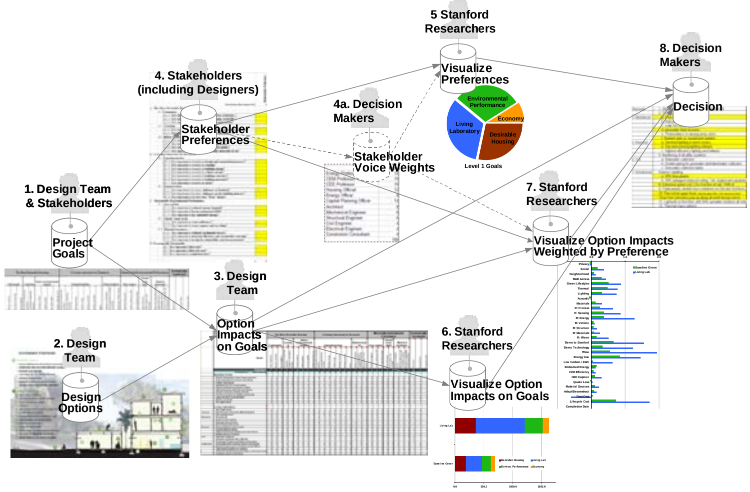

Figure 2: The MACDADI process involved seven steps, described below. The process is diagrammed using the Narrative formalism [5] in which processes are described as dependencies (arrows) between representations (barrels). The reasoning agent (in this case human) required to construct each representation is shown above each barrel.

1. Design Team and Stakeholders define the Project Goals: The architect and authors reviewed and synthesized many of the project documents and compiled a comprehensive set of hierarchically organized goals. To develop consensus, these goals were then sent out to the project stakeholders and feedback was collected on how well these goals matched each stakeholder's understanding. Another round of synthesis incorporated this feedback into a cohesive set of project goals. At the highest level, the goals state that the project should be the Most Desirable Housing on Campus, serve as a Living Laboratory for Research, achieve a high level of Measurable Environmental Performance, and should be Economically Sustainable. The project goals can be found across the top of the Matrix shown in Figure 3.

2. Design Team identifies Design Options: With input from the stakeholders, the design team proposed several design options, ranging from architectural solutions such as a green roof and clerestory windows, to mechanical solutions such as solar hot water and photovoltaic arrays, to structural alternatives, such as optimized wood framing and an earthquake resistant steel framing system. The design team coupled these many options into two primary alternatives: Baseline Green and Living Laboratory. The options are shown in the left-hand columns of the Matrix. The MACDADI process did not ostensibly impact the process of choosing options.

3. Design Team assesses Options' Impacts on Goals: Using the matrix the design team next assessed the impact of each of these options on the project goals. Other projects [6] have similarly used a matrix to evaluate project options with respect to goals, although the matrix shown in Figure 3 is perhaps more comprehensive in terms of the number of goals assessed. The assessment rated each option's impact on each goal with a numeric score. In this case the architects first completed the entire matrix, then consulted with the specialty engineers to validate their scores. Some assessments, for example the impact of the photovoltaic array on the Low/No Carbon Per kwh goal, are reinforced by rigorous analysis in the appendices of the feasibility report. Other assessments, such as the impact of the large roof deck on Dynamic Social Life, are more qualitative and rely on the assessing designer's experience and intuition.

