

COMPLEXITY – CONSTRUCTION IN A NEW PERSPECTIVE

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ABSTRACT

The general view of the construction process is that it is an ordered, linear phenomenon, which can be organized, planned and managed top down. The frequent failures to complete construction projects on budget and schedule give rise to a thinking that the process maybe not is as ordered and predictable in its nature as it may look. A closer examination reveals that construction is indeed a complex, nonlinear and dynamic phenomenon, which often exists on the edge of chaos.

The paper introduces the world of complex systems and examines construction in this perspective, and by that it proposes several new elements to the understanding of project management.²

KEY WORDS

Construction, complexity, project management

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INTRODUCTION

Construction projects are in general rich in plan failure, delays, cost overruns and grief; indeed, more so than in successes. A general statement would be that the reason for this is the poor standard of project management. And the critics may be right. But not in the way they think. In order to manage properly, one has to understand the nature of the system to be managed. And it seems that we have not as yet a proper understanding of the nature of the projects we through project management try to manage. As Lucas (2000b) states: We have a considerable bias towards simplification and in many situations will reduce a complex multi-dimensional issue to a one-dimensional form more conducive to an either/or decision.

Koskela and Howell (2002) deal with our perception of project management in great detail, and in a careful analysis challenge the lack of a firm theory for the understanding of the project. This paper challenges the foundation for project management as well, but from another point of view, and it proposes at the same time a complete new hypothesis for the understanding of the construction process and thus for the nature of project management.

The hypothesis proposed is that construction – along with most phenomena in our living world – must be perceived as a complex system, operating on the edge of chaos. This understanding forces project management to leave the traditional approach to its task, which is looking at the project as an ordered phenomenon – expressed as management-as-planning and the associated top down approach to the leadership – and enter the new world of self-organization and co-operation.

The paper starts with a brief introduction to the world of complex systems. The recent history in the understanding of such systems is outlined, and terms like dynamic, non-linear, self organized criticality and chaos are introduced as a framework for the understanding of the nature of complex systems and of their behavior. Next, construction is looked at as a complex phenomenon and it is shown that construction is indeed very complex, non-linear and dynamic, not only seen by the individual project but from an industry and a social perspective as well. From this, the view moves to the behavior of complex systems and how to manage them where some general principles are introduced and brought into the framework of construction in the form of a proposal for a new kind of project management. Finally some examples of this new form of project management thinking are presented and discussed.

Several authors have looked at project management from the complex systems' point of view. However, often these authors use a specific angle. Williams (1999) characterizes complexity as structural uncertainty and uncertainty in goals and methods only, whereas Wild (2002) looks at the social system in projects. These authors usually use complexity as a general characteristic of projects without applying the complex systems theory to their studies. Gidado (1996) as well as Kim and Wilemon (2003) even take an ordered approach to assess complexity in projects.

Jenner (1998) proposes that lean organizations are successful because their fundamental structure embodies many of the characteristics of complex systems such as self-organization, and balance between order and chaos, an argument highly relevant to lean project management as well.

The principles outlined in the paper are made with building projects in mind primarily. However, they will probably work just as well in any kind of construction. They may also

work in other kinds of projects such as development of computer programs or the making of movies. Even though the author has some experiences within both areas, it is not tried to stretch the principles any further than construction. Other kinds of projects may be more different than they seem when dealing with the way we organize and manage the cooperation.

And it is all about cooperation!

COMPLEXITY

A NEW WAY OF UNDERSTANDING NATURE

We have all been brought up with Isaac Newton's understanding of the world. The almanac showed us when it was Easter and when the moon's eclipses took place, and our teachers in school told us that the way an apple falls down from the tree and the behavior of the planets are predictable phenomena. And we believed them. All phenomena in nature seemed to be predictable if only we reduced them to their basics and put them into proper formulas.

