AEC 2000-2025: Visions, Opportunities and Issues

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Abstract

The AEC industry *will* change fundamentally in the next generation, say 25 years. The computer has started to have profound but predictable effects on AEC professional practice. This paper argues that AEC Design and Construction will move toward *Desktop Engineering*, in which small numbers of computer-based professionals have major responsibility for design and management of entire facility development projects. Most individual practitioners will beconme experts or generalists. Business practice will become more integrated than is now the routine case. Information Technology enables Desktop Engineering, providing educational and professional development requirements and research opportunities. Simultaneously with these dramatic developments, competition will increases for the attention, time and budgets of clients, partners, students, and sponsors. Positive outreach will be needed to develop good clients and vendors, attract good students, and support research. These changes suggest a set of practical and research needs for the AEC academic and professional communities, including modeling tools, methods and examples; significantly improved visualization. In addition, there is need for effective outreach to current and prospective clients, students and sponsors. Research issues relate to the needs: modeling, visualization and validation. At a high-level, this paper introduces effective methods to assess research status.

Vision of future design and construction

The AEC industry *will* change fundamentally in the next generation, say 25 years. The product – built facilities—will become increasingly complicated and integrated into the local, regional and global communities. The design-construction time will shrink markedly from current practice. The work of practitioners will change dramatically as computer methods impact the routine practice of design and construction management. The industry and practice *may* change in other ways. Increased outreach may involve more stakeholders in design-construction review. The stature of the Civil Engineering professional may rise in western society, but it may fall. For similar reasons, the quality and number of Civil Engineering students and the Civil Engineering research support may also rise, but they may fall.

AEC Design and Construction will move toward Desktop engineering

Desktop publishing has revolutionized the way that authors prepare papers. In the "old days" before the mid-1980's, an author would write a paper, probably longhand, and give it to a secretary for typing. Over a period of days or weeks, text and illustration drafts would be received, modified, updated, and finally integrated. A paper typically had a small number of drafts. In the contemporary era of ubiquitous desktop publishing, authors prepare all facets of a document, including text, formatting, graphs, tables, and all but the most complex illustrations. Aided by desktop publishing tools, authors do copyediting, spell checking, grammar checking, figure preparation, tables of content and indices. Authors share scores or hundreds of drafts with each other electronically.

Desktop engineering tools have started to enter AEC practice. Desktop engineering will have similarities with the current practice of desktop publishing. Using integrated desktop engineering tools, a single specialist or small team will develop a design concept. The small development team will consider the suggestions from multiple computer-based critiquing systems in developing an initial concept. The designer will send design versions electronically to human engineering consultants for their review and suggestions. Powerful and inexpensive computers enable the movement to desktop engineering. Effective and well-integrated suites of CAx applications also support this movement. There are now functioning examples of a number of theoretical and technical developments that contribute to the emergence of desktop engineering, including formalization of engineering process theories, integration of diverse engineering practices, and the rapidly emerging effectiveness of symbolic models of artifacts and systems to represent designs and processes.

Desktop publishing and engineering systems share a number of properties.

Small number of users

Desktop engineering centralizes authority and decision-making responsibility on one or a handful of users. Decision-makers can obtain automated suggestions from multiple perspectives and can send a set of recommendations to other human analysts. The total number of design and construction management professionals may decrease, or increased volume and complexity may increase the numbers of practitioners.

Individual practitioners are experts or generalists

The Desktop engineering users necessarily are generalists: they setup the computer to analyze a number of engineering perspectives, and they balance the competing demands of different perspectives. The generalist will need specialist consultants to help understand and resolve difficult engineering issues. The semiconductor fabrication industry has developed large numbers of highly specialized engineering disciplines, for example design, fabrication and installation of small bore piping made of exotic materials. Current academic training and the business models of many design and construction firms lie firmly in the middle of this generalist-specialist spectrum, and staying there incurs the risk of becoming marginalized.

Business practice will become more integrated

The benefit of desktop engineering comes from implementing a systems approach to design and construction. The cost, risk and reward need to be distributed across all business participants. An integrated business model must emerge to incent designers to develop “improved” facility models and to incent contractors to help designers develop improved design practices. Integrated design-build companies are one current step in this direction.

