Design for Life

For buildings and infrastructure facilities, the current adage is “design to build”. The goal of the design team is to create a set of paper documents which convey to the contractor how the facility is to be built. If we instead consider the entire life of the facility, the goal should instead be “design for life.” By considering the maintenance and operation phases of the facility as well as subsequent improvement projects, the results of design will be more cost effective facilities.

I have been a long time advocate of a life cycle approach to facility management, beginning with my work at Penn State on Dr. Albright’s Project MODCON over twenty five years ago. Over these twenty years I have participated as an academician, a practicing civil engineer, and a software developer and consultant. I have worked with Stanford’s CIFE, Penn State’s Architectural Engineering Department, the National Academy of Sciences / National Research Council / Building and Transportation Research Boards, ASCE, AASHTO, ANSI, ISO, the OpenGIS Consortium, and numerous clients, focusing on the vision of an integrated approach to facility life cycle management.

The technology framework has certainly changed over those twenty five years. My current laptop dwarfs the IBM mainframe used for MODCON in every aspect except physical size and cost. Relational Data Base Management Systems are now ubiquitous. Having saturated the market for mainstream business applications, RDBMS vendors are now ready to address less conventional markets with support for full text, spatial, image, and temporal data. The forthcoming SQL’99 and SQL/MM Spatial standards will soon usher in a new era of object-relationalism. Objects are finally gaining acceptance, with new methodologies (UML), and languages (Java). They offer the potential to change the very sustenance of our design lives, as CAD products such as MicroStation are transformed into ECM (Engineering Component Modeling) products like MicroStation/J. And the Internet provides an entirely new forum for cooperative engineering.

We have come a long way in these twenty five years with regard to our application of computer technology to the construction industry. Computer Aided Engineering (CAE) on a mainframe with COGO, STRUDL, and DOE-2 has been replaced by desktop software with a GUI instead of a POL. CAD is now the norm, with de facto standardization based on DGN and DWG. CAE Integration with CAD has progressed considerably. CAD and DBMS integration has shown less progress but Spatial Data Base Management Systems, requisite for enabling GIS to achieve its ambitious enterprise-wide goals, will help this over the next decade.

Utilizing these new technologies, horizontal integration within the design phase of the facility life cycle is progressing. Enough knowledge has been gleaned from prior research to enable adoption and implementation. It is therefore time to focus our breakthrough research efforts relating to the vertical integration across life cycle phases.

I have participated in several vertical integration efforts. At the Building Research Board's Woods Hole Workshops on an Integrated Database, we demonstrated how information could pass from planning to design to construction to maintenance. With 85% of a facility's cost occurring after it is built, it made sense to spend more on design and construction if it meant saving during maintenance and operation. The approach appeared sound, though the requisite SQL*CAD (object-based CAD plus RDBMS) technology was just emerging.

An integrated database was constructed as part of the design of the $6 Billion Wastewater treatment facility. Over a dozen engineering firms contributed to what appeared to be a single, integrated design. Design contracts focused on a single facility at a time. The goal was to provide a database for maintaining the facility once it came on line. Then, the focus would be on systems, not facilities. Though the design came in on time and under budget, the Woods Hole vision was never achieved. It was a constant struggle getting the designers to think of the contract documents as a report generated from a facility SQL*CAD model. It was impossible to get them to enter even a minimal amount of design intent information, like what a valve was needed for, even if this would be invaluable to the owner. We were not allowed to speak to the people who would maintain the plant to determine their information needs. The owner failed to recognize the value of the information in the design database. In the end, they converted a subset of the design database into layer-based CAD drawings, losing all of the rich semantics of the SQL*CAD database that was delivered.

Yes, our culture must change. First, we need to demonstrate the benefit of an integrated approach. Then we need to overcome the monetary and litigious design-centric interests that prevent vertical integration. Since the primary beneficiary is the facility owner, I will let him deal with these issues. I am concerned more about process improvement and the technology to support it.

Many modeling efforts have attempted to learn more about the design process. How many have focused on maintenance and operations. How many have focused on multiple life cycle phases? How many have focused on the life cycle phase interfaces? Understanding design is important. But understanding what design can begin with from the planning phase and what it needs to deliver to the construction and, more importantly, subsequent phases, is critical if we are ever to achieve this vision. At Woods Hole, we debated about whether we should "push" all of the design data ahead to maintenance and operation or if instead we should gain a better understanding of what is needed there and then "pull" only what we may need to support these later activities. The cost of collecting, entering, storing, and maintaining data argues for the latter.

