TOWARDS THE THEORY OF (LEAN) CONSTRUCTION

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Abstract

Issues related to the formulation of the theory of construction are considered. The roles of a theory in science and in practice are discussed. It is argued that many theoretical problems related to construction are due to general deficiencies of engineering and production theories, caused by one of their conceptual foundations, the conversion model. The origin and evolution of the conversion model are discussed. The shortcomings of the conversion model are illustrated by the case of project management. The beginning of a transition from the conversion model to alternative models is observed in a number of engineering and production disciplines. A similar paradigm shift is needed also for construction.

What is a theory?

The first obstacle regarding the formulation of the theory of construction is that the goal may not be clear or worthwhile for all in the construction audience. In construction usage, the word theory is most often used in its meanings[1] "speculation" and "not dealing with facts as presented by experience". However, this word has also other meanings, through which, I think, the concept of the theory of construction becomes somewhat clarified.

Theory in scientific work

From the point of view of scientific work, a complete theory must contain four essential elements (Whetten 1989):

- What. Which factors (variables, constructs, concepts) logically should be considered as part of the explanation of the phenomena of interest?
- How. How are factors related? Here, causality is introduced.
- Why. What is the rationale that justifies the selection of factors and the proposed causal relationships? An explanation is required.
- Who, Where, When. The boundaries of generalizability, and thus the range of the theory, have to be set.

Of course, the business of scientific work is largely to deal with the interaction of theory and fact: "determination of significant fact, matching of facts with theory, and articulation of theory" (Kuhn 1970).

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[1] From The Concise Oxford Dictionary, 1964.

Theory in connection to practice

Another, not totally distinct meaning of theory is that of "foundational ideas". This is illustrated by the Figure 1. When considering a practical approach to construction (or design, production), we can discern three layers. The topmost level is made up of the conceptual notions of the approach. Factually, it answers the question: What is construction? The intermediate level consists of principles, heuristics, etc., which describe the relations between the concepts. The bottom level consists of methods, tools, practices, etc., which embody the respective concepts and principles.

Here, the two uppermost levels roughly correspond to the scientific notion of theory. This theory-in-action may be identical with a scientific theory, or it may not be. Even if the theory-in-action is not explicit, it certainly exists.

Note that development of an approach may occur in two directions: top-down or bottom-up. The former situation is typical when a scientist-originated method is marketed to practice. In the latter case, new methods are applied without an explicit conceptual and theoretical foundation. By and by, the practice pushes also towards clarification of concepts and theory.

The related terminology is not coherent. Often, the concepts of paradigm, foundation, philosophy, model, etc., are used in discussing the chain from theories to action or parts thereof.

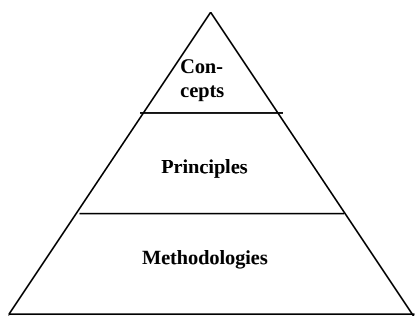

Figure 1. Practical methodologies are based on concepts and principles.

What should we require from theories?

What should we require from theories, especially from those purporting to have practical impact? In the following, we discuss three important requirements: explicitness, modelling power and decision power. The last two requirements are inspired by Kochikar and Narendran (1994).

Explicitness

Often theories are considered so self-evident that they are hardly mentioned. For example, textbooks in industrial engineering or construction engineering rarely begin with the foundational theories of the subject, but proceed to the treatment of individual techniques after introductory remarks.

However, there are several problems associated with implicit theories. Such theories are not generalizable or testable; their domain of feasibility is not known so applying them to new situations is problematic; their transfer and teaching is difficult. Thus, it is natural that the progress of a field often leads to increasing explicitness and formalization of the paradigm or philosophy.

The lack of explicit, coherent theories seems to be a common problem in the sphere of production and related engineering sciences. Thus, the Committee on Foundations of Manufacturing, assembled in 1989 by the National Academy of Engineering of the United States, calls for the development of "foundations of manufacturing" (Heim & Compton 1992):

"The foundations for a field of knowledge provide the basic principles, or theories, for that field. Foundations consist of fundamental truths, rules, laws, doctrines, or motivating forces on which other, more specific operating principles can be based. While the foundations need not always be quantitative, they must provide guidance in decision making and operations. They must be action oriented, and their application should be expected to lead to improved performance."