Information Technology enables Desktop Engineering

Desktop Engineering requires extensive design and process models to be implemented in the computer. Additional emerging technologies have started to enable interoperability of applications and ability of stakeholders to share desktop applications. New interface technologies enable new displays and allow non-AEC stakeholders to analyze and comment on design and construction models.

Competition increases for attention of clients, partners, students, and sponsors

Stakeholders in the AEC process include clients, facility users, business partners, current and potential students, and research sponsors. All of them receive large numbers of solicitations of their interest, some of which appear compelling. Most academics want increased interest of students, partners and sponsors. With the internet, consumerism and competing educational, career and research demands, it will be difficult for the AEC community to maintain its current position in the minds, hearts and budgets of current and especially new stakeholders.

Practical needs

The AEC field has practical needs that translate directly to research and outreach needs.

Modeling tools, methods and examples

AEC design and construction management are well served by mathematical models. Graphic modeling tools are well established but comparatively primitive. Symbolic models are just starting to penetrate into the research community and software vendor development projects, but they have not had significant impact on education or practice. Researchers, students, software developers and users require vastly improved tools to develop symbolic models of facilities and processes, improved modeling methods and many new practical use examples. Appropriate computer science tools are available; the research issue is to identify the appropriate engineering content of product and process models.

Visualization

AEC projects are maddeningly complex, and clients impose acute time-pressure on development. Effective visualization of both product and process models is required to enable all facility stakeholders to understand models, identify their impacts on their own lives and work plans, and identify impacts on other stakeholders. The opportunity for new model visualization is completely open.

Outreach

The AEC community needs to solicit the heart, time and budget of stakeholders. NASA is one example of effective outreach; it continues after 40 years to attract passion from highly gifted young students and enormous research funding. Internet companies new attract passion from the gifted young and deep-pocket investors. AEC competes with space and the Internet startup for students, corporate attention, and research support.

An important observation is that the stakeholders will need to collaborate on outreach. Academia needs to solicit the guidance, test cases, validation procedures, and financial support of industry and government to develop outreach programs that engage the interest and passion of professionals and non-professionals alike. Facility stakeholders lie throughout the economy, so outreach needs to include secondary schools and universities, business and governmental groups, and AEC professionals. Outreach objectives include developing awareness of the role of the built environment on people's lives, developing a sense that appropriate tools now enable the engaged interest of stakeholders, and developing an interest in and skills to participate in the facility development process.

Methods to Assess research status and progress

CIFE Assessment methods

CIFE researchers have used a broad range of research methods. Table 1 shows the way that we summarize research objectives and methods of recent projects. In general, earlier investigators focused their work using objectives and methods summarized on the left side of the table, and later investigators have focused their work using objectives and methods summarized on the right side of the table. In addition, earlier investigators focused their work on a small number of objectives and methods, while later investigators have considered multiple objectives and methods. Much AEC research can be assessed in the issues that this table summarizes.

Research Objectives:	Benchmark Processes	Automate existing process	Integrate processes	Reengineer process
Major deliverable:	Survey results	Algorithm(s)	Architecture	Symbolic model
Kind of analysis of system behavior:	Complexity	Formal	Informal	
Research method:	Present algorithm	Formal methods	Define model semantics	Formulate, test hypothesis
Example type:	Abstract	Synthetic	Industry	
Number of tested examples:	None	1-2	>2	
Kind of knowledge modeled:	Statistical	Heuristic	Engineering Principles	
Conclusions about:	Prevalence	Performance	Generality	
Testers:	Developer	Students	Industry engineers	
Compare results with:	Developer Specification	Theory	Experts 'Specification	Observed Practice

Table 1: Research methods. The principal research objectives and research methods of AEC research projects fall into one or more categories. Projects can be assessed by where their work fits in the issues of this table.

