# ACCELERATING NANO-TECHNOLOGICAL INNOVATION IN THE DANISH CONSTRUCTION INDUSTRY

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By viewing the construction industry as a technological innovation system (TIS) this paper discusses possible initiatives to accelerate nanotechnological innovations. The point of departure is a recent report on the application of nano-technology in the Danish construction industry, which concludes that opportunities are generally poorly appreciated by the industry and research communities alike. It is found that the construction industry is characterized by low-tech trajectories where dedicated innovation networks are often too fragile for innovations to stabilize and diffuse. The institutional features of the system are furthermore poorly equipped at identifying potentials within high-tech areas. In order to exploit the potentials of nano-technology it is thus argued that an alternative TIS needs to be established. Initiatives should identify and support "incubation rooms" or marked niches in order for the different elements of the TIS to evolve. This could involve nano-visioning including scenarios of future technological applications and industrial dynamics.

Keywords: nano-technology, systemic innovation.

## INTRODUCTION

During the last decade it has been proclaimed that nano-research is likely to develop into a technology-platform capable of initiating a new industrial revolution, thus affecting a broad range of manufacturing industries, and opening up entirely new markets. Massive funding is currently going into nano research both in USA and Asia and to a lesser extent in Europe (Andersen *et al.* 2007). Despite heavy funding into research the commercial application of nanotechnology is still limited.

Nano-research and nano-technology is about the understanding and manipulating of materials at the atomic level. By manipulating materials at this fundamental level it is possible to tailor material according to specific purposes in characteristic new ways. Nanotechnology is currently entering a decisive transitory phase, developing from generic techniques into functional technologies applicable to industry. As a multi purpose technology platform, the technology may take different forms and directions. Already at an early stage nano-technology was seen as promising to the development of the construction industry, opening up new opportunities of high performance materials and new ways of designing and shaping the built environment (Davies and Gann 2002). ECTP, a EU technology platform responsible for developing strategic research programs within the construction industry has accordingly defined nanotechnology as a technology with the potential of creating a 'breakthrough' within the manufacturing of building materials.

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The point of departure of this paper is a recent report on the actual and potential application of nano technology in Denmark (Andersen *et al.* 2007). One of the conclusions in the report is that a few large manufacturers of materials and components to the building industry are currently engaged in development and exploitation of nano-technological solutions. However, a more fundamental conclusion is that on a range of possible areas of applications, the innovative activity within the construction industry is weak or non-existent. Mostly, the scientific community around nanotechnology is neither able nor willing to appreciate the construction industry as relevant to nano-technological research. They rather tend to lean towards collaboration with traditional high-tech industries. Also the players in the construction industry seemed hesitant to appreciate the potential gains from nano-technology (Andersen *et al.* 2007).

By taking a systemic approach to innovation this paper aims to identify barriers to nanotechnological innovation and suggest initiatives to facilitate a more widespread exploitation of nanotechnology in construction. The systemic approach utilized is that of "technological innovation system" originally formulated by Carlsson and Stankiewicz (1991). However, the conception in this article is highly influenced by works of Jacobsson (2004, 2006). Furthermore, we modify the framework by adding an understanding of the process of innovation network building as a political one (Mcloughlin *et al.* 2001).

The paper is designed as follows. First, the concept of Technological Innovation Systems are presented and discussed. Afterwards the main finding of a recent report on the nanotechnology in the Danish construction industry is presented concluding that innovative activities are weak compared to potential benefits. This gap is discussed utilizing the TIS approach. Finally, possible initiatives to accelerate nanotechnological innovation in construction are discussed.

## METHOD

The theoretical argument is primarily build on the systemic innovation approach (Carlssons and Stankiewicz 1991; Carlsson 1997; Jacobsson and Bergek 2004; Jacobsson 2006), combined with political process and learning approaches (Mcloughlin *et al.* 2001). The focus is on the relation between technology and industrial processes. It is thus broader than a narrow technological one and more specific than one on general public discourse like e.g. *upstream public engagement* (Wildson and Willis 2004).

