Evaluating Construction Project Complexity

Christian Brockmann, brockmann.christian@t-online.de
Bremen University of Applied Sciences, Germany
Kalle Kähkönen, kalle.e.kahkonen@tut.fi
Tampere University of Technology, Finland

Abstract

Complexity is a key characteristic of construction projects. It is the degree of complexity that determines the overall approach to a project, specifically the required resources as well as tools and techniques. While we have means to quantify the complexity of e.g. a mathematical algorithm, no ways have been proposed today to quantify the complexity of construction projects. To this end we propose to conceptualize complexity with five dimensions (task, social, cultural, operative and cognitive complexity) and a number of factors determining each of these dimensions. The evaluation process is carried out by a group of experts that determines a value for each factor and accordingly for each one of the five complexity dimensions. In addition, the experts determine a weight for each dimension. The data allow calculating a complexity index of the project. The index is then compared to thresholds of a predefined classification system that represents the experience of the company for which the group of experts is doing the evaluation.

The result is a robust index expressing the inter-subjectively shared opinion of the group of experts. The process breaks down the construct "complexity" into a large number of factors. The quantification of each single factor might be somewhat of target. Some will be overestimated with regard to complexity; others will be underestimated. However, if no bias prevails, the index as the weighted sum of the factors represents a fair evaluation according to the law of large numbers. The complexity index cannot be compared when different groups of experts evaluate projects since the evaluation process is based on the groups' ability to deal with complexity. Experienced companies will find the same project less complex than inexperienced ones. Since the complexity index shall be used to determine what resources, tools and techniques are appropriate for a specific project, this subjectivity is not a drawback but welcome: it allows each company to tailor an approach that is in harmony with their past project experience.

This paper shall provide a discussion of chances to develop and apply the kind of complexity assessment application presented above. A first stage solution is under development and the early results from that together with previous research form the basis of the paper.

Keywords: Construction projects, complexity index, expert evaluation, construct, benchmarking

1. Introduction

Complexity is an intriguing characteristic of construction projects. In almost every text on project management or its adjacent fields of studies such as estimating, scheduling, logistics, or supply chain management, the complexity of construction projects is mentioned (e.g. Bennett 1991, Mubarak 2010, Sullivan et al. 2010). It has become a term such as "large" and "beautiful" where evaluation and understanding lie in the eyes of the beholder. Scores of articles have been written on complexity, alas there is no agreement!

Sargut and McGrath (2011) define a simple system by a low degree of interaction and dependable predictability; complicated systems comprise many elements and many interactions functioning according to clear patterns, they are also predictable; complex systems are identified by the terms of multiplicity, interdependence and diversity, their outcomes are difficult to foresee. The same system configuration at the start allows for different results. Gidado (1996) is taking a different approach by concentrating on components (inherent complexity, uncertainty factors, number of technologies, rigidity of sequence, overlap of stages) and interactions between these. For him, complexity purely has a technical character. These positions are representing two ends of a continuum for the definition of complexity: the first one is highly abstract and flexible, the latter one concrete and more rigid. Seeing complexity not only from a technical perspective is a rather new topic (Antoniadis et al. 2012). An abstract definition allows to incorporate nontechnical perspectives and for this reason we will approach the definition of complexity from this end of the continuum.

It seems to be difficult to define complexity without a framework. A suitable one is Luhmannian system theory which understands the world as unmanageable due to its overwhelming complexity. Therefore, we are required to create systems in order to reduce complexity to a manageable degree. Construction projects are one type of system. Depending on how we draw the system borders of a construction project (one family home or petro-chemical plant) we are facing a remaining complexity, an eigen-complexity (Luhmann 1995). Drawing on the definition of Sargut / McGrath, we would like to add another dimension to the discussion, i.e. impact. It does matter whether a cause at one point of a system has a large or a small effect to the configuration of the system (Wilke 2000). The interactions between the elements are loaded or weighed (Geraldi 2008). This is, of course dependent on the diversity of the elements. Diverse elements allow for different types of impacts rippling through a system. Strength of impact is a more direct characteristic and therefore better suited for a definition than diversity.

