The Inherent Complexity of Large Scale Engineering Projects

Originally published in:
Project Perspectives 29

The Inherent Complexity of Large Scale Engineering Projects

There are no other undertakings that illustrate complexity as comprehensively as international large scale engineering projects (LSEs). Complexity and LSEs are almost synonyms for a construct that is not precise. Project complexity is just one of several concepts, but in the world of construction of paramount importance. It can be demonstrated that a distinction among four different types of complexity helps to understand LSEs best. One is the overall project complexity, the other three are task, social and cultural complexity. Normally, literature (Gidado, 1996) has only been concerned about task complexity. If the others are not addressed as well, a LSE is set for failure. Contractors in LSEs reply to overall and to task complexity by a functional organization with decentralized decision making, to social complexity by trust and commitment, and to cultural complexity by sensemaking processes.

Prof. Dr.-Ing.
Gerhard Girmscheid
Swiss Federal Institute of Technology Zürich

Prof. Dipl. Ing.
Christian Brockmann
Swiss Federal Institute of Technology Zürich

Introduction

The notion of complexity is not used with consistency. Therefore, it needs to be specified. A very basic definition starts by describing the number of different elements in a system alone as its complicacy and the numbers of elements in a system and the possible relations among these elements as complexity (Simon, 1969 or McFarland, 1969). Also abstract, but with much more content is the definition given within the Luhmannian system theory.

Here, complexity is the degree of *manifoldness, interrelatedness,* and *consequential impact of a decision field.*

The advantage of this definition is that it takes us to one of the core concepts of organizational science: decision making (March, 1988) and thus also to the topic of LSEs. Manifoldness refers to the differentiation of functions in a LSE. This could be client, designer, contractor, subcontractors, suppliers, banks, authorities, and the public or it could be the internal differentiation of the contractor's organization. The interrelatedness describes the dependencies between supersystem and the different subsystems or among the latter ones. The consequential impact, finally, draws our attention to the number and importance of the causal chains or the consequential processes set in motion by any one decision. The degree of complexity is then the sum within each of the three components and over all three of them.

There are five layers that need to be considered: task complexity, social complexity, cultural complexity, operative complexity, and cognitive complexity. While task complexity can be defined as the density of activities in a given spatial and temporal frame, social complexity depends on the number and diversity of actors communicating and working with each other. Cultural complexity comprises the history, experience, and sense-making processes of the different groups that join their efforts in a LSE and that have taken place before its start.

Operative complexity denotes the degree to which organizations of the project are independent when defining their operations to achieve given goals. Cognitive complexity can be treated on the level of a person or the level of a group. Only the latter perspective is different in LSEs and it identifies the degree to which self-reflection (and thus sense-making processes, the emergence of an identity, or even an organizational culture) is possible (Wilke, 2000). Due to the project character, operative and cognitive complexity have no time to develop in LSEs and they can be discarded for the topic. What needs to be added is an overall complexity that encompasses the other three (figure1).

Focus and Data

Contractors normally face a greater complexity than the client since they employ the large amount of resources of a LSE directly. These are normally build by international construction joint ventures

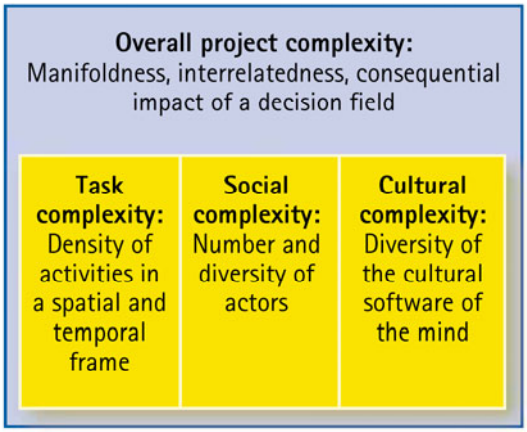

Figure 1. Overall, task, social, and cultural complexity

(ICJVs) that comprise at least two parties, which again is more complex than the organization of a single contractor or a client. Design/build approaches are also common for LSEs, at least in newly industrialized or least developed countries and this is more complex than the traditional design/bid/build approach since the contractor organized in form of an ICJV has to coordinate the design besides his other tasks. With these antecedents, the question becomes: What constitutes task, social, and cultural complexity in ICJVs that carry out a LSE in a design/build setting, how does this complexity develop over time, and how do ICJVs deal with it?