The empirical material is drawn from Andersen *et al.* (2007). This report is based on surveys and interviews with Danish nano-scientists and nano-active companies. The aim of the report is to map both existing and potential areas of application of nano-technological in construction industry.

Ideas on nanovisioning build on material from a Finnish initiative and a number of contributors to the EASTT conference 2006 (European Association of Science and Technology Studies). Other innovation programmes on nanotechnology in construction can be identified such as Nanohouse in Australia, Nanoc in Spain and NRC-IRC in Canada. However, the approach of these activities is more narrowly technical and thus less focused at industrial processes and the systemic nature of innovation of interest to this paper.

## TECHNOLOGY-SPECIFIC INNOVATION SYSTEMS

As argued above a range of nano-technological possibilities are currently left unexploited and largely unattended to by the construction industry. In order to understand why such potentials are left unexploited the route from basic technological findings to commercial innovation needs to be elaborated on.

During the last decade much work has been done to develop the understanding of innovation (Storey 2004). A main interest has developed around the importance of industrial clusters. Industrial clusters are characterized by the concentration of large number enterprises working in the same technological field and located within spatial proximity to each other. An example of an industrial cluster is Silicon Valley. A Danish example is the medico cluster north of Copenhagen. These findings indicate that dense industrial networks and institutional infrastructure specific to the technological field in question is important to the development of innovative capabilities.

Drawing on these findings a main argument by the systemic approach to innovation is that entrepreneurship in complex industrial systems can not be adequately explained at the level of the single company or by reference to internal resources. Accordingly entrepreneurship and technological change must rather be conceived as phenomena which are the outcome of patterned processes of interaction between different players in different kind of networks. Taking such a systemic approach Carlsson and Stankiewicz (1991) defines a technological system as:

“a dynamic network of agents interacting in a specific economic/industrial area under a specific institutional infrastructure and involved in the generation, diffusion, and utilization of technology (Carlsson and Stankiewicz 1991)”

In their original approach to technological innovation systems Carlsson and Stankiewicz (1991) very much saw entrepreneurship as individual agency, empowered and constrained by environmental conditions. We should outline a more dynamic picture, not drawing such a very hard line between structure and agency. A softening would suggest that innovative agency should be seen as the outcome of collaborative network processes rather than individual agency, and that such network agency does contribute to the structural formation of the system. This also seem to be the approach of a later contribution by Carlsson (1997) focusing more on knowledge generation and spill-overs in networks at the expense of individual agency.

Accordingly, our view on Technological Innovation Systems (TIS) is influenced by works of Jacobsson (Jacobsson and Bergek 2004; Jacobsson 2006). Aside from the learning and knowledge dynamics, which are also a core concept in the works of Carlsson and Stankiewicz (1991) and Carlsson (1997), Jacobsson also point more systematically to the importance of political dynamics and the shaping of institutions.

According to Jaccobsson (2006) a TIS is made up of (i) firms and other organizations (ii) networks and (iii) institutions. Firms refer to firms within the entire value chain and other organizations include universities, research institutions, industry and other professional organizations etc. Each new firm or organization entering the TIS may bring new knowledge and resources to the system and influence demand or supply. At the aggregate level a division of labour is formed and a process of specialization and accumulation of knowledge is initiated.

Networks are formed to shape the structure of connectivity in the system. According to Jacobsson networks may either be learning networks or political networks. The learning network facilitate processes which include the diffusion of knowledge, competences and technology and influence the image or interpretation of desirable and possible direction of technological change. The political network processes refers to the formation of technology specific coalitions aiming to influence the political agenda.

It may be argued that the distinction between learning networks and political networks is a highly analytical one, and that actual network formations may display a mix of both types of processes. The political process concept outline above may be too limited, as politics is seen as the result of shared interests within the network. In contrast to this view it has been argued that political process should be conceived as omni present phenomena which involve intra-network dynamics in which the actors are aiming to maximize their control over resources within the network by forming alliances (McLoughlin *et al.* 2001). Studies by McLoughlin *et al.* (2001) furthermore indicate that learning processes and political processes should not be seen as opposed to each other.

