MANAGERIAL AND SOCIAL PROBLEMS OF ROBOTIZATION IN THE UNITED STATES OF AMERICA

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Abstract

The historical cultural setting of construction is a fiercely competitive marketplace. The predominant volume of work is done by more than a million small, closely held, weakly capitalized companies. Layers of contracts and subcontracts effectively spread risks but also restrict the capital formation required for significant technical progress. The principal factor that will encourage robotics is the labor supply, which is dwindling in numbers and skill level. International competition, forcing improved productivity, will also promote robotics. Management is changing and taking on the flexibility necessary to adapt to artificial intelligence at opportune times.

Historical Perspective

Two hundred years ago Thomas Jefferson glorified the American agrarian ideal as the fertile ground for the development of a society of independent property owners who would be self-reliant, democratic and progressive. The steam engine was welcomed by the innovative Jefferson as an instrument of increased prosperity to the thousands of family farms. Even someone as farsighted as the third President of the United States, however, could not see the ultimate consequence of mechanization as being the complete reordering of American Society.

Like most of us, Jefferson saw new implements in terms of existing processes, not as harbingers of whole new processes and resultant social changes.

Having learned a little from history, many social observers today contend that the new era of artificial intelligence will bring about whole new approaches to making things, building buildings and functioning in society. This will probably ultimately be true. But let's pause a moment and remember that it took more than a century for the United States to move from a predominantly agricultural nation to a predominantly industrial nation; and while events move more quickly in the Twentieth Century than in the Nineteenth, the barriers to change are, in many ways, more rigorous now. Governmental regulation, litigation and the conservatism of an aging population all will inhibit radical changes in our mature industrial society.

The U.S. Construction Industry

Let's look at construction as something of a subculture within the prevalent industrial/financial culture. In the United States,

construction has historically been a bastion of opportunity within a free enterprise economy. Generations of immigrants found ready employment in construction, and many quickly moved into positions of leadership and ownership based on hard work, trade skills and risk-taking. The construction industry today remains characterized as being populated by fiercely independent operatives who disdain regulation and who are prone to take greater risks than the general population. Part of the risk-taking mentality includes operating under high debt and little capital. The notoriously poorly capitalized construction industry has one of the highest failure rates in U.S. business.

A response to the high failure rate has been to spread the risk. Whereas once general contractors self-performed a majority of the trade work, now subcontracting typically covers 85% of major building projects. With construction management type contracts, all actual site work is let to dozens of separate specialty contractors, who in this model are technically prime contractors, but who still operate as closely held trade contractors. See figures 1 and 2.

Increasing complexity of buildings, more specialization, stricter regulations, and pressure from bonding and insurance companies have all contributed to the distribution of operations — and risk, and control — out to a myriad of relatively small specialty contractors. One upshot of this fragmentation is that it actually takes longer to build most habitable buildings today than it did 60 years ago. Also it greatly inhibits the capital formation required for significant technical advance.

The management of construction has changed in the course of increased distribution of responsibility. Fewer up-through-the-ranks supervisors now emerge and more college educated managers come to construction. Leadership style has become less impromptu on-site decision making and is more attuned to resource management, scheduling, cost control and documentation (to prepare for litigation among other things).

