The prevalent theory of construction is a hindrance for innovation

Koskela, LJ and Vrijhoef, R

THE PREVALENT THEORY OF CONSTRUCTION IS A HINDRANCE FOR INNOVATION

Lauri Koskela[1] and Ruben Vrijhoef[2]

ABSTRACT

It is argued that construction innovation is significantly hindered by the prevalent theory of construction, which is implicit and deficient. There are three main mechanisms through which this hindrance is being caused.

Firstly, because production theories in general, as well as construction theories specifically, have been implicit, it has not been possible to transfer such radical managerial innovation as mass production or lean production from manufacturing to construction. Direct application of these production templates in construction has been limited due to different context in construction in correspondence to manufacturing. On the other hand, without explicit theories, it has not been possible to access core ideas of concepts and methods of these templates, and to recreate them in construction environment. In consequence, theory and practice of construction has not progressed as in manufacturing.

Secondly, it is argued that the underlying, even if implicit, theoretical model of construction is the transformation model of production. There are two first principles in the transformation model. First, the total transformation can be achieved only by realising all parts of it. Thus, we decompose the total transformation into parts, finally into tasks, ensure that all inputs are available and assign these tasks to operatives or workstations. Second, minimising the cost of each task, i.e. each decomposed transformation, minimises the cost of production. It is argued that these principles, in which uncertainty and time are abstracted away, are counterproductive, and lead to myopic control and inflated variability. Practical examples show that these deficiencies and related practical constraints hinder the top-down implementation of innovations.

Thirdly, empirical research shows that also bottom-up innovation - systematic learning and problem solving - is hindered by this deficient theory. Thus, the advancement of construction innovation requires that a new, explicit and valid theory of construction is created, and business models and control methods based on it are developed.

KEYWORDS

Production theory, innovation in construction, radical innovation, top-down innovation, bottom-up innovation, diffusion of manufacturing templates

1 Senior Researcher, VTT Building Technology, Concurrent Engineering, P.O.Box 1801, FIN-02044 VTT, Finland, Phone +358 9 4564556, Fax +358 9 4566251, E-mail lauri.koskela@vtt.fi

2 Research Scientist, TNO Building and Construction Research, Department of Strategic Studies, Quality Assurance and Building Regulations, P.O.Box 2600, NL-2600 AA Delft, The Netherlands, Phone +31 15 2695228, Fax +31 15 2695335, E-mail r.vrijhoef@bouw.tno.nl

INTRODUCTION

In the discussion on lean construction, it has been a leading argument that the prevalent theory of production (or specifically, theory of construction) is counterproductive, and leads to added costs and reduced overall performance through the deficient production control principles based on the theory (Koskela 1992, Ballard & Howell 1998, Santos 1999). In this paper, the angle of analysis is widened: the prevalent theory of construction production is analysed from the point of view of innovation. It is generally viewed that there is a need for more innovation in the construction industry (Slaughter 1998, Winch 1998). The causes for this low rate of innovation have been investigated, and among other issues, institutional factors or peculiarities of construction have been pointed out as reasons. This paper ends up with a new, emergent explanation that is complementary to the prior view on institutional factors as hindrance for innovation. The conclusion is that the prevalent theory of construction is deficient and implicit, and this is the major barrier for innovation in the construction industry.

MODELS OF INNOVATION IN CONSTRUCTION

Innovation has been defined as the actual use of a nontrivial change and improvement in a process, product or system that is novel to the institution developing the change (Freeman 1989). Innovation scholars have presented a variety of models of innovation in construction and related explanations for the lack of innovation. In the following, we review and evaluate three theoretical strands: innovation typology, institutional view, and firm view.

Slaughter (1998) presents a typology of innovations in construction. An *incremental* innovation is a small change with limited impacts on surrounding elements. A *modular* innovation is a more significant change in the basic concept, but also with limited impact on its surroundings. An *architectural* innovation may consist of a small change in the respective component, but with many and strong links to other surrounding components. In a *system* innovation, there are multiple, linked innovations. A *radical* innovation is based on a breakthrough in science or technology and changes the character of the industry itself. Slaughter rightly argues that the implementation of these different types of innovation requires different levels of management and supervision.