Stanford Green Dorm	The Most Desirable Housing									A Living Laboratory for Research										Measurable Environmental Performance								Economically Sustainable		
MACDADI Matrix	Community			Learning		Indoor environmental quaility				Experimentation							Demonstration			Zero carbon			Closed water cycle		Material resources					
	Sense of privacy	Dynamic social life	Good neighbor	Access to research and education	Facilitates sustainable lifestyle	Thermal comfort	Lighting quality	Acoustic quality	Healthy materials & air	Design and construction process	Sensing (monitoring systems)	Building energy	Vehicle enegy	Building structure	Building materials	Water	Influence at Stanford	Proving ground for building technology	Noteworthy ("Wow" factor)	Reduced energy use	Low/no carbon per kWh	Low embodied energy	Water efficiency	Water capture and recycling	Reduced earthquake losses	Material efficiency and sustainable sourcing	Design for adaptability and deconstruction	First Cost	Lifecycle Cost	Completion date
Preferences	1	2	1	2	5	4	3	1	1	2	5	5	1	4	2	5	5	5	3	5	5	3	3	4	1	2	2	16	5	1
Baseline Green																														
Shared "Information Center"(foyer) and entry	-1	2	2	3	3	0	0	-1	0	2	3	2	1	0	0	1	3	2	2	2	0	0	1	0	0	0	0	0	1	0
Solar orientation for passive solar design	0	0	-1	0	0	2	3	0	0	1	0	1	0	0	0	0	1	1	0	3	0	0	0	0	0	0	0	0	3	0
Radiant slab heating	0	0	0	0	0	3	0	1	0	1	1	1	0	0	0	0	1	1	1	2	0	0	0	0	0	0	-2	-1	1	0
Optimized. 24" O.C. wood framing	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	2	1	1	1	0	1	0	0	0	2	1	0	0	0
Natural ventilation for passive cooling	0	1	0	0	1	3	0	-1	3	1	1	1	0	0	0	0	0	0	0	2	0	0	0	0	0	2	1	1	2	0
High-performance light and water fixtures	0	0	0	0	1	0	1	0	0	1	1	1	0	0	1	2	1	0	0	2	0	0	1	1	0	0	0	0	2	0
Fly ash or slag, low-cement concrete	0	0	0	0	0	0	0	0	0	2	0	1	0	2	2	0	2	2	1	0	0	3	0	0	0	1	0	-1	0	0
First floor location for building systems lab	-1	0	0	2	1	3	0	-1	0	0	0	0	2	0	0	0	2	0	1	0	0	1	0	0	-1	*	3	2	1	0
Large roof deck at second level	-1	3	1	2	1	2	2	-1	0	0	2	1	0	0	0	1	1	0	2	0	0	0	0	2	0	0	0	-1	0	0
Electric car garage	0	0	1	2	3	0	0	0	1	1	2	0	3	0	0	0	2	2	3	0	1	0	0	0	0	-1	0	-1	0	0
80% daylit interior	0	0	0	0	1	0	2	0	0	1	1	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	1	0
Living Laboratory																														0
100% daylit interior	0	1	0	0	2	0	3	0	0	1	1	1	0	0	0	0	3	1	1	3	0	0	0	0	0	0	0	-1	2	0
Steel structure w/concrete-filled metal deck	0	0	0	0	0	0	0	1	0	2	2	0	0	3	3	0	1	3	3	0	0	-2	0	0	3	1	3	-2	1	2
FSC-certified wood	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	3	0	-1	0	0
5 kw fuel cell	0	0	0	0	0	0	0	0	1	2	1	3	1	0	0	0	1	3	3	0	2	0	0	0	0	0	0	-2	2	-1
Solar hot water system	0	0	-1	0	1	0	0	0	0	1	1	3	0	0	0	0	1	1	2	0	3	0	0	0	0	0	1	-1	3	0
Greywater heat recovery	0	0	0	0	0	0	0	0	0	2	1	3	0	0	0	1	2	3	3	0	3	0	0	0	0	0	0	-1	3	0
60 Kw Photovoltaic array	0	0	-1	0	1	0	0	0	0	1	1	2	1	0	0	0	3	1	3	0	3	-1	0	0	0	0	1	-3	3	0
Dimmed lighting in dorm rooms	0	2	0	0	1	0	3	0	0	1	1	1	0	0	0	0	2	2	1	2	0	0	0	0	0	0	0	-1	1	0
Evening lighting setback	0	0	1	0	1	0	1	0	0	1	1	1	0	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	1	0
Highest-performance lighting and water fixtures	0	0	0	0	1	0	2	0	0	1	1	2	0	0	0	0	2	1	0	3	0	0	2	0	0	0	0	-1	1	0
Building systems monitors	0	1	0	3	3	1	0	0	2	1	3	3	1	2	1	3	3	3	3	3	0	0	2	0	0	0	0	-1	2	0
Rainwater collection	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	3	1	1	2	0	0	0	0	3	0	0	0	-2	1	0
Greywater and blackwater collection	0	0	0	0	1	0	0	0	0	2	1	0	0	0	0	3	2	3	3	0	0	0	0	3	0	0	1	-2	1	-1
Stormwater Features and Native Landscaping	0	0	2	1	2	0	0	0	0	1	1	0	0	0	0	2	1	0	1	0	0	0	0	2	0	0	0	0	1	0
Sustainable finish materials (interior and exterior)	0	0	1	0	0	0	0	0	2	1	0	0	0	1	3	0	1	2	2	0	0	2	0	0	0	3	0	-1	0	0
Extensive green roof, 2 to 4 inches of soil. 1400 sf	0	1	1	1	0	1	0	0	0	1	1	0	0	0	0	1	1	1	2	0	0	0	-1	0	0	0	0	-1	0	0
Triple-paned, double low-e windows	0	0	0	0	0	2	1	1	0	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0	-1	0	0	-1	1	0
Three foot clerestory pop-up at upper, north-facing rooms	0	0	-1	0	1	2	2	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-1	0	-1	1	-1
Ventilation atrium on first floor	0	1	0	0	1	2	2	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	-1	0	0

