White Paper for Berkeley/Stanford CE&M Research Workshop:
Gregory A. Howell, Lean@micron.net

Kevin Kelly observes that there is a difference between things that are born and things that are made[1]. And until recently the simplest thing born was more complex than the most complex thing made. But the balance is shifting; we see ever more complex "things" such as the internet, power grids, and construction projects being made, and the techniques of making applied to things born; genetic engineering. Kelly proposes we will shift from central control models to biologic as we come to understand how complexity is managed in living systems.

Construction projects and the construction industry are becoming more complex, and the pressure for shorter duration increases complexity[2] on otherwise simple projects. Current approaches to managing the firm or project leave much to be desired and will be swamped by increased complexity. Kelly among others proposes that the coming century will be "biologic" because principles and techniques of biologic control of complex adaptive systems will be widely employed, and he makes a good case. These systems, on the boundary of chaos and order, are characterized autonomous agents that make decisions and continuously evolve in response to one another[i].

This sounds like the construction industry. Each organization or group of organizations is always changing in response to changes in behavior or technology of the others. Yet we have the dimmest understanding of co-evolution. We recognize that it does happen, but we believe, or act as if, or at least draft contracts that presume it happens outside the boundaries of the project.

Unlike complex adaptive systems, managers in construction hold fast to models of central planning and control in project management, contracts, and standards. The owner should know what they want and these desires translated by the designer into orders to suppliers, subs and workers. People should do what they are told, and what they are told should be clear and stable. The fractured nature of the industry is an obstacle to this orderly process and integration the answer. Centralized governance of the integration is assumed. Change is the enemy.

In reality, the business environment and technology surrounding both the client and the construction organization is always evolving. And while freezing design appears to be a great idea to constructors, value is created by the ability to respond to new forces and opportunities over the birth and life of a facility.

To be fair, there are some hints of some shift from central control to biologic. The internet makes distributed organizations more plausible (although trying to run one makes me wonder how plausible they really are). Research by Laufer on the management of uncertainty suggests that projects evolve as a continuous negotiation between ends and means. The rise of lean production and integrated supply chain management with their reliance on distributed decision making and pull systems is another hint of a step away from central control.

[1] Kelly, Kevin, *Out of Control*, Addison Wesley. 1994.
[2] By Complexity, I mean the number of pieces that interact with one another.

I am not in touch with all that is happening in the research community and so may have missed work in this area, but it appears to me that consideration of biologic techniques is limited to the application of neural nets to decision making and genetic algorithms for problem solving. I do not know of any work on understanding and applying to construction the knowledge from the developing field of complex, adaptive systems[3]. Some of the innovation research may have also touched on this but I have not seen anything that considers innovation as a co-evolutionary response. Maybe we aren't complex enough, yet. But I think we are or are very close.

So let me propose biologic models will replace central control in response to ever more complex, uncertain and quick projects. These lifelike systems have four distinct characteristics, 1) absence of central control, 2) autonomous sub-units, 3) high connectivity between sub-units & 4) nonlinear causality of peer influencing peer. Here is Kelly's list of the benefits and disadvantages of these systems with my comments.

Benefits	**Disadvantages**
Adaptable – We have long talked about the need to be flexible. But imagine a project managed to adapt to changing circumstances.	Non-optimal – Complex efforts without central control will appear to be less efficient as resources are used in support of multiple conflicting goals.
Evolvable – A short term adaption in one area may lead to more permanent change in another.	Non-controllable – Control is linked to central authority. Precise definition of the final state is impossible but the broad dimensions can be defined. Truly emergent systems are beyond central control. Consider sheep herding, the market and the swarm.
Resilient – Redundancy, parallel processing allow many small failures and keep crashes bounded.	Non-predictable - Emergent's dark side is surprise. Fun in some places, a disaster in others.
Boundless – Nonlinear responses can lead to new order. Information creates more information.	Non-understandable – Cause and effect is impossible to trace back through the web.
Novelty – Initial conditions matter, exponential possibilities, individuals are less important.	Non-immediate – Organic systems take time to grow.

Some combination of central and organic control makes the most sense. The table suggests that our projects may already be more organic than we realize. We desire great adaptability and it is often impossible to trace cause and effect back through the web of

[3] See also the Web Site of the Santa Fe Institute: http://www.santafe.edu/

events that make up a project. I suspect we already rely on both but think only central control is “doing it right.” Another perspective:

Robots: Robots can be divided into two groups. Centrally controlled and those that are Out-of-Control[4]. The central mind group is always struggling to write complex rules enable the robot to know where it is and what to do. Complex rules are required under central control to govern complex behavior. The problem becomes impossible in conditions of uncertainty. Then the number of sensors and nerves will be overloaded or the processing capacity of the central brain inadequate.

