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DESIGN AND CONSTRUCTION FOR THE REST OF US

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ABSTRACT
Civil engineering academics are caught between a science-based university culture on one side, and on the other the expectations of students and practicing engineers in industry who want practical knowledge to apply today. The science-based culture primarily measures faculty by research projects and funding, Ph.D. students produced, and by papers refereed primarily by academic peers for publication and citation in scholarly journals. There are strong pressures to produce these outputs, which are duly quantified for tenure and promotion decisions, but the system does not directly reward time spent gaining practical experience in full-time or part time jobs prior to academic employment, or later in summers or sabbaticals, or in solving problems through consulting.

This paper will address the balance between academia and practice, and will focus on the residential building sector of the design and construction industry as one largely neglected by engineering programs. In particular, it will show where the design and construction of residential structures can provide opportunities to enhance engineering education and open new avenues for broad, interdisciplinary research that are different from those where engineering academics normally travel. In conclusion, it will focus on academics who successfully bridge from academia to the world around them.

KEYWORDS
Construction, Design, Education, Research

1. INTRODUCTION

With apologies to Apple Computer for slightly adapting their slogan, this paper will focus on preparing our students for the ordinary, everyday world of engineering, design, and construction where the majority will spend their careers. To those accustomed to my past talks on the enormous and complex engineering works in Japan and Europe, or the as yet unfilled promise of "advanced" technologies such as robotics, computer-based simulation, or "virtual reality," this may be a good time to take a break.

I will first address what I see as significant problems with engineering academia today, and in particular the scientific and cultural pressures the so-called "research universities" exert on young faculty that may be making them less and less relevant to the needs of the majority of their students who go into practice in civil engineering consulting firms and in various parts of the construction industry. Then I will focus on the residential design and construction sector, and explore the prevailing gap between its needs and its being virtually ignored in most university engineering programs. Next, I will show the potential for a renewed focus on the residential sector to enrich the knowledge and experience of professors as well as their students, even if they go into other sectors of industry Finally, I will suggest that housing can provide new opportunities for researchers in design and construction who have grown weary of pursuing ever more focused niches to develop new knowledge and innovative concepts to attract research funding and publish papers within the well-trodden paths of structural, geotechnical, and construction engineering.

2. ENGINEERING ACADEMIA TODAY

There is a tendency in engineering education to illustrate lectures with some of the largest and most complex projects or disasters – tall buildings, undersea railway tunnels, mile-long bridge spans, etc. In past years I have tried to impress students with pictures and statistics drawn from my visits to the Akashi-Kaikyo Bridge, the Channel Tunnel, German autobahn viaducts, nuclear power plants, and large hydroelectric, subway, and pipeline projects where I actually worked. Other faculty do similar things – structural engineering faculty bring pictures of the most spectacular structural collapses in great earthquakes, geotechnical faculty show large dams and some failures, etc. In research we tend to focus on niche markets, such as advanced management tools to handle the speed and complexity of electronics and biotech manufacturing facilities, 3D CAD visualization and 4D planning tools for the complex shapes encountered in buildings designed by avant-garde architects, robotics for work in hazardous waste sites or even in space, or prototypical fuzzy-set and neural-network software to address limited aspects of management or design problems.

These tendencies raise a number of questions. What fraction of our students will actually work on projects at the high ends of scale, complexity, and technology? How many faculty actually understand the details of the design and construction processes behind the pictures they show in class or appreciate the practical limitations of the research topics they address? Is it really useful to devote substantial class time to small niche markets of little interest to most potential employers of our students, or to devote whole courses to technologies that may – or may never – materialize into practical applications by the mid-points of their students' careers? Some argue that, by being exposed in school to the large and complex, the mundane and the ordinary will be simplified subsets that young engineers can then easily understand. But is this really likely to occur if neither the students nor their teachers had more than a superficial understanding of the complex examples? Others argue that by taking time in school to expose students to technologies still primarily at the research stage – robotics, neural networks, virtual reality, etc. – they will be better positioned to cope with technologies they will encounter later in their careers, and can actually become "change agents" to accelerate the rate at which technologies are introduced. In years past I certainly have been one of the proponents of these lines of reasoning. But as I look back, much of this seems more like rationalizations for subjecting students to the sorts of things that result from professors having to behave primarily according to the norms of academic culture – writing proposals on esoteric things to get funding from government research agencies, writing papers about "new and original contributions to knowledge" primarily intended to pass muster with similar professors who act as peer reviewers for scholarly journals, and requiring Ph.D. students to behave similarly to satisfy the academic requirements for their degrees and become ready to perpetuate this culture when they, too, become young professors, most with little or no professional or industry experience.

