IMPROVING BUILDING LIFE-CYCLE INFORMATION MANAGEMENT THROUGH DOCUMENTATION AND COMMUNICATION OF PROJECT OBJECTIVES

Robert J. Hitchcock[1]

ABSTRACT

Most currently available computer tools for the building industry proffer little more than productivity improvement in the transmission of graphical drawings and textual specifications, without addressing more fundamental changes in building life-cycle information management. This paper describes preliminary research into the development of a framework for the documentation and communication of the project objectives of a building project. When implemented in an interactive networked environment, this framework is intended to promote multiple participant involvement in the establishment and use of a common set of explicit goals, from the earliest phase of a project throughout its life cycle. A number of potential applications for this framework are identified. The requirements for integrating this life-cycle information with a product model of the physical design of a building, in an attempt to document and communicate design intent, are also discussed.

INTRODUCTION

Fragmentation is a defining characteristic of the building industry in the United States. This fragmentation has evolved in parallel with increasing specialization in the professional building disciplines, and is greatly exacerbated by the business model presently in place within the industry. While advancing computer technology has continuously promised a revolution in building information management, most currently available computer tools proffer little more than productivity improvement in the transmission of graphical drawings and textual specifications, without addressing more fundamental changes in building life-cycle information management.

This paper describes preliminary research into the development of a structured framework for the identification, elaboration, communication and interactive application of the project objectives of a building project. This framework will provide an informational foundation for an interactive forum intended to promote multiple participant involvement in the establishment and use of a common set of explicit goals, from the earliest phase of a project throughout its life cycle.

---

[1] Lawrence Berkeley National Laboratory, Building Technologies Program, Mailstop: 90-3111, Berkeley, CA 94720, USA, e-mail: RJHitchcock@lbl.gov, URL: http://eande.lbl.gov/CBS/BTP.html

The overall objective of this research is to develop innovative information management methods that can be used to facilitate communication between the numerous and diverse participants in the life cycle of a building or facility. This study addresses information flow in both forward and backward (as feedback) directions between all phases of the life cycle, including: conception and planning, design, engineering, construction, commissioning, operation and maintenance.

An underlying focus of this study is the potential for increasing energy conservation in buildings and mitigating other environmental impacts through improved life-cycle communication. However, the conceptual basis for this information management is generalized to all life cycle issues.

This research is part of a more extensive study of life-cycle information systems and building performance, being undertaken at the Lawrence Berkeley National Laboratory (LBNL). The Building Performance Assurance (BPA) program uses a life-cycle perspective on how information is managed in the building sector, to study means of promoting the achievement of energy, health and productivity performance potentials. This program seeks to develop a comprehensive information infrastructure for building project data exchange and archiving, with an early focus on the provision of information required to support standardized building commissioning process tools, and performance monitoring and evaluation tools for use during building operations and maintenance.

Assuring the desired performance of a building requires that commissioning agents and operations and maintenance personnel have access to the rationale behind the design of a building. The documentation and communication of project objectives is therefore part of the BPA program research because it is seen as an integral informational element in the representation of design intent.

BACKGROUND

Building Life-Cycle Information

The building life-cycle process is clearly complex and prone to fragmentation as it moves through its various stages. The number of participants, and the diversity, specialization and isolation (both in space and time) of their activities, has dramatically increased over time. This has been a requisite variety response to the ever increasing complexity of the act of designing, constructing and operating a building in today's world. The building industry has attempted to adapt to this increased level of complexity in a number of ways, but the predominant adaptation has been the development of growing numbers of specialists such as architectural programming firms, design and engineering consultants, construction management firms, and facilities managers. The prevailing business model within the US building industry, which tends to isolate the interests of client, architect, contractor and occupant, also exacerbates fragmentation by promoting adversarial relationships.