GENERAL CONTRACTING
Typically 15% Self-performance

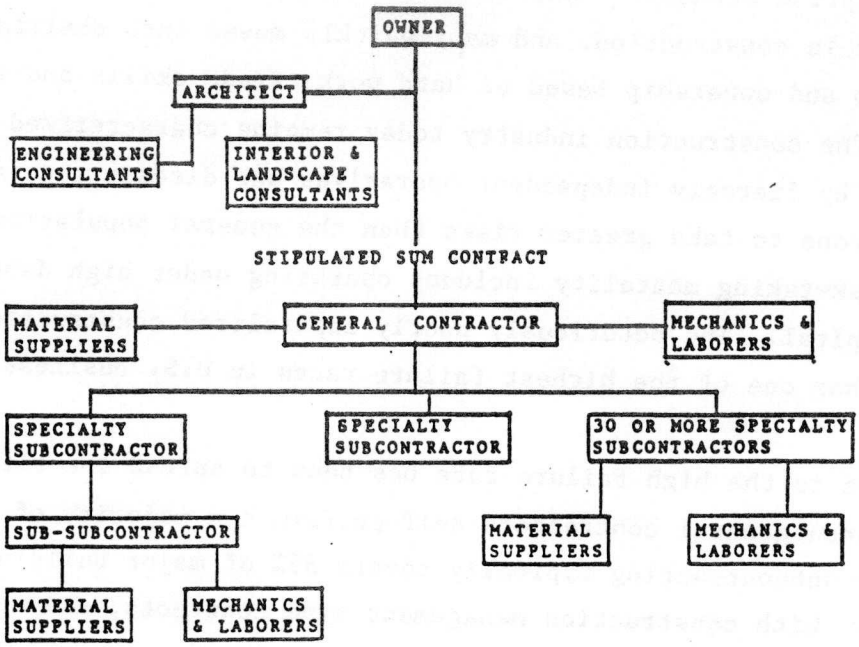

figure 1

CONSTRUCTION MANAGEMENT
No Self-performance

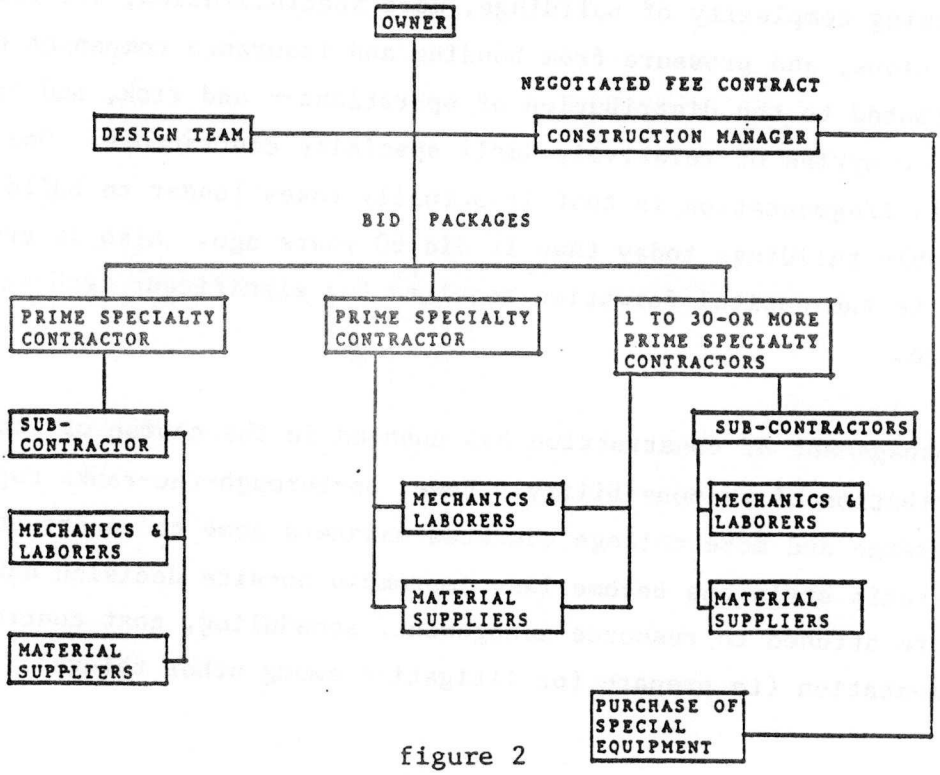

figure 2

Construction management itself has become a marketable commodity in an economy which is progressively becoming more service oriented. Firms specialize in "professional project management," with no labor, materials or machinery, but with valuable guidance for owners on how to program, cost and build a new project.

Through it all, construction productivity is believed to have declined. While data is very unreliable, the conventional wisdom is that since World War II, construction productivity improved for two decades to the mid-1960's but has been declining since. The explanations for this curve are as unreliable as the notions on which the curve is based but some of the popularly held beliefs are:

1. Generally better quality tradesmen in the '40's, '50's and'60's than later.
2. More experienced, motivated foremen and superintendents.
3. Less litigation then and thus more energy was directed toward actual construction than toward documentation and inspection.
4. Todays's larger, more complex projects (e.g., nuclear power plants) cause decreased efficiencies.
5. Overall change in the society's work ethic; and the attraction of the best workers to the service sector.
6. An "S" curve of technical development, begun in World War II, carried over into the succeeding decades in material movement systems (cranes, etc.), mass production of modular products (plywood, concrete masonry units), and prefabrication; and a natural leveling-off followed.