In this late stage of my career, as I spend most of my "free time" in the multi-unit housing design and construction industry in roles ranging from board member of a large non-profit developer and owner of over 5000 affordable housing units to my regular Saturday supervision of Silicon Valley's volunteer builders on smaller Habitat projects, I have become increasingly uncomfortable thinking that much of the time that I spent in research and teaching – and much of that spent by my peers – served our own academic career interests better than it served our students. Starting in the 1970s, I made my students devote considerable time to preparing and running simulation models of construction operations. While this enhanced their understanding of principles to some extent, promises that they would be the ones to bring these capabilities into everyday practice in industry remain unfilled, even a quarter century later. In the 1980s I tantalized them with similar visions of construction robotics, and even into the early 1990s I foretold advanced virtual modeling techniques (being developed by others) that might somehow enable novice engineers to quickly rise to or surpass the capabilities of their seniors who only had years of hard-won experience to hone their engineering and management judgment. I rarely mention such topics now.

As university courses in timber structures long ago were displaced by high-strength steel and concrete design and finite-element analysis techniques, and as academic research focused more and more at the component, connection, and micro-material level, I have found that the most useful structural engineers are those who can design a three- or four-story timber-frame building as a complete system. Such practical designs not only will stand up in a Zone-4 seismic event, but also be detailed well for ease of building and long-term durability, coordinate well with the complex web of mechanical, piping, electrical and architectural elements it takes to serve dozens or hundreds of condos or apartments, and sit atop a post-tensioned concrete parking structure that will not crack and leak due to poor design-construction understanding of embeds, penetrations, concrete creep, and expansion joints. Given that wood-frame structures account for 70% to 80% of the enclosed floor space in the United States and the bulk of building energy consumption, it seems odd to me that they are mostly ignored in engineering education. The resulting ignorance accounts for many of the design and construction problems encountered in this sector. The few engineers who were taught timber design decades ago or have gone on through self-education to master this field are much in demand and greatly valued because timber remains the most economical and flexible way to build many structures.

As I write this I sit on a cross-disciplinary search committee that is interviewing prospective faculty for positions in our structural, geotechnical, construction, and design-construction programs. Geotechnical engineers are generally perceived as being fairly practical in the civil engineering academic spectrum, and two of the three we interviewed had some years in consulting practice before 5 to 15 years of academic experience. In each case their current research focus was typically of the narrow, scientific type that it takes to get proposals funded and papers published, so I asked them why, with all this science now available to underpin the art of geotechnical engineering, for a typical apartment project located on fairly conventional soil conditions in the San Francisco Bay Area, we can go to three different geotechnical firms and get soils analyses and design recommendations that translate into construction costs differing not by 3% or 30%, but by 300% or more. My father often repeated the saying that "an engineer can do for one dollar what any damn fool can do for two." So what of the engineers that need three dollars? We might get post-tensioned slab-on-grade at the economical end from one firm, and a "belt-and-suspenders" combination of piles or drilled piers capped by grade beams that in turn carry post-tensioned slabs from the most conservative firm. In one case the latter design was to support a light two-story town-home development that was right next to an older three-story building sitting on top of ordinary reinforced concrete footings that showed no cracking or settlement even after 40 years. I asked these prospective Stanford geotechnical professors to explain how their research, such as the micro-mechanical behavior of a certain type of soil particles, will help their students going into firms that produce such a wide range of answers, or to explain the gap between academic research and the apparently uncertain state of practice. Their answers typically said that practice has a long way to go to catch up with state-of-the-art research and benefit from the fruits of their advanced thinking. If they had been exposed to practice, they also acknowledged that the driving force for conservative design behavior is high errors-and-omissions insurance costs and fear of lawsuits – neither of which have much if anything to do with their narrowly focused research. One further said that a prudent engineer must protect himself against worst-case scenarios, but agreed that it was not professionally responsible to design so over-conservatively as to kill the economic viability of much needed projects.