Research Objectives: Projects include one or more of the following objectives:

- Benchmark processes using industry surveys to identify the nature, extent or effectiveness of some industry process
- Automate an existing process
- Integrate two or more automated processes
- Reengineer a process using IT in new ways. This objective has the greatest opportunity to make significant impact on research method and industrial practice.

A project might develop and present different kinds of conceptual artifacts as a major deliverable, including:

- Survey results;
- Algorithms**;**
- Architecture of a system that is designed to serve some function;
- Symbolic model of a product or process. This last kind of deliverable has had the most impact on future research and practice.

Usually, investigators analyze their deliverables (survey results, algorithms, models or architectures), not simply present them. They could analyze their deliverables statically, although such static analyses have been used only occasionally in CIFE research. More commonly, they may analyze behavior of their systems against industry test cases. Kinds of analyses of performance include:

- **Complexity analysis** to describe the theoretical or actual time that an algorithm requires to analyze a carefully described range of problems;
- **Formal analysis** to describe the results of proofs about some property of an algorithm or well-designed statistical analysis of some survey data.
- **Informal analysis** to describe the results of validation studies of the use of an algorithm or model.

Projects use one or more research methods. Creating model semantics and testing hypotheses have the greatest impact on research methods and industrial practice. Projects:

- Present **algorithms** to describe procedures to perform some task in support of automation, integration or reengineering.
- Develop **formal theorems, proofs or statistics** to describe algorithms or observations about industry practice.
- Define **model semantics** by building a symbolic model of products and processes and building methods to analyze those models.
- Create **testable hypotheses** that describe some interesting aspect of current or potential engineering practice.

The research always analyzes some sort of example for problem definition and, often, for testing of the behavior of a system or algorithm. Types of test cases include:

- **Abstract cases;**
- **Simple, realistic cases** defined by the investigator to demonstrate some approach.
- **Industry-supplied realistic test cases**. Industrial test cases are far more interesting and influential than other types of cases.

Projects consider different numbers of test cases. A small number of cases (1-2) is easier for the investigators to manage and analyze in detail, but small numbers make it difficult to make claims about generality. Larger numbers enable statistical studies and conclusions about generality, but it usually is difficult to analyze more than a few cases in any significant engineering detail.

Investigators build theories by representing and analyzing different kinds of knowledge. Each of these kinds of knowledge has a valuable role in AEC research and practice.

- **Statistical**
- **Heuristic**
- **Engineering Principles**

As part of the validation process, investigators may make conclusions about the prevalence in engineering practice of certain procedures or outcomes or the accuracy (i.e., performance) of their models with respect to a set of test cases. They may also try to identify the generality, or the extent to which a method covers the breadth of an area of practice. The most interesting projects consider performance and generality.

Developers may test their own software implementations of theories, although developers often do not recognize the limits of their own designs. Recently, some investigators have done testing with students in classes who can use computers with little additional training, although they lack broad industry experience. Some investigators also bring industry engineers to the laboratory, train them in the use of a new computer system and ask them to test their systems. Successful industry involvement generally precedes industrial interest.

Ideally, testing involves comparing system performance results with a "gold standard" method that makes repeatable, accurate predictions. Because engineering practice involves so much judgment, it is unusual to be able to define gold standards for interesting problems. In the absence of a gold standard, investigators take different approaches to testing. Typically, it is valuable to use all of these methods.

- **Developer specification**
- **Experts' specification**
- **Observed practice.** Using this method, it is possible to turn the question of the potential impact of research on practice into an empirical question, which is always the most interesting kind of question.

Personal statement

My academic interest in AEC started as an undergraduate at Thayer School of Engineering at Dartmouth College, the first American school of Civil Engineering with a tradition that was inculcated by both lore and practice. This experience provided a first serious exposure to the joy building things that got used, interdisciplinary engineering, and methods and value of modeling. Subsequent professional experience included use of Information Technology — later Artificial Intelligence — in medicine, manufacturing, and many fields of engineering. My underlying professional passion focuses on teaching, development and use of non-numeric (symbolic) models in engineering and use of scientific methods in research. Current and recent projects include developing models of engineering products and processes, organizational modeling, automated construction planning, developing symbolic P&IDs, and automated building code checking.