APPLICATION OF DESIGN RATIONALE SYSTEMS TO PROJECT DEFINITION – ESTABLISHING A RESEARCH PROJECT

Michael Whelton,[1] Glenn Ballard[2], and Iris Tommelein[3]

ABSTRACT

Better design decision management is possible through the use of lean production planning and control techniques, group decision-making, and knowledge management tools. Central to the success of these tools is the capture and timely management of the design rationale underlying design decisions. This research views design as a collaborative decision-making process, and highlights the need for supporting group technologies. The literature is summarized regarding relevant design processes, decision models and group support systems available to designers. Design viewed as an explicit decision making process is discussed and background research on group decision-making is documented. This paper also explores the benefits of employing design rationale systems to promote quality design assignments, value generation, and team learning among project stakeholders. A need for understanding the interfaces of design process, group decision-making and information technology support is established. A research model is proposed to integrate design rationale management with design process planning and control for the project definition phase of project delivery.

KEYWORDS

Collaboration, design rationale systems, group decision-making, knowledge management, lean design, organizational learning, project definition,

---

[1] Ph.D. Student, Construction Engineering & Management Program, Department of Civil & Environmental Engineering, University of California, Berkeley, USA, mwhelton@uclink4.berkeley.edu

[2] Adjunct Associate Professor, Construction Engineering & Management Program, Department of Civil & Environmental Engineering, University of California, Berkeley, USA, ballard@ce.berkeley.edu

[3] Professor, Civil and Envir. Engrg. Department, 215-A McLaughlin Hall, Univ. of California, Berkeley, CA 94720-1712, 510/643-8678, FAX 510/643-8919, tommelein@ce.berkeley.edu

INTRODUCTION

Building projects involve multiple design requirements, criteria, alternatives and constraints, which can be complex to track and manage, even within collaborative design teams. One of the goals of Lean Construction is to decentralize decision-making in project organizations and to make participants accountable for and capable of timely decision-making. Current studies reveal that the management of design rationale associated with design decision-making processes is insufficiently effective. The concurrency of design processes and tasks also adds to the complexity of design decision-making, as real time information is important to have disseminated to all design actors. It is not sufficient to simply document the design decisions that are made. It is necessary that the design intent or rationale underlying those decisions be developed collaboratively and be accessible by others during the process and later in the product life cycle. Further, the design process needs to be planned and controlled more effectively, in order to minimize the effects of complexity and uncertainty.

Designers and project decision makers interact continuously over the course of a project passing information and sharing knowledge in the development of processes and products. Continuous decision-making occurs in design, often involving collaborative group processes. This paper views design as an explicit decision making process. The background to decision analysis is outlined and group communications are described. Researchers observing design tasks suggest that much design communication time is spent explaining or exchanging information and less time is spent on creative and predictive decision-making. Understanding basic group or team behavior and their current means of communication systems is necessary in order to build effective process planning and control, and decision representation tools, required to better manage project memory.

The interaction and flow of decision information may be through virtual means via the Internet or physically, through verbal communications at face-to-face design meetings, or normally through a hybrid of communication methods. Capturing design rationale and making it available to support decentralized decision-making appears to be an area where information technology can help. It is proposed that computer-based design rationale systems can aid in identifying dependency of design variables and improve the quality of design work assignments. The background to design rationale and support tools is discussed. This paper proposes a research framework within which a design rationale model can be developed to promote design decision visibility and clarity, process, and organizational understanding and learning, and allow opportunity for positive change strategies to improve customer value. The research will focus on the project definition phase of project delivery.

In the first section of the paper, conceptualization of design as a decision making process and the role of group decision-making is presented. Methods of capturing and managing project memory are next presented, with design rationale systems as the most comprehensive methodology. Application of design rationale systems to the project definition phase of design projects is then presented as a proposed research project.

DESIGN VIEWED AS A DECISION MAKING PROCESS

Design by nature is an iterative process of analysis, synthesis, evaluation and decision-making. The Markus/Maver model argues for the undertaking of a decision sequence to be carried out for each stage of the design process (Lawson 1980). Analysis involves the exploration of relationships, looking for patterns in the information available, and the classification of objectives. Analysis is the structuring and organizing of the problem. Synthesis is the generation of solutions for the problem. Appraisal involves the evaluation of suggested solutions against the objectives in the analysis phase. A decision is then taken on the state of the design problem/solution and then the decision sequence is advanced. Return loops can exist for some or all steps in the decision sequence.