In the “Out-of-Control” group, actuators within the robot communicate with each other through internal wiring or simply through the world. In both cases, the parts follow simple rules to generate complex behavior. Let me propose an example from construction of how a complex activity can be managed by independent actors communicating through the world without direct connection. The example is to coordinate the forming, placing, stripping, clean-up, installation of studs. This could be done through central control. Each activity would have to monitored so the following activity is triggered by a sensor in the field or sufficient slack would have to built into the plan to account for variations in performance. This could work but often doesn’t because the slack is not available and updating the schedule all of the time in real time overloads the nerves and processing capability of the planning system.

Or we could have simple rules. When the forms are complete the crew will attach a blue tag. The iron workers installs rebar when they see a blue tag and leave an orange tag. The placing crew places concrete on finding orange tags and leaves white tags with strip date. Stripping crew finds and strips. Clean up crew sweeps floor when forms are stripped. Layout crew marks slab when the floor is swept. Bottom track crew etc. Here each crew finds and completes its own work. The job progresses with each crew following simple rules. The crews communicate with each other through the world. Of course subs on such a project might well decide to develop their own production planning system so that they could better allocate their capacities. (I suspect far more of the coordination in the field is already done this way but the central schedule makes management feel good.)

Can central control shorten duration and reduce cost on complex uncertain and quick projects? It can barely manage now and the future is certain to be more challenging. Could distributed control do a better job? This is the research question. Higher levels of performance appear possible by increasing the ability of the web of suppliers and users to communicate needs and capabilities in ways not currently possible. Kelly suggests the future of control will be in Partnership, Co-Control, Cyborgian control. He offers an example of such control in aircraft. Instead of having the computer fly the plane, the computer watches the pilot to assure structural and safety limits are not exceeded. He proposes that the computer will become a co-pilot with much out of reach of the pilot. Co-control will evolve from the struggle between two autonomous agents.

How might organic control affect design? Let us accept that a project is continuous negotiation between ends and means carried on by representatives of different value sets. I can imagine three levels of management and performance.

[4] See also the delightful movie of the same name.

1. Good design management includes contributions from all affected parties. The design supports the business case of the client.
2. Better design management has ways of timing the input and level of detail of the contributions from affected parties to assure they contribute t he right things at the right time. The designer has to have deep knowledge of all specialties and experience to coordinate their input. Design helps clarify the business case of the client.
3. Best design management engages all parties in a continuous but bounded process to assure the best-fit solution for all. Timing and input is controlled by the subcontractors because the Architect, unable to keep in touch with all of the latest developments in technology, doesn't know when to call on the expertise of each specialty or group of specialists. The design experience reveals new potential business opportunities areas for the client and participants.

Moving down the list, control of the process becomes more decentralized and the value to the client increases.

I am not smart enough to identify all of the possibilities here:

> Microchips on steel beams that talk to milling machines and designers at the same time, and then cause the beam to move to the right place at the minimum cost in response to weather reports and truck availability.

But I am convinced that construction can be understood in organic or complex adaptive system terms and that such understanding is our best hope for managing the complexity of the future.

The NSF could play a central (if ironic) role here because much of the current debate in construction centers on who or what should be in charge. Consideration of organic control is unlikely to receive funding from sources attached to one side or another.

Proposal:

This is a long term exploration. We need to develop a construction related understanding of adaptive systems, challenge current practice experimentally and find the best balance between central and organic control. The place to start is with some smart independent thinking graduate students. Find, fund and challenge them to answer these questions.

1. Is the construction industry a complex adaptive system? Where and to what extent?
2. Are construction projects complex adaptive systems? Where and to what extent?
3. How might organic control in design and site assembly modify current practices and what would be the benefits?

[i] I am quite taken with this line of thinking. My favorite set of rules are Kelley's proposed "9 Laws of God for making something out of nothing" Construction as an industry edges up on most. (Chapter 24,*Out of Control).*

1. Distribute being – Large complex systems are made up of many smaller autonomous "agents" each acting on their own.
2. Control from the bottom up – "A mob can steer itself and only a mob can steer in times of great change." Bees build hives.
3. Cultivate increasing returns
4. Grow by chunking – make up large complicated systems out of small reliable pieces
5. Maximize the fringes – healthy fringes speed adaption
6. Honor your errors – the provide steering and opportunity.
7. Pursue no optima: have multiple goals – "In creating something from nothing, forget elegance; if it works, its beautiful."
8. Seek persistent disequilibrium
9. Change changes itself – to get the most of nothing, the rules must be self changing raising the question of how are forces for stability and change balanced.