Regarding the lack of foundations, the situation is similar in various fields of design and certainly in construction.

This requirement of explicit theories has recently been emphasized by Drucker (1995), who argues for explicit and testable theories of enterprises.

Modelling power

On the conceptual level, we have an abstraction or idealization of the topic. An abstraction filters out irrelevant detail and represents only information relevant for the task (Petrie 1992). For manageability, abstractions are as parsimonious as possible; however, the danger of ending up in large deviations between the reality and the abstraction, due to the impact of phenomena filtered out, grows. It has to be realized that methodological sophistication can never substitute for shortcomings (that is, significant things filtered out) in the abstraction as a foundation. Once selected, we are prisoners of our abstraction.

Thus, it is critical that our theories have the power to model all features relevant for the task. As argued below, it is the deficient modelling power that I see as the major problem of mainstream theories.

Decision power

Decision power is related to the degree a theory supports the development of various practical tools. It has to be noted that scientific theories as such have only limited value in practice. For practical action, various models, tools and systems, where the theory is embodied, are needed. One interesting criterion is, how easily the theory lends itself to computational analysis, in which case simulation and optimization become possible. Thus, the significance of decision power will be accentuated along with the proliferation of computer-aided tools[2].

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[2] Fenves (1996) states: "The aim of research on the application of information technologies to civil and structural engineering design is to provide the kind of science base that the engineering science of structural mechanics has come to provide in the past 150 years." In his view, that science base should have one component that deals with the understanding of the processes of planning, design, management, etc.

Generally, there is a trade-off between modelling power and decision power: the more complicated model, the more difficult it is to handle and analyze. However, decision power is to some extent secondary in comparison to modelling power. This is because shortcomings of modelling power cannot be compensated through enhanced decision power. However, shortcomings of decision power, caused by an emphasis on modelling power, can be compensated for by hard work, in the short run, and methodological development, in the long run.

A good example of this trade-off is provided by the use of the Critical Path Method in construction. Obviously, CPM methods have been popular for decision power, and unpopular for lack of modelling power (for longer treatment, see (Koskela 1995)).

How different is construction?

Are the theoretical problems connected to construction more related to general deficiencies of engineering theories or to our lack of understanding in regard to construction's specific features? I would favor the first alternative. Most of the peculiarities of construction exist also in other domains of engineering, and they are subject to theoretical advancement by several scientific communities.

Let us consider the project nature of construction and the combination of design and production as implicit in construction.

Construction is realized as projects rather than as (continuous) operations. Thus, the project management is applicable. However, from the point of view of the supplying chain to construction, it is a question of continuous operations, and the discipline of operations (and production) management is applicable.

A construction project usually consists of two projects: design and production. The design project is comparable to product development, and such disciplines as design science, concurrent engineering, etc. are adequate. Regarding production, the theories of production science apply (even if continuous production is there more addressed).

Thus, "the theory of construction" (which we apparently do not presently have[3]) is characterized as being a synthesis of several related disciplines, and the theoretical understanding of the residual construction core peculiarities, not covered elsewhere.

Lack of explicitness: One key to the persistence of the conversion model

I have earlier argued (Koskela 1992) that the conversion model has been the foundational theory of construction (as well as many other fields related to production, design, etc.) and that the deficiencies of that theory have led to misguided action. The core of the conversion model is in (1) seeing production (operation, design, etc.) as a conversion[4] of inputs into outputs, and (2) in the idea of breaking up the total conversion into smaller, more manageable conversions (analytical reductionism).

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[3] It is illustrative that Ofori (1994) found that the discipline of construction economics has no common conceptual basis.

[4] The term transformation is also often used.

Lack of explicitness of the conversion model is a major problem when one tries to propose an alternative to it. As well in practice as in research settings, the conversion model is most often implicit, and when made explicit, it is rarely treated as a testable and discussible theory. This situation is connected with the long historical tradition of the model.