To counter all these arguments, the elements which should be improving productivity today are:

1. Better availability of craft training in vocational schools and other publicly supported programs.
2. Continued technical improvements in fastening systems, hoisting equipment, etc.
3. The ever broadening marketplace which allows overall construction to continue to expand thus allowing more duplication of processes and presumed improved learning curves.
4. The availability of computers.

The arguments will continue, but consensus has largely been reached that, in any case, construction productivity must improve beyond its current level. A number of studies show that less than half of all field time is actually spent in productive activity. Figure 3, illustrating collective time components of workers on large power plant projects, dramatizes the issue.

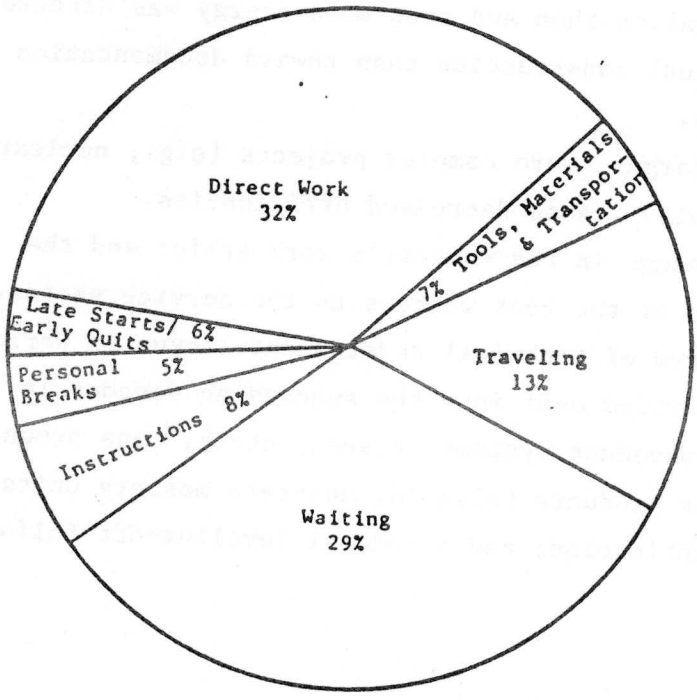

figure 3

CRAFT ACTIVITY ON
POWER PLANT WORK
Study by Margatta Strandell
University of Texas

Field video studies done at the University of Cincinnati, tend to corroborate the pie chart in figure 3. This growing concern about productivity makes computers, robotics and artificial intelligence relevant current concerns for all those interested in construction, as they have been relevant topics in manufacturing for many years.

Inhibiting Factors to Robotics in Construction

Construction lags about a quarter century behind manufacturing in technical development, and differs sufficiently from repetitive processes that many different issues will need addressing. Let's first look at the factors which will inhibit use of robotics:

1. The strong tradition as a "people" occupation, derived from a proud tradesman mentality and the value of seeing, feeling and inhabiting the fruit of one's labors.
2. The fragmentation of the construction industry as manifested in the hundreds of thousands of small and medium sized companies which constitute the U.S. construction industry.
3. Weak capitalization and high failure rate.
4. Liability associated with innovation. The current litigious overlay in our society is a wet blanket on new ideas and unproven methods.
5. Limited investment in construction research.

To put each of these points in perspective, I offer some broad data. In 1986, the value of construction put in place was approximately 370 billion dollars or ten percent of the Gross National Product of 3.696 trillion dollars. Approximately 5.5 million people were employed directly in construction, an all-time high. If we expand our data to include people and expenditures in various construction support

activities including design, manufacturing of construction equipment and materials, and the variety of legal, governmental, insurance, inspection and training services, construction is responsible for employing nearly eight million people in a 500 billion dollar activity. The scope of the industry causes it to be one of several barometers of the overall national economy. Since residential construction makes up about 40% of the total construction volume, housing starts are a regularly reported index (with two million units being the bench mark for a very good year). The fact that homebuilding is such a strong component of the total construction activity graphically demonstrates the fragmented nature of the industry. While a few large companies build hundreds of homes each year, the average output is less than ten homes per year by approximately two hundred thousand builders, each using extensive subcontractors, many of whom are one or two person operations, with a pick-up truck and a box of tools, but very little capital.

It is safe to say that over a million independent contractors function in American homebuilding, which allows easy entry, but high turnover. The residential segment of construction is very susceptible to swings in the economy and the employment numbers fluctuate markedly.

