STRUCTURES WORKSHOP

2011 EDIFCIA SIMPOSIUM

**The Linked Hybrid and My Manifesto for Growth**

**El Linked Hybrid y mi Manifiesto para el Crecimiento**

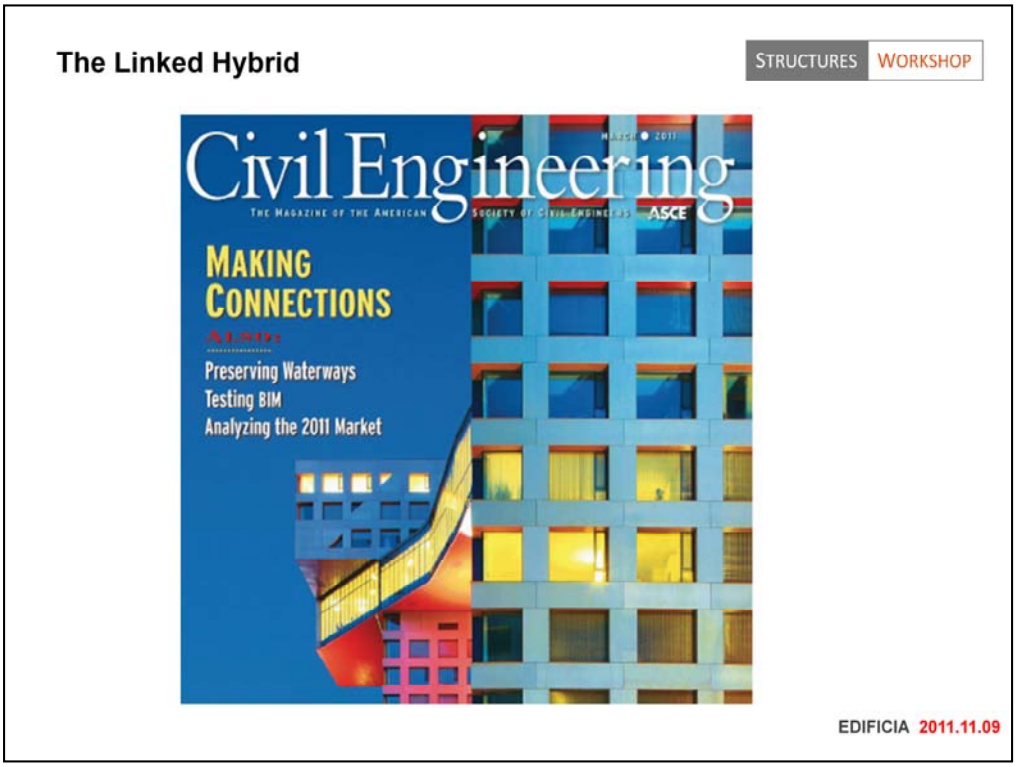
**Erik Nelson, PE, SE**
Structural Engineer and Owner of
Structures Workshop, Inc. in Providence, RI USA
Adjunct Professor at MIT and RISD

EDIFICIA 2011.11.09

Good morning everyone. First of all, I want to thank the symposium committee who invited me to the wonderful university and beautiful city. As a quick introduction - I am a structural engineer, own a firm in Providence RI called Structures Workshop – we do approx 70-80 building projects a year. I teach and am an Adjunct Professor at the Massachusetts Institute of Technology, MIT, and the Rhode Island School of Design, RISD. I apologize for not being able to speak Spanish, I took 3 years in high school and lived in Venezuela for 6 months, but I was unable to retain it. My English isn't particular good either, but I get away with that being an engineer. I did try an translate English to Spanish in the text using Google, so I hope it translates properly. Again, thank you very much for being here and I hope you will enjoy this presentation.


I understand the main theme of this years symposium is “leading cities” and therefore want to address how we as engineers can be leaders and innovators and create better infrastructure. This talk addresses some of my thoughts about my profession and how I see the future of engineering. The project example I will be using throughout the talk is the Linked Hybrid complex in Beijing. This complex was designed in 2003-2005 when I was employed with Guy Nordenson Associates in NY. The Architect is Steven Holl Architects, and we had help of engineering collaborators in Beijing called CABR.

The project was completed in 2008 and has since won numerous awards, most notably the “Best Tall Building Overall” for 2009 by the Council of Tall Buildings and Urban Habitat. The Linked Hybrid is a great example of the progressive, imaginative, and daring architecture that has emerged in China recently. The complex consists of 20 unique structures, including 8 residential towers (containing 644 apartments), a hotel, a cinema, a kindergarten, and an underground parking garage. The hotel and the eight approximately 60 m tall towers are connected at their respective upper levels by a series of eight bridges. These bridges are public spaces in which residents and visitors can walk and enjoy various pastimes and activities, including a café, a fitness room, a gallery, an auditorium, and other functional spaces. One of the largest bridges even contains a swimming pool.

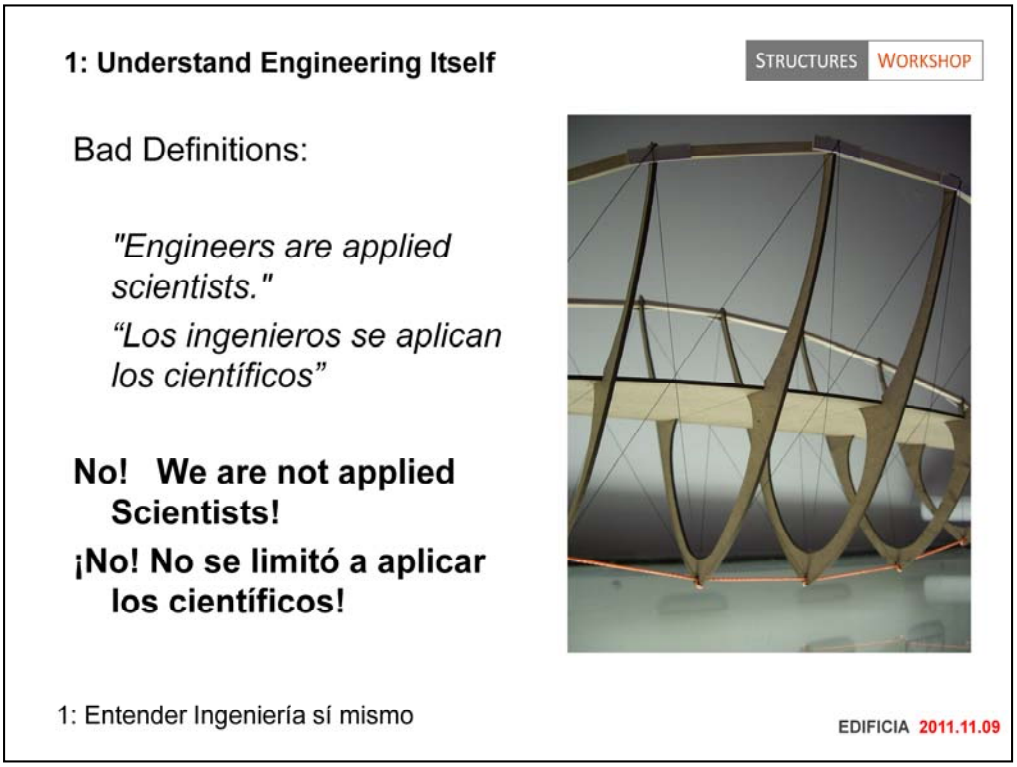



Steven Holl has described the project as follows: “The 220,000 sq meter Linked Hybrid complex, in Beijing, creates a porous urban space, inviting and open to the public from every side. As a ‘city within a city’ the new place has a filmic urban experience of space; around, over and through multifaceted spatial layers. A three-dimensional public urban space, the project has programs that vary from commercial, residential, and education to recreational.”

I understand the main theme of this years symposium is “leading cities” and therefore want to address how we as engineers can be leaders and innovators and create better infrastructure.  This talk addresses some of my thoughts about my profession and how I see the future of engineering.

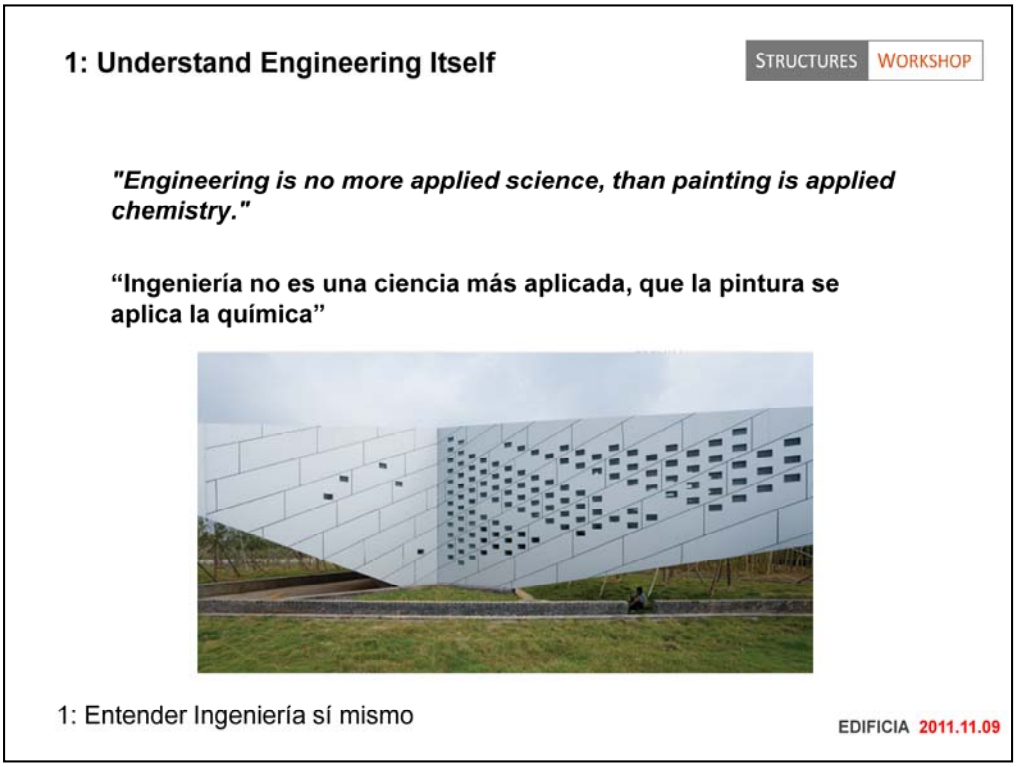

I will call this presentation “My Manifesto for Growth”. What this Manifesto means is really about how we as an engineering community (students, educators, and engineers) can grow as individuals and lead the profession into the future. How can we improve ourselves and therefore our profession. In so doing, we will improve our built world, and we will do this sustainably and honestly.

I am presenting this from the perspective of a structural engineer, but I think many of these ideas presented are similar to all of our engineering professions I need your patience as I will introduce 19 ways to grow as an engineer that I have discovered. So now, lets get to the Manifesto!