The historical overview by Grubbström (1995) sheds some light on why just the concept of conversion has dominated the scene. Apparently, economic science was maybe the first to consider production at an abstract level. However, in the eighteenth century, the point of departure was agricultural production. Indeed, the conversion model is an excellent abstraction of grain cultivation. The transformation, growing of the grain, takes care of itself, so we do not need to describe and understand its inner mechanisms. The quality of the output is primarily dependent on Nature, so that there is no need to consider customers or their requirements.

The conversion model was thus established in economic science, and it was later applied to other production settings, for which, unfortunately, it is a rather poor abstraction. It is conceivable that the conversion model has been transferred just from economics to other fields, even if there is little historical knowledge on this question.

Analytical reductionism, which characterizes the Western intellectual tradition, has its origin in the second rule of Descartes (Checkland 1981):

The second (was) to divide each of the difficulties that I was examining into as many parts as might be possible and necessary in order best to solve it.

Regarding the engineering sciences, the tradition of analytical reductionism has been amplified especially by Taylor (Gibson 1991). Gibson says that “the general style he set became the universal paradigm for American engineering practice and for engineering education, and remains so even today”. Taylor’s impact might not have been less in Europe and elsewhere.

Since the Second World War, analytical reductionism has been strongly criticized by the systems movement. It is argued that there exist, at certain levels of complexity, properties which are emergent at that level, and which cannot be reduced to explanation at lower levels. The idea is that the architecture of complexity is hierarchical and that different languages of description are needed at different levels (Checkland 1981).

However, the systems movement has not been able to convert the idea of emergency into practical tools, at least regarding management science. This is illustrated, for example, by the soft systems methodology. The critical argument behind this methodology is that in situations involving humans, like in management, problems cannot be stated clearly and unambiguously (Checkland 1981). Thus, a methodology that is more geared towards organizing discussion, debate and argument is needed. The soft systems methodology fulfils this requirement, while including also the appropriate parts of hard systems methodology. However, even this methodology primarily subscribes to the conversion model (called transformation process), with all its faults.

Thus, the conventional thinking, oriented towards conversion and its breakdown, has, by and large, not been challenged in scientific discussion about founding theories. Not until the 1980’s has engineering practice, through JIT, TQM, etc., started to cause cracks in the conventional foundation. We are still in the midst of this evolution, which, in my understanding, presents a major research frontier of engineering and management sciences.

Lack of modelling power in the conversion model or what is wrong with project management

Let us consider the deficiencies of the conversion model, and the needs to formulate alternative models, through its application in project management, highly relevant for construction.

In his highly recommendable book The Handbook of Project-Based Management, Turner presents an alternative view to project management (Turner 1993). He argues that the present project management produces an undue focus on the work, and completing it within time, cost and quality: the work is done for its own sake. I think this conclusion is true.

According to Turner's view, scope management is the *raison d'être* of project management, and so scope management is the principal project objective. He divides the purpose of scope management, where work or product breakdown structure is the primary tool, into three key elements:

- an adequate, or sufficient, amount of work is done
- unnecessary work is not done
- the work that is done delivers the stated business purpose.

These three purposes describe excellently the issues at stake in project management. However, exactly here we have the crucial divergence of opinion between the conventional thinking and the Lean School. According to the Lean School, the work breakdown structure (which, of course, can be seen as a hierarchical decomposition of the total conversion) is most adequate for figuring out what should be done, i.e., the first element above. However, for the two other elements of purpose, the work breakdown structure is not sufficient, even if necessary.

Are re-doing, waiting, or say, accidents, necessary pieces of work? Obviously not. However, the work breakdown structure gives no conceptual means to handle this kind of work, called non-value adding, in the jargon of the Lean School. It is a question of an idealization error, which, along with growing complexity of projects, has increased to notable, often unbearable dimensions. As the author (Koskela 1992) and numerous others before and after him have argued, the conceptual framework of flows makes it possible to manage towards this purpose: unnecessary work is not done. By means of the concept of flow, such important features as time, space and uncertainty, abstracted away in the conversion model, can be addressed. The focus is changed from managing activities or contracts to managing physical material, information, and workflows.

The theory of flows is not well-developed, but solid enough for providing a basis for remarkable improvement when applied industrially. It is reasonable to anticipate that further theoretical development and related testing, as well as tool development and implementation issues, will occupy the attention of researchers for many years.