Most of these academics typically ended presentations about their research by confessing that "more research is needed" before their work can be ready for practical applications, or be useful in an overall system (not just at the component level), or otherwise escape the limitations of university experience, laboratory scale, or Ph.D. student understanding. Industry moves on.

These are but a few examples of the gaps of varying sizes that exist between the world of academic classrooms and research, and the type of everyday practice in which most students will spend their careers. Are we serving these students as well as we could? Is industry really happy with the products of four years of undergraduate engineering education even when capped by master of science degrees? How can professionally savvy engineering faculty balance what they know to be the needs their students will face in industry against strong academic cultural and employment pressures (such as that nerve-wracking drive for tenure) that tell them to write proposals, recruit Ph.D. students, and publish papers rather than, for example, gain experience in a summer or sabbatical spent in industry. I am happy to say that I have seen some of the leading young faculty enrich both their research and teaching by going "against medical advice" to integrate exactly this type of industry experience into their teaching and research, but they are the exceptions rather than the norms. Enormous pressures force most into conformance with the prevailing science-based academic culture.

3. ALTERNATIVES FOR TEACHING

In moving into the housing sector several years ago, I ran against prejudices that I also had fostered not long before. In engineering-based construction we tend to ignore this sector of our industry as somehow being too mundane or simple to be worth our time and that of our students. Never mind that these structures are the ones most intimately part of people's lives, or that residential is the largest sector of the construction industry by a considerable margin, or that safe, affordable housing is the focus of some of the most important social and economic problems in the U.S. – at least insofar as they involve our field. To me the ultimate projects were those on which I grew up and worked – a hydroelectric project with a concrete dam and an 18-mile tunnel in Australia, the BART railway system in the San Francisco Bay Area, and similar "real" civil engineering works. Homebuilders were "pick-up" contractors and their estimators were doorknob counters, not the diverters of rivers, levelers of mountains, or those who spanned the Golden Gate. For the first 30 years of my university education and professional and academic experience, my prejudices caused me to ignore what I now see as one of the most fascinating, interdisciplinary, complex, and challenging fields of any that are within my experience. It has also proven to be an accessible and valuable source of first-hand knowledge and experience to give my students a better understanding for design and construction

Three of my four courses now involve students directly with local industry and government organizations, projects and professionals in the residential sector. While the logistics required to sustain this "world as laboratory" approach are far more difficult and time-consuming than, say, assigning problems 3, 5 and 7 from the back of chapter 9 to the class, the results seem to make it worthwhile. Lessons learned from experience seem to be better understood than those memorized primarily to pass exams. One of my colleagues – who came to us with some 30 years of heavy construction experience -- has something like this posted on his wall: "If I hear, I'll forget. If I see, I'll remember. If I do, I'll understand." The latter rings especially true.

I will illustrate with what might seem like simplistic examples from a graduate construction class I teach called "The Analysis and Design of Construction Operations." This is a fancy academic way of saying that it tries to get students to see things from the perspective or workers, foremen and superintendents. Its three-credit lecture component is conventional, but its Friday "labs" have made it different for the last six years. Last Fall, the class had 40 students, many with engineering experience in the military or the private sector. In alternating weeks, teams of students each spent four full days on a 36-unit Habitat condo project experiencing the application of some of the principles taught in class, and gaining experiences that in turn they brought back to class to share with each other and thus broaden the understanding of other students. For many it was their first and possibly their last hands-on construction experience. Here is a small selection of unexpected lessons encountered in the field.

For want of a nail – One team took on the construction of a timber-frame stairway and balcony deck that provided access to a second-story unit. Structural hardware included beam and joist hangers, bolts, and galvanized nails. Like most students, some lacked hands-on tool experience beyond picture hanging with tack hammers, so they typically grasped their hammers by the throat and tried to gently tap 20-d galvanized nails into place – bending 5 for every success. In one instance, three students cut, placed and nailed a 10-ft. 2x8 board to laminate it over a 2x14 board to make a decorative surround for the deck. Back in class, we asked those who did not see this task to estimate how long it should have taken. As engineers they figured, "four blows per nail times 20 nails times, say, 2 seconds per blow," and said it should take about three minutes if one held while another nailed. When this team said it took them well over an hour of bending and extracting nails, considerable discussion ensued regarding why – high friction nails? mismatch of small hammers? not knowing how to hold and use a hammer? Typical lessons were that good workers do have skills that exceed those even of engineers supervising them, and that engineers doing cost estimates or production schedules better understand and allow for skill levels in their computations.