Figure 3: The Matrix: The top rows of the Matrix show the current consensus on project goals. Each high-level goal is broken down into lower-level goals that, if achieved, would positively impact the higher-level goal. The left side of the Matrix shows the options, aggregated into two alternatives. The body of the matrix contains an evaluation of each option with respect to each goal (3 = high positive impact, 0 = no impact, -3 = high negative impact).

4. Stakeholders report Preferences: Step 1 established the stakeholders' goals. However, that effort provided no indication of the relative importance among these sometimes-competing goals. To determine their relative perceived importance, each stakeholder was asked to represent their preferences by allocating 100 points amongst the lowest level (detailed) goals. Lower level goal preferences were summed to approximate the preferences for higher-level goals. 23 responses were received: 3 from students, 3 from engineering faculty, 8 from designers, 1 from the school of engineering, 3 from housing, and 3 from facilities. Responses within each stakeholder group were averaged to approximate an aggregate perspective for each constituency. To calculate a single aggregate perspective, all stakeholder constituencies were weighted equally (i.e., the collection of student voices count equally to the collection of faculty voices). Figure 2 (see 4A) shows that a decision maker can optionally add weights to the voices of different constituencies, if certain groups' opinions are considered more relevant to a collective decision analysis, although on this project that was not deemed desirable.

5. Analyze Preferences: Having collected the goals, options, assessments, and preferences, this information was visualized in illuminating ways. For Example, Figure

4A shows that taken together, the stakeholders feel the dorm should equally balance the goals related to Living Laboratory, Desirable Housing, and Environmental Performance. According to the stakeholders, Economic Sustainability, which includes first cost, lifecycle cost, and project schedule, is important, but is not as critical to project success. Follow-up discussions revealed some confidence that a profoundly innovative project might offset first costs through fund raising, and as long as the project is ready for a fall move in schedule is not important (which year the move in occurs is not critical). Figure 4B shows the relative preferences of all of the lowest level goals, broken out by different Stakeholder constituencies. For example, reducing energy use and creating that “wow” factor are considered to be extremely important, while project schedule, and research in vehicle energy are not considered to be as important for this project. Closer inspection reveals the relative importance of each of these goals for individual stakeholder constituencies.

