Chapter 2: How Engineering Software Has Changed The Way We Work

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2.0 Introduction:

Let's face it: Our jaws drop watching the speed with which software can generate designs. I've seen it happen, watching engineering software vendors demonstrate how to design an entire steel building in a day or so. This is awesome stuff. This powerful thing, the computer, can be intoxicating. On the flip side, this power can be disturbing, particularly if it challenges the way we presently do our jobs. The playing field is constantly changing below our feet, and each of us is asking what we need to learn next.

What exactly is that software vendor doing? Is he "designing"? Or is he "pushing buttons"? And does it matter if "pushing buttons" achieves the same – perhaps even better – results than the old timer doing hand calculations? Is our profession defined by what software we use? These are big ethical questions that every engineer should think about.

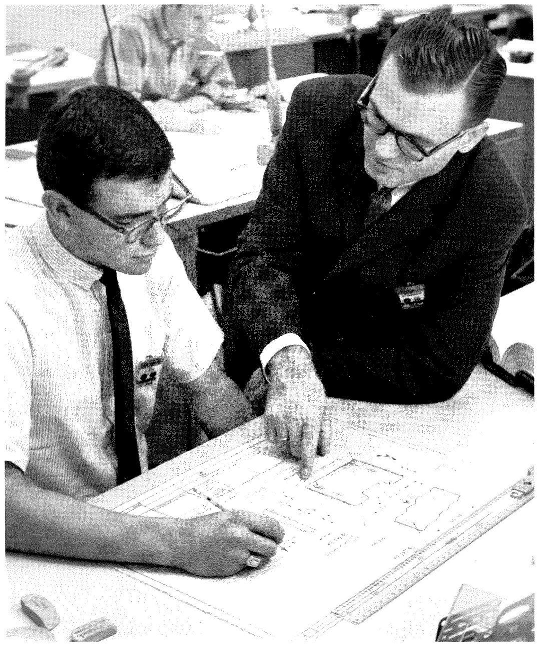
In this chapter, I offer my own perspective about our profession and how it is changing. In my view, we are at a crossroads, with the rest of the world, where computers have changed forever the way we do things.

2.1 A Personal Perspective on How Engineering Is Changing:

Presently, two generations of engineers coexist in the working world: The Boomers (children of World War II Greatest Generation), and the Children of the Boomers. I myself fall into the category of the Boomers. After I graduated from college and began my engineering career, there were no personal computers. Some of the older engineers still used slide rules, not even trusting calculators! I listened and learned from older engineers telling stories about the projects they worked on and the approaches they used.

Now I'm going to sound like an old timer. The following will be a lecture about the changes that I've observed in our profession recently. A lot has been written about great engineers of the past. I believe that a proper perspective of our profession's recent past is also needed, because changes have occurred at warp speed in terms of history. (For a larger perspective, the book to read is "The World Is Flat – A Brief History of The 21st Century", by Thomas Friedman).

Since personal computers were introduced, the way engineers work has changed radically. The world has undergone dramatic changes due to computers and the Internet, no less significant than the invention of the printing press. The old days were not "all good", and I will try not to reminisce. The future has tremendous potential; but there are potential abuses that we need to anticipate.



Courtesy Douglas Aircraft, Inc.

<u>"The Old Days"</u>
(A picture taken from my old drafting book, "Technical Drawing", 1968.)

In "the old days", sometime before 1990, prior to personal computers,

- Engineers worked in a linear fashion.
    - They worked everything out "by hand", using a No. 2 pencil on graph paper.
    - They understood every number (otherwise they could not proceed with the design)
    - Structural analysis was a "big deal". Many engineers did analysis using moment distribution and other methods in lieu of paying for mainframe computer time to run structural analysis packages.
    - For every structure a philosophy was developed for the flow of forces, prior to doing analysis. This also remains true today, but it had particular relevance before personal computers because of simpler methods used.
- Engineering work was checked in a linear fashion
    - You could not check the design until the calculations were finished.
    - The "designer" and the "checker" were usually different people
- Engineering codes were simpler
    - Fewer equations and shorter specifications. (If we go way back, at one time there was only one way to design: Allowable Stress)
    - Many engineers used simple shortcuts for their designs (I knew one man who could design four grade beams on one calculation sheet! He was phenomenally productive)
- Engineering books and journals were the only technical resources
    - There was no Internet, "Help" files or "wizards". Books were it. Engineers consumed a staple diet of the writings of Timoshenko, Terzaghi, Peck,