From the five types of innovation presented by Slaughter (1998), it can be argued that the incremental and modular innovations are the most frequent in construction. Most construction innovations originate from material and component producers (Pries 1995), and their diffusion is easier if no changes in surroundings are needed. However, the most powerful is radical innovation. Such an innovation may be related to new materials, but also to managerial and organisational methods (Slaughter (1998) presents the example of steel construction).

The institutional view focuses on the structural features of the construction industry from the point of view of innovation (Winch 1998). Based on analyses of other complex systems industries, it is possible to distinguish the *innovation superstructure*, consisting of clients, regulators and professional institutions, *system integrators,* consisting of principal designer and principal contractor, as well as the *innovation infrastructure*, consisting of trade contractors, specialist consultants and component suppliers. Winch (1998) recognises several problems in this system. Especially, the systems integrator role is shared between the principal architect and the principal contractor. Other research has stressed the weakness of the client behaviour (Pries 1995).

Another variant of the institutional view focuses on the peculiarities of construction. For example, Nam and Tatum (1988) argue that the characteristics of the constructed products result in limitations for construction technology. They describe five characteristics: immobility, complexity, durability, costliness, and a high degree of social responsibility.

Brouseau and Rallet (1995) argue that certain institutional characteristics and organisational principles of construction itself constrain innovations and restrict parties to apply innovations. Particularly, decentralised decision-making and informal co-ordination prevent all systematic optimisation and innovative evolution (Brouseau & Rallet 1995).

In the firm view, the focus is firstly on the *top-down* adoption and implementation of innovations emanating from an outside source, and secondly on the *bottom-up* problem-solving and learning in projects. Winch (1998) finds such barriers for top-down innovation as lack of incentives, split role of systems integrators and relative lack of demanding clients. Regarding bottom-up innovation, he sees it as a problem that downstream system integrators do no or little actual site work, so whatever problem-solving goes on remains outside the firm.

In this paper, a complementary explanation for the low innovation activity in construction is put forward. The central argument is that the deficient and implicit theory of construction, as presently in use, is one root cause for low innovation activity. Instead, an explicit and more powerful theory is needed for further innovation, which is 'to manage new ideas in good currency' (Van de Ven 1986).

From the innovation types as defined by Slaughter, theoretical problems related to construction affect those requiring system-wide changes, especially radical innovation. Thus, the following analysis is restricted to radical innovation regarding this typology. Both firm innovation types, top-down and bottom-up innovation can be argued to be affected by theoretical problems related to construction. Thus, the relations between theory and innovation as depicted in Figure 1 will be discussed in the following.

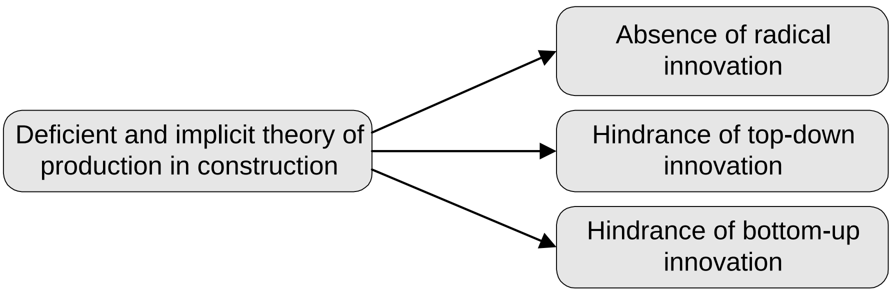

Figure 1 Relation between deficient and implicit theory, and hindered innovation

THEORY OF CONSTRUCTION

WHAT IS A THEORY OF CONSTRUCTION?

The theory of construction should answer to three fundamental, interrelated questions (Koskela 2000):

- What is production in general?
- Which principles should be used for achieving the goals set to production?
- Which methods and tools can be used for translating these principles into practice, taking the peculiar characteristics of construction into account?

The first two questions deal actually with the concepts and principles of production in general (i.e. theory of production), and the third with their application to construction.

THEORY OF PRODUCTION

Analysis of literature (e.g. Koskela 2000) shows that scientists have proposed three different theories of production. Production has been viewed as transformation, flow and value generation. All these views have been practically applied, but the patterns of diffusion have been drastically different.