Gero, (2000) regards design as a purposeful activity, which is "*a goal-oriented, constrained, decision-making, exploration and learning activity that operates within a situation that depends on the designers perception of the situation and results in the description of a future engineering system*". Kalay (1999) suggests the use of a performance based design paradigm to assess how design is carried out to create quality-building products. Quality can only be achieved by determining a multi-criteria performance evaluation objective, which comprises a sum of satisfaction/behavior functions and subsequent trade-offs in design solution selection. Performance-based design is interrelated with form, function and context of the design situation, which determines the behavior of the proposed solution. Kalay (1994) provides an in-depth analysis of methods, tools, and techniques for evaluating and predicting design performance. It is intended that designers should assess decision-making using multiple criteria and at multiple levels using rational decision methods. Consideration for design process workflow as proposed by Ballard (2000a & 2000b), establishes a framework for performance measurement by collaborative designers.

There is support by researchers for viewing design as a decision making process (Manning et al. 1994, Ganeshan et al. 1994, and Beheshti 1993). Beheshti describes the role of design management as a process of accounting for: a chain of known constraints; design constraints that emerge from the interaction of other design variables, values, priorities or criteria; impacts of unknown design variables introducing uncertainty; and consequences of alternative courses of actions interacting with known or unknown decision factors. Dieter (2000) similarly proposes that a decision-making model should contain six basic elements:

1. Alternative courses of action;
2. States of nature (of the environment of the decision model);
3. Outcome: the result of a combination of an action and a state of nature;
4. Objective: the statement of what the decision maker wants to achieve;
5. Utility: the measure of satisfaction or value which the decision maker associates with each outcome;
6. States of knowledge: the degree of certainty that can be associated with the states of nature.

GROUP DECISION-MAKING

At present the communication problem between the team members is often a cause for delays in product and process design decision-making. Project teams form to work together on a common goal; e.g., designing a product. Within these teams, there is normally some degree of shared understanding of the goals and objectives required in achieving a valued project. However, shared understanding is never perfect in organizations and teams, and some degree of specialization implies unequal distribution of know-how. Frequently nobody knows all there is to know about an issue. Team actors may frame the problem within constructs of their own expertise or experience. Assumptions may be different in the minds of each actor and this can result in ill-defined decision problems and there can be a lack of clarity of decision options (Beach, 1997). Most of the effort in organizational decision-making is not directed at reaching a decision by "selecting from multiple alternatives". As in teams, people frame the problem differently and decision-making becomes a disorderly process in which the search for a good definition of the problem engenders ideas about possible solutions that, in turn, influence the problem definition and further thinking about options (Beach, 1997). Equally in design projects, team decision-making is based on problem elicitation and clarification. Liston, (2000) reported, based on design meeting observations, that the design team spends more time describing, explaining and evaluating the information on hand than using the information to perform rational and objective decision making. Liston's research on interactive workspaces aims to support defined tasks such as descriptive tasks, explanative tasks, evaluative tasks and predictive tasks. Predictive tasks are less frequent but add most value to a design discussion and need to be supported.

McGrath (1994) views group collaborative work as a complex matter, with or without the use of electronic technology. The process of collaboration is more than just the exchange of information. It entails cognitive aspects of communication: Group members transmit, receive, and store information of various kinds, from each other and various other sources. Collaborative work also entails emotional and motivational aspects of communication. Group members are also transmitting, receiving, and storing the affect and influences aspects of those same messages. The type and difficulty of the tasks the group is performing effect group interaction and performance. McGrath, 1984 defines a task classification schema from previous research for group tasks. These are grouped into four main types, which are represented as the four quadrants of a whole:

1. To generate plans or ideas through structured task planning methods and or creativity methods;
2. To choose a correct answer or a preferred solution through structured task problem solving and or decision making methods;
3. To negotiate conflicting views or conflicting interests through structured task procedures;
4. To execute activities in competition with an opponent or in competition against external performance standards through structured tasks.