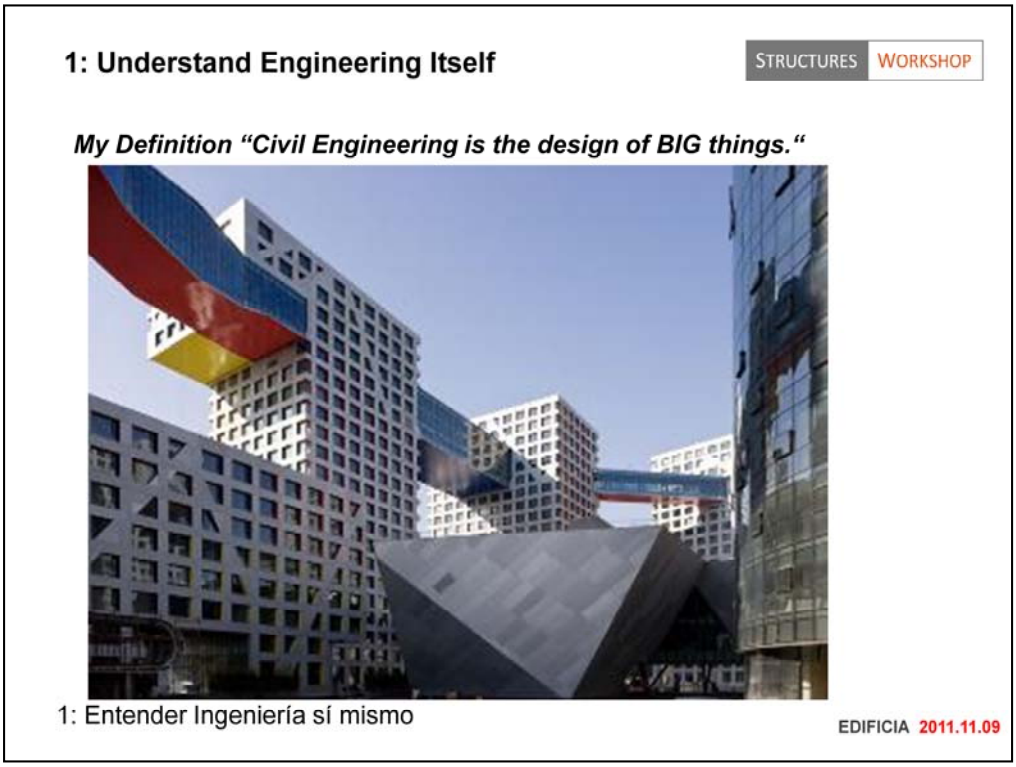

The first way to grow in my Manifesto is to fully understand who we are. I know many of you are students here at this prestigious school, some of you are educators, and some engineers. All of us Engineers and Educators have a responsibility to understand who we are and to translate that to the young people, our future, the students here who desire to be an engineer. They need to know who we are, so as an Engineer, I am pursuing this now. So 1 - What is engineering exactly? We need to understand who we are before we can grow. We can start with a definition. The most common one is "Engineers are Applied Scientists". No!!! Scientists are applied scientists. Here is more of the same from the National Society of Professional Engineers (NSPE): *"Engineering is the creative application of scientific principles".* This "application of science" notion is so pervasive that it sounds like it is pretty much all that we do and suggests that our creativity is not employed for artistry, self-expression, costs, or constructability, but solely for science. That is just plain weird – and wrong.

The applied science portion of what we do is actually the easiest and most straightforward. It is objective and has its own linear, -wise methodology. That is why the young engineers are doing the calculations and the modeling, while more experienced engineers are doing less. Yes, it needs to be right, so there is a lot of responsibility in this phase; but that does not necessarily make it difficult. The experienced ones are doing the other 90% of what we do, the more difficult tasks that require much more than calculations. Design is the other 90% of engineering that is only achieved after one graduates from being a mere applied scientist (or technician) to being an engineer! Engineering is an incredible profession, I believe the greatest profession, so we need to get this definition right.



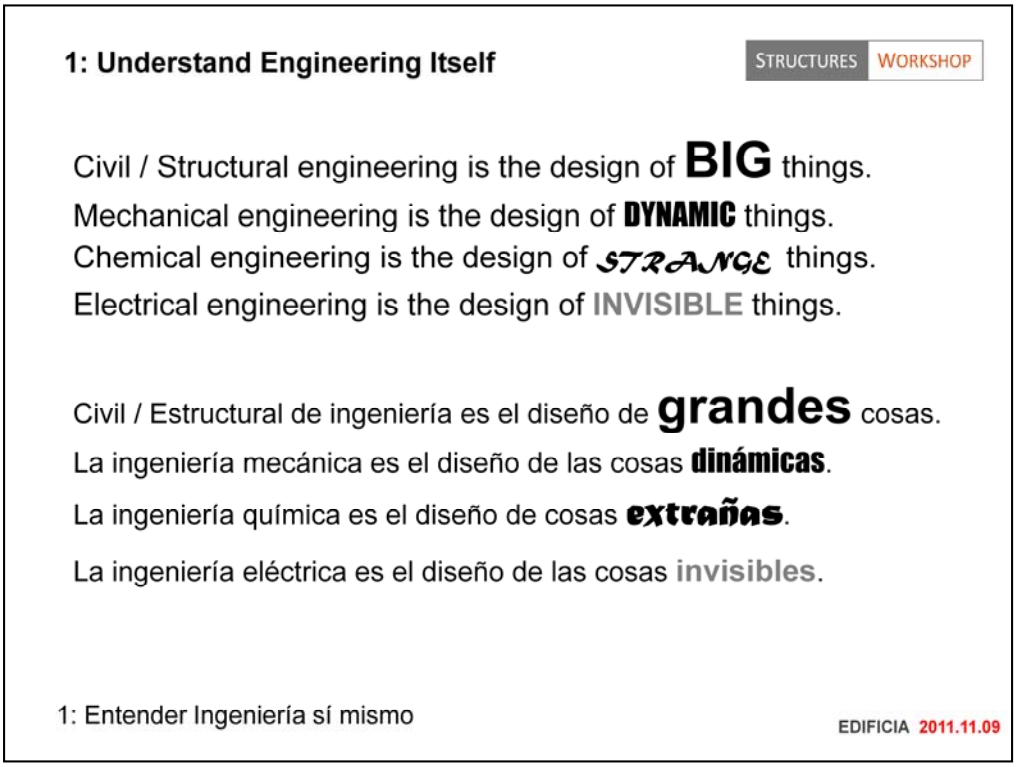

Scientists make sense of what exists in nature. They test and examine nature. Scientists discover. Engineers take nature and make what exists outside of it. Engineers invent, create, and make. Engineers are makers. Engineers are designers. Alan Harris put it succinctly "Engineering is no more applied science, than painting is applied chemistry." Stress and strain are necessary calculations but represent only a small fraction of all that we do. Yes, we proportion members based largely on forces, but that is only one of many design considerations – we also have to take construction practices, architectural constraints, client needs, and many other factors into account. As Hardy Cross put it, "Strength is essential, but otherwise unimportant."

So why do we align ourselves so closely with science? Because it is "hard"? No, it is because we have allowed the educators of our profession to define it for us. Our educators are generally not engineers, they are scientists. I love science, but I am as much an artist as a scientist, and I suspect that you are, too. We differ from scientists in that we absorb ourselves in practical problems. We have great educators and researchers in our Universities, and I am incredibly impressed by them – but they are rarely engineers. Unlike other disciplines (Law, Architecture, etc), they are not rewarded for doing the thing they are teaching. They are really "practical" scientists. Therefore, science is learned in school and design in learned in practice. That is fine and for a different article. I am merely describing who most of our educators are, and I think that our educators have the responsibility to know who we are, so this article is for them too. After all, they serve as mentors to our future staff.




The know-how required to do this is immense and requires lifelong learning.
Engineers are 1% to 10% of each of the following:

Scientists, Mathematicians, Computer Scientists
Information Seekers (State of the Art)
Specialists in Systems, Experts in Construction
Citizens of a Locality of Construction Practices and Material Availability
Cost Estimators or Experts on Best Practices to Reduce Cost
Experts on Local Fabrication and Construction Technologies
Experts on Building Codes, Specifications, Standards, Guides, and Regulations
Risk Evaluators and Code Interpreters
Experts in Calculations, Experts in Three-Dimensional Representation in the Mind
Experts in Synthesizing Complex/Unsolvable Things into Simple/Solvable things.
Experts in Analysis Modeling Using Software and Skeptics of Engineering Software
Debaters of Efficiency, Economy, and Elegance
Artists, Philosophers, Poets, and Dreamers with Unconstrained Self-Expression
Drafters and/or BIM Specialists
Collaborators Working Within Design Teams
Listeners of the Vision and Needs of the Project/Client/Architect
Users of Rules of Thumb (Heuristics)
Experts in the Ability to Make Decisions Under Great Amounts of Uncertainty



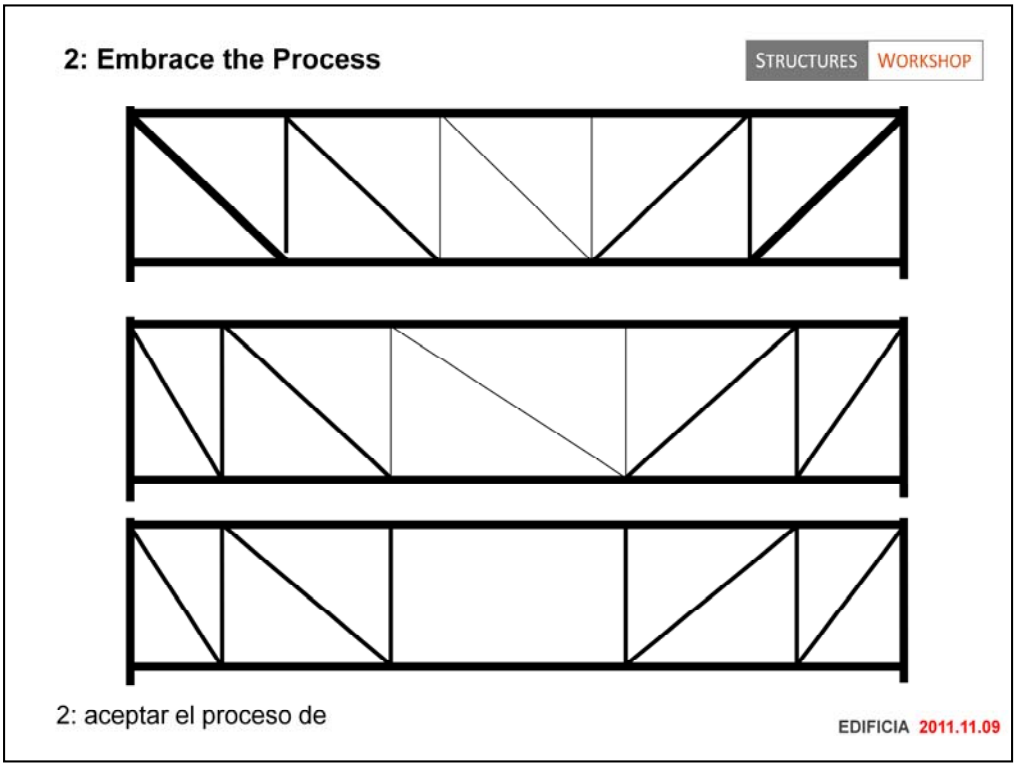

Civil / Structural engineering is the design of BIG things.

Mechanical engineering is the design of DYNAMIC things.

Chemical engineering is the design of STRANGE things.

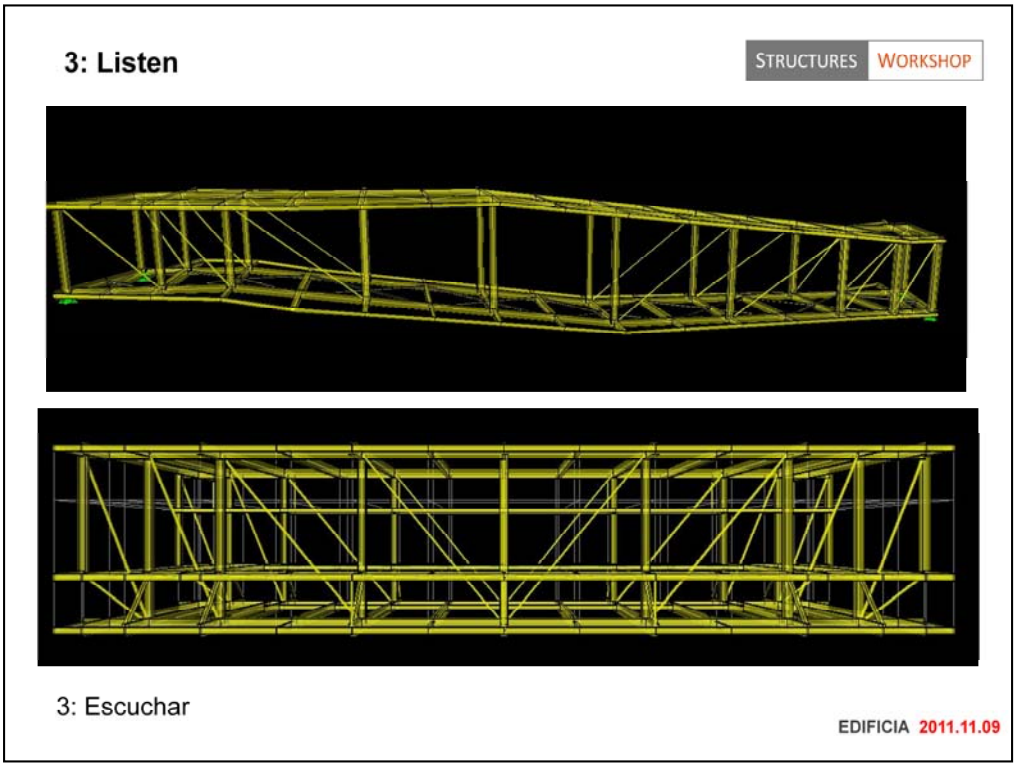
Electrical engineering is the design of INVISIBLE things.