The view of production as a *transformation* was sharply defined by Walras (1952) at the end of the 19th century. In this view, production is conceptualised as a transformation of inputs to outputs. There are two first principles in the transformation model. Firstly, the total transformation can be achieved only by realising all parts of it. Thus, we decompose the total transformation into parts, finally into *tasks*, ensure that all inputs are available and assign these tasks to operatives or workstations. Secondly, minimising the cost of each task, i.e. each decomposed transformation, minimises the cost of production. In turn, for minimising the cost of each task, a number of ways are available: division of labour, economy of scale and technology. This has been the dominating concept in production and business management in the 20th century. An early proponent was Taylor (1913) who viewed that the task idea as the most prominent single element in scientific management This view can also easily be recognised as the underlying theory of project management, for example.

Frank and Lillian Gilbreth (1922) suggested the view of production as a *flow*. The central idea was to introduce time as a resource of production. Two types of activities consume time when viewed from the point of view of the product: transformation activities and others, apparently non-transformation activities, categorised by the Gilbreths as transfer, delay and inspection activities. The first principle of this theory is to eliminate waste, i.e. non-transformation activities. The maybe most important insight related to the flow concept is that *time compression* leads to waste reduction. Another powerful principle states that *variability reduction* leads to waste reduction. This is the underlying concept of JIT, lean production and business process re-engineering.

The conceptualisation of production as *value generation* was proposed by Shewhart (1931) at the outset of the quality movement: "looked at broadly there are at a given time certain human wants to be fulfilled through the fabrication of raw materials into finished products of different kinds." The first principle in this view is to fulfil the requirements and wishes of the customer, i.e. generate value for him. This has been the founding concept of the quality movement, customer-oriented management and similar approaches.

The first two of these theories have been the root cause of two radical innovations in manufacturing in the 20th century, leading to new production templates. First, mass production and the associated "modern enterprise form" was primarily based on the transformation model, and secondly lean production, based on the flow model. At both instances, the productivity was significantly improved across manufacturing industries. Also in both cases the innovation diffused as a practical template, whereas the underlying theory tended to be neglected or forgotten.

THEORY OF CONSTRUCTION: APPLICATION OF THE THEORY OF PRODUCTION TO CONSTRUCTION

Regarding practical implementation, the generic theory of production has always to be applied to the specific situation in question. Thus, the theory of construction is an application of the generic theory of production to the characteristic context of construction: one-of-a-kind production, site production and temporary project organisation (for a more detailed discussion on the characteristics of construction, see Carassus 1998). These characteristics of construction are shared by many other industries, even if usually not in the same combination.

Thus, for example, mining and agriculture share site production. One-of-a-kind production is relatively common in manufacturing industries. Temporary project organisations are widely used in the film industry. Thus, construction faces similar problems regarding tailoring solutions to the characteristics of the situation as any other industry. However, the characteristics of construction have theoretically not been understood well, as discussed below.

ABSENCE OF RADICAL MANAGERIAL INNOVATIONS IN CONSTRUCTION

As discussed above, two radical innovations of manufacturing, mass manufacturing and lean production have not replicated in construction. The template of mass manufacturing was based on the powerful principles of economy of scale, division of work, centralised control and mechanisation, but due to the peculiarities of the constructed product, they could - and can - be utilised only to a limited extent in construction. The bulkiness of buildings prevent economy of scale, work was already divided into trades in construction, centralised control does not match well with the uncertain site conditions and the need for mobility on site is a barrier for mechanisation. Nevertheless, mass production has fascinated construction professionals, and already in the 1930s, a house factory with a moving belt was organised in the United States. However, ‘Fordized, mass-produced housing never caught on’ (Hounshell 1984).

Like mass manufacturing, also lean production originated in the car industry. In contrast to mass production with focus on a highly visible moving belt and regimented work, lean production is based on rather subtle principles for production and material flow control, and it has required a long time to get a grasp on it from the production science community. The concepts and methods used to promote lean production, such as JIT, andon, one-piece-flow, etc., have been too far from the situation of construction to make direct diffusion possible.

Lillrank (1995), who argues that organisational innovations do not transfer well in their original setting over industrial borders gives a theoretical explanation for the absence of corresponding radical innovations in construction. The core idea or concept of organisational innovations must be abstracted and then recreated in an application that fits local conditions. Thus, an explicit theory is needed. In reality, there has not been an explicit theory of production; rather the new production templates have diffused on the level of methods and practices. In consequence, neither of the templates of manufacturing - mass production and lean production - has yet been successfully introduced into construction. The reason for this has essentially been the inability to abstract the theoretical core of these production templates and to apply it to the situation of construction (Figure 2).