After we understand the process, and therefore the needs, we can begin to apply some of this new and wonderful technology finally at our disposal.

During design, CAD and CAE have become the dominant technologies. Not being mainstream IS, they have evolved somewhat in isolation from the rest of the enterprise. During planning, GIS has made some progress lately, but mostly by a relatively few, specialized individuals within an organization. Maintenance and operation are the next fertile ground. Served mostly by legacy, mainframe, file-based software systems, the opportunity exists to reengineer the technology as well as the process. I predict that a melding of GIS and CAD technologies will emerge and evolve into spatially, temporally, audibly, and visually enhanced Operations and Maintenance Information Systems. But this must be integrated with the isolated technologies currently prevalent in planning and design if we are to achieve our vision.

In order to achieve this Integrated Database vision, there are still many technology issues to solve. Several of these have profound implications on our ability to implement such systems.

Integrating levels of abstraction. GIS basemaps are typically 1:24,000 scale whereas engineering drawings may be 1"=50' (1:600). A GIS may use raster or linear approximations whereas engineering requires precise curves. A GIS may represent an interchange as a single node yet a oversize vehicle routing system may require knowledge about the individual loops and ramps which comprise the interchange and a snowplow routing program may need to further understand the individual traffic lanes. How are these different levels of abstraction integrated?

Continuous objects. Most object technology, including object modeling, is predicated upon objects being discreet. This works fine for windows and doors. But where does a road start and end? When does it become the next road object?

Object evolution. Planning deals with concepts; design with projects; construction with contract pay items; and operation and maintenance with systems. During planning, we may specify that exposed interior columns should be massive, square and painted drywall in the atrium of a building. All the columns are dealt with as a collective whole. The as-planned columns begin at the floor and end at the ceiling; it is their appearance that is of concern. During design, we add more detail to what is behind the drywall, analyzing candidate steel sections from loads and structural properties. Columns take on an individual identity as each may be subjected to different loads. The designed column may now extend across floor levels. As we move into construction, columns may again be grouped, but this time based on similar size, shape, and connection details. If the column at B-1 is identical to the ones at B-2 and B-3, there is no reason for the steel fabricator to distinguish them as three separate object instances. For maintenance, the column becomes a paintable surface, indistinguishable from other neighboring columns and even perhaps from nearby columns from an different design project. The facility may have a clear life cycle, but it may not be quite as simple for individual facility components.

Each phase is concerned with its own set and view of objects. First we need a better understanding of these objects and views. Then we need to better understand how objects in one phase evolve into objects in a subsequent phase. We need ways to trace their lineage back to previous phases. It is not a simple schema evolution problem where object attribution changes over time. We have to be able to deal with object transformations as we move from as-planned components to as-designed components to as-constructed, as-maintained and as-operated components.

Heterogeneous data sources and clients. As we move across phases, it will often be the case that data may be stored in a variety of manners in different systems on different hardware and software platforms. How do we decide what the “best” source of a particular data item is, and then combine it with other data to present it to a client software which may expect it in yet another format. There will never be a single, “best” data storage technique. Even if there were, by the time everyone was convinced to use it and migrated all of their data and applications, there would be a new “better” solution.

Project vs. facility. A facility may be constructed over time by a continuum of design / construction projects. How do we assimilate the individual project outcomes into a unified model of the facility while at the same time, retaining the project lineage and temporal implications.

Temporal. Design and construction projects may span decades; facilities may live for centuries. Unless we can better deal with temporal aspects of facility components, vertical integration over these long periods of time will be impossible.

It is time to change our design focus. The next great breakthroughs in research need to address the vertical integration across the planning, design, construction, maintenance, operation, and retirement phases of the life cycle of a facility. We need to begin to design for life, not just construction.

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Penn State Project MODCON; Life Cycle Modeling Project
Woods Hole Integrated Data Base Workshops
NCHRP 20-27(3) Linear Referencing Workshop
JCCE paper review
OpenGIS Consortium Technical Committee
ANSI NCITS H2 Database Committee (SQL'99)
ISO SQL/MM US Delegate

Massachusetts Water Resource Authority Deer Island Project – designed the CAD applications resulting in the SQL*CAD integrated design database.
Boston Central Artery Project – designed the life cycle drawing management system.
Minnesota DOT – technical lead on Linear Referencing and Design Data Conceptual Modeling efforts