Six cases in the data set used here are from the Taiwan High-Speed Railway. Two other cases are from Thailand, one a subway and the other an expressway project. All projects were worth more than one billion US dollars.

The Construct of Complexity

The starting point for a LSE is described by one of the interviewees as follows: *"Setting up this project is competitive in many ways when you go into another country and set something up. It comes down first of all to get acquainted with all the local rules and habits and customs of the country. That is manifold. It starts with the fact that you are setting up a limited company, a company of a limited duration which is set up overnight, has to function overnight, with a bunch of people thrown together, sometimes not knowing each other. The latest status here: we have twenty-eight nationalities here, to give an example how it is grown. And then it is liquidated after the period of the contract, four years, five years, whatever."* This quote not only names task complexity (setting up a limited company), social complexity (a bunch of people thrown together), and cultural complexity (twenty-eight nationalities) but also the tremendous time pressure (has to function overnight).

Development of overall complexity with time

Complexity clearly is a construct that is not used by practitioners in the way defined above. In the interviews they rather describe the outcome of complexity without referring to the construct itself. In the beginning of a LSE there is chaos, a mess, disorder or there are just simply "headaches".

Complexity within the project can be reduced in many ways. Normally a functional organization is the first step, thereby transferring a part of the complexity to the departments (subsystems). In this case the project management as supersystem delegates a good part of the control over the project. In return the coordination becomes more difficult and risk compensation a priority for project management. It must also adapt the ICJV to any changes in the environment.

Project management as well as departments then reduce complexity further through decisionmaking, coordinating, communicating, and learning. A decision connects different parts of the project with each other in a specific way by allocating resources and choosing a technology. Coordinating allows to treat a variety of problems at the same time and then bringing them to a planned result. Communication works specifically in the areas of social and cultural complexity because such barriers can be found, discussed and brought to a conclusion. Learning helps to standardize solutions and thus limit the search. The result is a reduction in the required resources (cf. learning curve). Of great importance in ICJVs is also the question whether the core management group has already learned to know each other on previous projects. This way cultural complexity is reduced right from the beginning.

At the end of a project, task complexity for the contractor is reduced to zero, he has fulfilled his contract and he can move on to the next project. This is a great difference between project and process complexity. The latter one might never come to an end. As social relations and cultural encounters are processes, their complexity will not be reduced to zero at the end of a project.

Figure 2 summarizes the discussion above graphically by distinguishing a theoretical and a practical level of the construct "complexity". While practitioners see chaos and start working on it until the project is completed, task complexity on a theoretical level is reduced to zero over time.