A word of caution needs to be added. We are only concerned about complexity when we have to consider it for decision-making. An esoteric view of complexity is never taken in this paper. The whole point of systems theory is creating manageable entities that enable us to make decisions. This has consequences since the work of Simon (1972); we deal with bounded rationality and incomplete information. The first one is seen as a human condition, the second one as a result of the system's remaining eigen-complexity. Construction and construction projects appear to be systems where their complexity is linked to uncertainty of different actors and factors forming the actual system. It is likely that complexity management can be improved if the nature of complexity is identified and unnecessary complexity decreased (Pennanen & Koskela 2005).

2. Methodology

Evaluating project complexity involves several steps: (a) describing projects as a framework; (b) defining complexity; (c) deducing the construct “complexity”; (d) developing a method to measure complexity; (e) determining the value of project complexity. Through steps (a) to (c) project complexity is conceptualized; this is elaborated in chapter 3. Steps (d) and (e) are operationalizing project complexity and are treated in chapter 4.

The methodology used is logical deduction. Projects are embedded in Luhmannian systems theory (Luhmann 1995) and as such they form a distinct system through differentiation from the environment. The New Institutional Economics (NIE – Williamson 1985) are used to describe construction projects from a contractual point of view as contract goods. A nominal definition of project complexity is given based on a literature review (e.g. Baccarini 1996), combining this with a systems and NIE perspective. The construct is deduced from literature again embedded in Luhmannian systems theory (Wilke 2000). The construct is multi-dimensional and multi-factorial. As such it can be tested by a variance analysis; however, this is not described in this paper.

Steps (d) an (e) are of a more practical nature. The quantification of project complexity is determined by a group of experts to achieve an intersubjective agreement. We do not propose an objective measuring theory. This is due to the nature of complexity: this is a construct, nothing that exists in nature in a way similar to gravity. Thinking of complexity as a physical phenomenon has no ontological foundation whatsoever. With regard to a comparison between physical and social science and especially with the possibility of translating social theories into predictions of specific events such as it is possible with natural laws Hayek (1967) observes: “*There is no justification for the dogmatic belief that such a translation must be possible if a science of these subjects [social subjects]is to be achieved, and that workers in these sciences have merely not yet succeeded in what physics has done, namely to discover simple relations between a few observables. If the theories which we have yet achieved tell us anything, it is that no such simple regularities are to be expected.*”

3. Conceptualizing project complexity

3.1 Prologue: construction projects as contract goods

Projects are at the core of the construction industry and are typically defined by a contract, uniqueness of the task, a specific organization, an estimated budget and a given construction period. A little less common is the definition of construction projects as contract goods. Contract goods are defined by a contract (with a scope, parties to the contract, a budget and a timeframe) and they cannot be handed over when signing the contract. It takes the construction period to deliver them. The opposite is found in exchange goods such as a car which the buyer can view and test drive before concluding a contract. During the construction period the immaterial contents of the contract are transformed into the material structure by cooperation between client, consultants, contractors and suppliers. Contract goods are embedded in the principal/agent-theory and thus allow for a thorough analysis (Holmstrom/Milgrom 1991, Sappington 1992, Varian 1992, Nicholson /Snyder). Immateriality and integrativity characterize contract goods and there occurs a change in essence over the production period. If we think of contract goods to be delivered in three phases (before signing the contract – ex ante, during production, after finishing – ex post), then we can distinguish between two alternatives for contract goods: goods that remain from beginning to end immaterial such as hair cuts or those that are being transformed into something material such as construction projects (fig. 1).