A skeptic of this structural engineering definition might ask, "Well, architects design big things too, don't they?" This is correct, but they are not hired precisely because the thing is big. We are. This definition may contribute to a positive "rebranding" of the profession which may improve career appeal to our profession (hopefully help with the dismal 50% retention rate in our engineering schools). We have a marketing problem of clearly describing what we do. Our educators are generally not good engineering mentors, and they likely mislead our students into believing that engineers merely complete calculation procedures. Engineering is so much more than that!




Now that we understand who we are we can proceed to 2 “embracing the design process”. Engineering is really all about design. Design is everything in my earlier definition, and much more than science and math. “Embracing the process” means that design is a process not a output, not a final thing. Let the design process push and pull you constantly. It is healthy. Design is nonlinear. It goes backwards as much as forward and it curves around back on itself. That is okay.

Above is a bridge truss, the top one may be familiar with, but the bottom one is new and novel. How does one do this improvement? You start with what you know and proceed. You ask questions “how can I improve this boring Pratt truss (the top truss A)?” Well maybe I can study the shear and moment diagrams and adjust the spacing of the verticals such that the axial force in the diagonals is always the same. The cost saving will be significant if the rods, gusset plates, welds, bolts etc are all the same. Then you can proceed from B to C and remove the middle diagonal – (zero shear). This is a new truss, a novel and beautiful truss - an economic, efficient, and elegant truss. One that is created – a new and novel type of bridge.




The most radical aspect of the Linked Hybrid project is the eight bridges (a progression of one is shown schematically above). These which were never part of the client's original program. Instead, their presence in the final design attests to the tenacity of Steven Holl's vision and to the client's openness during the design process. The bridges not only link the towers but also incorporate spaces that can be shared by the residents, reinforcing the sense of community, and provide visual links to the city at large. The bridges' functions are public and alternate between the practical and the whimsical, including a lap pool, a tea seating area, and a group exercise space. The bridges themselves were born out of the design process

The Manifesto for Growth 3 is to listen. Be a better listener and collaborator. Architects (and other clients) will make you a better engineer, but you have to listen. In this case Steven Holl was the one who challenged us to create something exceptional. He understood engineering intuitively and knew that the center diagonals could be removed. He understand the forces working within a truss and knnew the center of a truss has zero shear, so diagonals may not be necessary. I listened. I went back and studied the bridge and removed the diagonals. His design for transparency, fed the design process, and led to challenging me as a structural engineer. He improved me. In turn, improved the project.

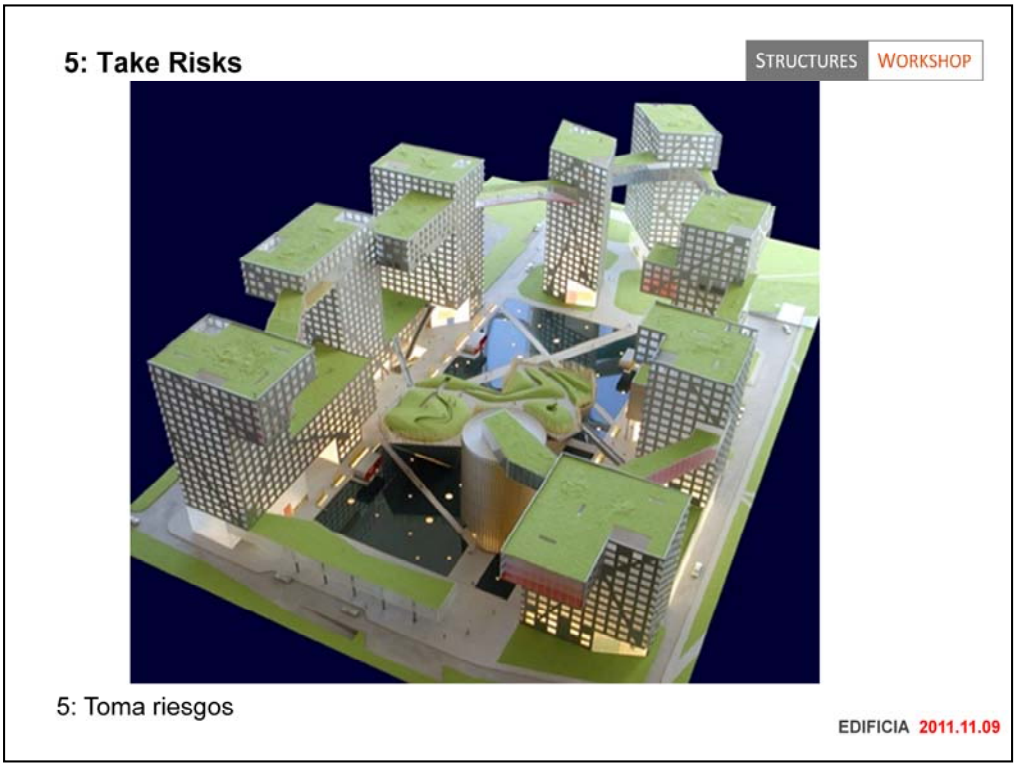

The Manifesto for Growth 3 is to Become a Lifelong Learner. Become a lifelong learner. Not because it is a goal, but because you want to maximize your well being now. Engineering, like the good life, requires lifelong learning. Ask stupid questions often and pursue answers. These stupid questions are really smart…*Who am I? What is engineering? What is a weld, really? How can something turn from a liquid to a solid within a liquid (concrete underwater)? How come I don't add that tension force I calculated to the pretension already within the bolt shank from tightening? Can I really put a pool on a bridge up in the air spanning between two buildings?*

If these are the types of questions you constantly engage in, you are in great shape. What is amazing about engineering, is there are infinite amounts of things to learn. Get into it and do it.


Take Risks. Design of big things requires risk taking. Design of new and unique solutions to problems takes even more risk. Because engineering requires ingenuity, it requires risk. Be daring. We need to continue to be leaders in design and construction and we need to take more active roles in pushing our projects forward, not getting pushed.

*Lord Kelvin, the physicist ,said, "It's no trick to get the answers when you have all the data. The trick is to get the answers when you only have half the data and half that is wrong and you don't know which half."*

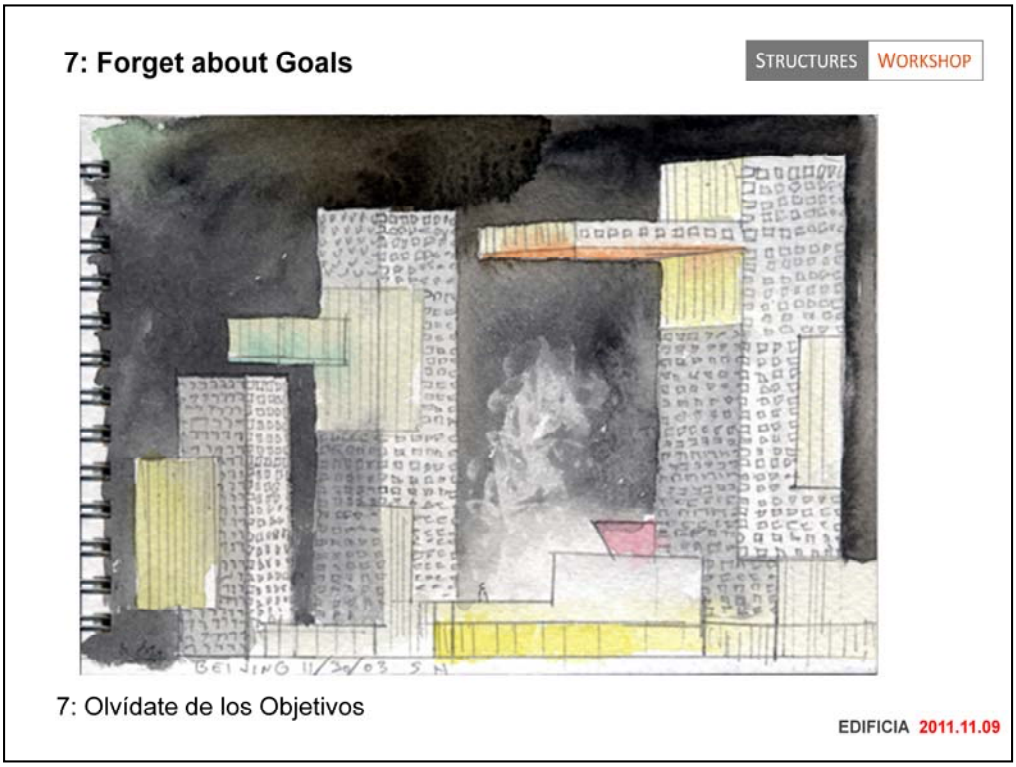
Scientific application or procedural calculations is about the known-knowns. Design is much more about the known unknowns. Embracing that requires risk.



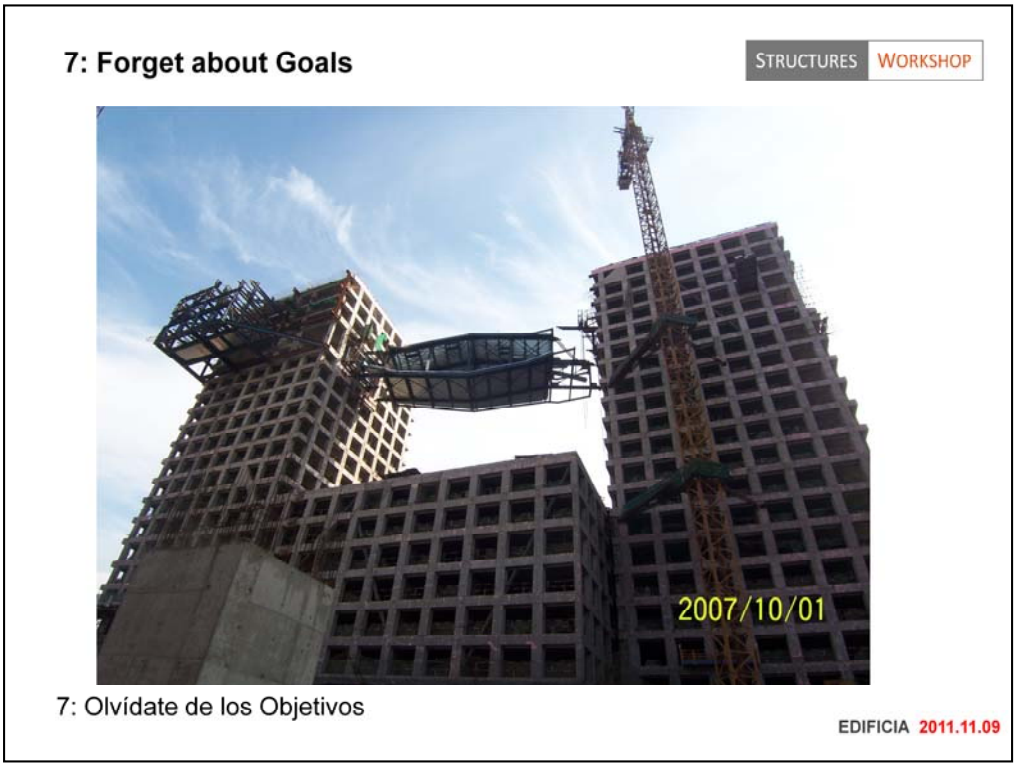

The Linked Hybrid required this. I was fortunate to get to be the project engineer for the Linked Hybrid.  In China, it is possible to design and construct certain buildings that are inconceivable elsewhere, except perhaps in the Persian Gulf. We took risks even with great amounts of reservations, but we worked with courage and honesty to overcome any obstacles.


6: Embrace Imperfection. If there is not a perfect solution, it follows that, all solutions are not perfect. That means that there is always a better solution than the one you just submitted for construction. The design has many compromises such as code requirements, construction skill, material limitations, conservativeness on new construction techniques, possibly errors of design, bad decisions early, etc, etc. Get accustomed to that, own it, it is a good thing. All designs are fallible. All designs can be improved. Guess what, your design you submitted last week has numerous problems or design compromises, that is okay. Learn and do better next time. Take your imperfect project to a lower state of imperfection on the next project. Here you can see a joint that affected the clear glass. The joint was required when the bridge extended to the cantilevers. The cantilever is fixed on the building, whereas the bridges floats freely on large friction pendulum isolators.