Bowles, Lin, Teng, Winter, Heins, Blogett, Salmon and Johnson, to name a few of my own favorites.
  - Books with design examples, such as the "US Steel Highway Structures Design Handbook" and "Design Of Welded Structures", were commonly referenced and used as a model for writing calculations.
  - The best engineers had - and remain to have - a good understanding of fundamental "Strength of Materials" by Stephen Timoshenko and his contemporaries.
- Computers were mainframes.
  - Engineers connected to mainframes through clumsy terminals.
  - The time using a mainframe program cost money.
  - Input was required in fixed fields. It was very easy to make a mistake causing programs to crash.
  - Engineers did not do their own word processing. Typically secretaries or word processing personnel did these tasks.
- Some engineers wrote their own software applications
  - Engineers programmed in Fortran.
  - Later, with the introduction of personal computers with DOS, some engineers wrote applications in Qbasic and QuickBasic
- Larger firms developed their own software applications
  - Many of these firms employed engineer/programmers to develop proprietary software
- Engineering software was not commercialized in the manner that it is today
  - Many applications were developed at universities paid by federal grants. Much of this software was free public domain software.
- Spreadsheet programs did not exist.
- The Internet did not exist.
- CAD did not exist
  - Detailers and draftsman prepared drawings for engineers. Many detailers were highly skilled. Engineers prepared pencil sketches for the detailers.
  - All engineers had taken drafting courses, usually in high school and college.
  - Preparing drawings was much more labor intensive.
  - The location of a hand drawn detail stayed put. Hand drawings could not be moved around or zoomed.
  - Most of us didn't know what the word "font" meant. Detailers simply used block letters. Each detailer had his individual style of lettering. "Good lettering" required talent, a steady hand and a sharp pencil!
  - Of course, there was no such thing as "layering" or "Xreferencing"
  - There was no such thing as "cutting and pasting" details from other jobs, unless this was done photographically.
- Project Management was practiced differently than it is today
  - Supervising usually involved "squad bosses" updating drawing progress using drawing lists.

<u>Today's Engineering Office</u>
("where's the drafting board?")

Today, due to personal computers engineers work in quite a different manner:

- Spreadsheets have had the most significant impact on the way we prepare calculations.
    - These applications empower non-programmers to write static project specific solutions. Many firms are heavily reliant on reusing spreadsheets and math/word processing calculations from project to project.
- Structural analysis packages can solve complex structures without the engineer needing to learn a bit of theory.
- Engineers no longer need to solve complex geometry problems, because CAD provides geometrical information.
- Engineers buy software products in lieu of creating their own software solutions.
    - We are essentially "buying knowledge"
    - No longer do engineers need to discuss the fundamentals of F.E.M. analysis methods. Instead, engineers discuss brand names of analysis software and how these programs operate.
    - We are constantly exposed to advertising hype for software applications in engineering publications
- Very few engineers are able to write programs for the Windows operating system
    - There is a conflict in methodologies between old Fortran based applications and today's graphically oriented software.
    - As a result, many practicing engineers and researchers who in the past could write their own applications stopped writing code.
- The Internet is an incredibly powerful new resource in our lives and work
- Today's engineers have many more resources available to them besides books
    - The Internet, "Help" files, "wizards", website, web user groups, software tools supplement information found in books and journals

- A paradigm shift has occurred from book oriented design to software oriented design.
    - Younger engineers easily jump into performing complex analysis prior to making conclusions about a structure's behavior.
- Drawing production has changed radically since the introduction of CAD
    - Many of the old time detailers did not make the transition to CAD. As a result, we lost people with knowledge of proper detailing methods.
    - Today's engineers know how to use CAD. Many firms have reduced or eliminated detailing positions.
    - We are now concerned about "fonts" and "layering"
    - We can copy details and notes from past projects
    - We can move around and scale details
    - "Xreferencing" is used to overlay plan views made by interdisciplines.
    - Many CAD literate clients also require the engineer to provide CAD files conforming to a particular standard.
- Engineers are no longer restricted to working in a linear fashion
    - With the computer, there are many things that can be generated automatically "without understanding". In effect, an engineer can generate a design that looks like "it's done" *before* it is thoroughly understood.
- Engineering codes have become increasingly more lengthy and complex
    - Research goes on, refining design codes, introducing caveats and addendums to pre-existing versions
    - Codes such as the AASHTO LRFD specification are much more complex and lengthy compared to former codes
    - In an effort towards exactness, codes include more mathematically complex formulas than they had in the past.
    - Some codes, such as AASHTO's LRFD and AISC's specifications, have undergone complete reorganizations. The same material is there than in previous versions, *however everything is in a different place!* There also seem to be more Greek symbols than previous editions!
- It has become increasingly more difficult to master several design specifications.
    - Let's not kid ourselves; engineers are only human, with limited mental capacities
    - Many engineers specialize in designing with certain materials. An engineer may be a concrete specialist, a post-tensioned specialist, a steel specialist, a wood specialist, a geotechnical specialist. It is somewhat of a rarity for an engineer to cross these boundaries comfortably.
    - Consulting firms tend to be fractioned into specialties dealing with either buildings or bridges, and further subspecialties of those.
- Projects are now managed by Project Managers
    - There is a differentiation in roles between the engineer-as-manager and engineer-as-designer.

    - Spreadsheets and project management software now factor into the management of projects in a big way. No longer does a simple drawing list suffice to manage structural plan production.
    - The appeal of becoming a technically oriented engineer has diminished to many young engineers starting out their careers.
    - A structural engineer's role on a project can be obfuscated by many non-structural duties such as writing reports and forms, management of technologies, as well as the generalist concerns of the PM versus technical concerns of the engineer.
    - Quality Assurance/Control (QA/QC) has become a very important goal in the project management process. "QC" is the term for what used to be called "checking".
- Increasingly the construction industry is transitioning to Design/Build contracting methods as a preferred method of contract delivery. This has a significant impact on the way structural engineers work.