Despite a degree of mechanization, most construction remains labor intensive, and some pride of craftsmanship endures, at least among those who have deliberately chosen construction careers. A large part of the labor force, however, moves in and out of construction routinely. Also, many young people view construction as interim employment until something better comes along.

While the workforce may fluctuate, the spectre of liability has become a constant. But, the liability issue is not reserved to construction. All of American industry is affected by product

liability, which seriously restricts the introduction of new implements and methods. Legislative bodies and courts, after decades of supporting the consumer, are now recognizing the chilling effect that their actions have had on innovation and product improvement. But, a true turn-around in this problem is not yet in sight.

Research in construction processes has historically been done by equipment and product manufacturers. Government does some research through such agencies as the U.S. Army Corps of Engineers and the National Science Foundation. Construction Companies themselves do very little research. This is discussed further later on in this paper as a factor which may encourage robotization.

Encouraging Factors for Robotics in Construction

With all the reasons why robotics and artificial intelligence will be inhibited from entering construction, there are compelling reasons to expect that the scene will soon be set for change:

1. The U.S. construction industry is awakening to the reality of the world marketplace through two initiatives, the insistence of manufacturers and processors that construction become more efficient (the Business Roundtable Construction Industry Cost Effectiveness Study) and the increasingly competitive players in the international marketplace.
2. The overall American workforce will shrink, with the most telling losses in occupations like construction.
3. A renewed interest in standardization of building components.
4. Gradual growth in construction research, with seeds being planted which may yield much fruit in the near future.

The Business Roundtable's CICE studies are now broadly known and are having at least outward effects on construction productivity. The manufacturers themselves are reviewing their construction programs and are seeking efficiencies; and contractors doing business with them are wise to understand the objectives of CICE. Philosophically connected to CICE is the Construction Industry Institute which has begun a broad based investigation of the issues raised by CICE. Based at the University of Texas, CII is national in scope with manufacturing, construction and educational participants.

Probably more of a motivation for improved productivity, however, is the decline of oversees markets for the U.S. construction industry and the targeting of domestic construction by foreign contractors, particularly Japanese. The involvement of Japanese construction companies came with the building of Japanese plants in the U.S., and the contractors subsequently have spread into other work, including competitively bid, tax supported public projects. Approximately four billion dollars worth of construction was performed in the U.S. by Japanese contractors in 1986, and there is the sense that the American construction market is now receiving the same attention as the automobile and semiconductor markets earlier. With 30% of the world's construction activity, the U.S. is indeed an attractive market.

American demographics are perhaps the most persuasive argument that construction will soon be ripe for significant changes in production methods. The number of annual available entrants into the work force is now declining at the rate of about one hundred thousand per year. Five million people came of age in 1980 compared to 3.5 million projected for 1995. The current total workforce stands at about 105 million men and women, with approximately four million permanently leaving every year. Thus four million new job seekers are required annually to maintain a balance, with no growth. New native young

adults and immigrants (legal and illegal) supplied this need up until the mid-1980's, but now the declining birth rates of twenty years ago and increased restrictions on aliens will restrict the workforce renewal. Concomitantly, construction field work is becoming generally less attractive, as a greater percentage of youths go on to college and as service sector positions become more glamorous.

It is conceivable that dislocations in the manufacturing workforce due to advanced automation systems will cause spillover into construction, just as the mechanization of agriculture many years ago provided a surplus workforce for manufacturing. The more probable scenario, however, is that the sons and daughters of machinists will become computer operators and investment bankers. Also, one could conjecture that some component of the seven million adults unemployed at any given time could become gainfully employed in construction. Specifically there are large numbers of women and minorities who may be attracted to construction work, but serious efforts will be required to recruit and train them. While this may be a worthy social objective, it is not perceived that such will have a positive effect on productivity.

All conditions point toward a distinct shortage of qualified construction workers in the 1990's. Conditions will be in place for significant change in the ways things get built.

The renewed interest in the standardization of building components is seen in such products as pre-engineered metal buildings, which have become the landmarks along the interstate highway system, and now account for about half of all single story nonresidential construction in the U.S. Good applied research has allowed very efficient, largely factory-built structures to evolve. This process is only one step away from robotics now. Mechanical components such as chillers and elevators are now routinely factory finished.

The segment of construction which seemingly would best adapt to modularization is residential. Yet this market has actually moved away from prefabrication in the past two decades. The much celebrated Operation Breakthrough of 1970, rather than opening up the housing component market, effectively closed it. Volumes have been written on Breakthrough, so suffice it here to say that the research and administration associated with the operation ignored marketplace realities.