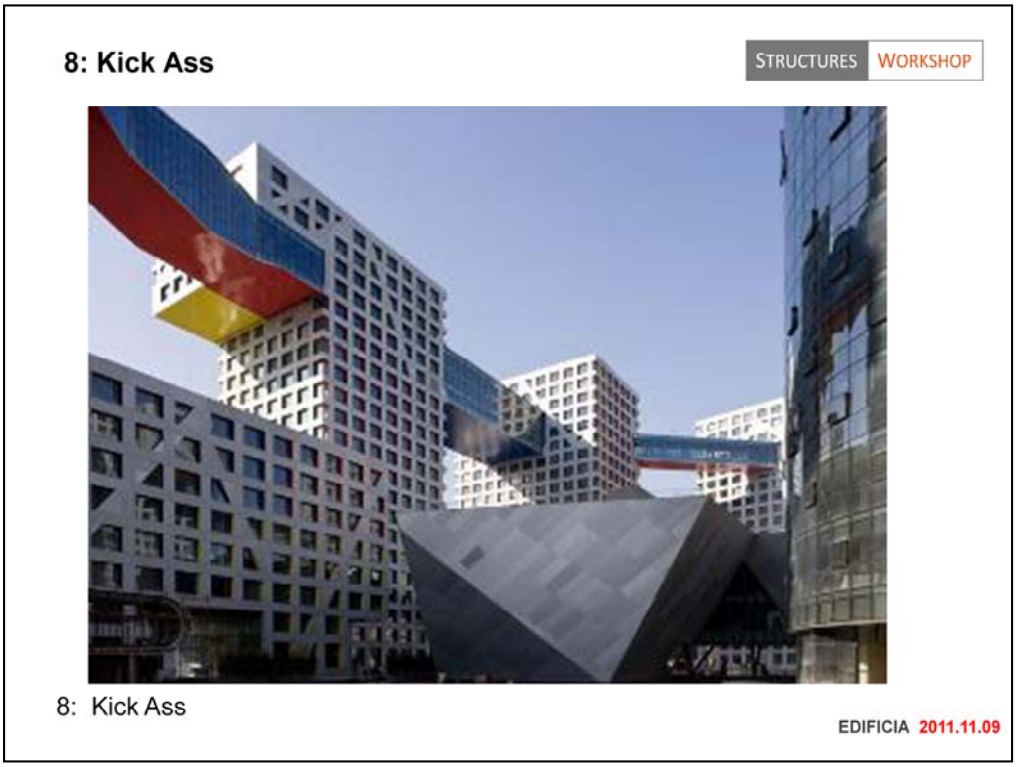
The bridges are light and delicate; to protect them from the effects of tower deflection at the upper floors under an extreme seismic event, Xiao Congzhen—our brilliant collaborator and a CABR structural engineer—suggested that we isolate them entirely. Initially we had imagined adding rollers, elastomeric bearings, or friction-pendulum bearings to one side, leaving the other side fixed. But this fixity at one end of the bridge would have translated into large torsional forces in the towers resulting from the eccentricity of the bridge mass. When Xiao suggested we simply isolate the bridges on both sides so they would be entirely free, we were delighted and astonished by the practical but poetic suggestion. Isolating the bridges from the towers not only reduces the forces on the towers, but it also protects the light bridges from the movement of the towers. Thus, we took our design to a lower state of imperfection, and that is the goal of design.




7 is about ignoring goals. Structural Engineering is a process without a goal. Yes, of course, there are design constraints. Design constraints are not goals, they are ways to make decisions and the move the project forward in the present, the now. That is, engineering is an evolution from a concept (site plan) to a built project. Let the project be unknown during the design process. Understanding that design is inherently goalless is good for you. It is means that design is means driven, not ends driven (not the outcome). It is the present, not the future. Ask “What am I doing right now?” Ask yourself that question often. How are you improving the project now? Today, not tomorrow. How are you increasing your well being, your team around you, and your project? If you have an end product first, that is less effective than if you live and work honestly in the present. When you take meaningful s in the present, the next day the project will evolve to a higher level. This repeats itself day after day. The end product (building / structure) simply becomes. Let it become. Nurture the process. Be patient.




We don't know the end product, the final construction is unknown. So it is pretty reasonable to suggest that the goal of achieving this or that building is useless. How could something unknown obligate us? I would submit that even known goals are useless whether it is to be successful or to win something. These are not only obvious, they are superfluous. Goals themselves are always good things for the person, so I am not debating whether this or that goal is a worthy pursuit. A worthy pursuit (or goal) like *yearning for the vast and endless sea* is fine, but the more immediate task is building the boat. Focus on the boat not the sea. The sea is a useless goal, it is obvious. Freedom to float on the water is inherently good. Freedom in the sea or the goal of greatness is obvious. The goal of the sea is superfluous – how can something superfluous, obligate us? Just like the goal of being great. That is just as useless. Be great instead. Let the design process produce the next evolution of the concept. Try to design the boat by asking what materials are available first, and keep proceeding. The built project, the boat itself in its final state should not be known. Let the boat become, and then hop on board. The sea will be reached. Greatness will be achieved.




This is not rendering, this is the finished project. Design is an incredible process (again, from 7 we learned it is not an end). It is good for you to make the process of design your own. Drive the process and in so doing you will grow and become a better engineer. Cooperate, listen, be humble, but don't let that prevent you from kicking ass, which is 8.

You need love of learning, pursuit of excellence (not the goal of excellence), you need process, you need means. Ends are useless to process. If you focus on the present and work to maximize your well being, others' well being, the building's well being - now – what results is the achievement of any goal. That is why I reject the idea the we need to categorize ways to achieving goals (being better innovators or leaders, for example). Yes, we all want to be better engineers (and citizens, spouses, parents, etc), so saying "my goal is to be a better engineer" is superfluous and useless. Take action now. Act as though everything you do will become universal law. Your pursuit of well being will help others, which will in turn come back to yourself and everyone benefits. Do not picture yourself as a great engineer, a rich engineer, or a famous engineer. Do great engineering now and you will be great (not in the famous type of great, the un-famous type of great which is more worthy of the word).


Talk to materials. You can ask if steel likes to slide on tephlon or if a friction pendulum isolator is the right product for the task of protecting the bridges from the buildings unders seismic shacking. I asked the isolator this question. On another project, say masonry, ask if bricks like to take compression. Go ahead and ask a brick. This may sound bizarre but participating in a conversation with an inanimate object is healthy. Feel a brick (or bolt, concrete sample, etc) in your hand and discuss with it what it wants and where it wants to be in the building. You can only become an expert by becoming the thing itself, by manifesting yourself on the building, beam, connection, or bolt.

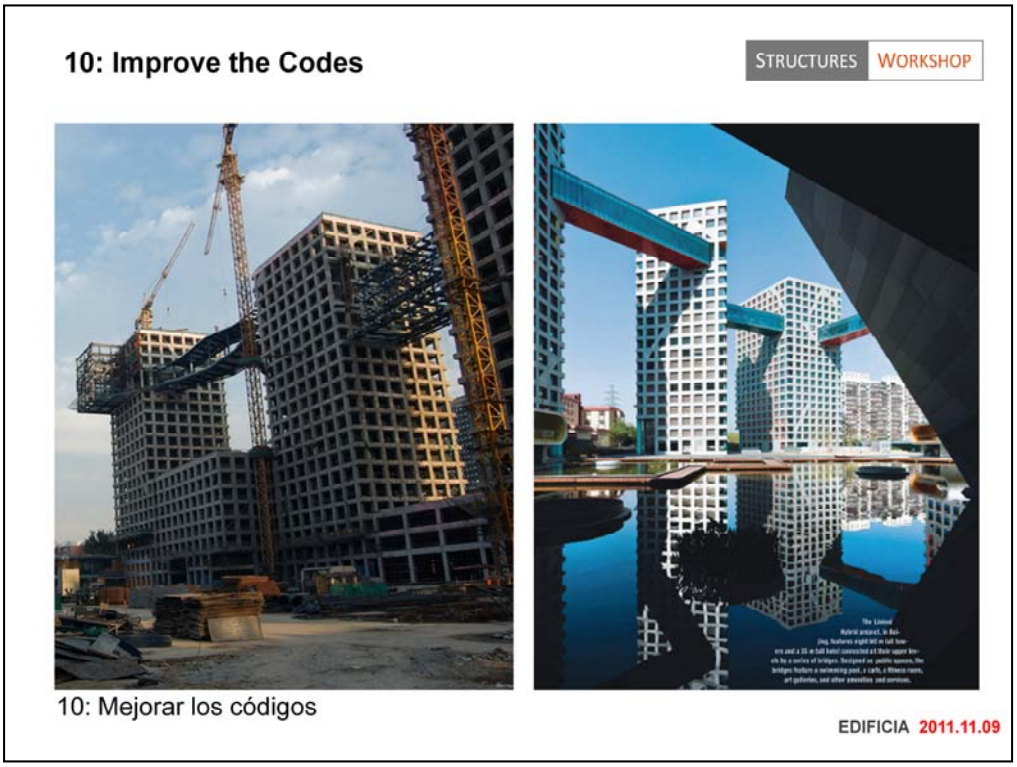
I remember visiting a project where I designed all the connections for a large box truss that supporting four stories of concrete and spanned 100 feet. The erector was proud to show me his work and described the installation, weld and details as a master craftsman would. He wasn't self serving when describing this – he was describing the work itself. He and I both knew the architect was going to cover it all up for no one else to see (just like this FP isolator you see here that supports the bridges on all four sides). He was still deeply satisfied, as was I. I realized much later that the satisfaction was not really about the truss or even the workmanship (craft). What he was really showing me was himself, a manifestation of himself on the steel connection. Yes, the weld was beautiful and well crafted of course and that is satisfying too, but that isn't really what he was indicating. He was really showing me was that he was a good human being, he is quality just like the connection. The inanimate object was him and it was beautiful. We can learn a great deal about ourselves the same way.


I think this idea is similar to Robert Pirsig's metaphysics of quality. In Zen and the Art of Motorcycle Maintenance, Pirsig suggests:

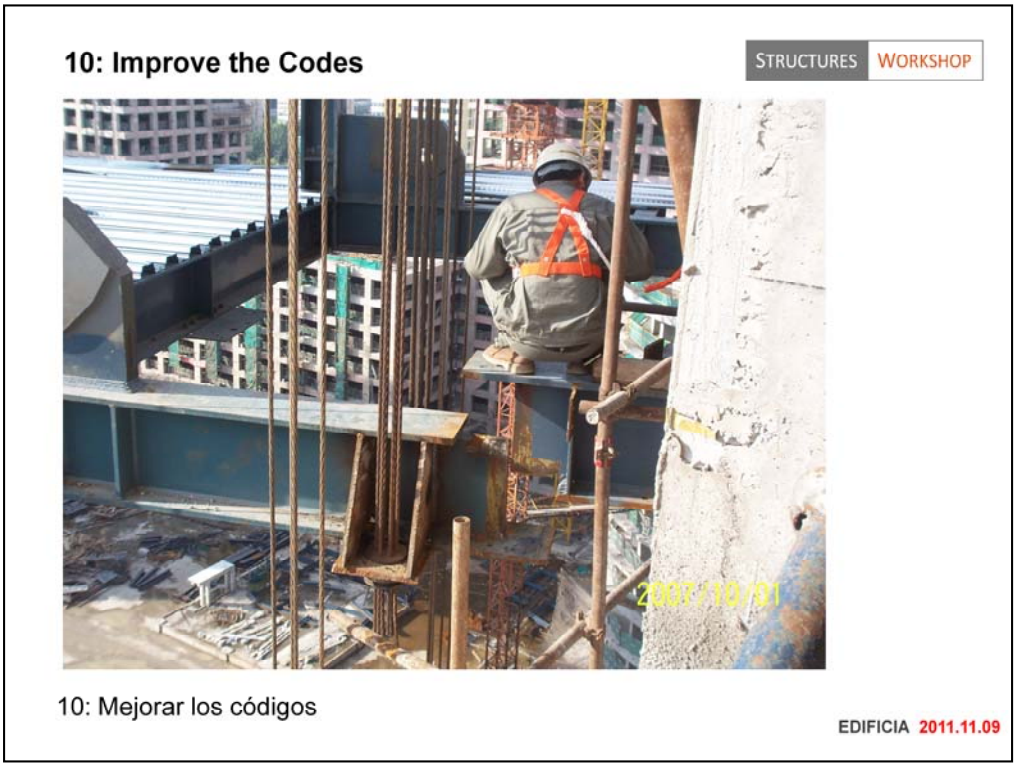
*You want to know how to paint a perfect painting? It's easy. Make yourself perfect and then just paint naturally. That's the way all the experts do it. The making of a painting or the fixing of a motorcycle isn't separate from the rest of your existence… The machine that appears to be "out there" and the person that appears to be "in here" are not two seperate things. They grow toward Quality or fall away from Quality together.* [Pirsig 1974: 332]

Therefore, according to Pirsig, if you want to become an expert structural engineer, make yourself an expert structural engineer and then do engineering. You may notice this sounds similar to my idea of recognizing goals are useless (from 7).