2.2 A Strategy For Using Computers to Get the Job Done Right:

The preceding section describes a lot of issues – perhaps too many for some of you – but I am leading up to a point. We can all agree that the structural engineering profession is changing, along with the rest of the world. However, *one thing has not changed - our responsibilities*:

> The public expects structural engineers to act responsibly and design safe structures. We may each differ in the way we get the job done, but we are all expected to get the job done right.

Today's engineers are expected to do more work than previous generations. For structural engineers in particular, it can be a difficult task accomplishing plan production, design work and report writing. We can get swamped and miss things. There can be distractions of an insidious nature, such as hyped technologies and non-engineering related duties, which can mislead us from taking the time we require to understand our structures. Somehow, we must use computers to our advantage to get our jobs done. We need a strategy.

We can use computers to do better work than engineers did in the past.

- Today's engineers are juggling many more tasks than in the old days. We can use computer software to assist us with these tasks.
- Design codes are far too complicated for any individual to remember. We can use computer software to guide us through the codes.
- Experts are expensive and hard to find. We can use computer software that will write calculations like an expert.
- Design software can improve accuracy.
- Design software can accomplish repetitive tasks.
- Design software can improve efficiency.
- Design software can provide realism.

- The 3D capabilities of CAD are absolutely amazing. Today's engineers can get a true picture of what a structure looks like. Designing in virtual reality may be the ultimate goal!
- Database approaches (example:"BIM"-"Building Information Model") may eventually define all components of a structure. With these tools, interdisciplines can coordinate their efforts to a level never before thought possible. In the future, engineers using tools such as these will be able to identify conflicts and eliminate errors.

In a sense, today's engineers can use computer software as a form of artificial intelligence to assist in day-to-day tasks. This is the big difference from how engineers worked in the past, before personal computers.

2.3 Is There A Down Side to Automation?

There are risks to our profession as we attempt to do more and more work. Anytime we take on additional responsibilities, we risk that our primary responsibilities are not finished. Above all, we must understand our designs; this is of primary importance.

To eliminate risks, consulting firms must increasingly use quality control procedures – what we simply use to call "checking". The best ways to check can be debated, with a wide range of opinions. People have written whole master's theses on this topic! For those of us without an MBA, the following is some good advice from an excellent little book, "Preparing for Project Management", by David Williams, ASCE Press, 1996, p 48:

> "Two thoughts occur regarding checking. The first dictates that *everything* will be checked and all will be well. The second allows *spot* checking with only critical phases being checked. Analysis by quality consultants finds that designers will leave errors and omissions for checkers to find if the work is *totally checked*. In reality, checkers will not catch all the errors in most cases. People who are given the responsibility of design with *random* checking take many more precautions and learn to do quality work initially."

Put another way: Given a choice between (1) 80 design hours/ 20 checking hours or (2) 50 design hours/50 checking hours – the 80/20 approach may be "more correct" the first time around.

Concerning checklists, another gem of advice from the same book:

> "Checklists have been offered as a cure for many design and management problems. This has been overrated, as checklists can be burdensome with staff reluctantly and inefficiently using such tools. Checklists can be a help, however, for entry-level staff, and, if not too lengthy, they can be useful as a reminder for major activities."

Experienced designers develop certain internal principles for checking. I myself go by a simple rule when preparing and checking plans: "Could I build this myself?" This is a good common sense rule. Even if an engineer doesn't have much hands-on building experience, construction practices can be learned from books, visiting sites, and especially from talking to the people who actually do the construction.

Sometimes quality can be thwarted by a firm's own procedures, however well-intentioned, if the procedures are too difficult. For example, despite the Hubble Space Telescope Project's 6 feet thick stack of quality control manuals, the telescope had flaws!

Software verification is another subject falling under the broad category of quality control. Software can be verified from published example problems. Some software vendors provide a selection of verified problems, saving the consulting firm the time to do their own verification. A more common approach is verify software output using another similar piece of software.

Software, spreadsheets and math/word processors that produce automated calculations provide another way to verify software. "Automated calculations" print results similar to hand calculations, showing all the steps. This approach has several advantages:

- Engineers who check automated calculations a few times become confident in the software's output. After they take the time to thoroughly check an automated calculation, they will not hesitate to use that software again in the future.
- From a psychological basis, automated calculations provide a connection to an engineer's own thinking.
- Automated calculations – even if provided at a limited number of points – show the logic and are much more easier to check than black-box output.

This is not to advocate that all software should provide automated calculations. A mix in software approaches is probably the best solution. Given the shear number of beams in a building, it does not make sense to generate detailed calculations (which no one will read) for every beam. In terms of efficiency, black box programs win the race. But in terms of understanding, automated calculations provide a deeper understanding for engineers who take the time to read them.