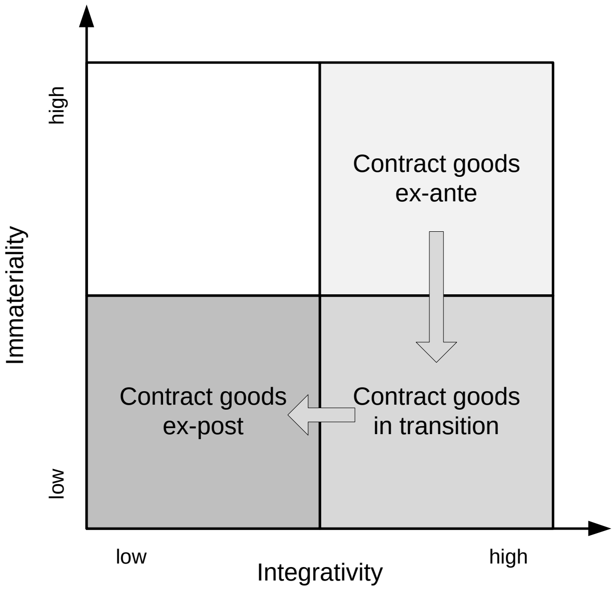

Figure 1: Construction projects as contract goods

As the nature of construction projects change when understood as contract goods, it is also clear that its complexity changes. Therefore we have to decide for what state we want to evaluate the project complexity. It seems natural to choose the moment of signing of the contract, thus we propose to take an ex-ante perspective. In this case we are confronted with the full complexity of the project execution (this might include design) but we do not worry about the complexity of the tendering phase. Such an ex-ante complexity allows the client to assess the capabilities of a bidder against demands and the contractors to submit a correct offer.

3.2 Definition

Following the discussion in chapter 1, we like to put forward a nominal (or stipulative) definition of complexity comprising number of elements, number of interactions and the strength of the impact that ripples through these interactions to the elements. Such a definition does not aim to reveal the essence of complexity and thus it cannot be right or wrong; however, it can be practical or impractical. The further discussion will reveal its practical usefulness. This definition is abstract in line with Sargut/ McGrath (2011) and a number of other authors. It seems that the efforts of finding a definition converge on such three characteristics with two of them (elements and interactions) being fixed and the third one under scrutiny.

Complexity = (def.) the number of elements, their interactions and the strength of impacts of a defined system with regard to decision making

It should be noted that this definition is a general one referring to any type of system. For a construct of construction project complexity we will find further determining factors. Complexity does not remain constant over the life-span of the project (compare chapter 3.1). In the end, the aim is to reduce it by decision-making. Therefore we are faced with different configurations of complexity at different times. Construction project complexity is subjected to dynamic change. As complexity here is seen as a state of a configuration, dynamics cannot be part of the concept of complexity itself. However, a dynamic environment produces different configurations and levels of complexity (Girmscheid and Brockmann 2008).

3.3 Construct dimensions of complexity

As mentioned, the discussion on complexity has progressed from just considering the technical complexity to include other categories. Baccarini (1996) for example distinguishes between organizational and technological complexity. Girmscheid and Brockmann (2008) introduce task, social and cultural complexity based on Wilke (2000). Task complexity combines technological and parts of organizational complexity, especially planning and organizing. It excludes leadership which is part of the social complexity. There can be little discussion that the number and diversity of stakeholders in a project along with the strength of their impact (interest and power – Chinyio and Olomolaiye 2010) increases its complexity; this we term “social complexity”. The same holds true for the influence of culture on construction projects (Tijhuis and Fellows 2012, Kähkönen 2008). In all cultural studies the point is to show how much the stakeholders’ cultural diversity influences project outcome. The more cultures meet in a project, the more complex it becomes since it requires coordination of an increasing number of different cognitive maps (Brockmann 2009); this we term “cultural complexity”. Geraldi (2008) also refers to dynamism with regard to complexity. We subsume something like dynamic complexity under the term “task complexity”. A stable environment certainly facilitates all tasks.

Two additional forms of complexity can also capture dynamics: cognitive and operative complexity. They both develop over time. Cognitive complexity mirrors how differentiated we think about a construction project; this increases with time as we understand a project better. Operative complexity is the degree of freedom for members of a project with regard to its operations and the project sponsors. Are most operations determined by the sponsors or does the project develop its own more specific operational approaches and thus become more complex?

A confined space influences task and social complexity. Restricted space for the tasks (i.e. a limited construction site) and social interactions (i.e. limited office space) increase these two types of complexity. All five types are becoming more complex as less time is available. This is a result of the decision-making perspective. The discussion can be summarized in a graph (fig. 2).