The bridges, one shown here framing below a cantilvever, are the highest base-isolated structures in a seismic region in the world—an achievement made possible by the stiffness of the tower structures.




Improve the codes. Codes are good and extremely important, but they are getting completely out of control (IBC, ASCE, etc). I remember listening to a great lecture by Ronald Hamburger regarding this same topic at an AISC conference. He used the example of a provision in the ASCE 7-10 code regarding how QCQ methods should be employed when combining model results where translational and torsional modes are intermixed. While admitting not knowing what this meant himself (and for Ron, that is saying something) and how to go about determining if in fact QCQ-4 should be used, he discussed if the provision was actually important. He questioned the code provision, something we all need to do. This also helps us understand them better. The questions we may ask in this case are: "Why do I care about exact modal superposition methods when I am doing Response Spectrum Analysis, which is exceedingly approximate?" and "Do I really need to be exact when I just took my elastic response spectrum and divided by 500% (R=5 for example)?" Of course not. We had these same problem on the Linked Hybrid and the stringent torsional percent criteria in the Chinese codes.



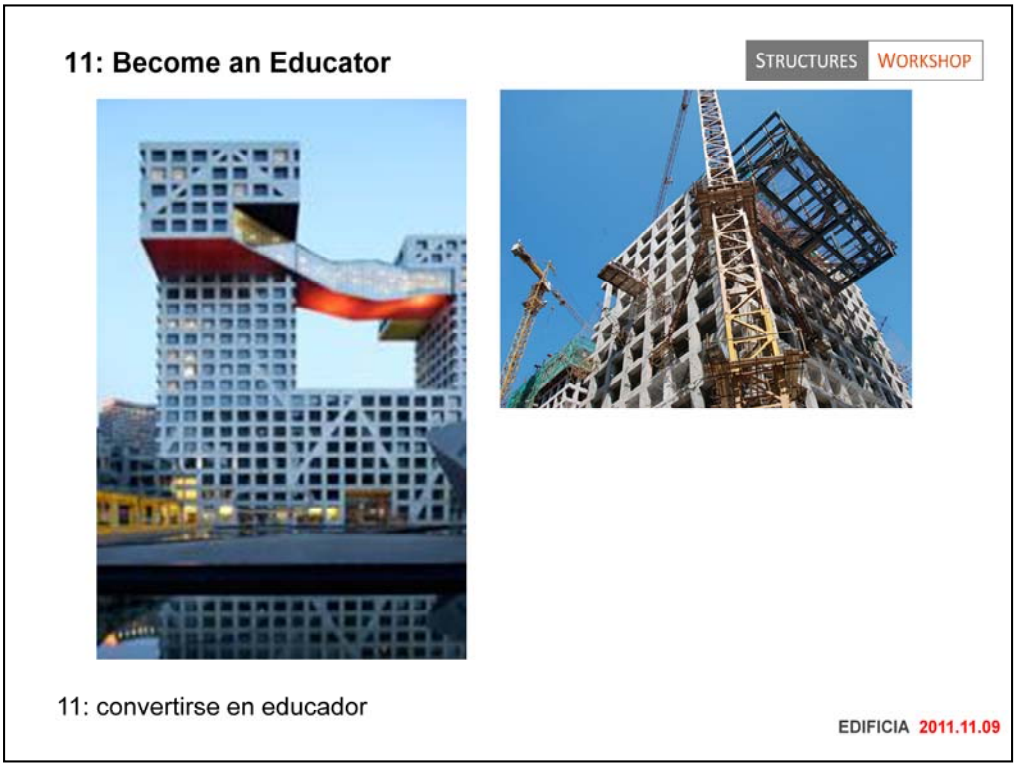

The code committees should keep in mind the approximate nature of this enterprise called structural engineering. Not only are there large uncertainties in our loads and material strengths used in design, there are huge uncertainties in construction and should ask themselves the following two questions:

Is this provision important to the design of safe structures?

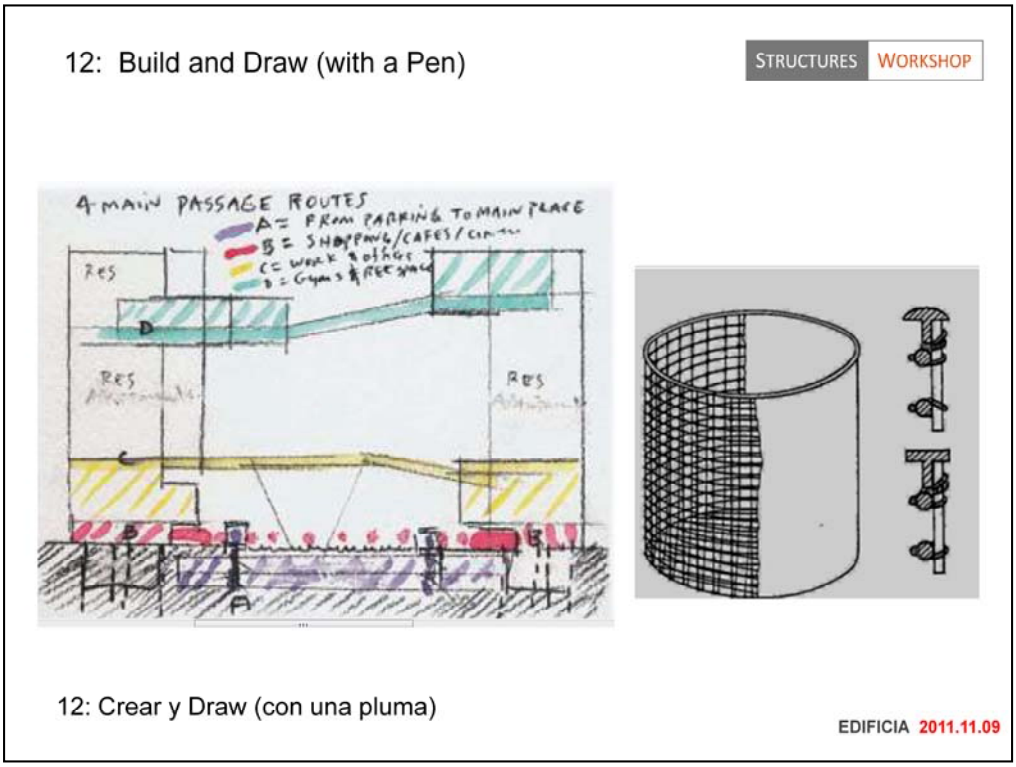
Is the provision too exact?

If they asked these questions, the codes would not balloon to the size they are now.

Codes are getting so large it hurts the profession. Should we stop updating codes? No. Should we slow down? Yes, absolutely. The updates to the codes are out of control and unsustainable. Codes already contribute to the need for fully automated applied science because no one would be able to apply the amount of code information to a particular problem. What does automation foster? Non-thinkers. But there was a time when people understood that code requirements needed to exist to ensure public safety, and that was the standard that they needed to meet. That should be the only standard. We need to join code committees and take our profession back.



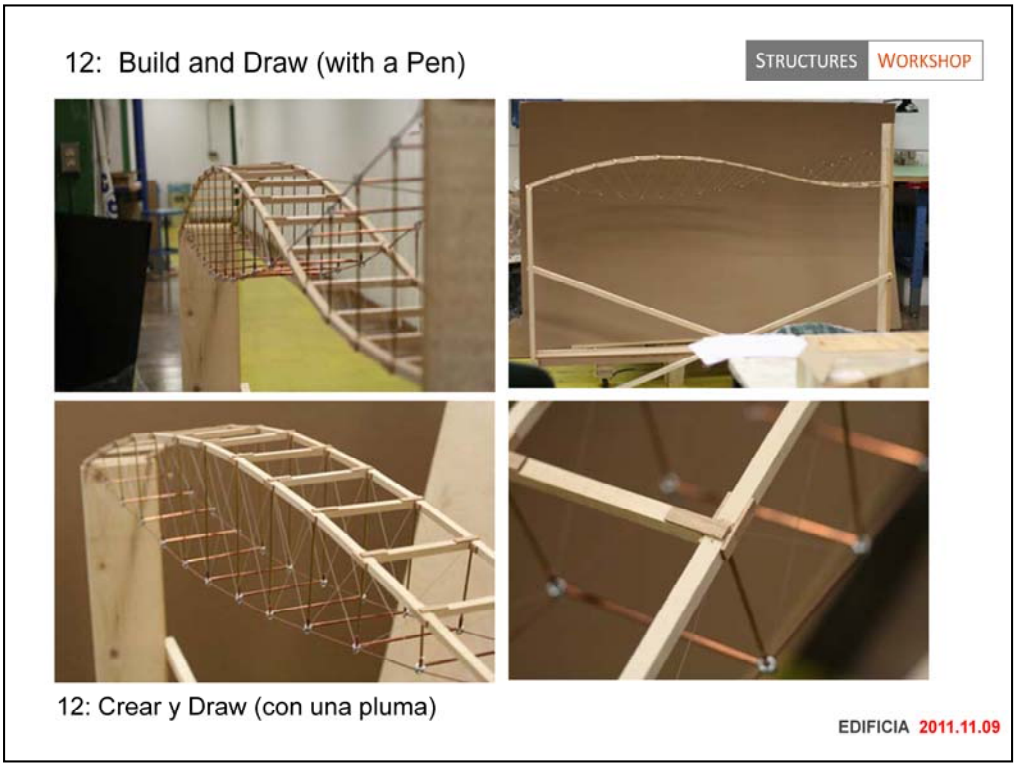

I never thought being a teacher would make me a better engineer. It is undoubtedly the best decision I have ever made as an engineer. Teaching makes one focus on the fundementals and therefore you become an expert at explaining complex phenomena in simple terms because you fully understand the subject.




If you don't like to write words, sketch ideas of structural systems or buildings. Buy a sketchbook and use a pen, so you can't erase your mistakes. Mistakes are important reminders that you are an idiot (like everyone else). The best preparation for life as an engineer is the understanding of our ignorance.

In 1850 J. Monier, a French gardener, developed a flowerpot with reinforced concrete in the hand sketches above on his patent shon on the right; in 1867 he patented reinforced garden tubs and, later, reinforced beams (which is the main structural system of the Linked Hybrid – so I owe a debt of gratitude to this gardener.

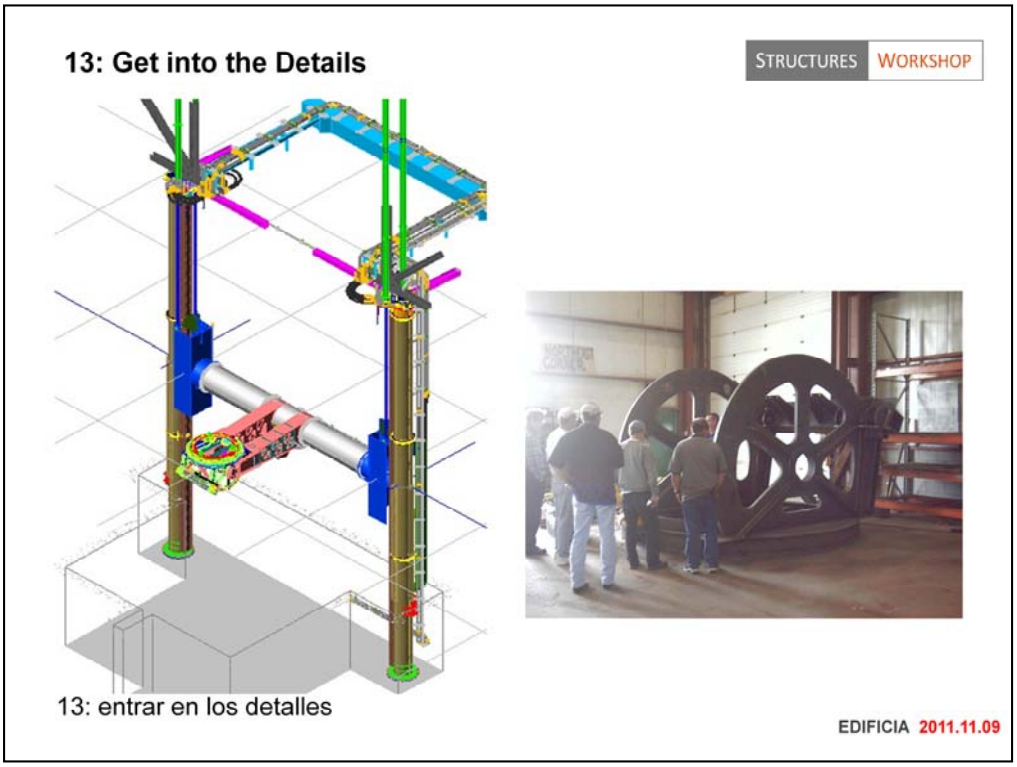
The sketch on the left show the Archtiect's program used on one of the bridges. The 9 buildings and 8 bridges form a circle around the center court yard. The key to this concept is the relationship between the "courtyard" formed by the buildings—an analogy to the quadrangle house type common in Beijing—and the openness of the building complex to the city around it. Unlike many gated communities that have been developed in Beijing, the Linked Hybrid complex is generally open to the public. The bridges create both a landmark and an inextricable visual connection between the complex and the surrounding city. This balance of community and citizenship are what makes this project unique among the many characterless developments occurring in China. The positioning of the eight main towers and the circuit of bridges that link them was skillfully calibrated to shape the central shared space as well as the views to the city beyond. The walk along the complete bridge circuit provides an exhilarating and unique promenade in the air.