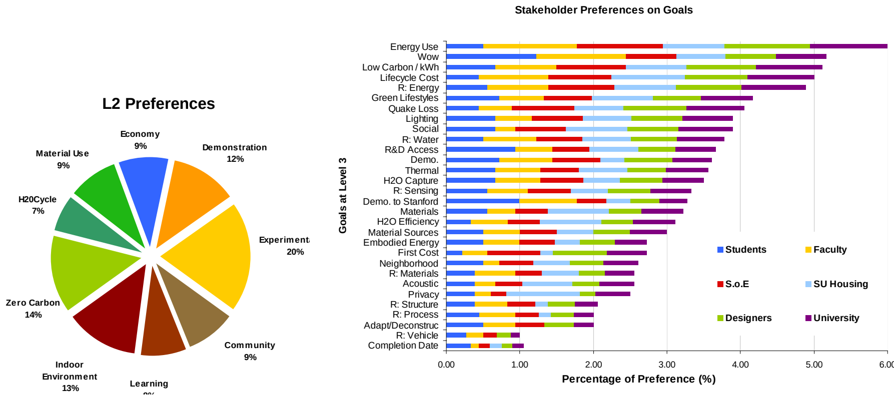

Figure 4: Visualization of stakeholder preferences amongst goals. **A.** Level 2 preferences show relatively equal preference among level 1 goals of Environmental Performance (green) Desirable Housing (red-brown) ad research (orange-yellow) with lesser emphasis on Economy (blue). **B.** Preferences for Level 3 goals, broken down by stakeholder.

6. Analyze Options’ Impacts on Goals: Visualizations of the designers’ assessments of the impact of each option on each goal without taking preference into account can also be constructed. For example Figure 5A shows the assessment of the impact of each option in the Living Laboratory alternative on each goal. The overall impact is broken down to show the impact on each level two goal.

7. Analyze Options’ Impacts, Weighted by Preference: Combining designer’s assessments of the design options’ impact from Step 3 with stakeholder preference data collected in Step 4 generates a prediction of the *perceived* costs and benefits of each design option – or a measure of overall Stakeholder Value. For example, Figure 5B compares the average value of the Baseline Green and Living Laboratory Options for all stakeholders, showing that these stakeholders find the Living Lab option to be far more valuable. Figure 5C illustrates the relative value of the Baseline Green and Living Laboratory Options with respect to the Level 3 goals.

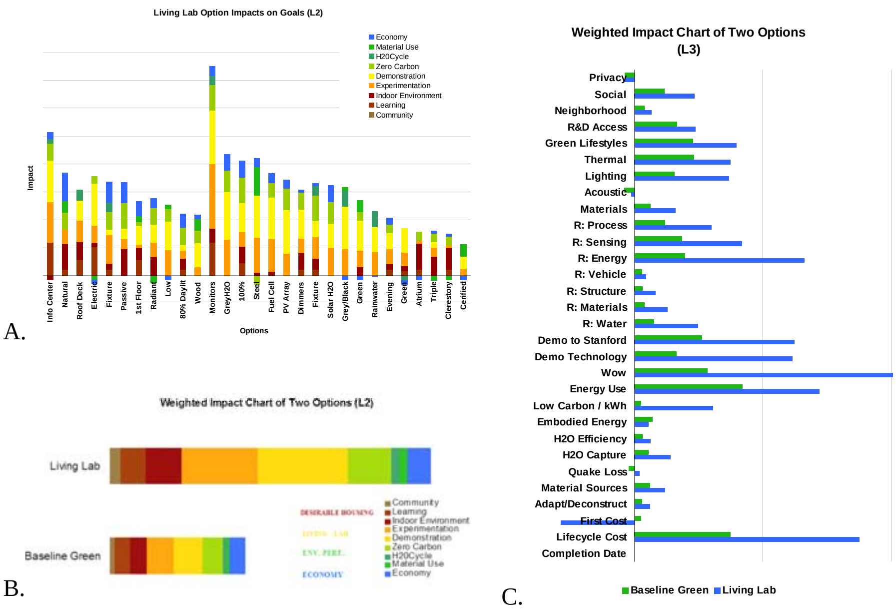

Figure 5: Impacts of Options on goals. **A.** Impacts of the Living Lab Stakeholder Value of the Baseline Green and Living Laboratory Options. **B.** Weighted Impact of the Living Laboratory and Baseline Green Alternatives broken down to level two goals. **C.** Weighted impact of the Baseline Green and Living Laboratory alternatives on each level three goal.