Nonetheless factory-built mobile homes have successfully provided housing for low income families in both rural and urban communities. A real opportunity for robotics exists here.

Construction research overall has been grossly inadequate, amounting in dollar volume to no more than 25 million dollars per year including every expenditure possible to count among construction companies, equipment manufacturers, associations, government and universities, or .0005% of the total annual investment in all construction related activity. This is compared to 3% in the pharmaceutical industry and a similar amount in aerospace. But, this embryo of construction research may soon see significant growth. Efforts of the Business Roundtable, the Construction Industry Institute, and various bodies such as the Associated General Contractors of America, are focusing broad attention on the need. The aforementioned foreign competition is also affecting the American research effort. Research investment by European countries and Japan are factors in their improved competitiveness in international construction markets. State and national governments are being lobbied, and universities and research institutes are generating an increased number of proposals regarding construction. Much of the anticipated research will necessarily be on the use of robotics in construction.

Future Directions

Just as Thomas Jefferson could not foresee the dramatic impacts of mechanization on agriculture, it is difficult for us to accurately project how robotics will change construction. Just as machines did much more than replace farm workers, robotics will do much more than replace construction workers. Ways of producing components will be found to utilize the efficiencies of robots. This will cause fundamental changes in building design. The notion of "constructability" will take on clearer meaning as the necessity to merge design and execution becomes critical to production efficiency. Standard modular open flexible buildings may evolve to house a variety of operations over time, analogous to flexible work stations. Those modular buildings themselves can be made of mass produced components, fabricated in the field by robots under human supervision.

Componentization will surely undergo another iteration, a necessary condition for robotics to really have an impact on construction. Mobile homes, as mentioned, are a near term prospect. They are repetitive, short lived buildings, and are thus scorned by most Americans. But, they provide quick ready housing for many and may be replaced on fifteen year cycles, therefore providing an ongoing market. Market aggregation for truly mass modularized housing has never occurred in the U.S. as it did in Europe following World War II, and since Operation Breakthrough, the national government has shown little interest in pursuing such.

The aging population may allow an opportunity. The number of people beyond the age 70 is growing dramatically, and while they are becoming ever more affluent, an increasing number are impaired and

require special accommodations. Large numbers of specialized living units may provide sufficient aggregation for mass produced modules. With the scale of production of one unit possible with flexible work stations, repetitive units may take on sufficient variety to better address a diversified marketplace.

The Changing Management of Construction

Construction management seeks to become a profession parallel to architecture and engineering. "Constructor" is the preferred professional term. This is manifested in the growing number of college curricula in construction and the increased reliance on degree holders rather than on up-through-the-ranks managers, and also on the changing mentality among contractors that they are no longer the makers of buildings but rather the providers of valuable services. As craftspersons are now more frequently employed by subcontractors rather than by general contractors, the generals' staff time is more focused on financial and marketing efforts. Most contracts in the private sector are now negotiated through a special quasi-professional selection process. Only the public sector, which in a typical year accounts for 25% of all construction, retains competitively bid hard money contracts.

The construction profession seeks to become more involved in critical decision making throughout the project, not just after design is complete. A key concept of the construction management form of contract is that the constructor is hired by the owner concurrent with the design team and advises on the constructability of design proposals. As constructors become more familiar with robotics, they can advise on making design more compatible with robotics either through componentization or sufficient repetitive processes on site to allow interactive robots to perform efficiently.

The growth of computer use by constructors has been impressive, largely caused by schools of construction using them more for estimating, scheduling and drafting. It follows that robotic use must penetrate college undergraduate building design and construction curricula.

Summary

While current forces of fragmentation, weak capitalization and inadequate research inhibit the application of robotics and artificial intelligence to construction, these will probably yield to the pressures of international competition, a shrinking labor force and declining craft skill. However, rather than approach tasks in a machine-replaces-man mode, the whole approach to construction should change. Componentization will become more relevant to allow manufacturing technology to blend better with construction technology.

The management of construction is becoming more flexible as it attracts better educated personnel. Construction managers are already doing less direct personnel management and can readily shift to the condition of fewer workers on the job, but more prefinished components to coordinate.

Construction over the years has made steady improvement in technical application, from material handling systems to computers, in a series of small deliberate steps. Application of robots will similarly be made in a series of steps, some the results of careful study and others caused by reactions to marketplace challenges.

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