Upon small footings do lessons grow – A team consisting largely of strong "can-do" officers from the Army Corps of Engineers and the Navy Seabees took on the construction of a 40-ft. long, 10-ft. high structural trellis that spanned the front of a community building. It began with five simple concrete column footing and post anchors embedded in 2-ft. by 2-ft. by 1-ft. deep holes in the ground. In preparing for this task they learned from an estimating manual that big, strong men like themselves should be able to excavate one half to one cubic yard per hour. Five footings at 4 cubic feet each, they figured, could quickly be done by three of them while others prefabricated rebar and forms. Suspecting that it would be more difficult than they thought, I had ordered two electric paving breakers for their team, and they made a start. By mid-afternoon, long after the rebar was ready and the forms were built, not only were they still digging but they were ready to drop from heat exhaustion. What they had failed to appreciate in reading the specifications and planning this task was that the building pads were on top of some 1500 cubic yards of imported material that was not only machine compacted two feet deep to raise the building above a FEMA-mandated flood plain, but that the soil had also been lime treated while compacted to stabilize it through winter rains expected during construction. These students learned new respect for the properties of soil in various states, and also learned not to simply look up numbers in estimating manuals. Strong and fit as they must be for military service, they also learned to appreciate the strength and endurance of a good laborer putting out a fair day's work for a fair day's pay.

There but for fortune we'd be digging trenches – On the other side of that building, another team was excavating for retaining wall footings for a concrete ramp needed for a three-foot grade change for wheelchairs. They too were doing this while other students pre-fabricated reinforcing steel and built about 20 form panels. They excavated quickly in soils that had not been machine compacted. Occasionally I stopped by to suggest that they might better control the bottom depth and keep the trenches straight, but they seemed to think that for lowly trench digging I was being awfully picky. When it came time to set the steel and form panels in place, they could clearly see their folly. Much of the steel came closer to soil than specified tolerance allowed, some panels – after allowing for their 2x4 frames – could not even fit within the trenches and allow the concrete walls to remain straight. After installing and removing panels and rebar cages a few times, they finally settled down to excavate and trim the trenches to the correct size and alignment. They also gained a better appreciation for workers that they had previously thought of a people who couldn't do anything else and thus ended up digging trenches. Are engineers, who set the specified tolerances and dimensions, less capable of performing simple tasks to the standards they specify for others?

What did you say was in that wall? – Back at the deck, two other students had to move quickly to get a 4x14 beam hangar nailed to the corner of a building wall in order that this and other beams could be placed between walls and columns to become the main frame to carry joist hangars and joists, which in turn were to hold the 2^{nd}-story deck. While others performed related tasks, and eventually waited, this team struggled to drill some 20 nail holes first through the fiber cement siding, which they could see, then, after switching to a drill with a steel bit, through a 14-gauge steel strap that transferred wind and seismic tensile loads from one floor to the next (a strap that was on their drawings but which they missed), and finally they reached the wood into which to drive their galvanized nails (bend and extract 5 for every success again). Two hours later they had the hangar in place and the crew could continue – a hangar they thought to be a few minutes of incidental work in their task planning. Lessons here included those of design coordination and constructibility, the potential importance of even tiny details in those contract drawings, and how one insufficiently planned incident – be it ever so humble – can throw off the productivity of a whole crew.

There were innumerable other examples. The design and layout of the aforementioned wheelchair ramp was still being debated between architect and field supervisor even as the day of construction neared, so the students – with Habitat's permission – took the city's and the federal ADA design standards, which were not fully consistent themselves, and redesigned it from an "L" shape to a "U" shape that better fit the site. Others learned how small dimensional differences in, say, wall framing can make subsequent operations such as gypsum wall board more difficult than they need be, and how building inspections called too soon can pressure crews into hasty mistakes that cause the inspection to fail anyway, to the annoyance of all concerned. These lessons and others like them generally are not found in textbooks, where "theoretically things ought to always turn out as designed and planned," nor are they found in the journal papers that make up part of the reading required for my course. But they are very important and bring at least a small taste of the practical realities that await the students when they go out to apply what they learned in school in the practice of engineering and construction. They also experience how teams that do indeed work as teams move more quickly and effectively than those that are poorly led and coordinated, and they learn that not all the information they need to build is accurate, well coordinated, or even provided at all, in the contract documents. I hope that they also learn that construction people can solve problems and fill in the gaps to keep work moving without stopping to turn everything into an "RFI" or a "changed condition" claim.