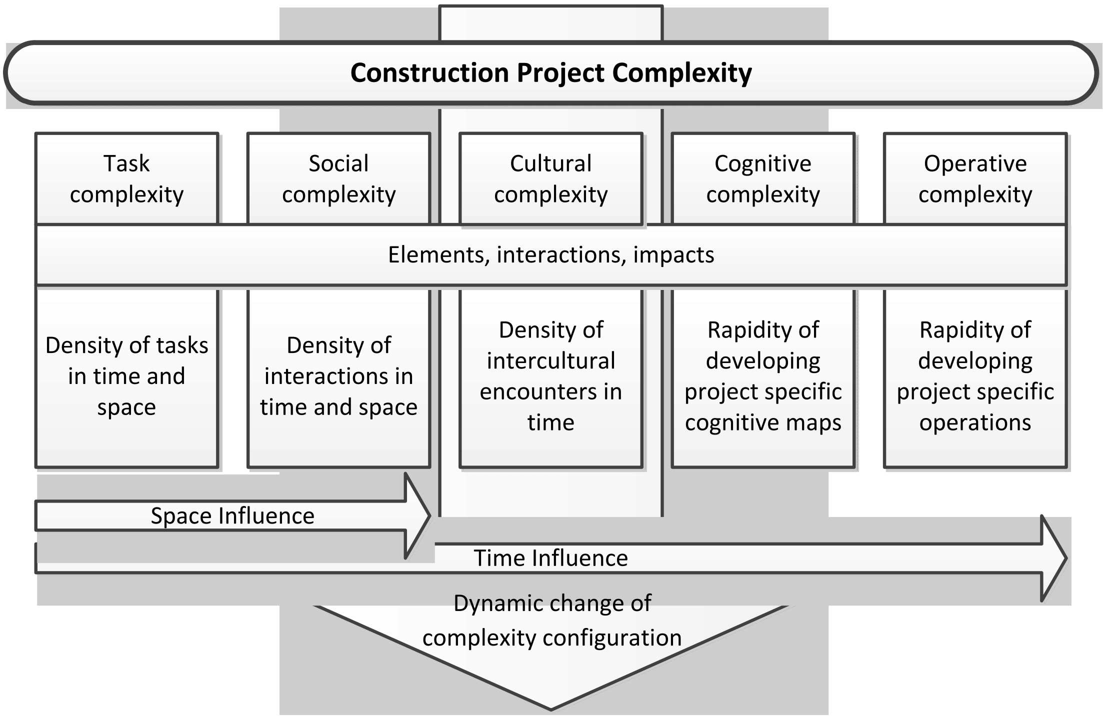

Figure 2 : Concept of construction project complexity

Returning to the discussion of construction projects as contract goods, it becomes clear that with the fulfilment of the contract all five complexity dimensions are reduced to zero. The task is completed, the project organization dissolves, cognitive maps are used for other purposes and operations cease. While this is true for the project it is not true for the institutions involved, their people might meet again in another project and bring along a – large or small - bag filled with history.

3.4 Factors of the construct dimensions

Up to now we have elaborated five construct dimensions. These are again determined by different numbers of factors and these we will discuss in this chapter. Number of elements, interactions and impacts are factors of all five dimensions as they are part of the general definition.

Task complexity: The concept of “density” has two categories. The first one applies to decision making and here time pressure increases complexity. There is not enough time to gather information and to analyze the situation. Space limitations also increase complexity. We only have to think of large numbers of subcontractors working in a confined space. It takes good planning to avoid an avalanche of claims and good luck to finish with just a few.

Social complexity: Similar to task complexity, social complexity rises when interactions take place in a short period. Time pressure comes across as chaos because there simply is not enough for coordination. Space limitations are not a real problem, the opposite is true: the scattered locations (dispersion) of a project team increase complexity (Dainty et al. 2006). This is definitely a challenge for international projects.