How can we be sure, in advance, that the work that is done delivers the stated business purpose? It is difficult to see how the mere work breakdown structure could give a definite solution here. There are methods that can be used in this context. For example, quality function deployment helps to manage the flow-down of requirements through the different phases of the project. However, these tools provide no structured approach to the whole problem. In the final analysis, we have to frankly admit that theoretically and conceptually, we do not really understand how value is generated during a project. Consider the well-known conceptual scheme of supplier-customer (Fig. 2). Actually, again we have here a black box, the inner mechanisms of which we only poorly understand both at the level of individuals or, say, projects. This situation is a call for and a challenge to theoretical research.

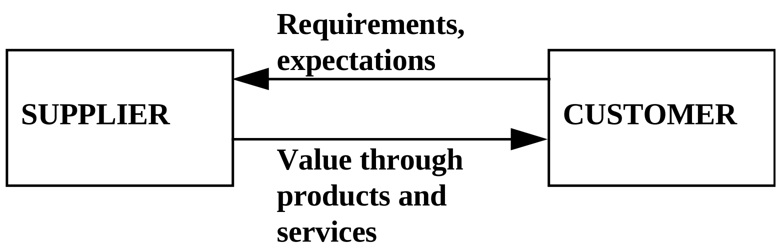

Figure 2. The conceptual scheme of a supplier-customer pair.

The landscape of disciplines

It is interesting to examine to what extent the transition from the conversion model to alternative models has proceeded in the disciplines relevant to construction. The reactions vary from total unresponsiveness to the formation of new fields based solely on alternative models. The following characterizations are impressionistic and invite to further discussion.

Project management

As discussed above, the discipline of project management has almost exclusively been based on the idea of the conversion break-up. Thus, not unexpectedly, the project management community has been reluctant to accept contrary views. This becomes very clear when reading the new Guide to the Project Management Body of Knowledge (Project Management Institute 1996), which is based on the conventional view. For example, the important and generic ideas of concurrent engineering are treated with a short, two line entry in the list of definitions.

However, the theoretical mainstream views are being questioned, even if not exactly for the reasons forwarded in this paper. This is exemplified by the International Research Network on Organizing by Projects (IRNOP):

“IRNOP was initiated in 1993 with the intention to support and enhance efforts aiming at the development of a theory on temporary organizations. We consider the "mainstream" Project Management approach, as it is expressed in textbooks and PMI:s PMBOK, to be highly advanced in prescribing how projects should be organized. But the theoretical models for planning and control do not provide accurate descriptions of what actually happens in project organizations. From the beginning, IRNOP therefore set out to develop theories on what we called "temporary organizations", theories departing from concepts such as leadership, motivation, learning, renewal and quality of work life.” (From IRNOP Home page.) The first IRNOP conference was held in 1994 and the second in 1996.

Concurrent engineering

Concurrent engineering is the equivalent of lean production on the product development and design side. A vigorous scientific community has rapidly formed around concurrent engineering. Also theoretical issues are considered to a large extent.

Product development always happens in projects. However, this departure point is rarely acknowledged in concurrent engineering, and vice versa, as noted above; the new generic ideas of concurrent engineering, have not diffused to the mainstream project management.

Operations (and production) management, industrial engineering

The explanation of the success of the Japanese production philosophies has recently been the major focus in these disciplines. However, as evidenced by the popular book "The machine that changed world" (Womack et al 1990), the explanation addresses often only techniques, rather than theory. Thus, the following statement is largely true, even in a sense obviously not intended by its originator: "Operations management's heart lies in its core, the development and management of value-adding processes, and the tools, techniques and methods to support this" (Voss 1995). The consideration of non value-adding process parts is still on the fringe.

Re-engineering, process management

The recent fields of re-engineering and process management are more or less directly based on some ideas related to the flow model. Unfortunately, especially re-engineering is almost totally focused on implementation issues, rather than on building a solid foundation for action.

Conclusions

As construction researchers, we are in the challenging and maybe disturbing situation, caused by the transition from a paradigm in crisis to a new one, that Kuhn (1970) has so eloquently described:

...[I]t is a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field's most elementary theoretical generalizations as well as many of its paradigm methods and applications. [...] When the transition is complete, the profession will have changed its view of the field, its methods, and its goals.

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