Decision analysis forms a recognized and established research discipline within operations research. A range of analysis techniques has been developed to allow decision-makers to perform within a logical decision process. Decision making of all kinds involves the choice of one or more alternatives from a solution set. The aim of rational decision-making is to maximize positive effects and minimize negative effects within the context of multiple measures of performance or multiple criteria. Multiple Criteria Decision-Making (MCDM) includes a range of analytical techniques to support the decision-maker. These are broadly classified as (Sen et al., (1998):

- Selection from a menu or catalogue based on prioritized attributes of the alternatives (multiple attribute decision making);

- Synthesis of an alternative or alternatives on the basis of prioritized objectives (multiple objective decision making).

This model is grounded on goals/objectives, alternatives, consequences and optimality. The model assumes that complete information regarding the decision to be made is available and one correct conception of a problem, or decision to be made can be determined. Lootsma, (1999) & Lahti, (1996) reviews the distinct approaches associated with decision-making. The descriptive approach describes how decision-makers behave when selecting alternatives. Many studies are concerned with individual and collective decision making with an analysis of the rationality of decision-makers. The political decision-making model considers the preconceived notions that decision-makers bring to the table in the decision process. In contrast to the preceding model, the individuals involved do not accomplish the decision task through rational choice in regard to objectives. The decision makers are motivated by and act on their own needs and perceptions. More specifically, this process involves each decision-maker trying to sway powerful people within the situation to adopt his or her viewpoint and influence the remaining decision-makers. An opportunity to make a decision is described as a garbage can, when many types of problems and solutions are dropped independently of each other by decision-makers as these problems and solutions are generated. The problems, solutions and decision makers are not necessarily related to each other. They move from one decision opportunity to another in such a manner that the solutions, the time needed and the problems seem to rely on a chance alignment of components to complete the decision. These components are the combination of options available at a given time, the combination of problems, the combination of solutions needing problems, and the external demands on the decision makers (Lahti, 1996). With the process model, decisions are made based upon standard operating procedures, or pre-established guidelines within the organization. Actions and behaviors occur in accordance with these procedures or guidelines.

PROJECT MEMORY REPRESENTATION AND DESIGN RATIONALE SYSTEMS

Knowledge engineering and management are the primary disciplines within which research on managing project memory has developed. Knowledge is reasoning about information and data to actively enable performance, problem solving, decision-making, learning and teaching (Beckman, 1999). Knowledge Management (KM) is the formulization of, and access to experience, knowledge, and expertise that create new capabilities, enables superior performance, encourages innovation and enhances customer value. KM has emerged as an integrated, multi-disciplinary and multi-lingual discipline providing methodologies and tools for identifying, eliciting, validating, structuring and deploying knowledge within the enterprise. Two major strands have developed within the discipline (Vergison, 2001):

- Micro-scale knowledge management which focuses on the capture, structuring and use of knowledge at local levels;
- Macro-scale knowledge management, which is sensitive to company strategic plans, addresses corporate and transverse inter-business unit concerns.

Micro knowledge management focuses on the capture, validation and diffusion of shop floor knowledge through the use of modern technologies from a variety of disciplines: e.g.

information technology, artificial intelligence and cognitive processes (Leseure et al., 2001). This research adopts basic micro-level KM methods as a means of improving information visibility and flow in design decision management. Central to this approach is the learning capability of the project team or organizations. Garvin, (1993) defines organizational learning as a process "for creating, acquiring and transferring knowledge, and modifying individual behaviors to reflect new knowledge and insights". Explorations of learning techniques (e.g. plan process failure analysis and product design analysis within a design management setting) and methods described by Seymour et al. (2000) should allow for a more interactive and collaborative approach to design decision-making.