Cultural complexity: Culture becomes only problematic when different cultures meet. A good help for measuring the differences between cultures is the work of Hofstede/Hofstede (2005). They provide data for many different cultures and use five factors for describing culture: power distance, uncertainty avoidance, masculinity, individualism and long-term orientation.

Cognitive complexity: All the people in a project come with somewhat different mindsets, i.e. different cognitive maps. This is captured in the dimensions social and cultural complexity. Cognitive maps provide us with orientation without the necessity to analyze the situation from the beginning. The important point is that the people in a project dispose of appropriate maps. When a project is unique, we have to adapt our maps to the situation at hand, this is a learning process. However, the maps we start the process with should be as applicable as possible. A little simpler said: we need to have the required know that. Cognitive maps have also been called frames. Snow / Benford (1988) and Gamson (1992) define three types of sub-frames: (1) diagnostic frames, (2) identity frames, and (3) prognostic frames. These can serve as factors for cognitive complexity. The question for evaluating project complexity is here to determine ex-ante whether the people that will be decision makers for the project have access to applicable cognitive maps or not and whether they are capable to develop these maps in accordance with the project. Should this not be the case, then this fact will increase the project complexity. Diagnostic frames help analyzing situations appropriately, identity frames reduce coordination needs and prognostic frames allow assessing the future properly.

Operational complexity: As cognitive complexity is concerned with know that, operational complexity deals with know-how, the ability to do the correct things. Again, this is a learning process and again what is of importance, are the available operational skills at the beginning of the project. These can be differentiated into technical and management skills.

3.5 Overall construct

The discussions of this chapter 3 are summarized in table 1. The table provides the construct of construction project complexity and thus complement the general definition.

Table 1: Construct of project complexity

Dimension	*Factor1*	*Factor2*	*Factor 3*	*Other factors*
Task complexity	*Elements*	*Interactions*	*Impact*	*Time pressure, space limitations*
Social complexity	*Elements*	*Interactions*	*Impact*	*Time pressure, dispersion*
Cultural complexity	*Elements*	*Interactions*	*Impact*	*Power distance, uncertainty avoidance, masculinity, individualism and long-term orientation*
Cognitive complexity	*Elements*	*Interactions*	*Impact*	*Diagnostic frames, identity frames, prognostic frames*
Operational complexity	*Elements*	*Interactions*	*Impact*	*Technical, management skills*

4. Operationalizing the construct

4.1 Developing a method to measure project complexity

The construct elaborated in chapter 3 allows measuring project complexity in the form of an index only when categories are established that can be used routinely by any one group of experts. These categories reflect the values and attitudes of those using them. Therefore, these experts must establish their own categories. This is similar to determining risk thresholds in risk management. The following categories are only an example. To this end, we propose the following categories and values for the first three factors of the construct (elements, interactions, impact):

Table 2: Categories for the factors elements, interactions, impact

Factors	*Category 1*	*Category 2*	*Category 3*	*Category 4*	*Category 5*
Value	*20*	*40*	*60*	*80*	*100*
Elements (X_1)	*few*	*average*	*Many*	*a large number*	*extreme*
Interactions (X_2)	*few*	*average*	*Many*	*a large number*	*extreme*
Impact (X_3)	*negligible*	*average*	*Strong*	*very strong*	*Extreme*
Other factors (X_i)	*negligible*	*average*	*Strong*	*very strong*	*extreme*

Finally it becomes necessary to attach a weighed to each factor so that they can be summed up to the dimensions. These are given in table 4.

Table 3: Weights for the factors

Factors	*Elements (a)*	*Interactions (b)*	*Impact (c)*	*Factor 4(d_i)*	*Sum*
Weight	*0,225*	*0,225*	*0,300*	*0,250*	*1,000*
Time pressure	*Task complexity*			*0,150*	d_1 *= 0,25*
Space limitations				*0,100*	
Time pressure	*Social complexity*			*0,100*	d_2 *= 0,25*
Dispersion				*0,150*	
Power distance	*Cultural complexity*			*0,075*	d_3 *= 0,25*
Uncertainty avoidance				*0,075*	
Masculinity				*0,033*	
Individualism				*0,033*	
Long-term orientation				*0,033*	
Diagnostic frames	*Cognitive complexity*			*0,075*	d_4 *= 0,25*
Identity frames				*0,100*	
Prognostic frames				*0,075*	
Technical skills	*Operative complexity*			*0,125*	d_5 *= 0,25*
Management skills				*0,125*	

The criteria established so far allow writing mathematical equations for the five dimensions of construction project complexity. It should be kept in mind, that while the form is mathematical, the contents are not exact and in consequence, the results are also not exact.