Later we found out that maybe not everything was so simple. Some phenomena were more complex, and they did not behave in accordance with our nice and linear formulas. There seemed to be something more to nature than Newton and Galileo had taught us. Indeed, when we looked closer we found that most of the world was not mechanistic and guided by simple cause and effect.

You believe in a God who plays dice, and I in complete law and order.

Einstein in a letter to Max Born on the interpretation of quantum mechanics

It started around 1900 with the emergence of the quantum mechanics, which challenged Albert Einstein to the above statement because of the need for dealing with the systems in a purely statistical way. A shock for the established scientific society who then believed that physics now knew almost everything about the world with a few, minor details missing only. The work of Niels Bohr taught them at the same time that the observer and the observed object are not independent – they interact, and the observed system can thus not be considered as ordered in its own right. The act of observing it disturbs the order the system might have possessed before the observation.

Later came the world of complex systems, which can be said to lie between the ordered Cartesian world and the statistical world of quantum mechanics. Today it is more and more recognized that most systems in our surroundings are not linear and ordered but non-linear, complex and dynamic. The science of complexity looks at these systems and does it in ways that are organic and holistic.

But what do we mean by complex? The dictionary says: *Consisting of parts, composite, complicated*. The term comes up in science more and more, but scientists themselves seem to be a bit in doubt, and one of the complexity studies' fathers Edward Lorenz does not even include the word in his otherwise fairly comprehensive glossary in his book *The Essence of Chaos* (1993). 'The efforts are still so new that there is not yet even a generally accepted, comprehensive definition of complexity', claims Stuart Kauffman (1995).

And Horgan (1995) continues: 'The problems of complexity begin with the term itself. Complexologists have struggled to distinguish their field from the closely related pop-science movement, chaos. When all the fuss was over, chaos turned out to refer to a restricted set of

phenomena that evolve in predictably unpredictable ways. Various attempts have been made to provide an equally precise definition of complexity. The most widely touted definition involves "the edge of chaos." The basic idea is that nothing novel can emerge from systems of high degrees of order and stability, such as crystals. On the other hand, completely chaotic systems, such as turbulent fluids or heated gases, are too formless. Truly complex things – amoebae, bond traders and the like – appear at the border between rigid order and randomness.'

Maybe it is not the definition as such that matters, but the way we look upon the system. 'Complexity studies ... comprise the connections between things and not the things themselves' as Chris Lucas states (Lucas 2000a). This may hit the nail on the head. Complexity is not a new science but rather a new way of looking upon systems. By doing so we find characteristics normally ignored or considered noise. Baccarini (1996) proposes that complexity can be defined as 'consisting of many varied interrelated parts' and can be operationalized in terms of *differentiation* and *interdependency*. And he suggests that this definition can be applied to any project dimension relevant to the project management process, such as organization, technology, environment, information, decision making and systems. The characteristic features of complex systems are dealt with in great detail in Lucas (2000b) who identifies 18 distinct characteristic of complex systems.

BRIEF HISTORY

Since the publication of Isaac Newton' *Philosophiae naturalis principia mathematica* in 1687 the scientific community has by and large looked upon nature and all its systems as ordered and linear. The laws of nature made its systems predictable, and time could be moved backwards as well as forward in a study of the development of a system. The linear nature of the laws made this possible.

The present state of the system of nature is evidently a consequence of what it was in the preceding moment, and we conceive of an intelligence which at a given instant comprehends all the relations of the entities of this universe, it could state the respective positions, motions and general effects of all these entities at any time in the past or future.

Philosophical Essay on Probabilities, Pièrre Simon de Laplace (1749-1829)

Not until the 1980'es was this understanding challenged broadly and in earnest. Only a few – mostly mathematicians such as Gaston Julia and Henri Poincaré – had since the beginning of last century pointed out that not all systems were that simple and linear, and that nonlinear systems did from time to time present some irregular behavior. However, most scientists considered these phenomena curious details, not being of any importance in the greater picture.