Conclusions and Next Steps

While still in the early development stages, MACADADI has shown benefits, and more value is expected as the research advances. Step 1 helped to formally define project goals, leading to a statement of objectives that clarified team members' discussions. These goals became the organizing framework for the feasibility study. Step 3 guided the design team to methodically and explicitly analyze the design options (resulting in over 900 explicit analyses) and helped them communicate the impacts of each option more clearly to the stakeholders. Step 4 helped the project team gain explicit understand of the importance of each of these goals, and through step 6, helped them to assess consensus of the various stakeholders. Step 7 lent confidence that the proposed design addresses stakeholders' preferences equitably, and can guide the team when additional options are explored in future phases. The charts stimulated particular and explicit discussion about the importance of the economic goals and of the reasons for the electric vehicle, and serve to illustrate and lend specificity to a range of claims in the final report. In addition, the overall structure of the feasibility report was influenced by the goals collected in Step 1, and twelve MACDADI charts are being included in the feasibility report [7]to explicitly communicate goals, preferences, assessments, and project value.

This MACDADI process deserves further research. In Step 1, we collected goals by culling documents, synthesizing these goals, and asking stakeholders for comments. More collaborative methods of developing project goals should lead to greater goal congruence. Case-based reasoning methods may be used to retrieve goals developed on previous projects. Standard templates for capturing goals [8], and incorporating more specific definitions of goals and ranges could also be incorporated. In Step 2, the design team aggregated options into only two alternatives. The ability to systematically propose and manage more options and collect these options into more alternatives [9] is also an area of future research. In Step 3, the design team systematically assessed the impact of each option on each goal. However, there may be benefit in using more precise and uniform methods to assess the impact of options on goals. Additionally these analyses should capture the emergent effects of complementary or conflicting design options. It may also prove valuable to investigate a link that would consider the stakeholders preferences (step 4) when assessing impacts on goals. Further, in step 4, there is potential for finer grained preferences that can account for nonlinear preferences (for example, cost is not important until a certain threshold is reached) or interactions among preferences. In step 5 – 7, there are opportunities for more advanced tools to visualize the rich information MACDADI produces. Moving forward, we intend to first develop a web based application that will enable the method to be deployed on many projects in order to popularize the method. We also intend a more detailed literature review to establish the relationships to prior work. Finally, we will more clearly define and embark on the roadmap for future development outlined above.

References

1. Gero, J. S. (1990). Design Prototypes: A Knowledge Representation Schema for Design, AI Magazine, Special issue on AI based design systems, M. L. Maher and J. S. Gero (guest eds), 11(4), 26-36.
2. Kunz, W., & Rittel H. (1970). Issues as elements of information systems. Working Paper No. 131, Institute of Urban and Regional Development, University of California at Berkeley, Berkeley, California, 1970.
3. Howard
4. Keeney R., and Raiffa, H., (1976), “Decisions with Multiple Objectives: Preferences and Value Tradeoffs,” John Wiley and Sons, Inc.
5. Haymaker J, Fischer M, Kunz J and Suter B (2004). “Engineering test cases to motivate the formalization of an AEC project model as a directed acyclic graph of views and dependencies,” ITcon Vol. 9, pg. 419-41, http://www.itcon.org/2004/30
6. BNIM (2002), “Building for Sustainability Report: Six scenarios for the David and Lucile Packard Foundation Los Altos Project”, http://www.bnim.com/newsite/pdfs/2002-Report.pdf
7. EHDD, 2006, Stanford University Green Dorm Feasibility Report, In production
8. Kiviniemi, A. (2005), "PREMISS - Requirements Management Interface To Building Product Models" Ph.D thesis, Stanford University.
9. Kam, Calvin (2005). "Dynamic Decision Breakdown Structure: Ontology, Methodology, And Framework For Information Management In Support Of Decision-Enabling Tasks In The

Building Industry." Ph.D. Dissertation, Department of Civil and Environmental Engineering, Stanford University, CA.