Complexity $_{\text{task}}$ $= C_{ta} = a * X_1 + b * X_2 + c * X_3 + d_i * X_4$

Complexity $_{\text{social}}$ $= C_{so} = a * X_1 + b * X_2 + c * X_3 + d_i * X_4$

Complexity $_{\text{cultural}}$ $= C_{cu} = a * X_1 + b * X_2 + c * X_3 + d_i * X_i$

Complexity $_{\text{cognitive}}$ $= C_{co} = a * X_1 + b * X_2 + c * X_3 + d_i * X_i$

Complexity $_{\text{operational}}$ $= C_{op} = a * X_1 + b * X_2 + c * X_3 + d_i \quad X_i$

These five equations give us values for each complexity dimension; they need to be summarized as an index, the complexity index. The procedure is again the same as before, the experts determine for each of the five dimensions a weight (v, w, x, y, z) and then calculate the index. The maximum value is 100:

Complexity index for the project i: $C_i = v * C_{ta} + w * C_{so} + x * C_{cu} + y * C_{co} + z * C_{op}$

At the very end we need a classification for the project and propose the following terminology:

Table 4: Categories for projects

Description	*Highly complex*	*Very complex*	*Moderately complex*	*Normally complex*	*Simple*
Complexity index	*100 – 80,1*	*80 – 60,1*	*60 – 40,1*	*40 – 20,1*	*20 - 0*

4.2 Determining the value of project complexity

Evidently it is not easy to determine a value for project complexity. A tested approach to such problems is to divide the overall problem in a sufficiently large number of sub-problems and to evaluate these individually. By our bounded rationality we will most often be a bit off the target. If no bias exists (i.e. we deal with a normal distribution of errors) then we will at times overestimate a value and at others underestimate another one. Overall these have a tendency to cancel each other out. This approach is for example used on a daily basis in estimating the price of construction projects around the world.

In order to increase reliability we propose to evaluate project complexity by a panel of experts. A reasonable number will be between three and five. Each expert calculates the complexity index by himself and then an average is produced that represents inter-subjectivity, the very best we can do in a non-physical world. Larger differences will of course be discussed. A reconciliation of data is not required but an understanding of why differences occur. There should be an agreement on premises.

What can we practically do with a complexity index? We can avoid disaster. There are innumerable examples of construction projects around the world where one or more parties have been overwhelmed by an unforeseen degree of complexity. It can also alert us to what set of tools we need for a specific project, what type of experiences.

5. Conclusion

We have found that the conceptualization of project complexity yields a construct that is complex by itself. This is the paradox of struggling with complexity in theory and in practice: complex problems demand complex structures as an answer. This understanding is at the core of the works of Luhmann, Weber and Parsons: In modern societies the class structure has been replaced by an ever increasing and more specialized number of functions such as politics, economics, science, religion or the different professional fields. Each function allows dealing with an unprecedented high degree of complexity in its own right. However, the overall structure of society has become much more complex and integration becomes one of the main objectives.

A second understanding is that complexity is by nature not a physical entity. Throughout we have called it a construct, clearly identifying it as a social construction. We are dealing with a social construction of reality (Berger and Luckmann 1967). This does not imply that we are leaning in general towards constructivism. We subscribe to Popper's idea of three worlds (1979): a physical world, a world of our conscious experiences and a world of logical contents. Complexity belongs to the latter two worlds. It is none the less as real as a physical entity.

As a consequence we have proposed to evaluate project complexity through a subjective expert evaluation process that is in a second step elevated to an inter-subjective appraisal by the cooperation of a number of experts. The Degree of or the identified nature of complexity can be an important criterion for a project typology capable to classify also the anticipated managerial challenges.