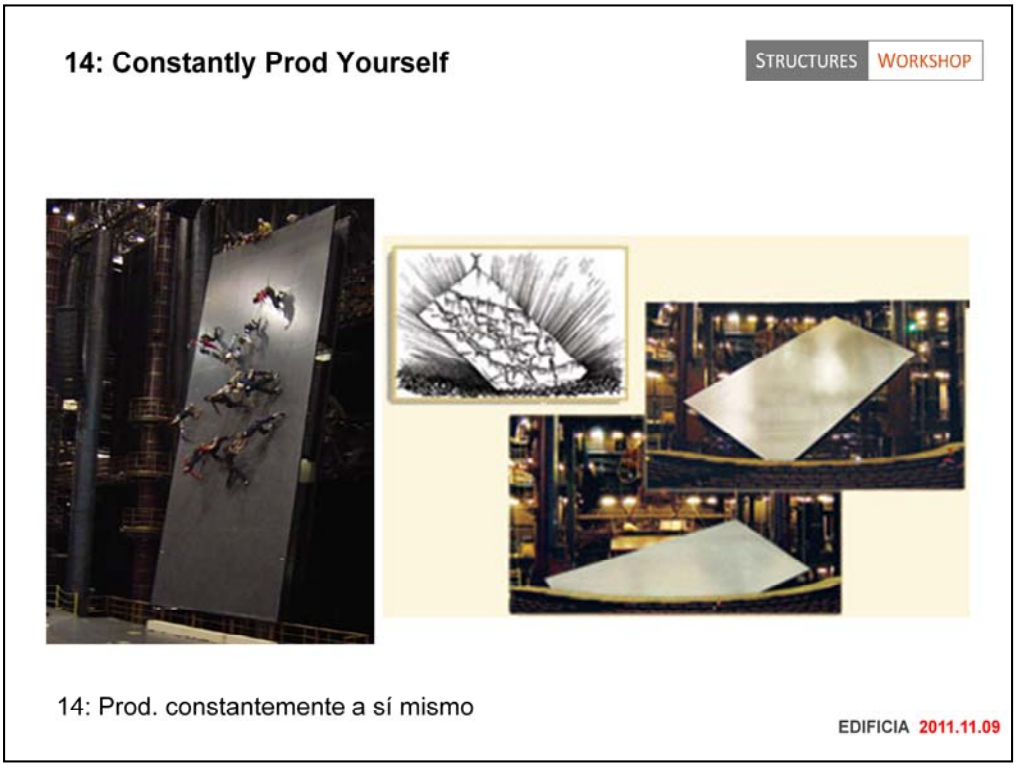

We also need to make scale models of our structures and turn off the computers sometimes. Architects do this and it is incredibly useful. You can even test your model with loads for fun. The computer will never replace the importance of the pen or the physical model. In the terrific book "Structural Engineering: The Nature and Theory of Design" William Addis states:

*Up until the turn of the century, it was standard practice for engineers to keep their own notebooks containing annotated sketches of hundreds of interesting designs and details they have seen in their travels; this formed a body of knowledge upon which a designer could draw and provided an important link to the past. Also, until the present century, engineering textbooks and encyclopedias often used to contain many examples of successful designs, both ancient and modern. Nowadays, young engineers are generally brought up without a good knowledge of precedent and to believe that mathematics of engineering science encapsulates all they need to know*. [Addis, 1990:xii]

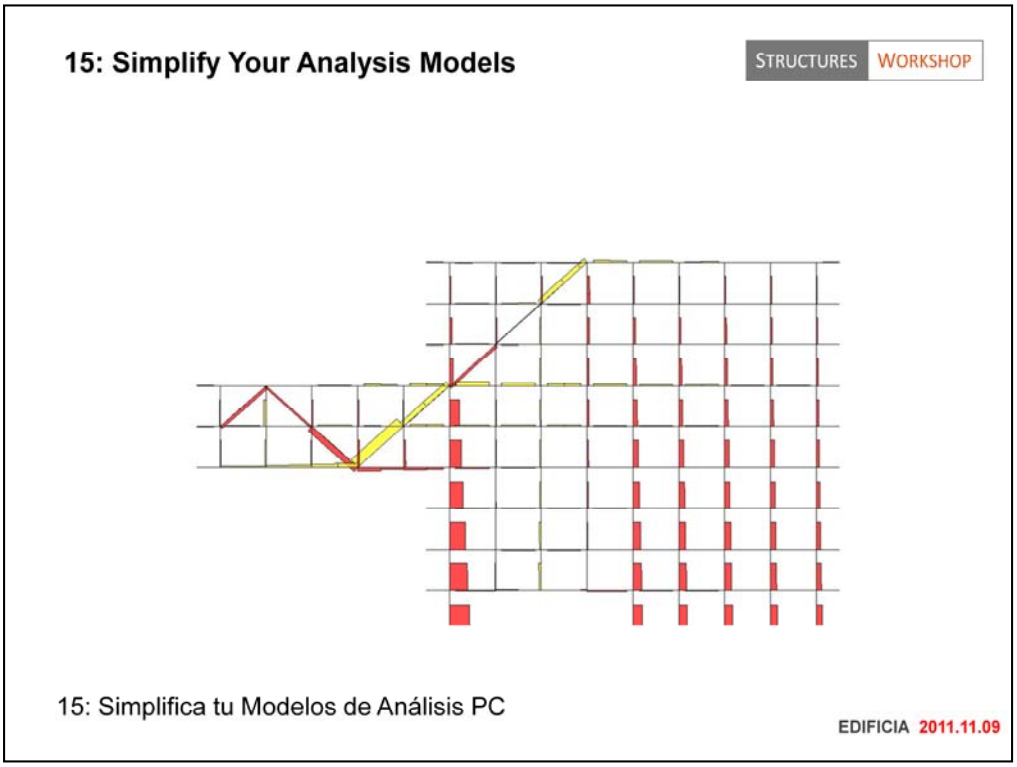

13: Get into the Details. Become super technical and share your technical knowledge with others (for exmple – know the root pass tolerances of CJP bevel welds of the HSS columns shown above for the Cinema base of the Linked Hybrid) because actively understanding our codes and science is essential. It is also unlimited. Yes it is knowledge, but knowledge is an inevitable result of doing engineering (knowledge is mainly the experience portion of our know-how). This is why are schools need to continue what they are doing, providing a good theortical and applied science background to the students. Engineering can wait until the workplace, although it is good to introduce design within the curriculum as well.



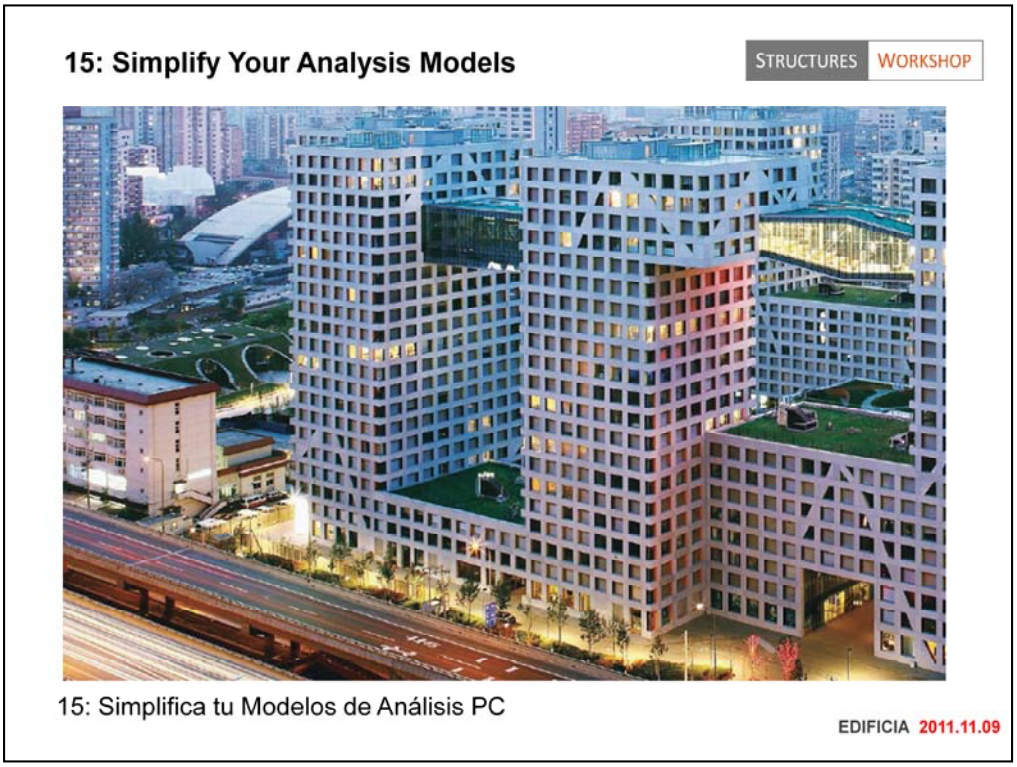

We will start to look at different projects I have worked on. This is Cirque du Soliel's incredible show called "Ka" in Las Vegas. This represents 13 very well. You can see the complexity of this machine and 13 "getting into the details" is critical to the projects success. This is a stage that can lift, rotate, and spin above the audience that I designed in 2003. 13 is about how memorization is less important since engineering is not knowledge based, it is know-how based. Knowledge like "A490N bolts cannot be galvanized" is important but this knowledge simple comes through experience, through process, through work. The know-how of where to look for knowledge is more important than knowledge or facts themselves. The other way to gain knowledge is through ignorance and knowing when you need help. With understanding of your own ignorance, comes desire to learn. That is really all you need.




14: Constantly Prod Yourself. We need to constantly prod those around us to wakefulness by asking questions like “why did you chose this over that” or “what factors led to the decision to do that?” etc. These should be internal questions too. If no one is around to prod you, prod yourself. If you need a poker to prod yourself, buy one. Don’t get lost in the codes, details, loads prior to looking at the full picture. If you have trouble looking at the structure as a whole (or connection as a whole, weld as a whole), then you are not effectively managing your time. You will have trouble seeing what you need to focus on. You need to determine which areas of the project need special attention and which do not. The only way to do that is to look at the big picture and focus on the project.