Institutions refer to the regulatory aspects, patterning or guiding the interaction between actors. Institutions may range from informal norms or culture to formal institutions such as legal frameworks. Institutions may be decisive to the firms' beliefs regarding what is possible or desirable, to the extent that such beliefs are rooted in routines and norms. Existing institutions may thus counter-act changes in the learning structure such as changes to the problem agendas and search principles.

According to discussion above the establishment of a new TIS requires a co-evolution of three interdependent processes; the entry of firms and other organizations, the formations of network and the influence on institutional design. Jacobsson identifies three characteristics to the formation of new TIS. First, the actors entering an emerging TIS are faced with high level of uncertainty. Second, the establishment of new a TIS is typically a very long process which lasts for decades. Thirdly, the establishment of a new TIS is a cumulative process of many small changes (Jacobsson 2006)

The aim of this paper is to identify potential initiatives to support the establishment of a nanotechnological TIS directed at the needs of the construction industry. In order to identify potential key areas to such initiatives the level of analysis need to be directed towards the functions of the innovation system rather than the structure. Jacobsson (2006; 2004) identifies seven key processes which have direct influence at the performance of the system and which could thus be target areas for such initiatives.

*Knowledge development and diffusion*. A key process of a TIS is the establishment and evolution of a knowledgebase. Network and other channels of information constitute the structure of connectivity in the system.

*Influence on the direction of research*. Firms and organizations entering a TIS do not only have to be able to identify new opportunities. There should be enough pressure/incentive for them to undertake investment in the TIS. The propensity to invest could be strengthened by e.g. regulation and articulation of demand by lead costumers.

*Entrepreneurial experimentation*. For the TIS to evolve it is necessary that technical experimentation, characterized by high levels of uncertainty is conducted, in order to discover at create new business opportunities. Initiatives should ensure as many experiments as possible as many are likely to fail.

*Marked formation*. For an emerging TIS markets may either be non-existing or greatly underdeveloped. In the early stages of development "nursing markets" sheltered from the normal competition needs to be evolved in order to create a "learning space". Such markets may be commercial, with unusual selection criteria and/or subsidized. Such markets may not only be important for improving the performance of the technology, but may also be important for the different elements of the system to adapt (Jacobsson and Bergek 2004:820).

*Legitimacy*. New technologies need to be considered appropriate and relevant to key player in order for resources to be mobilized. Legitimacy is not given, but is formed through conscious action. The formation of political coalitions is important in order to gain legitimacy.

*Resource mobilization.* In order for at TIS to evolve, different resources need to be mobilized. These include technical, scientific and financial resources.

*Development of positive externalities.* As markets develop and the TIS evolve, some of the functions may be strengthened as a result of this process. New entrants may reduce some of the uncertainties regarding technologies and markets, and thereby strengthen the propensity to invest in technological development. At the same time new entrants may help to legitimate new TIS and strengthen the political power of political coalitions.

## NANO-TECHNOLOGY IN THE DANISH CONSTRUCTION INDUSTRY

Nanotechnology is currently entering a decisive transitory phase, developing from generic techniques into functional technologies applicable to industry. The Long-term trajectories to the application of nano-technology are likely to be strongly influenced by the outcome of this transitory phase. The current development is thus highly critical and characterized by competition between industrial sectors to influence the direction of research and development.

Construction is one of the industrial sectors with the potential of taking advantage of nano-technology. In a recent study on nanotechnology in the Danish construction industry six areas of relevance were identified (Andersen *et al.* 2007): nanostructured materials, nanostructured surfaces, nano-optics, nanosensors and electronics, nano-related integrated energy production and distribution, and finally nano-related integrated environmental remediation.

While it was concluded that Danish nanoscientists and nano-dedicated companies do research on a high international level, it was also found that they are only limited involved in or oriented towards the construction sector (Andersen *et al.* 2007). Most of the nano-active or nano-interested companies in the construction sector (not very substantial in number), are identified in the manufacturing industry, i.e. at the supply side. The most mature example of applied nano-technology is found in the nano-concrete area were Aalborg Portland is involved in the development of nano-tailored cement products. Other companies which are currently assessing nanotechnological potentials include Danfoss, BASF DK Construction, Maxit, SCF Technologies, Icopal, Rockwool, Velux and Velfac.