It was the modern computer, which brought the nonlinear systems to attention. This tool made it possible for more than the few, highly skilled mathematicians to study these odd systems, and a new world was opened up, even though it had a hard time finding its place in the scientific society. These systems were still considered peculiarities without any practical implications for the well-established sciences.

By and large a broader attention was brought to the non-linear systems, and scientists as Edward Lorenz with his butterfly effect and Benoit B. Mandelbrot with his theory of fractals (Mandelbrot 1982) pioneered the more popular perception that a new science was born.

The popular book *Chaos* by James Gleick (1987) really brought the new science into focus. From now on the word *chaos* was attached to all kinds of complex, non-linear phenomena, and studies of the development of life, stock market fluctuations, heart rhythms, anthills, business management, traffic and almost everything else were executed along the line of complexity. The term chaos is still somewhat undefined though.

... the term is often used to imply the absence of some kind of order that ought to be present.

Edward Lorenz (1993)

But complex systems are not always chaotic or completely chaotic. They can be chaotic in their behavior in detail, but not necessarily so in a global picture. Lorenz' basis – the meteorology – studies weather systems. Their development – and thus the weather forecasts – is unpredictable for more than say five days ahead, whereas the weather as such – in the form we call climate – is fairly predictable over a large number of years. The weather stays within certain limits even though it in its details shows a chaotic behavior.

Many non-linear systems, when studied mathematically, show another odd behavior in their otherwise chaotic conduct. Certain states may never occur even though the system seems to move unpredictably through space. And even more surprising: possible states intermingle with not possible ones at any scale. Chaos is indeed there, but there seems to be states that are off limits for any system when left to itself – without a policeman, doorkeeper or manager to keep it away. Also complex systems may stabilize themselves in fairly stable patterns as attracted by an odd force.

‘Chaos, fascinating as it is, is only part of the behavior of complex systems. There is also a counterintuitive phenomenon that might be called antichaos: some very disordered systems spontaneously "crystallize" into a high degree of order. Antichaos, I believe, plays an important part in biological development and evolution.’ says Stuart Kauffman (1995).

Bertelsen and & Koskela (2003) deal in detail with the issue of chaos in construction projects.

COMPLEXITY IN CONSTRUCTION

Generally, project management understands the project as an ordered and simple – and thus predictable – phenomenon which can be divided into contracts, phases, activities, work packages, assignments etc to be executed more or less independently. The project is also seen as a mainly sequential, assembly-like, linear process which can be planned in any degree of detail through an adequate effort and executed in accordance with the plans. As a consequence, project management acts top down, mainly by management-as-planning as proven by Koskela and Howell (2002).

This paper proposes that the perception of the project's nature as ordered and linear is a fundamental mistake, as the dynamics of the surrounding world is not taken into account. Project management must perceive the project as a complex, dynamic phenomenon in a complex and non-linear setting.

Most systems in the world are complex. And so is construction. It can be ascertained by the wicked nature of the design process, which is caused by the fact that there is no optimal solution to the problems faced, and where preconditions are defined in parallel with the solutions. The same kind of wickedness is often found in the construction phase as well. Different stakeholders have different targets and objectives, but have to collaborate in order to complete the project successfully. Compromise is the way ahead in great many cases.

The project may look like a sequential assembly-like process, and so it is in a distant perspective. But in detail, the process is highly parallel. Many project activities are not interdependent and may be executed in any sequence or even simultaneously without any effect on the overall result.

Starting from the bottom, it is up to the individual craftsman to choose his way of doing the job at hand. No formal process description is normally provided, and the industry practice of not interfering across contractual boundaries with the way work has to be carried out, enhances this informality in the low level process design.

But also at higher levels is the process not sequential. The trade contractor may have his own way of executing the job. The weather may change the sequence, and unforeseen events may enforce further changes in the sequence, which to a great extent can be made without any impact on more than the general schedule.

The plans and schedules present an idealized linear picture of what *should* take place, but not of what actually does take place. Planning does not reflect reality, but dreams!