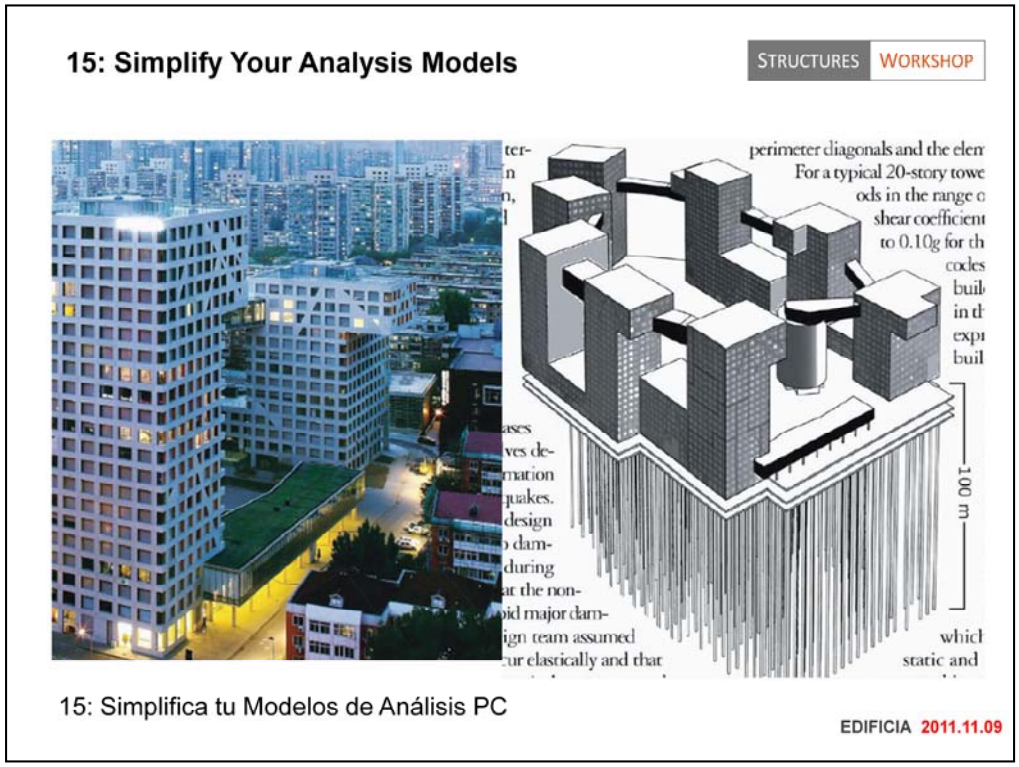



15: Simplify Your Analysis Models. The best structural engineers do not need complicated models. Be skeptical of computer results and don't over complicate analysis models. It is commonly said, that computer software can be a valuable and reliable tool only to those who otherwise do not need it. This is true. In your work, make this true.



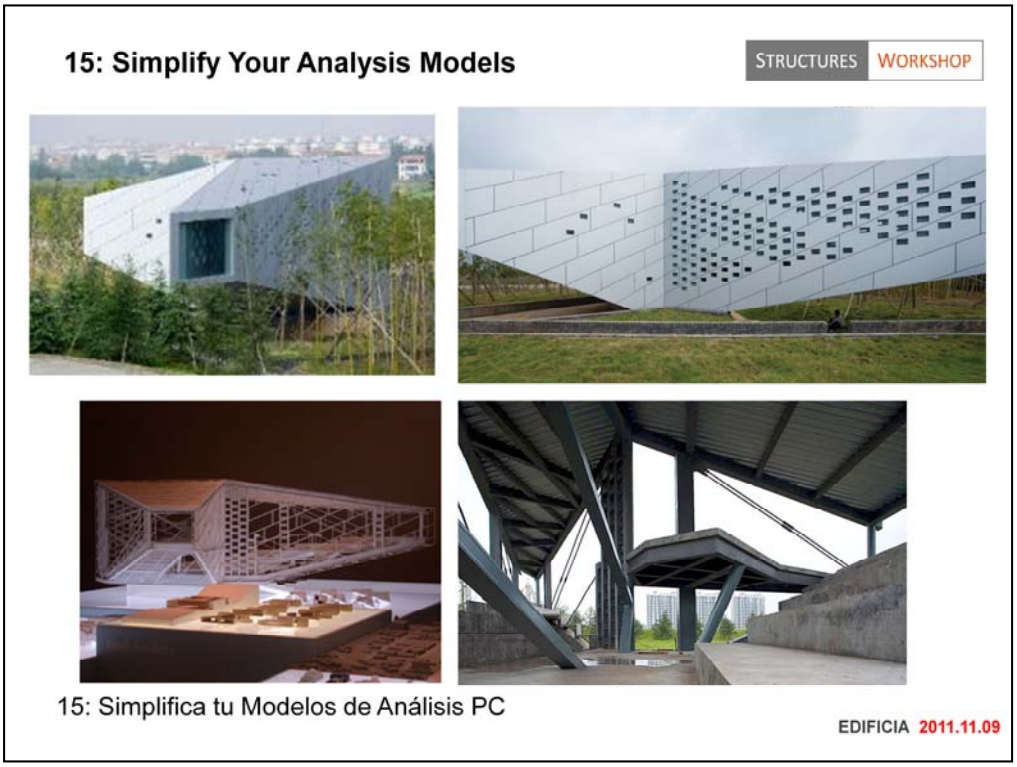

Our software writers that work on integrating BIM with FEM/Analysis Models completely do not understand this (for example Revit/Robot or ProSteel/RAM). They think it is actually useful for engineers to model the entire building, every floor slope or offset, every little filler beam around slab openings, etc. They believe this is how we do our work! I tried to help reduce this misunderstanding when writing *BIM and the Structural Engineering Community* in December, 2008 of *STRUCTURE*. Computers should be used as a tool to make a design decision, it shouldn't *make* the decision. We can model base plates and foundations as shell elements, or we can do a 3-second hand calculation or quick spreadsheet. This is not about trying to take short cuts. This is about knowing what the software can provide and what it can't.

The kindergarden structure you see on the left was designed by hand in two days and has a sloped green roof with large penetrations. This was later modeled in Etabs to refine proportions of members but it proved to make little effect. The kindergarten serves the young families of the 2,500 inhabitants of the project. It is a cast-in-place, 2-story, concrete structure with a sloped concrete roof that extends from the roof to the ground. The roof has large round opening to allow light to enter the classrooms. At the end, a computer model was completed to simply verify the assumptions and provided stress/strain and code checks.

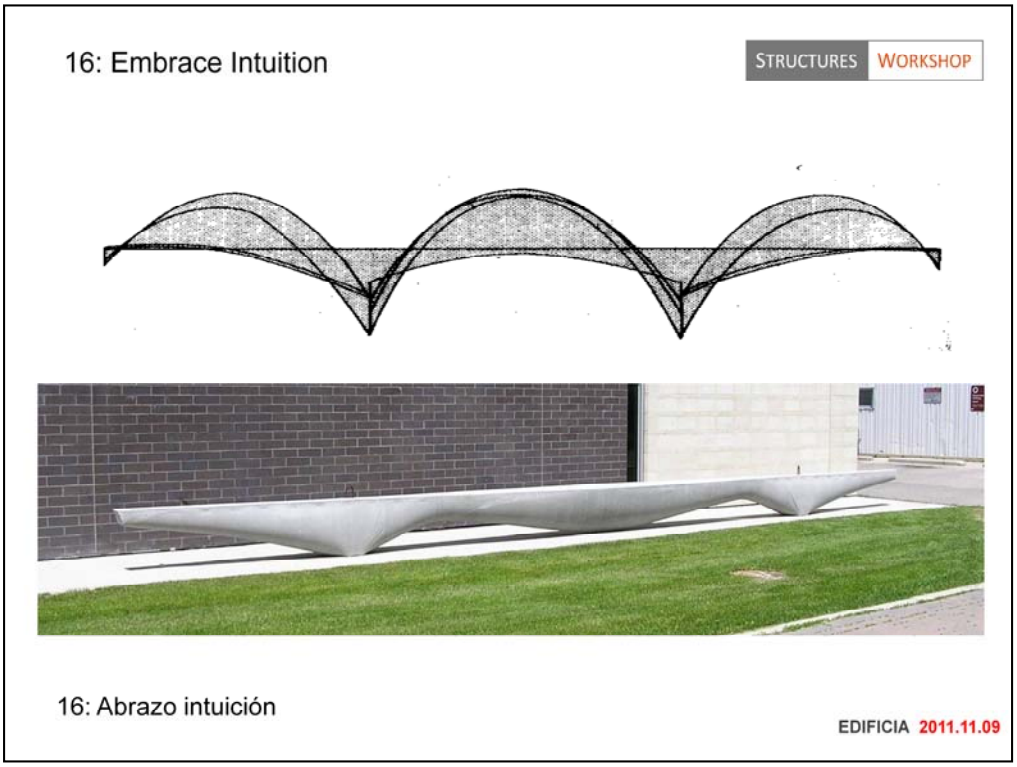



The steel diagonals within the concrete moment frame that you see exposed were placed on the building ad-hoc with an artists sensibility and an engineer's intuition. A major concern in the design for the lateral force-resisting system was the mass eccentricity caused by both the tower cantilevers and the bridges. We had difficulty in meeting the code requirement that the maximum deflection on a particular floor could not exceed the average deflection by 40 percent or more. In order to meet this deflection criterion—which is intended solely to minimize seismic-induced torsion—we had to to place bracing members on the perimeters of the towers. In addition to the concrete moment-resisting frames on the tower exteriors, the diagonal bracing provides the required stiffness to resist the large torsional demands of the cantilevered upper levels.

On the right, installed beneath the complex is a series of more than 600 geothermal wells that descend to a depth of 100 m, helping to cool the Linked Hybrid buildings in the summer and warm them in the winter. These were not part of the structural analysis would only complicate decision making for the designer.




If you already know the software cannot come close to mimicking reality, where do you draw the line? Is the concrete you are modeling Hookean (linear-elastic)? Do plane sections really remain plane? Is that foundation or base plate a true pin or a fixed point? Is the soil perfectly stable and uniform? Do our buildings never decay? Does our concrete not harden over time? My point with these question is to convince those who rely too heavily on computers that these models, no matter how complex, still fail at mimicking reality. I am not suggesting that we don't need to know about the state of the art in analytical modeling, I am just pressing the point that they will never achieve reality. Sometime complex FEM modeling is unnecessary and does not contribute to a good design decision.

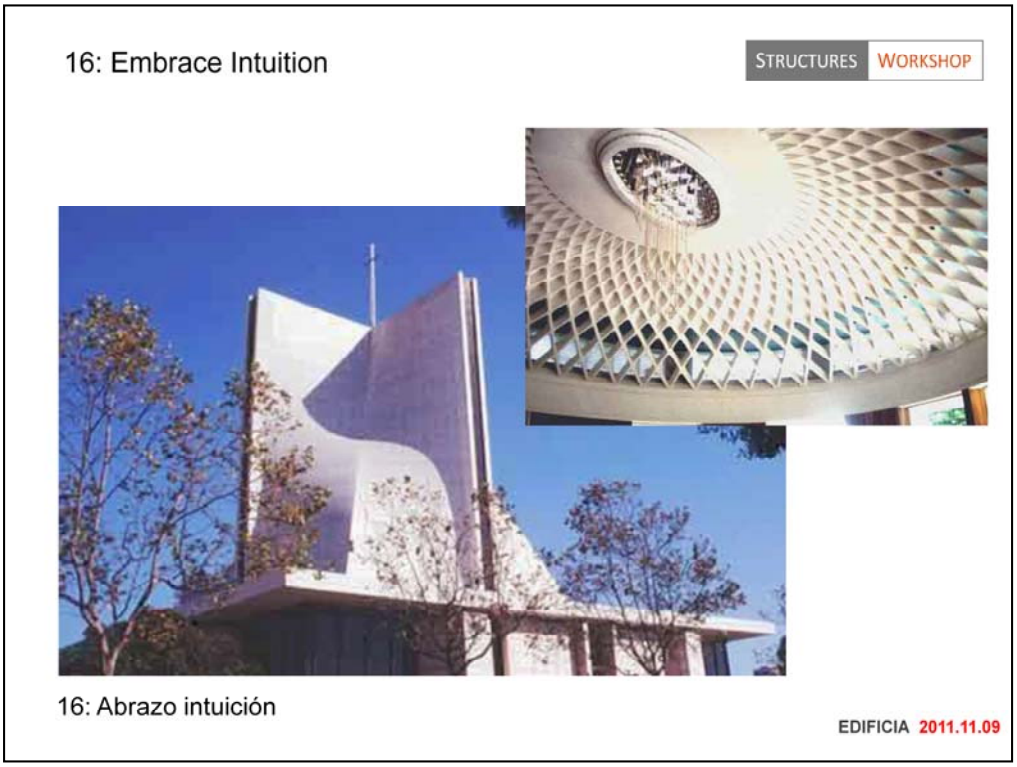



Embrace intuition, is 16. Mathematical abstraction or physical laws are secondary to the primary feel (direct apprehension) and intuition of structures. If you don't believe me, please read from our greatest engineers like Peter Rice's *An Engineer Imagines*, Eduado Torroja's *The Philosophy of Structures*, or Pier Luigi Nervi's *Structures.*

Nigel Cross, widely recognized as the leading figure in design research and teaching, summed up the importance of intuition this way in his book "Designerly Ways of Knowing" (2006):