At the demand side, interest and knowledge about nanotechnology is even lower. Clients, FM-managers and contractors are generally unaware of the nanotechnological potentials, and hesitant because of potential harmful environmental impacts of new materials. Architects are more interested. However, their knowledge is limited to very general expectations of new architectural potentials of nano-materials. The market is thus either underdeveloped or non-existent.

While technological potentials relevant to the construction industry could be identified in all six areas mentioned above, neither the industry nor the scientific community display sufficient interest in exploiting them (Andersen *et al.* 2007). A further barrier to the exploitation of nano-tech in construction is the policy on the area. As a consequence of limited resources a Danish nano-technology foresight suggests that resources should be concentrated within strategic areas (VTU 2004). The construction industry is not mentioned among these. However, nano-tech in construction could relate to the focus area “Nano-materials with new functional properties”. But even in this area the construction industry should expect competition from other industries, more accustomed to research driven innovation.

## INITIATIVES TO ACCELERATE NANO-TECHNOLOGICAL INNOVATION

As for the industry in general, the construction industry is met with increasing pressures to accelerate innovation. These pressures are, however, especially strong in the construction industry which has been characterized by low growth in productivity and weak innovation throughout several decades compared to the industry as a whole (EBST 2002).

A key issue in order to understand (the lack of) innovation in construction is the actual length and complexity of the value chain. Building materials are part of established heterogenous networks of design, retailers, manufacturers, building production and consumer interests which can be a barrier to the introduction of new materials as knowledge, competences and support needs to be dispersed among a wide range of players.

Especially the fragmented organization of the construction part of the value chain is usually considered an important barrier to innovation, as experiences are not easily used across individual building projects and coalitions among players are not easily established. A hindrance to systematic learning is the decoupling between project and enterprise (Winch 1998) and the temporary constellation of players, which to a degree is unique in each project (Bresnen *et al.* 2003; Thomssen 2004). A further consequence of the fragmentation is that in order to comply with the different capabilities of the various trades within construction, new products often merely replaces conventional products.

Some institutional conditions further support the maintenance of status quo. An example is that strong traditions and interests within the construction industry promote the use of bricks and tile, and thus hinders the introduction and diffusion of new technological solution (Andersen *et al.* 2007). Also some type of regulations support the use of traditional and well established materials. It has earlier been found that the Danish fire-code has been an obstacle to multiple story wooden buildings and the development of new insulation materials (Clausen 2002).

Beside these general barriers to innovation, nanotechnology is faced with specific challenges as it is highly research driven. Nanotechnology thus clashes with the traditional low-tech trajectories which characterizes much of the construction industry. The low-tech trajectories of the construction industry are reflected in R&D spending which are low compared to the industry as a whole and has been characterized by a negative growth during the last years (EBST 2002). Most innovation in the construction industry is thus incremental in character and driven by trial and error, and with marginal differentiation between the activities of production and the activities of innovation. A study of product innovations in building renovation in Denmark thus shows that innovations networks are often too fragile for new product innovation to diffuse across projects. Accordingly, it is argued that product innovations need to be detached from the single project, and that ownership needs to be more clearly defined (Simonsen *et al.* 2005).

Thus the exploitation of the nano-technological potentials in the construction industry is in conflict with the existing TIS of the construction industry. First, high tech solutions and research driven innovation are not embedded in the institutionalized framing of problems and solutions. Second, the ability to establish cross-project innovations network, detached from production, is weak. An acceleration of the application of nano-technolgy thus presupposes the build-up of systemic competences into specific new technological areas in order to modify the existing patterns governing learning and innovation.

According to Jacobsson the performance of a TIS is characterized by the seven key processes mentioned in the previous section. To the establishment of a new TIS the identification and support of “incubation rooms”, i.e. market niches characterized by special selection criteria and/or subsidized markets, can be seen as the most fundamental one. The strength and direction to most of the other processes thus depends on the establishment of such marked niches. The direction to entrepreneurial experimentation and research are thus likely to mature within the frames of such niches. As the initial fuzziness of the technology field develops into functional solutions applicable in industry the TIS is furthermore likely to engage more resources.