COMPLEXITY IN THREE PERSPECTIVES

This complexity aspect must be seen in – at least – three perspectives.

Firstly, the project itself as an assembly-like process is often more complicated, parallel and dynamic, and thus more complex than traditional project management envisages. The mistake is the ordered view of the surrounding world. All supplies are believed to be made in accordance with the project's – unreliable – schedule, and all resources such as equipment and crew are supposed to stand by, ready for the project's beck and call. And changes will not occur. However, this is not the way the world operates.

Secondly, almost all construction projects are divided into parts that are subcontracted to individual enterprises. The construction industry is thus highly fragmented and its firms cooperate in ever changing patterns, decided mainly by the lowest bids for the project in question. They are also interwoven, as every firm at the same time participates in more than one project, utilizing the same production capacity. Mapping the supply chain in any project is thus next to impossible.

Thirdly, the project and the construction site is a working place for humans and a place for cooperation and social interaction, which – because of the temporary character – forms a highly transient social system. This aspect is often hidden by the fact that the staff at the production facility – the construction site – is not hired and reimbursed by the place where they work. Their loyalty is thus divided between their own firm and the job at hand, often with the firm as the one with the highest priority. Traditional project management often overlooks this aspect and does not perceive the gangs on the site as their own employees in the virtual firm, which is formed by the project.

Bertelsen (2003) analyzes in detail the complexity in these three perspectives based on Lucas' (2000b) introduction to 18 characteristics of complex systems and shows that all of the 18 characteristics can be found in construction, even though some to a lesser degree. And they can be found for all three dimensions.

The dynamic nature of the project stems from the uncertainties in the flows feeding the actual tasks. Koskela (2000) identifies seven flows and demonstrates that even small uncertainties in these flows give rise to substantial uncertainties in the planned execution of the activity itself. Studies of the use of working time indicate that only app. 30 percent is used for the task itself, app. 30 percent for preparations which may or may not be part of the activity and the rest is waste (Hammarlund and Rydén, 1989, Nielsen and Kristensen (2001). The uncertainties are indeed there in construction.

However, the unforeseen events are not evenly distributed. Some activities run smoothly and take maybe as little as the net time plus say ten percent, whereas other may take as long as ten times the net time. Studies of the variability of the productivity by Radosavljevic and Horner (2002) indicates that the distribution of the duration is not even normally distributed as one may expect, but rather chaotic. These fluctuations even out more or less over the project lifetime, but they make it obvious why schedules are never followed in detail.

The reason is simply that schedules are not followed *because they can not be followed!*

MANAGING COMPLEX SYSTEMS

THE NATURE OF COMPLEX SYSTEMS

Complex systems' complexity can seldom be reduced without loss of vital features. They are characterized by the whole being more than the sum of the details, and the whole often shows emergent behavior which can not be predicted by studying the elements. The individual bird does not tell us much of the behavior of the flock.

The Danish physicist Per Bak has studied complex systems' behavior. His primary research object may seem somewhat peculiar being a pile of sand in the laboratory. What he studied was the size of the avalanches occurring when more sand was added to the top of the pile. He found that the sizes of these avalanches, plotted against their frequency on double logarithmic scales, formed a straight line. Not in itself exciting, because what he found was Zipf's law. George Kingsley Zipf observed in the 1930s the same distribution when he looked at the distribution of words in the English language. Later the distribution was found in the size of earthquakes in California, in the pulsation of quasars in the universe, in highway traffic pattern, and in fluctuations in market prices for commodities such as cotton as well.

Thus it seems that this so-called power law is universal for any complex system, and Bak proposes that the linearity is a sign of the system having stabilized itself at a self-organized criticality. Moving to this position is in the nature of all complex systems because this is where they operate optimally.

Interference from outside – proposes Bak – may increase the system's performance, but only for a short while. The system can be stabilized temporarily on a higher performance level, but not forever. And when the slide comes it will be such a big avalanche that we were better off with the system behaving in its own way, giving us a number of small and medium

sized slides. Bak suggests that this may also hold true for the national economy, and he mentions the dramatic collapse of the plan-economies in Eastern Europe as a possible example.