Information technology has been widely recognized as an enabling technology that can support communication of information and make the process more visible to all parties. The SEED[4] research project is one example of a design environment supporting early phase design. This system promotes concurrency of design tasks and facilitates collaboration of design teams. The technologies adopted by an organization influences how communications and information flows between stakeholders. Understanding group design behavior is important if support tools are to be developed effectively. A general definition of technology-supported collaboration is GroupWare, software that supports the ability of two or more people to communicate and collaborate. Groupware, the cornerstone for most electronic knowledge sharing (Coleman 1999), is an umbrella term for describing electronic technologies that support person-to-person collaboration, including email, electronic meeting systems (EMS), desktop video conferencing as well as systems for workflow control and business process re-engineering (BPR). Coleman, (1999) further describes the taxonomies of GroupWare available for collaboration purposes and Coleman, (2000) describes a method for quantifying the strategic value of collaboration. Quite often, capturing and managing the design rationale behind decision making through these communication systems is not feasible given the generic uses these tools allow.

Where decision problems are more complex and cannot be easily defined[5] by the decision-makers, rational and process methods are more difficult to apply. Conklin (1998) describes the “pain in organizations” that have to solve “wicked” problems. Such problems involve solving a set of interlocking issues and constraints by multiple stakeholders. Resources and changing decision criteria impact the process over time. Rittel, (1972) proposed the IBIS (Issue Based Information System) method to aid groups to actively discuss problems by raising issues. Lee (1991) developed a more expressive schema in the form of a decision representation language. Shum (1998) details this area of development. Group decision support systems[6] have been developed based on Rittel's work to support group memory and collective sense making in collaborative environments. Ganeshan et al. (1994) supports the view that these group decision support systems require more formal representation structures when applied to design management.

---

[4] SEED: A Software Environment to Support Early Phases in Building Design. Available at web site: http://seed.edrc.cmu.edu/

[5] Rittel, (1972) defines such problems as "wicked problems".

[6] Commercial group support systems available include: http://www.gdss.com , http://www.compendiuminstitute.org/Default.htm , http://www.groupsystems.com & http://www.enviros.com/drama

Project memory can be defined as "lessons and experiences from given projects or as project definition, activities, history and results" (Matta et al., 2001). Project memory is also expressed using the term "Design Rationale". Design rationale can be defined as an expression of the relationships between a designed artifact, its purpose, the designer's conceptualization and the contextual constraints on realizing the purpose (Moran et al., 1995). The design intent of a designer's work is often lost in the interpretation of design drawings or specifications. This may lead to design conflicts or failures further downstream in the project delivery process. The reliability of the quality of the design is compromised without this design information. A design rationale document communicates information answering the questions how, why, and why not about the information implicitly embedded in the design drawings. Design Rationale (DR) systems also assist in coordinating the design efforts of the numerous designers working concurrently on various aspects of a single building project. DR helps designers understand the reasoning behind the design decisions made by other designers, especially in other fields, and allow understanding and resolving of conflicts where conflicts arise. Design Rationale Systems (DRS) support the management of project memory. DRS allow capturing and accessibility of rationales. The benefits of employing the services of a DRS may: provide greater support to project management, improve dependency management, provide greater design support, help support collaboration, support downstream users of design, allow more detailed documentation, help in requirements engineering, aid in design re-use and ultimately provide a learning tool for evaluating design (Lee, 1997). The developer of a design rationale system is faced with what to explicitly represent. Entire rationales are impossible to represent. Three layers identified by Lee, (1997) as representative of a generic structure of a design rationale system include:

- A decision process layer that subdivides into five sub layers: issue, argument, alternatives, evaluation, and criteria;
- A design artifact layer: e.g. a product-process model;
- A design intent layer: meta-information underlying design decisions, such as intents, strategies, goals, and requirements.

Other implementation issues raised by researchers (Lee 1997 and Moran et al. 1995) are as follows: are frameworks[7] and representations informal, semi-formal or formal[8]? How are rationales produced e.g. reconstruction, apprentice shadowing of designers or automatic generation? Producing and capturing design rationale is a major difficulty in creating a design rationale system. The ideal design rationale system would be non-intrusive. This is desirable because recording rationale is not only time consuming for the designer, it also can distract them from the design task they are performing (Burge, 1998). How can design rationale systems be developed and managed cost effectively? These issues require further research attention. Burge (2000) researches the "usefulness" of design rationale in product development. Active interaction by designers with design rationale can benefit the process design. By integrating design rationale management with process planning and control, designers can identify the benefits of working interactively in design process/product development. Integrating design methodology with design rationale development and

[7] Ganeshan, R., Garrett, J., H., Jr., Finger, S. (1994) present a framework for representing design intent.
[8] De la Garza and Alcantara (1997) describe a formal model of design rationale representation.

management can provide designers with greater understanding of collaborative design issues. This is the objective, of the proposed research. A working research model is proposed to examine the application of design rationale management, together with design planning and control techniques, during the Project Definition Phase of project delivery.