The power and flexibility of information management methods capable of supporting and integrating this variety of participants and activities over time and across space has not, however, grown proportionately. The required flow of information between all participants is enormously large, diverse and detailed. Yet this information flow must occur in an environment in which disconnected islands of information are created. Examples of these islands include the initial architectural program, building codes and regulations, design intent, architectural CAD drawings, design analysis models and results, contractor shop drawings, specification schedules, facility commissioning results, and operation and maintenance manuals and records. Under current practice, the bulk of this information is documented and communicated solely by means of voluminous hardcopy (printed) graphical drawings and free-form text documents.

Computers have had a noticeable impact on the mechanics of documenting these islands of building industry information through the use of productivity software such as word processors, and sophisticated computer aided drafting tools. Specialized computer tools have also significantly altered the work habits of existing building specialists such as structural engineers, and even spawned new specialists such as energy analysis consultants.

However, in many ways the advent of computerization has further isolated the existing islands of information and added to the complexity of information management rather than improved its performance. The proliferation of standalone computer tools, proprietary computer data formats, and the increasingly sophisticated manipulation of these data has made distributed sharing of the underlying information even more difficult.

The number and variety of papers presented at this workshop attest to the considerable effort that is underway in the areas of defining, implementing and applying electronic standards for the exchange of product models of a building. The international studies related to STEP (STandard for the Exchange of Product model data) and COMBINE (Computer Models for the Building Industry in Europe) described elsewhere in these workshop proceedings, and the recently announced Industry Alliance for Interoperability (Autodesk, 1995) are concrete examples of this work.

The research described here attempts to build on these efforts by adding the elements of project objectives and design intent to the information infrastructure of a building product model. Related work is underway at a number of universities and research locations in the areas of performance-based computer aided design (see Fenves et al., 1992; Kalay, 1994; Rosenman, 1992; Schmitt, 1992) and collaborative engineering (see Pena-Mora et al., 1995; Sriram, 1989). The content of this additional project information is identified, and its inclusion motivated, by a case study of the building life-cycle process.

Building Life-Cycle Process Case Study

A preliminary case study of a highly successful design, build and operate project in the San Francisco Bay Area identified project team-building, based on continuous participant communication, as the key element of project success. From the outset of this project, frequent meetings (at least one per week) were held between the principal decision-makers from each primary organization involved in the process, including: client/owner, architect, and contractor. According to interviewed participants, these meetings were allowed to deviate from a prescribed agenda, but always remained focused on relevant issues and never degenerated to the level of open ended conversation. Communication was always of high content quality and was free flowing between all participants. Minutes of each meeting were meticulously documented and distributed. The client/owner reported that excellent teamwork, communication and general rapport were established by these meetings.

The project architect agreed with the assessment of teamwork as the key contributor to project success and described the process of team building as built partly upon trust in each other's expertise and opinions, and partly upon understanding each other's interests and objectives. For example, the architect stated that the client team members were initially focused only on designing a facility that would house staff and efficiently group technical spaces. But through an educational process, the architect interjected aesthetic ideals without compromising function or budget. This was a two-way process that developed understanding and trust between the client and architect. The project architect stressed that participant buy-in to each other's project objectives was crucial. He felt that this buy-in could only be accomplished over time through explanation and education, and through give and take resolution of differences.

This case study indicates that there is a considerable amount of project related information that is not captured and communicated by means of production drawings and related documents, or even by electronic product models. The theme of teamwork focuses attention on the fact that a building project brings together participants from different backgrounds, with different areas of expertise and differing interests and objectives. To succeed, the resulting team must recognize these differences and work to develop a commonly agreed upon set of project objectives. How might this additional information be captured, represented and archived for best use by the project participants?

PROJECT OBJECTIVES

It is currently planned that a simple, yet flexible hierarchical organization of project objectives and their associated data can be used to represent and communicate this information through a distributed computing environment. In general, this hierarchical organization allows the representation of project objectives using an objective-goal-criterion structure. The root nodes of such a hierarchy allow the expression of high level objectives such as to "assure occupant comfort." Child nodes of the hierarchy then serve to refine these high level objectives by identifying constituent goals for achieving them (e.g., provide adequate illumination), followed by quantitatively defined criteria (e.g., minimum 500 lux illumination on work surface) by which to evaluate the satisfaction of each goal and its parent objective.