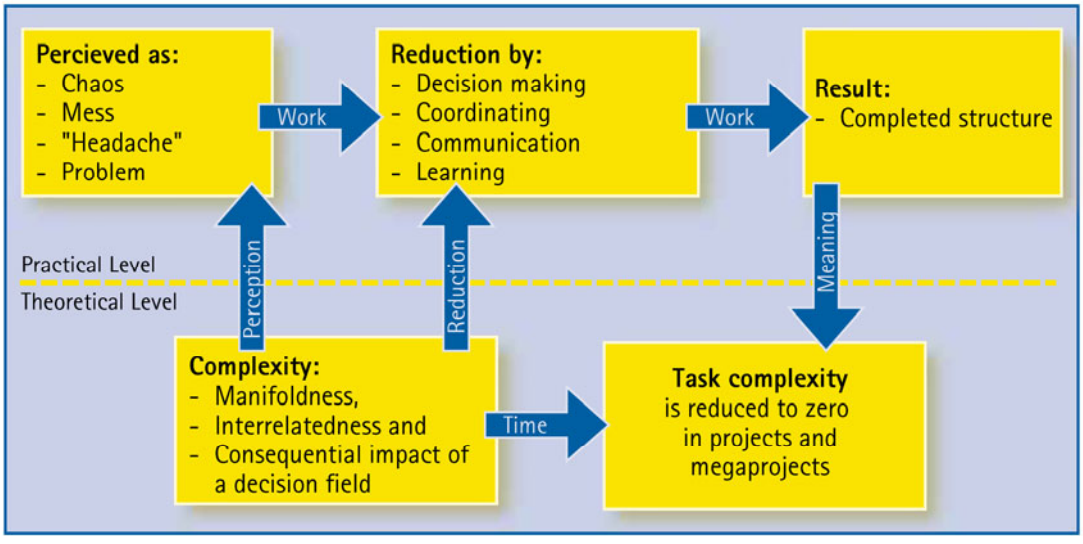

Figure 2. Complexity as practical and theoretical problem in LSEs

Going back to the theoretical level as a basis, how does complexity develop with time? Here, it is useful to differentiate between three phases of a LSE. In the beginning everything is in disorder: the management staff does not know each other, the partner companies want to see their views implemented, the design is only in a preliminary stage, often – at least in innovative projects – the technology has not been used before. Many decision are required, yet project knowledge is low. All tasks seem of highest importance, all are interlinked and the consequences cannot easily be foreseen. This period lasts in smooth running LSEs for several months, six is a good average. If the input from the clients is not coming forth timely, the period will be prolonged. From the outside there seems to be little progress.

The middle phase is characterized by a starting, then deepening routinizing of the work. A low level of complexity remains because of environmental influences or any other type of disorder (such as mistakes). Problems of social and cultural complexity always stay virulent.

During the end phase the complexity picks up again as new tasks need to be performed. The contract must be wrapped up and the site and the offices closed down.

In figure 3 there are three examples of overall project complexity shown for different environmental conditions. The first one is for a smooth running project, the second one for a project with an important change order, and the third one shows the case of a LSE where contractual disputes are not settled at the end of the project.

The complexity curves are different for the separate departments in an ICJV. The project management is faced with the overall complexity curves as shown in figure 3. The same curve for the design department is reduced much earlier to almost zero (pending the as-built status, figure 4).

The curve for administration has a very strong increase at the end because termination and sales of equipment are very different from the earlier tasks (figure 5).