*Conventional wisdom about problem-solving seems often to be contradicted by the behavior of expert designers. But designing has many differences from conventional problem-solving. Empirical studies of design activity have frequently found <u>intuitive</u> features of design ability to be the most effective and relevant to the intrinsic nature of design. [N. Cross, 2006]*

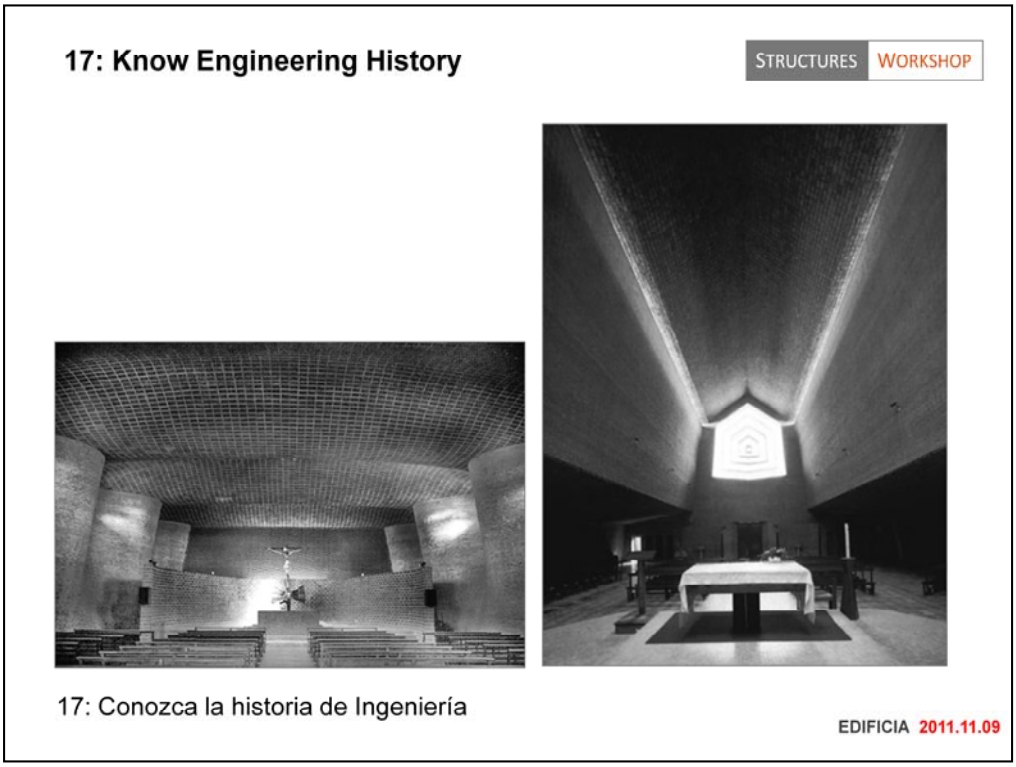
(Mark West)




The way we think  and feel about structures is more important than the abstract mathematical models or analytical techniques we use when solving problems.  Hardy Cross, our brilliant developer of the moment distribution method, once said:

*Design involves sound judgment as well as stress analysis; and judgment is more important.  [H. Cross cited in Addis, 1990: 72]*

Pier Luigi Nervi in S*tructures says* "It is highly regrettable that some of the highest qualities of the human mind, such as intuition and direct apprehension, have been banned from our schools and have been overwhelmed by abstract and impersonal mathematical formulas."

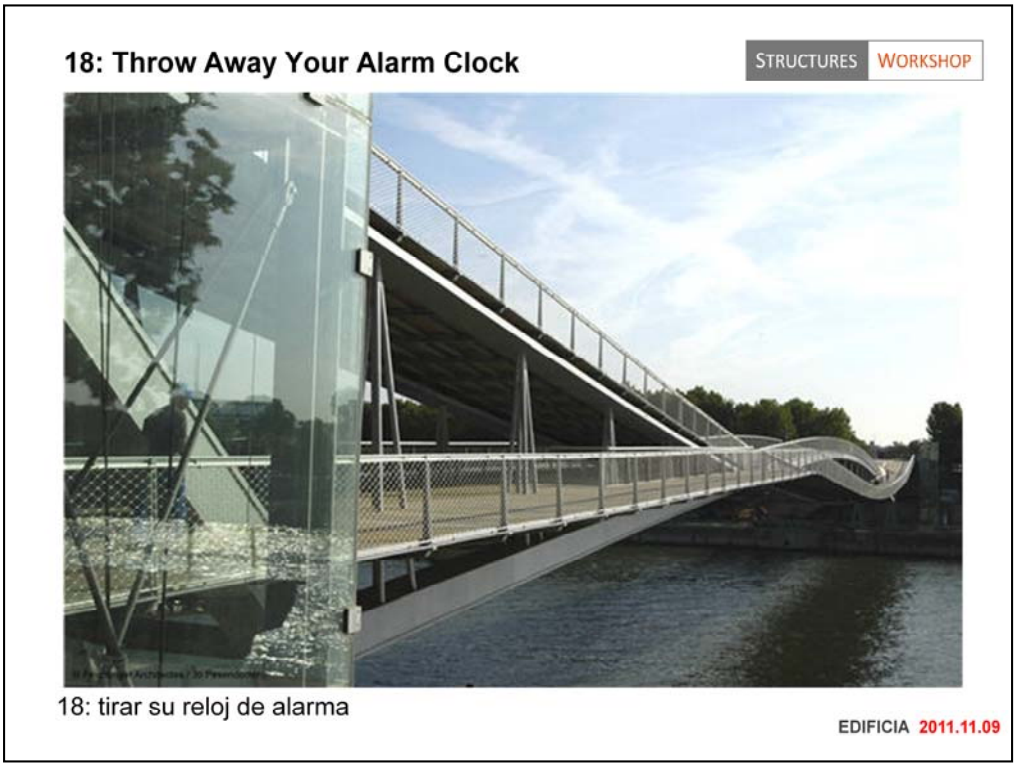



Knowing our history, our leaders, our heroes, our world's architecture is not something that needs an explanation. How is this not part of the curriculum? History helps us use our long tradition of building structures to push new boundaries in our workplaces. We can stand on the structures of the past and learn to improve future design. We need to try to work daily towards rejecting the status quo but only after we fully understand why. History will help us.

Eladio Dieste is shown above.

Born in Uruguay, a melding of architecture and engineering

Capitalizing on his revolutionary approach to building with reinforced masonry, Dieste built aesthetically stunning structures economically.




18: Throw Away Your Alarm Clock. I admit, this is sort of a luxury I have. I haven't needed an alarm clock for 15 years. The most important part of my day as an engineer is lying in bed awake for about 20 minutes or so after slowly and naturally waking up from sleep. The reason it is so important is that I am honestly the most creative and inventive at this time. Not only do I lay out my work day, I literally solve engineering problems in my head. I can view the entire project, rotate it in my mind, find problems with the design, prioritize where I need to focus on the project, and improve the design. I can think better because part of my subconscious is still present consciously. It hasn't scurried to the back of my brain yet. Also, it is super quite at 5am or 6am (my 3 boys are still sleeping). I think the combination of the fact that I was dreaming about many structural engineering issues and then waking up naturally in a peaceful and quiet state creates this clarity of thought. Throwing away my alarm clock helped me be a better engineer. It might be the secret to creativity or inventiveness.

The Simone de Beauvoir footbridge by PR firm in Paris.


I am grateful for projects that last more than one day because I will be able to sort them out in the morning.  Try not to finish deadlines at 6pm, finish them at 6am the next day (or 8am).  In Gorden Glegg's *The Design of Design* we find the following:

*History tells us that artists in various fields from music to mathematics, their key inspiration came suddenly and unexpectedly and never when they were working at it... Concentration and then relaxation is the common pattern behind most creative thinking* [Glegg 1969: 18-19]

So, make sure you have time for reflection (not "working") and it will be the best work you did that day.

This Simone de Beauvoir footbridge is a work of this type of reflection.


How do structural engineers design beautiful works of “structural art”? Nervi and Salvadori give us some clues. In the forward to Nervi’s inspiring and wonderful book Structures, Mario Salvadori reminds the readers:

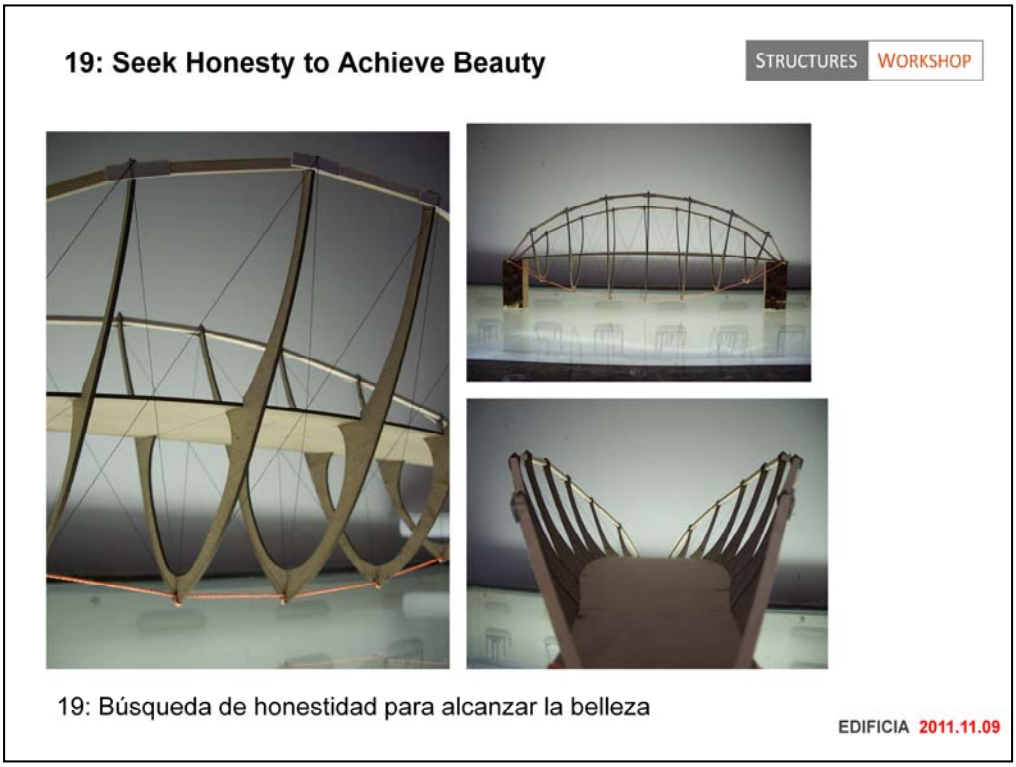
*Nervi’s results are not achieved by consciously trying to meet aesthetic demands, but by tackling the fundamental structural problems from the outset, and giving them an obvious and clearly articulated solution. Beauty, says Nervi, is an unavoidable by-product of this search for satisfactory structural solutions.* [Salvadori 1956: vi]

This idea of working with honesty and clarity is similar to the Manifesto s 7 (Forget about Goals). Like the last phrase of the poem I wrote about Nervi (Mar 2008 *STRUCTURE*) *Truth in form as the means, and beauty as the end* can be our contribution towards improving the aesthetics in the built world.

This picture above is the worlds largest portable hammock I designed last year that brings people together to a public park.


Nervi states the importance of structural honesty or correctness:

*Every improvement in the functionality and the technical efficiency of a product brings out an improvement in its aesthetic quality…there is no doubt that any product of high efficiency is always aesthetically satisfying. In the field of architecture, in which functional, statical, and economic needs are intimately mixed, truthfulness is an indispensable condition of good aesthetic results… architecture that satisfies these conditions – that is, a correct work – may be aesthetically insignificant or expressively beautiful, depending on the actual and unconscious capacity of its designer, but will never be aggressively annoying.* [Nervi 1956: 26-27]




*Truth in form as the means, and beauty as the end* can be our contribution towards improving the aesthetics in the built world.


This manifesto is complete - I hope I have stirred up some ideas and prodded the audience a bit. My intent is not to provoke; it is to seek truth, to be clear, to translate what I do as an engineer, as an educator, and as a citizen and human being. This manifesto will always be a work in progress – just like engineering – it is always changing so please visit my blog at www.structureworkshop.com/blog or email me at ean@structuresworkshop.com

Feel free to ask any questions. The picture on the left above is project I designed two years ago and is the largest commercial building in the US made out of shipping containers (35 total)