PROJECT DEFINITION

Ballard et al. (2000c) establishes a project definition module within the lean project delivery system. *"Project definition is the first phase in project delivery and consists of three modules: Determining requirements (stakeholder needs and values), translating those requirements into criteria for both product and process design, and generating design concepts against which requirements and criteria can be tested and developed".* Ballard et al. supports collaborative design processes though the specification of data collection methods and a project definition conference(s) to support group decision-making, leading to the production and alignment of requirements, criteria and concepts.

Research has identified early phase concept design as an ill-structured process often without an explicit decision process. Disorganized behavior within design teams may result due to the lack of a required structure or framework (Macmillan et al. 2001). Approaches to researching this design phase include framework development (Macmillan et al. 2001) and support systems to establish and process client requirements (Kamara et al. 2000). Woodhead et al. (2000) document the range of paradigms and perspectives owners use for decision making in the pre-design phases of capital projects. Design and construction organizations need a better understanding of these dynamic and changing influences. These influences set up or determine the main design constraints used in the preliminary stages of design. Hitchcock (1996) argues for a more complete and clear documentation of project objectives and their relationships to design decisions across the product-process life cycle. This research is primarily addressing project definition in its development of design rationale management.

APPLICATION OF DESIGN RATIONALE SYSTEMS TO PROJECT DEFINITION

Figure 1 illustrates a proposed framework for applying design rationale systems to design management[9]. The intent of the research model is to support proactive and interactive[10] design process planning and control, group decision making, value performance assessment and learning by project stakeholders. Understanding project influences is necessary and by utilizing design rationale systems, greater insights can be made into the decis ion process as the project definition phase develops. Project influences include the environment in which the design project is set. These paradigms can include marketing, strategy, and planning permission, financial, and property development to mention but a few. Organizations are often made up of complex decision making groups and decision processes. Understanding the decision-making procedures of these groups is important for timely decision planning and

---

[9] The authors have established a research in action program with a project management group in order to develop and test the proposed framework. For further information interested readers can contact the authors to access the research web site: http://www.cp.berkeley.edu/designresearch.

[10] Bea (2001) uses three approaches: proactive, interactive and reactive, in the analysis of Human and Organizational Factors: Risk Assessment and Management of Engineered Systems.

control. Stakeholders can understand design constraints and inefficient organizational structures and processes, and can learn by implementing positive change strategies to improve the impacts of project influences. Establishing a methodology for testing the usefulness of this framework in a design management organization is the current research objective.