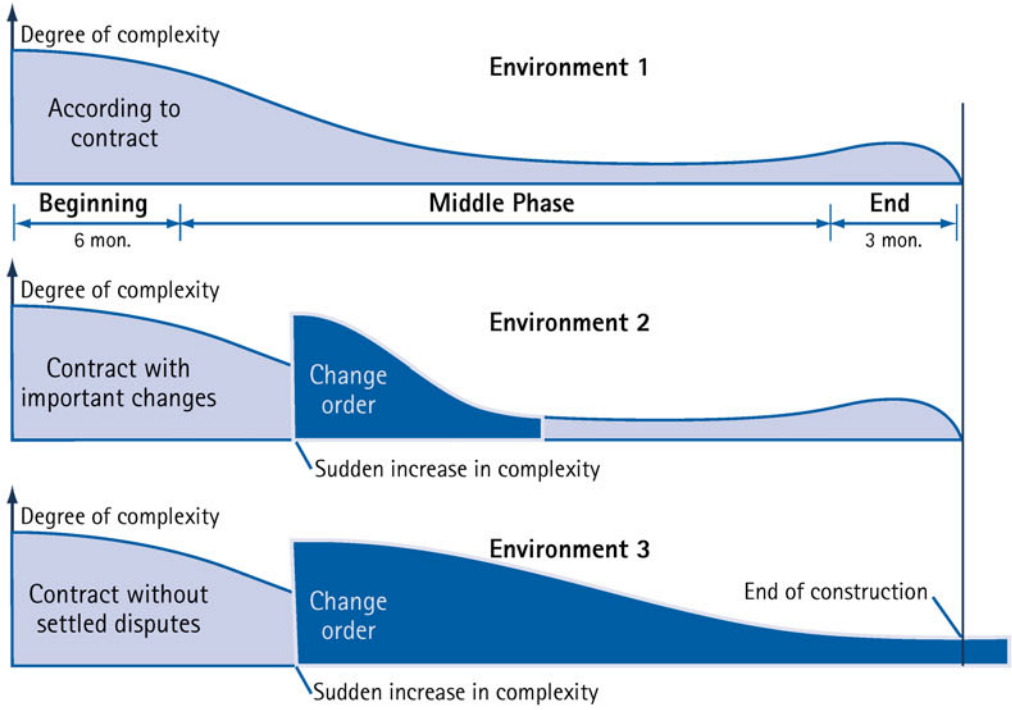

Figure 3. Overall complexity curves

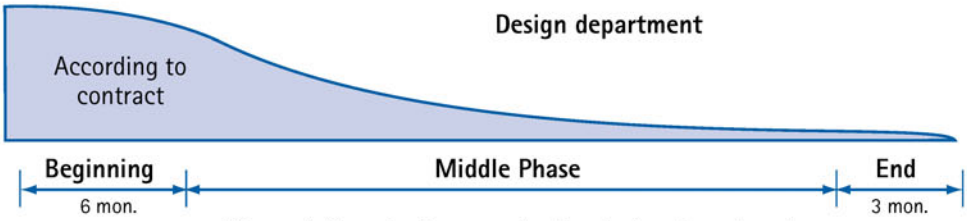

Figure 4. Complexity curve for the design department

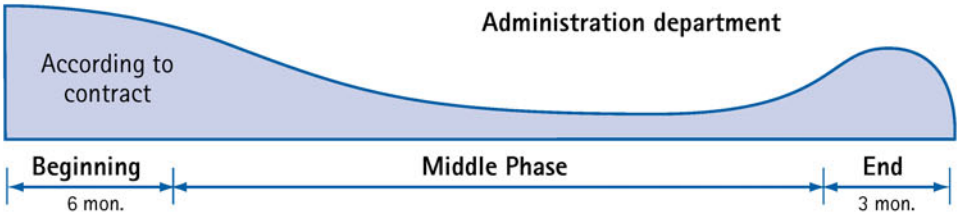

Figure 5. Complexity curve for administration department

The figures might imply that the degree of complexity is the same for the different departments. This is not true. One of the most basic ways to deal with complexity is through departmentalization. Each department (subsystem) has to deal with a part of the complexity that is considerably smaller than the overall complexity. Each department must have competencies and resources to solve their task. This independence increases on the other hand the overall complexity for the project management.

As the discussion has demonstrated, LSEs are more complex than normal projects, therefore they must deal with the overwhelming complexity by departmentalization. According to the task of each department, the complexity curves are different (figures 4, 5). The way a contract is executed by the client has also an impact on the complexity curve (figure 3).

Task complexity

Discussions about complexity are often enough rather abstract (as above) or they do not capture the completeness of the construct. To grasp complexity, a formula will not suffice and the story of complexity is a very long one. A way out of this dilemma is a table of the task to be fulfilled on a LSE. Yet this also has drawbacks, as neither interrelatedness nor consequential impact can be shown. They have to be guessed by the manifoldness of the topics in table 1.

Five main areas can be distinguished for LSEs: organizational planning, design planning, work preparation, site installation planning, and construction management. Organizational planning has much more importance than for normal projects, where standard solutions are used. The same holds true for site installation. The cost for site installation on a LSE is around 15%, this is for a billion-dollar-project 150 million dollars.

It should never be forgotten what size means in a LSE. When looking at the tasks some examples might suffice: Personnel management stands for employment of several thousand staff and workers, coordination of designs implies managing a worldwide network of engineers, construction methods means the use of an untested technology, labor camps mean setting up whole villages for one or two thousand people, and control of subcontracts represents coordinating a hundred contracts with subcontractors from around the world. All tasks are highly interrelated and a decision on one subject will have repercussions for many others.

Social complexity

Social complexity shall again be highlighted by just one example. Especially for all decisions in the area of organizational planning, all partner companies have their own experiences and preferences. Through their employees who they send to the ICJV they try to implement these preferences.