6. References

Akerlof, G. (1970) The market for lemons: qualitative uncertainty and the market mechanism, Quarterly Journal of Economics, Vol. 84, 488 – 500.

Antoniadis, D, Edum-Fotwe, F. and Thorpe, A. (2012) Structuring of project teams and complexity, *Project Perspectives* 2012, 78 – 85.

Baccarini, D. (1996) The concept of project complexity – a review, *International Journal of Project Management*, Vol. 14, No. 4, 201 – 204.

Bennett, J. (1991) *International construction project management: General theory and practice*, Oxford: Butterworth-Heinemann.

Berger, P. and Luckmann, T. (1967) The social construction of reality: a treatise in the sociology of knowledge, New York: Anchor Books.

Brockmann, C. (2009) Using cognitive maps for better success in post-disaster relief situations, in: *Proceedings of the Symposium on Post-disaster Reconstruction*, Surabaya.

Chinyio, E. and Olomolaiye, P. (2010) *Construction stakeholder management*, Chichester: Wiley-Blackwell.

Dainty, A., Moore, D. and Murray, M. (2006) *Communication in construction: theory and practice*, Milton Park: Taylor & Francis.

Gamson, W. (1992) *Talking politics*. Cambridge, Cambridge University Press.

Geraldi, J. (2008) The thermometer of complexity, *Project Perspectives* 2008, 4 – 9.

Gidado, K. (1996) Project complexity: The focal point of construction production planning, *Construction Management and Economics*, Vol. 14, 213 -225.

Girmscheid, G. and Brockmann, C. (2008) The inherent complexity of large scale engineering projects, *Project Perspectives* 2008, 22 – 26.

Hayek, F. (1994) The theory of complex phenomena. In: Martin, McIntyre (eds.) *Readings in the philosophy of social sciences*, Cambridge: MIT Press, 55 - 70

Holmstrom, B. and Milgrom, P. (1991) Multitask principal-agent analyses, *Journal of Law, Economics and Organization*, Vol. 7, 24 – 52.

Kähkönen, K. (2008) Monitoring degree of complexity in multicultural construction, *Proceedings of the Joint 2008 CIB W065/W075 Symposium,* Heriot Watt University: Edinburgh.

Luhmann, N. (1995) *Social Systems*, Stanford: Stanford University Press.

Nicholson, W. and Snyder, C. (2008) *Microeconomic theory: basic principles and extensions*, 10th edition, Mason: Thomson South Western.

Mubarak, S. (2010) *Construction project scheduling and control*, 2nd edition, Hoboken: Wiley.

Pennanen, A. and Koskela, L. (2005) Necessary and unnecessary complexity in construction, Proceedings of the First International Conference on Complexity, Science and the Built Environment, University of Liverpool, UK

Popper, K. (1979) Objective knowledge: an evolutionary approach, Oxford: Clarendon Press.

Sappington D. (1991) Incentives in principal-agent relationships, *Journal of Economic Perspectives*, Vol. 5, 45 -66

Sargut, G. and McGrath, R. (2011) Learning to live with complexity. *Harvard Business Review*, Sept. 2011.

Simon, H. (1972) Theories of bounded rationality, *Decisions and Organizations,* ed. by McGuire, B. and Radner, R., American Elsevier: New York, 161 – 176.

Snow, D. and Benford R. (1988) Ideology, frame resonance, and participant mobilization. In: Klandermans, Kriesi, Tarrow (eds.) *From structure to action: Comparing social movement research across cultures*, Greenwich, JAI Press, 197 –218.

Sullivan, G., Barthorpe, S. and Robbins, S. (2010) *Managing construction logistics*, Chichester: Wiley-Blackwell.

Tijhuis, W. and Fellows, R. (2012) *Culture in international construction*, Spon Press: Abingdon.

Varian, H. (1992) *Microeconomic analysis*, 3rd edition, Norton & Company: New York

Williamson, O. (1985) *The economic institutions of capitalism: firms, markets, relational contracting*, The Free Press: New York

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