Most important, at least some students who want to be designers and some who want to be construction managers learn that both can become better if they understand how things get built. They also learn, even in this increasingly subcontracted and specialized world, that it is good to have some broad, interdisciplinary technical knowledge of a variety of trades, not just structures or mechanical or electrical or geotechnical. It is some of the most experienced, mature and professional students who seem to best appreciate the lessons from the small but memorable personal experiences, from humble digging of footings and trenches to the framing of complex truss roof systems. Younger students who also have practical aptitude take note of these more experienced students and follow close behind. In spite of this experience, some will still think that "management" is a talent that can float above the mundane level of what is accomplished beneath it, or that designers can best dictate to constructors the way to build, and will continue to fail to see the value of understanding the practical details of what they are doing.

At the level of small residential buildings, it is possible for one person to design all aspects of a building and to construct it alone. It will take time, but it is within human grasp. Much of the knowledge required can be packed into a single book, such as (Willenbrock 98). But nobody can say that they fully understand a complex industrial plant, an underground railway system, or a high-rise office building at this level, and certainly nobody can live long enough to build such things by themselves. But the lessons from small detached and multi-unit residential structures, and even from small field experiences such as I have described, can benefit engineers who then go on to larger and more complex works. If nothing else, they can better appreciate the importance of every person who is capable and efficient at doing productive work to move projects forward, and they will be better team players as a result.

Near the end of last Fall's course, I took the students on a field trip to a 2700-unit apartment building complex under construction in San Jose. They were hosted by the developer's project managers, the general contractor's experienced superintendent, and the president of the design-build concrete subcontractor who is doing the intricately complex concrete parking garages that double as structural podiums for 200-plus-unit wood-framed buildings. The hosts were among the best in their fields, and even the more experienced students felt a bit like Little League baseball players meeting professional all-stars who thoroughly understood the details of their game. But most students could also see how things they had by then personally experienced scaled up logically to a much larger size, and thus they could better imagine a path by which they might reach the career successes of their hosts. Without the hands-on experience earlier in the course, for most such a field trip would not have taught them nearly as much.

4. RESEARCH OPPORTUNITIES

When I first seriously refocused my research, teaching and professional activities on the housing sector, I had in mind the post-Apollo-11 wag who then said, "If they can put a man on the Moon, then why can't they fix the potholes?" I thought that if enough technology and systems were brought in from other areas to improve the technology for design, materials, and production methods, and to advance project management for housing, that problems of affordability and shortages might begin to recede. I soon learned that the costs of designing and constructing the buildings themselves were well down the list of things that were causing more and more serious housing problems in supply-constrained markets such as we have in urban California and elsewhere in the United States. Nevertheless, as I looked at potential sources to fund research in this area – such as the National Science Foundation (NSF), the Department of Housing and Urban Development (HUD), and the Department of Energy (DOE) – I found that they, too, were focused mostly on components, materials, software and methods for analysis and design, and to some extent on building systems and management. Certainly there is a need for research to produce improvements in structural and fire safety, durability, energy savings, sustainability, and costs and schedules, but I did not see any breakthroughs coming that would really make a difference for those seeking decent, affordable housing in our market.

As I look back on my own research and publications, the concept that I have found most useful, and the one that practitioners have cited most over the years, was one that I did not invent at all. I was simply the messenger who took some ideas I learned from more experienced people when I worked for Fluor and put them into an ASCE paper in a form that others could use. It was called "Designing to Reduce Construction Costs," and might still be found on the dusty shelves of university libraries (Paulson 76). I wrote it during an intense experience when I was on a team helping to merge the very different cultures of Fluor with the engineering design and construction assets of an old-line builder of Hoover Dam and the like that Fluor had then acquired. The key concepts appear in Figure 1.

The basic idea here is that, while expenditures are low during the early stages of a project, the activities that happen then, and the decisions that result, have a far greater impact on the success or failure of the project than anything that comes later. Conceptual and schematic design have a greater influence than detailed design; the contact drawings and specifications in turn seriously limit the influence of construction; and the result of both design and construction largely dictate the facility's long-term functional and economic viability.