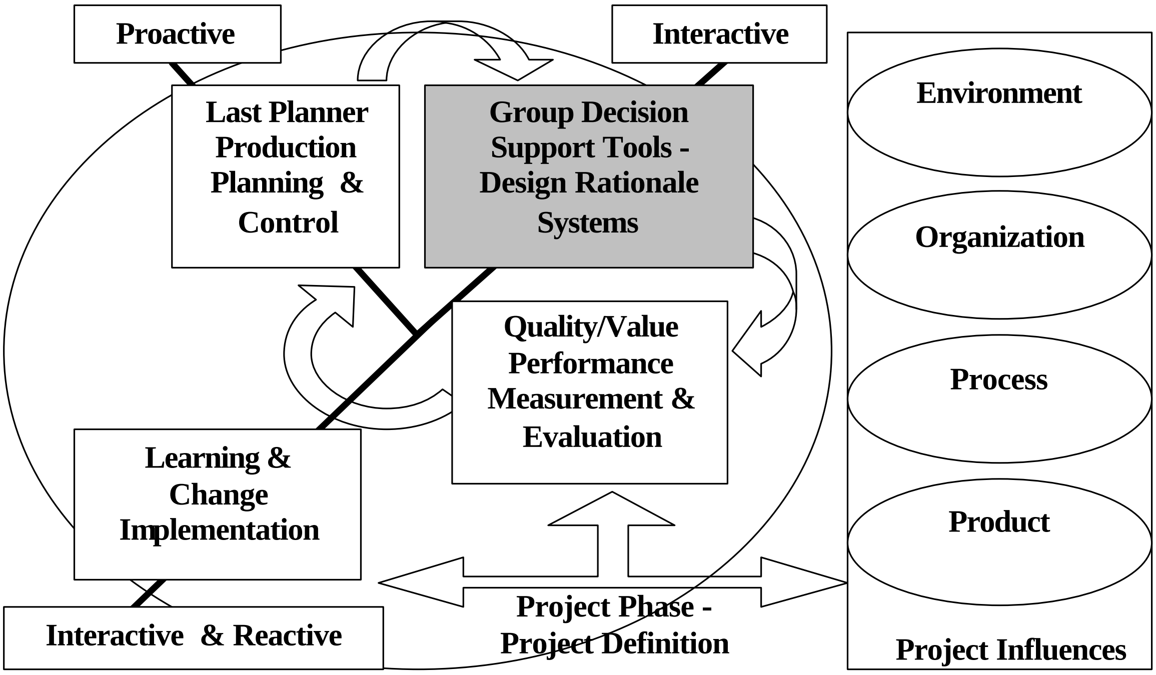

Figure 1 Design Management Research Framework

Figure 2 illustrates a conceptual design rationale framework upon which to further develop design activity research. The model proposes to develop process maps, associated decision networks, and design rationale management features to support designers. The design rationale model should contain stakeholder requirements, criteria, constraints, design concepts and options, conflicts, assignable and accountable design actions, and decision states with reference to design variable interdependencies and design product documentation. The model will be developed and tested on a number of design process cases. The structure and detail of the decision representations will vary depending on the decision-maker(s) involved and the design decision context. The decision framework will take advantage of web-based information technologies, graphical modeling techniques and appropriate lean design techniques as proposed by Ballard et al. (2000d). The experimental research will adopt an apprentice or shadowing role whereby the principal researcher will facilitate process development and decision process mapping with the project stakeholders. Feedback on the usefulness of the decision support tool will be sought from participating decision-makers. While the long-term research goal is to allow designers to interact with the support tool at group design meetings and during design activity, the immediate focus is to develop useful decision representations within planned and controlled design processes.

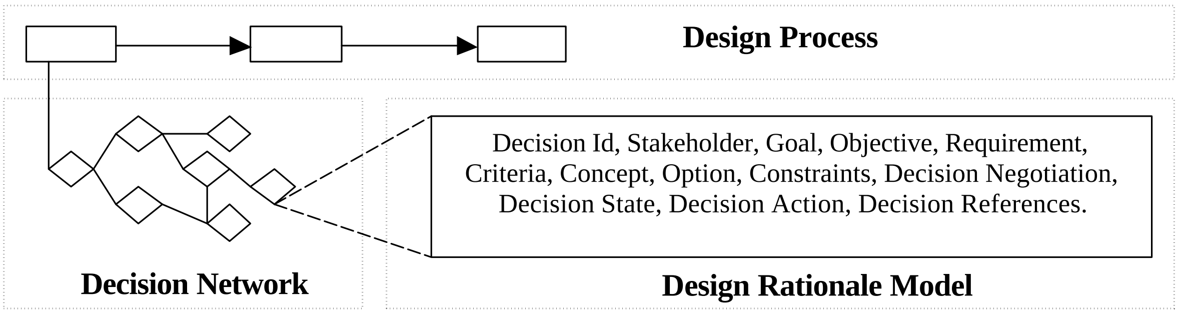

Figure 2 Interactive Design Rationale Framework

CONCLUSIONS

The objective of this research is to help improve design decision-making during project definition. Formal design process structures can support rational methods of decision-making. By establishing greater visibility of design rationale, designers can establish and resolve conflicting design constraints with greater clarity. An explicit decision process will allow designers to concentrate their design efforts on creative design tasks and to spend less time on explanative and descriptive tasks. Owner stakeholders can determine if their project requirements are being met and their performance goals achieved. Learning about the process is facilitated through explicit documentation and visibility of project influences. The proposed framework establishes a system for organizational learning and knowledge management at project and organizational levels. The research challenge will be to develop cost-effective and value generating methods for integrating design rationale management with design processes and methodologies.