Organizational planning	- Organization - Organization chart - Competency matrix - Job descriptions - Contract management - Quality management - Safety management - Personnel management - Purchasing - Financial accounting - Cost accounting - Communication - Correspondence and filing
Design planning	- Outsourcing of design - Coordination of design - Approval procedure - Design schedule - Documentation (as-built drawings)
Work preparation	- Work estimate - Controlling - Outsourcing - Construction methods - Scheduling - Deliveries - Planning of site installation - Logistics
Site installation	- Land acquisition - Purchase of plant and equipment - Utilities - Offices, labor camps, canteens, lavatories... - Waste
Construction management	- Production processes - Quantity and quality control of materials - Quantity and quality control of subcontracts - Deployment of plant and equipment - Deployment of work force - Deviations from contract - Hand-over - Warranty

Table 1. Manifoldness of task complexity in LSE

Type of Complexity	Description	Means of Reduction
Overall complexity	Degree of manifoldness, interrelatedness, and consequential impact of a decision field	Specialization, risk compensation, levels of complexity, adaptation
Task complexity	Density of activities in a time/space segment	Decentralization
Social complexity	Number and diversity of stakeholders	Trust, commitment
Cultural complexity	Diversity of the cultural software of the mind	Sensemaking

Table 2. Types of Complexity and Means for their Reduction

The project management includes employees from all partners who are urged to follow the wishes of their bosses. Yet on the other hand, the project management must decide on a coherent set of management procedures that assure efficiency under the terms of the contract. Moreover the client has through the stipulations of the contract also an influence on the organization. In the end it is amazing when despite of all these actors an efficient organization emerges out of the maze of ICJV politics.

The case would be different if the partners and their employees in the ICJV were committed primarily to the ICJV. Then they would have to forgo opportunism and indeed the interests would merge.

On a personal level trust is another mechanism often used to reduce complexity. By delegating work to a trusted person, the problem is solved for the superior (Girmscheid and Brockmann, 2005).

Cultural complexity

Culture can be described as the software of the mind (Hofstede and Hofstede, 2005). A first programming comes about by the family (national enculturation), a second by professional training (industry culture) and a third by the mother company (organizational culture). The diversity of the cultural software causes problems.

Even more practical than in the case of social complexity are the following two examples of cultural complexity: A Korean/Taiwanese ICJV subcontracted the design for the bridges to a world-class engineering firm in the USA. By the main contract they must also employ a contractor's checking engineer and the ICJV gave the contract to a German engineering firm of highest reputation. The two firms fought for a full year to settle the design fundamentals in the design/build contract with a four year duration. The ICJV tried to solve the problem on the task level and despaired. With 25 % of the contract time passed there existed no design and no construction. The two firms held different values and principles, big egos were also involved. At the end it became a bitter personal fight between the engineers over these values. The objectives of the contracts were lost out of sight.

A German/Thai ICJV contracted another world-class engineering firm from the USA for the design. Since most large German contractors are design/build companies, they insisted on supervising the design by giving directions. The American engineering firm was used to not being interfered with by American contractors. Again all kinds of distractions erupted because of neglect of these fundamental cultural differences.

The two examples highlight mostly the influence of different organizational cultures. Problems between national cultures are erupting in between and on top of the two explained cases.

A typical way to deal with problems of cultural complexity is through a managed process of sensemaking (Weick, 1995).

Conclusions

It is possible to differentiate between the overall and three further types of complexity. In LSEs, ICJVs find very specific ways to deal with them. These are strategies of choice and they are pursued regardless of the national background of the ICJV partners with the aim to reduce the project complexity (table 2).

References

Gidado, K., 1996
Project Complexity: The Focal Point of Construction Production Planning. Construction Management and Economics, 14, 213–225.

Girmscheid, G. and Brockmann, C., 2005
Trust as a Success Factor in International Joint Ventures. In Global Perspectives on Management and Economics in the AEC Sector, edited by Kähkönen, K. and Porkka, J. (Helsinki: VTT), 69–81.

Hofstede, G. and Hofstede, G., 2005
Cultures and Organizations: Software of the Mind, (New York: McGraw-Hill).

March, J., 1988
Decisions and Organizations, (Cambridge: Basil Blackwell).

McFarland, A., 1969
Power and Leadership in Pluralist Systems, (Stanford: Stanford University Press).

Simon, H., 1969
The Architecture of Complexity. In Organizations: Systems, Control, and Adaptation, Vol. II, edited by Litterer, J., (New York: Wiley), 98–114.

Weick, K., 1995
Sensemaking in Organizations, (Thousand Oaks: Sage).

Wilke, H., 2000
Systemtheorie I: Grundlagen, (Stuttgart: Lucius & Lucius).