This hierarchical organization provides a structure for representing project objectives at both qualitative and quantitative levels. The qualitative level facilitates human description and communication of individual objectives. The quantitative level identifies the metrics by which building performance can be evaluated to assure that an objective has been achieved. It is not required that each branch of the hierarchy strictly adhere to the objective-goal-criterion sequence. Objectives that are inherently quantitative in nature could begin at the criterion level and use child nodes to identify sub-criteria. Objectives that are more qualitative in nature might require several intermediate descriptive child levels that refine the representation of the objective to a level at which it can be more explicitly defined.

This hierarchical organization also provides a flexible structure for tracking project objectives as they evolve over the life of the project. A complete body of project objectives cannot be clearly defined at the outset of a project. The set of objectives is bound to change by the addition, modification and even deletion of objectives, goals and criteria over the building life cycle. A hierarchy in which branches can be expanded or collapsed, added or deleted, and easily modified, offers considerable flexibility over time. The hierarchical organization of project objectives is thus meant to be a dynamic archival repository for both high level project objectives and their constituent sub-goals.

Life-Cycle Cost is one example of a more easily quantifiable project objective. Estimation and control of project cost is an obvious objective for any building project, and one which will ultimately be comprised of numerous individual cost centers. An example hierarchical branch illustrating one possible breakdown of a *Life-Cycle Cost* objective is shown in Fig. 1, below. This branch is defined solely in terms of criterion nodes, reflecting its quantitative nature.

- **Life-Cycle Cost ($Total, $/m2)**
  - *First Cost ($Total, $/m2)*
    - Design ($Total, $/m2)
      - *Planning ($Total, $/m2)*
      - *Schematic design ($Total, $/m2)*
      - *Design development ($Total, $/m2)*
      - *Detailed design ($Total, $/m2)*
    - Construction ($Total, $/m2)
      - *Management ($Total, $/m2)*
      - *Labor ($Total, $/m2)*
      - *Materials ($Total, $/m2)*
      - *Equipment ($Total, $/m2)*
  - *Operation and Maintenance Cost ($Total/yr, $/m2/yr)*
    - Energy ($Total/yr, $/m2/yr)
      - *Heating ($Total/yr, $/m2/yr)*
      - *Cooling ($Total/yr, $/m2/yr)*
      - *Lighting ($Total/yr, $/m2/yr)*
      - *Ventilation ($Total/yr, $/m2/yr)*
      - *Equipment ($Total/yr, $/m2/yr)*
    - Labor ($Total/yr, $/m2/yr)
    - Materials ($Total/yr, $/m2/yr)
    - Equipment ($Total/yr, $/m2/yr)

Figure 1. Example hierarchical branch for Life-Cycle Cost objective.

The following description offers one scenario of the evolution of this branch over time. Initial feasibility assessments of a project are often based on order-of-magnitude estimates of total project cost. At the early planning stage of a project, therefore, the root level *Life-Cycle Cost* criterion may be all that appears in this branch of the hierarchy, quantified as either a total dollars or a dollars per square meter estimate based on previous similar projects. As project assessment moves ahead, component criteria of *Life-Cycle Cost* such as *First Cost* and *Operation and Maintenance Cost* may be added and similarly estimated using only historical data. When more detailed planning is undertaken, target values for cost centers such as those for *Detailed design* and *Heating energy* can be identified and added to the hierarchy. With these more detailed estimates available, *Life-Cycle Cost* could then be calculated using net present value methods for reference during later stages of the project.