In our multi-family residential projects, finding and entitling land is the key driver. Not only does land constitute one of the largest cost components of our urban and suburban projects (at costs ranging from $30 to $150 per square foot for building sites), but it comes with restrictions on the density, height, setbacks, coverage, floor-area ratios, on-site parking, daylight planes and similar constraints that limit the creativity of design architects and engineers. To what extent will local jurisdictions relax such constraints by allowing developers to propose "planned developments" that offer attractive packaging or amenities in return for some flexibility in site planning? Even if a project is optimized within regulatory constraints to produce maximum utilization or economic returns, will community, political and environmental opposition during the approval process force even greater concessions that cut the density by half or more, or even kill the project altogether after substantial sums have been spent on planning and design? What can researchers do to help designers create quality living environments that make best use of scarce and expensive land while also being at least palatable to entrenched forces that normally oppose new developments as a matter of principle? Can new 3D and 4D visualization and modeling technologies improve communications of a project's benefits to a community and facilitate the negotiations of design changes in a way that preserves essential building program goals while minimizing delays for revisions and compromise?

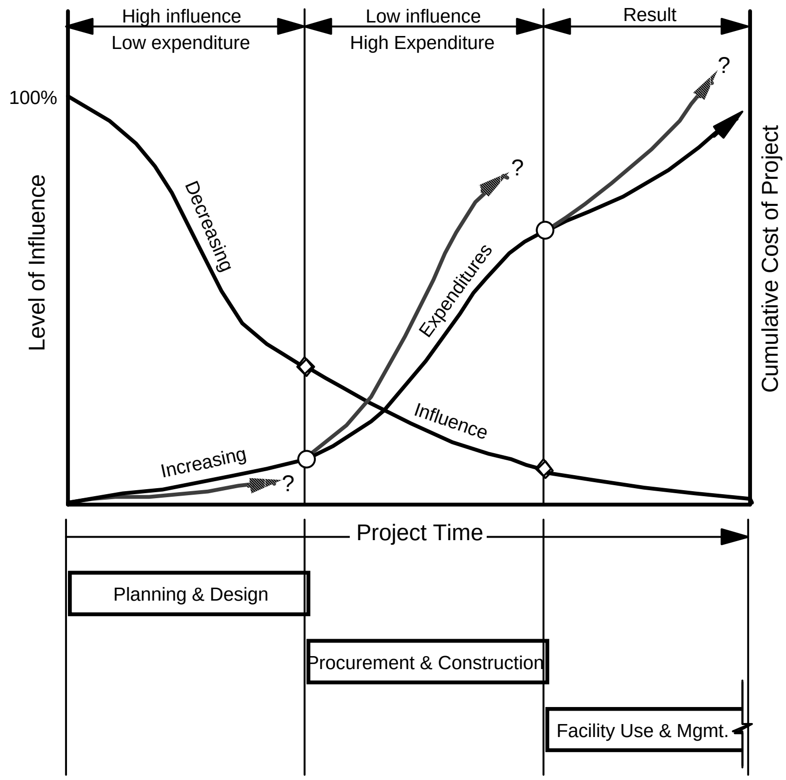

Figure 1: The Level of Influence on Project Costs

Once the basic design scheme has been approved by the developer, design consultants, and the community, we move down the influence curve to more detailed design and process decisions that nevertheless have considerable influence. For example, in the design of a 74-unit, 5-story affordable housing complex for seniors recently completed, we had an opportunity to use a design-build concrete subcontractor that would not only have produced a more durable and functional parking structure on which we framed 4 stories of timber-frame housing units, but would also have saved $300,000. Although it would have made little aesthetic difference, the project architect – famous for winning design awards – refused to consider it and in turn pressured the structural engineering firm working for him to refuse to analyze the alternative design. We had similar problems with the same architect – but with different technical issues pertaining to his refusal to comply with another city's above-UBC fire codes – on a 148-unit family project built concurrently in another city, and we eventually terminated him by paying a six-figure sum to buy him out, and let another architect take over as the "architect of record," but by then it was too late to achieve important cost savings. To top it off, the original design-bid-build method produced a parking podium that leaks, as, apparently, have numerous others designed by this reputable and large structural engineering firm that apparently lacks sufficient practical knowledge of what it takes to build their structures. For a new project we have switched to a design-build firm whose success structurally, economically and in performance (no leaks!) has enabled them to capture about 50% of the podium structures for multi-unit residential projects in our region. For researchers there are good questions here, but they have more to do with handling the egos of members of the building team, writing contracts that allow more flexibility in the "level of influence" impacts on project success, and exploring alternative procurement systems, than they do with technologies and concepts likely to be funded by government research agencies.