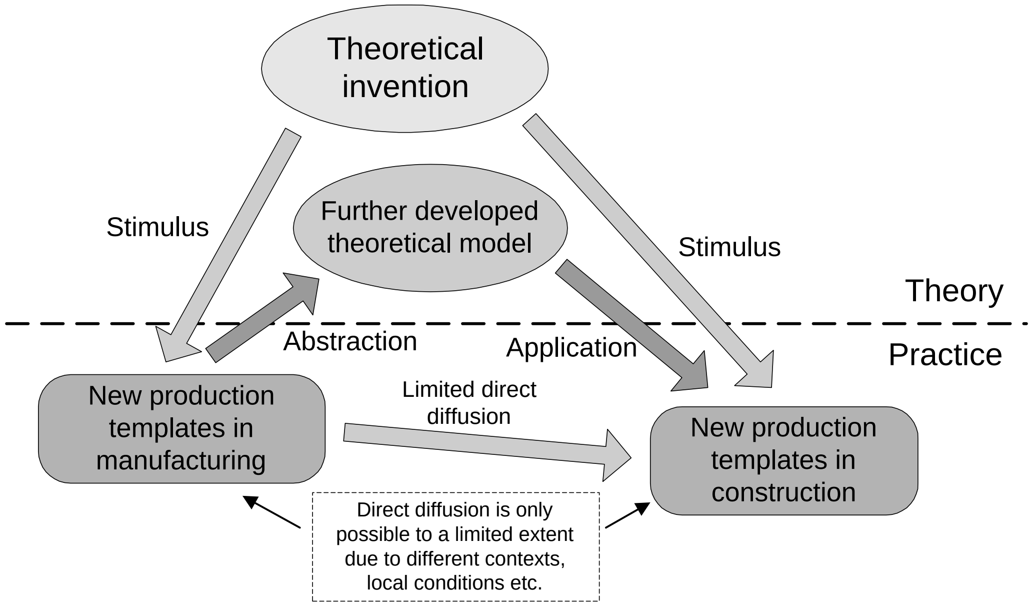

Figure 2 Different trajectories to diffuse production templates from manufacturing towards construction

PRESENT THEORY AND PRACTICE OF CONSTRUCTION

In consequence of the absence of radical managerial innovations, present practice of construction management is characterised partly by methods originating from the craft period, partly by leftovers from manufacturing, especially centralised control. According to recent empirical studies (Santos 1999, Koskela 2000), construction is predominantly managed according to the transformation concept. Management efforts are centred on task management and based on principles of the transformation concept. However, task management is not implemented systematically across all phases, resulting in added variability. Even where there is an intention to implement systematic task management, it corrupts, due to the high level of inherent variability, to unsystematic management, as already noted by Tavistock Institute (1966). Thus, *bad control* (i.e. deficient attention in control to the principles of production) across all phases results. The goal of not using resources unnecessarily is realised by minimising the costs of each task and each task input. Unfortunately, there are a variety of interactions between tasks that are assumed away. Thus, in practice, complexity and variability increase, leading to *unfavourable design* of the production system (i.e. production system design where the principles of production have been deficiently realised).

Thus, the present underlying theory behind construction management is simply counterproductive, and leads to a systematic creation of added costs and reduced functionality in construction. In fact, extensive evidence from different countries shows that managerial methods are neglecting or violating the principles related to the flow and value generation views (Koskela 2000, Santos 1999). One of the most evident consequences is the increase of variability in information and material flows, and the associated long cycle times needed for coping with this variability.

There is a second issue playing a role, namely *construction peculiarities* (one-of-a-kindness, site production, temporary production). Because of these, flows are more variable and complex than otherwise, and also value generation is hindered. However, to which extent they are root causes for waste and value loss is an open question: there are many practical examples where those peculiarities have been eliminated or mitigated.

TOP-DOWN INNOVATION IN CONSTRUCTION

The next argument is that the present managerial methods in construction significantly hamper top-down innovation, as defined above. In support of this hypothesis, two cases of top-down innovation are examined: industrialisation and information technology.