Occupant *Comfort* is a project objective that is less easily specified and quantified than *Life-Cycle Cost*. An example branch is shown in Fig. 2 that refines *Comfort* from its objective level node to some of its possible criterion nodes. At the root node, *Comfort* may be simply a textual statement of concern for this aspect of building performance, or it might be quantified by using some unitless metric based on a relative rating scale to indicate the desired level of comfort for a given project. For example, a lower level of comfort is required for a building intended for storage or circulation purposes as opposed to an executive office building. With sufficient information, *Comfort* might be more clearly specified using constituent goals such as *Thermal Comfort*, *Visual Comfort* and *Air Quality Comfort*. Since these sub-goals are also primarily subjective in nature, they might be only a textual refinement of the parent objective or, again, individual rating scales might be used to quantify them. It may not be until these branches have been extended to the next lower level that criteria in the form of concrete metrics become available. As one example, *Visual Comfort* could be defined in terms of desired *Illumination* level (e.g., 500 lux) and maximum acceptable *Glare* level (e.g., 10:1 luminance distribution).

- **Comfort (rating)**
  - *Thermal Comfort (rating)*
    - Heating (min °C)
    - Cooling (max °C)
  - *Visual Comfort (rating)*
    - Illumination (lux)
    - Glare (luminance distribution)
  - *Air Quality Comfort (rating)*
    - Ventilation (min cfm)
    - Filtration (TLV)

Figure 2. Example hierarchical branch for Comfort objective.

These two examples are meant to illustrate relatively simple representations of individual project objectives using a hierarchical framework. It is recognized that not all project objectives will lend themselves to such straightforward representation. Research is still required to identify flexible methods for representing more complex criteria such as probability distributions, time-series data and conditional criteria.

The ability to add or delete entire objective branches or individual goals or sub-goals within a hierarchy, and to fully define each objective with its relevant attributes, provides an extremely flexible, yet potentially comprehensive framework for the formal elaboration of project objectives. When implemented in an interactive networked environment, this framework would serve as a dynamic distributed forum for the explicit expression of what are often implicit, but always powerful motivating forces in the life of a project. Thus, while a hierarchical structure of project objectives may at first appear to be yet another isolated island of information, its contents and its dynamic nature allow it to become an integrating element within the maze of project information.

DESIGN INTENT RESEARCH

Research has begun within the LBNL BPA project on methods of documenting and communicating design intent over the life cycle of a building. It is felt that a flexible representation of design intent may become possible when the structured documentation of project objectives is integrated with a product model of the building design, and information related to the context within which the building will be operated. It is therefore proposed here that there are three primary informational elements required to represent design intent: project objectives, a product model of the design, and design context assumptions.

Project objectives are the stated performance goals that a particular building design is attempting to achieve. The product model is a complete detailing of the physical components of a building (e.g., walls, windows, HVAC system) and the dynamic operation of the building systems (e.g., lighting and HVAC system control). Context assumptions define the operating environment within which the building has been designed to achieve the stated project objectives. For example, the micro-climate at the building location contains a complex set of context assumptions. A simpler example might be the design day cooling load, and safety margin, used to size an HVAC system chiller.

Design decisions are the processes by which building components, systems and operation procedures are synthesized to achieve the identified performance objectives under the assumed operating context. It may therefore be possible to represent design intent by clearly identifying the relationships between project objectives, context assumptions, and design description elements.

Documenting the relationships between various design intent elements requires powerful and flexible methods for associating a wide range of element groupings. For example, a design intent may link a single visual illumination objective, 8760 hours of exterior illumination data (the context assumption), the visible transmittance of twenty windows, the visible reflectance of 6 interior room surfaces, and 10 electric lighting fixtures. Or, the intent might instead link multiple visual comfort and energy cost objectives with multiple climatic assumptions, a complex operation procedure, and all windows in the south wall of a twenty story high-rise. A method of documenting this variety of relationships has not yet been developed.

Also, some method of tracking the evolution of design intent elements over time is required. Each type of informational element, and individual elements within a given type, may be modified independently. For example, a context assumption regarding building cooling load may change due to a reassessment of the heat generated by a new model of computer used in the building. It is important not only to be able to track this change in a context assumption (the building cooling load), but also to be able to identify possible impacts on other design intent elements such as chiller size.