Developers and builders have also experienced various barriers in local codes and city building departments when they have tried to introduce new materials and components such as those being researched under HUD's PATH program and NSF's small program that handles PATH funds directed at universities. For example, one innovative developer-builder used light-gauge steel framing for 220 units of two-story, upscale town homes built on top of concrete parking garages that combined precast architectural and structural elements with post-tensioned, cast-in-place walls and decks. They became one the first in this area – which is also in seismic Zone 4 -- to use light-gauge steel in multi-unit structures, but they paid a price. It took nine months to get the structural engineer's drawings approved by the building department. This was mostly a process of educating building officials unfamiliar with the technology, and was not due to design deficiencies. They prevailed eventually, and the city now praises and virtues of the system, but carrying costs for the expensive land tied up during this process came to about $2 million. The education effort must be repeated jurisdiction by jurisdiction. Similar stories abound for other attempts to implement new materials and methods, and discouraged developers and builders become reluctant to be out there on the "bleeding edge" of technology. For researchers, it would seem that at least as much effort should be devoted to these institutional and process issues as it is to technologies that otherwise might not make it beyond the labs.

Under the pressures of the academic culture, young faculty in engineering must seek funding where it is available, regardless of whether the narrowly focused research has the potential to do much good. In the drive for tenure and for continuing promotions and raises, their university administrators will look mostly at the number of research projects, the amount or funding, and Ph.D. students produced, not at the practical application of research results. They will be measured also by the number of refereed papers published and the number of times other research publications cite their papers later, not on the usefulness of the papers or even on whether others cited their work critically or to commend them. Academic success is largely a numbers game. The rules are enforced by university administrators and program managers in funding agencies, most of whom also came up academic career paths where the culture is well entrenched in the peer evaluation and approval structure. For construction academics, the problem is magnified by having just a few, small, and often short-lived private and government research program opportunities available to them, so by mid-career such professors are often criticized by their peers for a lack of consistent, long-term focus needed to build excellence in a specific research area. These problems are well known to those working in this field, but few know of solutions.

5. CONCLUSION

While in retrospect it is easy for me to see the contrasts between what we do in universities and what might be most useful for our students, their employers, and consumers of engineering and construction services, I also recognize how difficult it is even for well-intended, practice-oriented faculty to succeed unless they perform according to the standards of the academic environment and the agencies that sustain it. Some faculty do remarkably well in bridging between their university base and the engineering professions they serve. They can be models and mentors for others. Others just teach their classes as best they can and do their research wherever they can find funds. There are no easy solutions, but it seems to me that those who most successfully span from one world to the other have a genuine passion for what they teach and for the potential usefulness of what they do in research. They stick to their goals regardless of the ebbs and flows of research funding and current fashions in technologies and systems. Some find they must leave academia – either by choice or by failure to get tenure – if they stray too far from what is expected of them, but this is not necessarily a good outcome if it leaves less employable students behind and makes their universities even less connected to the world outside.

In our classrooms we should continue to teach the basic theories and engineering fundamentals that will serve as a foundation for lifelong engineering careers. But we also need to be sensitive to the needs of the professions we serve and teach our students things that will make them more valuable to their employers in the short-run as well as well into the future. In research I think we can do better to consider the most important problems facing the various sectors of practice and application, and then encourage some academics to effectively prioritize their time where it can do the most good, regardless of short-term funding trends and the prevailing academic culture.

6. REFERENCES

Paulson, Boyd C., Jr. (1976). "Designing to Reduce Construction Costs". *Journal of the Construction Division*, ASCE, Vol. 102, No. CO4, Proc. Paper 12600, December, pp. 587-592.

Willenbrock, Jack H. (1998). *Residential Building Design and Construction*, Prentice-Hall, New Jersey.