REFERENCES

Ballard, G., (2000a) Managing Work Flow on Design Projects, Proceedings of CIB W96 Architectural Management, Atlanta, USA, May 2000.

Ballard, G., (2000b) The Last Planner System of Production Control, PhD Thesis, School of Civil Engineering, University of Birmingham, UK.

Ballard, G., Zabelle, T., (2000c) Project Definition, White Paper #9, Lean Construction Institute, USA. http://www.leanconstruction.org

Ballard, G., Zabelle, T., (2000d) Lean Design: Process Tools & Techniques, White Paper #10, Lean Construction Institute, USA. http://www.leanconstruction.org

Bea, B., (2001) Human & Organizational Factors: Risk Assessment and Management of Engineered Systems, CEE-OE 290A, Course Reader, Dept Civil & Envir. Engineering, UC Berkeley, CA, USA.

Beach, L., (1997) The Psychology of Decision-Making, People in Organizations, SAGE Publications, USA.

Beckman, T., (1999) The Current State of Knowledge Management, Knowledge Management Handbook / edited by Jay Liebowitz, CRC Press LLC, USA.

Beheshti, R., (1993) Design Decisions and Uncertainty, Design Studies, Vol 14, No 1, Butterworth-Heinemann Ltd, UK.

Burge, J., (1998) Design Rationale, Technical Report, Worchester Polytechnic Institute, Computer Science Dept., available at: http://www.cs.wpi.edu/Research/aidg/DR-Rpt98.html (accessed: 5/7/01).

Burge J. E., Brown D. C. (2000): " Reasoning with Design Rationale", Artificial Intelligence in Design '00, J. Gero (Ed.), Kluwer Academic Publ. Available at: http://www.cs.wpi.edu/~dcb/Papers/AID00-janet.pdf (Accessed: 5/7/01).

Coleman, D., (1999) Groupware: Collaboration and Knowledge Sharing, Knowledge Management Handbook / edited by Jay Liebowitz, CRC Press LLC, USA.

Coleman, D., (2000) The Black Hole of Collaboration: Examining Collaborative ROI and Value, White Paper, [available as http://www.collaborate.com/mem/hot_tip/tip1000.php3], Accessed: 2/21/01.

Conklin, J., Weil, (1998) Wicked Problems: Naming the Pain in Organizations, Group Decision Support Systems Inc., Available at: http://www.leanconstruction.org/pdf/wicked.pdf

de la Garza, J., Alcantara, P., (1997) Using Parameter Dependency Network to Represent Design Rationale, Journal of Computing in Civil Engineering, April 1997, ASCE, USA.

Dieter, G., (2000) Engineering Design, A Materials and Processing Approach, 3rd Edition, McGraw-Hill, USA.

Ganeshan, R., Garrett, J., H., Jr., Finger, S. (1994) A Framework for Representing Design Intent, Journal of Design Studies, Vol. 15, No. 1, p 59-84, Butterworth Scientific Limited, UK.

Garvin, D.A. (1993) "Building a Learning Organization", Harvard Business Review, July-August, pp.78-91.

Gero, J., (2000) Computational Models of Innovative and Creative Design Processes, Technological Forecasting and Social Change, 64, p 183-196, Elsevier Science Inc., USA.

Hitchcock, R., (1996) Improving Life Cycle Information Management through Documentation of Project Objectives and Design Rationale, PhD Thesis, Dept of Civil and Environmental Engineering, University of California, Berkeley, CA, USA.

Kalay, Y. (1994) Principles of Computer-Aided Design: Evaluating and Predicting Design Performance, Edited by Yehuda E. Kalay, John Wiley & Sons, Inc., New York, USA.

Kalay, Y. (1999) "Performance-Based Design", Journal of Automation in Construction, vol. 8, pp 395-409, Elsevier Science Ltd, Amsterdam.