The most straightforward use of design intent information over the life cycle of a building project is as human readable documentation of this information that can be collaboratively created and reviewed by all project participants. This interaction requires a user interface that allows easy yet powerful distributed modification and browsing of the design intent information. Modification capabilities provide the mechanisms for expressing and capturing design intent as a building project proceeds. Browsing capabilities could be used to perform a complete review of all objectives, context assumptions, design elements and their relationships. Alternatively, a user could selectively search through the design intent information for a particular purpose (e.g., identify all design elements related to a specific objective).

A second approach to making use of the design intent information is through computer automation. One such application could be automatic re-analysis of a newly proposed building design based on the objectives that are related to the proposed modified design elements. Another application, given an effective version control mechanism, could be the recreation of the intermediate stages of evolution in a building design. This application could be of particular use in commissioning and O&M tasks that require a history of the building design and its performance.

CONCLUSIONS

It is proposed here that both project objectives, and the building design, emerge and are continuously modified throughout the life cycle of a facility. This is an obvious fact for the design of the physical building, and much current effort is expended in communicating this design information. It is not so evident that the project objectives are also subject to significant modification over time. Nor is a great deal of effort expended in making these objectives explicit and sharable. It is further proposed that by making project objectives explicit and representable in a consistent format, much of the currently implicit (or even hidden, misrepresented, misunderstood) intent behind design, construction, and operation decisions can be more clearly communicated, and the overall building process can be more efficiently and effectively performed and managed.

The explicit structured representation of objectives has potential application in the following life-cycle processes:

- multi-participant identification and specification of project objectives beginning during initial facility programming and continuing throughout the life cycle.
- technology transfer of research expertise in the form of desirable and achievable objectives and their performance targets.
- structured dissemination of codes and regulations.
- multi-attribute indexing and retrieval of existing solutions from a design case-base.
- multi-criteria evaluation of proposed solutions during design.
- comprehensive assessment of design changes during construction, operation and maintenance of a facility.
- reference to design performance targets during commissioning of a facility.
- formal evaluation of the constructed and occupied building to provide organized feedback on the success or failure of the real building performance, both for

continuous commissioning of the occupied building and for the future design of similar buildings.

It is also proposed that a structured representation of project objectives is a primary informational element required for the representation of design intent. It is believed that design intent can be effectively documented and communicated by properly integrating this structure with a product model of a building design, and the design context assumptions. The principle requirements for this integration, identified above, are methods for representing the relationships between various design intent elements, tracking the evolution of design intent elements over time, and modifying and browsing the overall body of design intent information. Research is still required into the details of the development of these methods.

REFERENCES

Autodesk, Inc., 1995. Press release at A/E/C Systems '95, June 5, 1995.

Fenves, S., Flemming, U., Henderson, C. and Maher, M. 1992. "Performance Evaluation in an Integrated Software Environment for Building Design and Construction Planning," *Evaluating and Predicting Design Performance,* Y.E. Kalay, ed., John Wiley & Sons, New York, NY.

Kalay, Y.E. 1994. *Performance-Based Design: When Form Does Not Follow Function,* working paper. University of California, Berkeley, California.

Pena-Mora, F.; Sriram, R. and Logcher, R. 1995. "Conflict mitigation system for collaborative engineering" *AI EDAM* 9(2): pp.101-124.

Rosenman, M., Gero, J., and Maher, M. 1994. "Knowledge-based design research at the key centre of design computing." *Automation in Construction* 3(2-3): pp.229-238.

Schmitt, G. 1992. "Design for Performance," *Evaluating and Predicting Design Performance,* Y.E. Kalay, ed., John Wiley & Sons, New York, NY.

Sriram, D., Logcher, R., Wong, A. and Ahmed, S. 1989. "An Object-Oriented Framework for Collaborative Engineering Design." *Computer-Aided Cooperative Product Development: MIT-JSME Workshop,* Sriram, Logcher, Fukuda ed., Springer-Verlag. Berlin, Germany.