Could it be that construction projects were also better off without interference? And that project management in certain aspects causes more problems than it solves? If so, it may not be sufficient to master management-as-planning. One must also master management-as-a- nuisance.

TOWARDS A COMPLEXITY APPROACH TO PROJECT MANAGEMENT

The understanding of construction as a complex phenomenon opens up for the introduction of new management techniques. The ordered approach which gave rise to management-as-planning can now be supplemented with management-as-organizing, management-as-teambuilding, management-as-service providing, and even management-as-a- nuisance. These new approaches, which may all be needed in future project management, are outlined briefly in the following. It is to a certain extent speculation, but the author has participated and is participating in a number of projects where the principles to a certain degree have been used.

MANAGEMENT AS ORGANIZING

Management must be organized in accordance with the job at hand and management set up to suit the organization and the culture in the participating firms. Projects and project participants are all different and the big challenge facing the project manager – which the business manager is lucky to be almost without – is the need for establishing a construction site team spirit almost immediately.

The team is new. It is brought together for the project and its members are not chosen as team players but by the lowest cost. They are not the project's employees but leased for the job from their home firm, which probably has other criteria for success than the project in question, and their involvement in the project has thus the nature of hit and run. As the design is new and the site is unbroken, nothing at all is as is it was in the former project. And a new project may often have its different criteria for success.

Another serious problem facing the project manager is that he has to act fast. There is no such thing as a second try in a project environment. The gangs come and go and the site is a very transient working place. The culture of cooperation must be established from the very beginning and kept up all the time. Also service and support must be in place in order to gain confidence, and of course: the project's targets must be clear and communicated, particularly if the project is one where frequent changes may be expected.

When it comes to the operation of the project, the new kind of management should also look upon its role as management-as-organizing. The important issue here is to organize the execution as a self managing system to the greatest extent possible. In doing this, choosing the right players for the team – and not the cheapest – may be of paramount importance, just as setting up a suitable project management organization.

The superior objective of the organization should be to increase the reliability of the individual agents making it possible to distribute responsibility as much as possible. Any problem should be solved and any coordination be made at the lowest level possible with respect for the over all project analyses. This calls for as few and simple rules as possible. Last Plan-

ner (Ballard 2000) is thus a highly suitable tool for the delegation of responsibility for making sure that things *can* be done and – more important – that they *will* be done.

As claims and costs issues usually seem to hamper any form of cooperation in construction, a fruitful strategy may be to keep money-issues away from the construction site as much as possible. In Denmark this has been done by introducing a special process management parallel to the ordinary construction management, which mainly takes hand of the contractual – and thus the financial – issues. The process management is thus free to focus on the on site productivity mainly (Bertelsen and Koskela 2002).

Management as Planning

Even though nature handles complex system without planning, the nature of the construction project calls for an analyzing and planning effort.

This is very much the effort usually undertaken at the outset of the job in question, but with a much more limited scope. The prime objective of the planning is the project analysis, where the work to be undertaken is broken down into work packages and a feasible process along with an overall 'budget' for the available time for the project execution is established. No matter how much this effort looks like the traditional planning approach, this is not the plan for the actual project execution.

As the system is near chaotic, management must be based upon the fact that the execution will be unpredictable in detail more than a few steps into the future. But certain things can be organized such as the ordering of materials and long lead items, just as the contractual arrangements can be set up. By this it is envisaged what *should* take place, and certain steps are taken to make sure it *can* take place.

But planning is not only about putting the activities in order as CPM indicates. It is analyzing the process feasibility and establishing the criteria for success as well, just as it is assessing the complexity and identifying the pitfalls. But the general guideline should be: don't believe you can plan more carefully by going into deeper detail. You'll only find chaos if you look too deep from your present level.