INDUSTRIALISATION

Since the Second World War, the idea of industrialisation has received much attention both in Europe, North America and elsewhere. However, in spite of a great number of attempts, there has been a relative lack of success of industrialised building methods (Warszawski 1990). The share of prefabricated components has gradually risen, but a breakthrough for industrialised construction has still not occurred. According to Warszawski (1990), the main problem of prefabrication of today is the lack of a system approach to its deployment on the part of the various parties involved. But there is another significant point: when analysed as flow processes, industrialised construction shows widely different characteristics in comparison to site construction. In industrialised construction the flow is longer due to multiple production locations, the amount of design required is larger, the error correction cycle is longer, and requirements for dimensional accuracy are higher than in site construction (Koskela 2000).

Thus, the total process of industrialised construction tends to become more complex and vulnerable in comparison to site construction. It seems plausible that in design, prefabrication, and site processes of industrialised construction that are managed in the myopic mode suggested by the transformation theory, the increase of costs due to increased waste has often consumed the theoretical benefits to be gained from industrialisation.

INFORMATION TECHNOLOGY

It is well known that information technology (IT) has been a dominating theme in the development of construction in the last decade. Nevertheless, the impact of IT has been disappointingly modest. Howard et al. (1998) found high levels of benefit from IT in design and administration in Scandinavia, while management applications have resulted in little change: '(…) contractors (…) reported little change in productivity resulting from materials or site management'. Similarly, in their study on construction IT in Finland, Enkovaara et al. (1998) found that for contractors, *IT had not produced any benefits*, whereas in subcontracting and client procurement activities, *IT benefits were negative*, i.e. the benefits accrued have not offset the costs. In many cases, the level of personnel competence or the degree of structured data have not corresponded to those required by an IT application.

We relate this situation with the chaotic nature of construction. Implementation of new technology is difficult when there are many intervening disturbances (e.g. Hayes et al. 1988, Chew et al. 1991). Beyond that, there is some evidence for the claim that computers have for their part increased the variability of flows in construction.

The explanation to the lack of success of industrialisation and information technology is basically the same: the inflated level of variability in flow processes, due to prevalent managerial methods based on the theory of production as transformation (Figure 3).

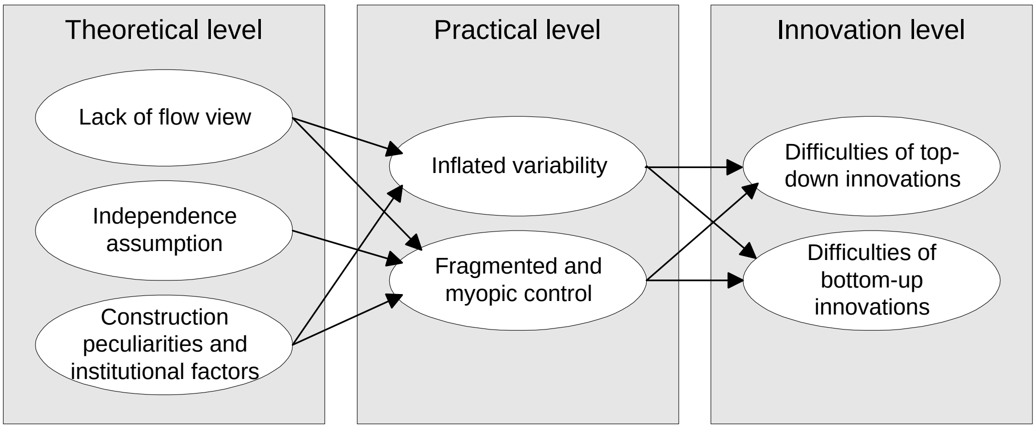

Figure 3 Theoretical and practical constraints of innovations in construction

BOTTOM-UP INNOVATION IN CONSTRUCTION

In addition to top-down innovations, bottom-up innovations have been constrained by the managerial methods, organisational deficiencies and institutional context currently present in construction. Basically, four mechanisms can be distinguished which lead to hindered bottom-up innovation:

1. *Many problems are not seen or ignored,* and are rated among the "normal features of the business" (Vrijhoef & Koskela 1999). Research shows that problems in construction are often of a basic kind and are deeply rooted in construction practice causing considerable waste and inconvenience (e.g. Vrijhoef 1998). However, many problems are often not classified as such. In this context, the transformation view of construction adds to the problem while neglecting the presence of waste, focussing only on value-adding parts of the construction process (Santos 1999), and therefore misunderstanding problems. The inability or reluctance to spot problems obviously hampers the urge to resolve them, and is thus hindering bottom-up innovation. It has been argued that within firms it is the management level that should create an atmosphere of awareness to spot and eliminate problems systematically involving the workforce, and by that supporting bottom-up innovation (Imai 1986).
2. *Many problems are caused in another stage of the construction process*, by another actor. Therefore, problems are often not accessible by the party that is encountering them, and not resolvable by that party alone neither (Vrijhoef & Koskela 1999). Research shows that there is often clear causality between problems within the supply chain (e.g. Vrijhoef 1998). The independence assumption that is included in the transformation view adds to the problems while overlooking causal relationships in the supply chain. Therefore, awareness of the interdependence is essential, including the intention to resolve the problems in a collaborative framework. This is rarely negotiated in construction projects, however, while the duration of co-operation within projects is relatively short, which prevents parties to invest resources and effort in the resolution of problems.
3. *Many problems are caused by myopic control* of the construction supply chain, while many actors in the supply chain seem unable or reluctant to recognise the impact of their behaviour on other stages and parties in the supply chain (Vrijhoef & Koskela 1999). An orderly approach to problem solving on construction sites suffers under "fire fighting" consuming managerial time (Oglesby et al. 1989), and thus frustrating systematic learning and problem solving.
4. *Diffusion of solutions is being complicated and hindered due to organisational and institutional problems.* In spite of all the difficulties discussed above, construction projects

involve considerable problem solving when accomplishing the building (Winch 1998). However, problem solving is only becoming innovation when the solutions found during the particular project are retained and reapplied to future projects systematically. As mentioned earlier, the problem here is that main contractors, i.e. downstream system integrators, often do no or little actual site work, so whatever problem solving goes on is not absorbed and retained by the firm. Instead, in most cases, the site work is subcontracted to various trade contractors on a competitive tendering basis. Therefore the trades have no incentive to share learning experiences for the sake of reapplying them on future projects of the main contractor. However, bottom-up innovation needs a clear definition of the institutional context and the innovation infrastructure involving all relevant actors into the innovation process (e.g. subcontractors and suppliers) (Winch 1998). In this context, it has been argued that the involvement of the supply base is important because most of the innovations in construction come from the supply base (Pries & Janszen 1995). Therefore, materials manufacturers play a key role in the diffusion of manufacturing technology and methods towards construction.

Thus, the basic issue is that managerial and organisational factors both on the theoretical level and on the practical level frustrate systematic learning and problem solving, and thus bottom-up innovation (Figure 3).

CONCLUSIONS

Analysis leads to three main results. *Firstly*, the present underlying theory behind construction management is counterproductive, and leads to a systematic creation of added costs and reduced functionality. A new production template for construction – implying radical innovation - is needed, based on a more appropriate, explicit theory of production and recognition of construction peculiarities.

Secondly, the generic problems of construction management, caused by deficient and implicit theory, are an obstacle for top down product and production process innovation in construction. The inflated level of variability in construction represents one form of this obstacle.

Thirdly, the underlying theory of construction is also an obstacle for bottom-up innovation. Especially, the myopic control and the fragmented, unstable organisation of supply chains frustrate problem solving and innovation between different actors and stages in the chain.

The issue is that construction cannot effectively innovate due to constraints caused by the intrinsic organisation of construction practice (peculiarities, institutional problems), and deficiencies in the present theory (theoretical deficiencies). On the other hand, the managerial mode and organisation of construction cannot be altered without radical innovation and adequate theory. Therefore, the way forward is to develop an adequate and explicit theory of production in construction that stimulates radical innovation, which in turn facilitates top-down and bottom-up innovation processes in firms.

These conclusions are based on initial evidence and illustrations. More research is necessary for charting all theory-related mechanisms hindering innovation and for confirming the empirical validity for the propositions presented. On the other hand, the impact of construction peculiarities, organisational characteristics and institutional factors on innovation should be clarified more thoroughly.

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