Kamara, J., Anumba, C., Evbuomwan, N., (2000) Establishing and Processing Client Requirements - A Key Aspect of Concurrent Engineering in Construction, Journal of Engineering, Construction and Architectural Management, Vol. 7, No. 1, pp 15-28, Blackwell Science Ltd. UK.

Lahti, R.H. (1996) Group Decision Making within the Organization: Can Models Help? Center for the Study of Work Teams, University of North Texas, Available at: http://www.workteams.unt.edu/reports/lahti.htm (Accessed on 5/3/01).

Lawson, B. (1980) How Designers Think, The Architectural Press Ltd: London, 213pp.

Lee, J., Lai, K., (1991) What's in Design Rationale?, Design Rationale, Concepts, Techniques, and Use, pp. 21-51, Edited by Moran, T., & Carroll, J., 1996, Lawrence Erlbaum Associates Publishers, New Jersey, USA.

Lee, J., (1997) Design Rationale Systems: Understanding the Issues, AI in Design, IEEE Expert, May/June, 1997,

Leseure, M., Brookes, N., (2001) Micro Knowledge Management: A Job Design Framework, Industrial Knowledge Management: A Micro-level Approach / edited by Rajkumar Roy, Springer, UK.

Liston, K., Fischer, M., Kunz, J., (2000) Requirements and Benefits of Interactive Information Workspaces in Construction, 8th International Conference on Computing in Civil and Building Engineering, August 14-17, University of Stanford, CA.

Lootsma, F. (1999) Multi-Criteria Decision Analysis Via Ratio and Difference Judgement, Kluwer Academic Publishers, Netherlands.

Macmillan, S., Steele, J., Austin, S., Kirby, P., Spence, R., (2001) Development and Verification of a Generic Framework for Conceptual Design, Design Studies, Vol 22, No 2, pp 169-191, Elsevier Science Ltd., UK.

Manning, P., Mattar, S., (1994) A Preliminary to Development of Expert Systems for Total Design of Entire Buildings, Principles of Computer-Aided Design: Evaluating and Predicting Design Performance, Edited by Yehuda E. Kalay, John Wiley & Sons, Inc., New York, USA.

Matta, N., Ribiere, M., Corby, O., Lewkowicz, M., Zacklad, M., (2001) Project Memory in Design, Industrial Knowledge Management: A Micro-level Approach / edited by Rajkumar Roy, Springer, UK.

McGrath, J., Hollingshead, A., (1994) Groups Interacting With Technology: Ideas, Evidence, Issues, and an Agenda, SAGE Publications, USA.

McGrath, J., (1984) Groups, Interaction and Performance, Prentice Hall, Englewood Cliffs, NJ, USA.

Moran, T., Carroll, J., (1995) Overview of Design Rationale, Design Rationale: Concepts, Techniques and Use, Edited by Moran, T., & Carroll, J., 1996, Lawrence Erlbaum Associates Publishers, New Jersey, USA.

Rittel, H.W. J., (1984) Second Generation Design Methods, Developments in Design Methodology, N. Cross (ed.) pp. 317-327, J. Wiley & Sons, Chichester, UK.

Sen, P., Yang, J., (1998) Multiple Criteria Decision Support in Engineering Design, Springer-Verlag, London, UK.

Seymour, D., Rooke, J., (2000) Commitment Planning and Reasons Analysis, Proceedings of the International Group for Lean Construction 8th Annual Conference, Brighton, UK, July 2000, available at: http://www.sussex.ac.uk/spru/imichair/iglc8/31.pdf

Shum, S., B., (1998) Negotiating the Construction of Organizational Memories, Information Technology for Knowledge Management, pp. 55-78, Springer-Verlag, Berlin, available at: http://d3e.open.ac.uk/general/negotiating-org-mem/ (accessed: 5/7/01).

Vergison, E., (2001) Micro-scale Knowledge Management: A Necessary Condition for Getting Corporate Knowledge Properly Implemented, Industrial Knowledge Management: A Micro-level Approach / edited by Rajkumar Roy, Springer, UK.

Woodhead, R., Male, S., (2000) The Conditioning Effect of Objective Decision-making on the Client's Capital Proposal, Engineering, Construction and Architectural Management, Vol. 7, No. 3, pp. 300-306, Blackwell Science Ltd, UK.