Management as Team Building

As the project is executed by a temporary production system and the construction site is likewise staffed by a temporary and very transient human system, team building becomes of great importance. Usually the welfare of the crewmembers is considered the sole responsibility of their own company. But understanding and managing construction as a complex, dynamic system makes it necessary for the project management to take over a great deal of this responsibility.

The success of the project becomes very dependent on the wellbeing of the workers, just as the success of any firm is dependent on its employees feeling at home on the job. The process management should thus initiate team-building activities, and at the same time strongly support a distributed management. Several methods may be brought into action in this respect. One is Action Language, particularly in the variety proposed by Hal Macomber (2001) using commitments as the tool of cooperation.

Indeed, in Denmark we more and more see planning on all levels as commitments. The phase plan is a commitment between the trades on how we *should* execute the project. The Look Ahead plan is a commitment to make sure that we *can* execute the assignments, and the weekly work plan as a commitment between the crews on what they *will* do in the next week.

An important part of the process manager's function is to ask and listen, and not least show confidence in the professionalism of the man 'on the floor'. A few Danish experiments using *multi skilled gangs* have shown remarkable improvements in productivity. The reason is obvious when looking from a complexity point of view: The multi skilled gang reduces the complexity in the both the production and the human systems and at the same time moves problem solving downwards in the organization. The same has been found in the Danish BygLOK experiments with a more formal team building between the workers (Dam and Elsborg 2003).

Management as Service Providing

Lean Construction distinguishes between two kinds of activities in accordance with Shingo (1988): Value generating and non-value generating. Obviously, value-generating activities should be executed as effectively as possible, whereas non-value-generating activities should be minimized.

Looking at the construction project from this perspective gives rise to a somewhat surprising observation: *Almost any management activity is non-value generating*. Management must thus be understood as a provider of service for the value generating activities, fi by providing the right materials, equipment and information.

It seems probable that this understanding of the role of the project management will be the most difficult to accept for the traditional project manager, being used to be the guy in command and the one issuing orders and instructions in great detail.

However, if one looks at the construction site's operation from this perspective, it can be recognized that the trade contractors' gangs are often left on their own. Tavistock (1966) seems to confirm that. They lack indeed an engaged and effective support from their home office. The reason is obvious. The trade contractors have other priorities than optimizing the workflow at any particular project. To them the key to a higher profit is to optimize the use of their total resources, i.e. their crews and their equipment.

As the process management takes over more and more of the responsibility for ensuring sound activities by establishing an efficient support and back up, they are taking over the workers' professional welfare as well and by that making them feel welcome on the site. Such efforts will inevitably move the workers' loyalty and focus away from the home office and to the project

Management as a Nuisance

All in all the new kind of management can to a great extent be characterized as management-as-a- nuisance. Management should interfere with the project execution as little as possible without letting the whole process turn into chaos. This recognition sounds very much like Per Bak's (1996) observations of natural systems, which seems to behave in an optimal way when left in a situation of self-organized criticality.

Now, this may sound quite easy. Just let the system take care of itself as much as possible, but it is not so. Self-organized criticality means that a cascade of unforeseen events – smaller or larger 'catastrophes' – will take place as a part of the system keeping itself in the optimal position. Most of these events will be small as the power law distribution dealt with earlier will be in operation, but they will occur, and a few will be larger.

How does a responsible management report to its superior level, that these events are just what have been expected and that they should not be avoided, as they take the strain out of the system and hopefully add to its learning?

Indeed a huge challenge!

CONCLUSION

Complexity seems to provide a fruitful new understanding of the construction process and in should thus be an inspiration to new approaches to project management: organizing, planning, and controlling the process. However, the understanding of complex systems in construction calls at the same time for further research.

One such area would be a deeper understanding of complex systems theory in relation to construction. Another area would be the use of modern business management principles in construction, not least on the cooperation on the construction site. Also closely monitored and analyzed experiments within project management based upon the management principles outlined above would provide useful new knowledge.

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