Thus a central feature of initiatives aiming to support nano-technological innovation should be the identification and establishment of such incubation rooms in collaboration with relevant players. First of all the establishment of incubation rooms should avoid to be stuck in the identification of general developments within nano research. In contrast, it should be concerned with the search for ends to specific needs by utilizing the technology. Second, the establishment of an “incubation room” is not just about demand, but also about shaping the industrial processes, i.e. the formation of networks and institutions.

An initiative aiming to identify and support the establishment of “marked niches” in relation to nano-technology is the Finnish Nano Vision platform. This Nano Vision programme has identified potential areas of application within the electronic industry, the forest cluster industry and in the chemical industry (Tekes 2007; Koskinen 2006). The Nano Visions are carried out under the FinNano programme, which is an innovation programme running from 2005-2009 with a budget of approx.70 million euros**.** The Nano Visions are carried out by representatives of Finnish companies in the key industry sectors in collaboration with top academic minds.

One of the visions is targeted at the forest cluster (Koskinen 2006). This vision has opted for a so-called down-to-earth approach, in order to cut through the hype of nanotech.

Following this strategy the vision identifies possible short term, mid term and long term (2030) perspectives of nanotech in the cluster. The vision pays special interest to the impacts of nanotech on the industrial dynamics. It is discussed how nano-tailored fibers might influence the production flow, the relation between SMEs and big companies, and the link between different industrial sectors. The innovation concept is thus not only concerned with technological change, as it also includes change to the industrial relation and new links of connectivity between sectors.

This vision thus aims to support some of the key processes identified by Jacobsson. It aims to give direction to entrepreneurial activity and research within a concrete field of application. Furthermore is discusses how the technological success might depend on specific changes in the existing industrial processes of the TIS. Visions like these are, however, always a matter of timing. Visions which are being formulated too early or which are too narrowly focused on specific trajectories may thus hinder the contingent process of development into new areas of application. At the same time visions may be too open for actors to identify with them by not moving beyond research-oriented potential. Thus visioning like these should not be one-time activities but should rather be a continuous process of learning.

In a Danish context “incubation rooms” could be established in a number of areas. Openness and concreteness could be balanced by a mix of generic crosscutting activities demystifying the technologies supplemented by in depth incubation rooms An example of such an in depth area could be the production of agricultural stables. Denmark has a very large production of pigs and chickens, and the application of nano tailored materials in stables could possible reduce infections by employing anti bacterial coatings and reduce unpleasant smells in the surrounding by employing materials with photo catalysts surfaces.

The systemic approach implies that the initiatives should not be confined to the identification of technological application. It should also discuss how the industrial network relations could be shaped in order to support the process. An example could be the integrating of some of the functions from design, construction, manufacturing of materials and operation and maintenance into a single organization or a dense network. Vertical integration and /or networking could be encouraged by innovation subsidies. Such organizational change could institutionalize innovation as an independent focus area detached from the processes of production. It could furthermore and support better learning across the present organizational borders and between design, construction and operations.

Supporting the identification and establishment of incubations rooms should be a main purpose in order to engage relevant player and support the build-up of networks. However, two other political processes may be of special importance. One of these is the question of legitimacy. Operating at the atomic level, nano-size particles can easily penetrate the skin, and thus be a potential risk to human health and the environment in general. Efforts should be made to picture nano-tech as safe technology (EU 2005; Gerritzen *et al.* 2006). Furthermore it should be noted that the risks are potentially significantly different from other sectors and between types of nanotechnologies (Rogers Hayden and Mohr 2006).

Second, innovation in relation to nano-technology is currently moving into different industrial areas. Construction thus competes with other industrial sectors in terms of political support and scientific interest. Political networks should aim to position construction on the nano-technological map. An example is that the approved technological service institutes, responsible for technological services to the industry, is currently in the process of building up nano-technological capabilities. However, these are currently not targeted at the need of the construction industry.

## CONCLUSION

As a multi purpose technology platform, nano-technology may take different forms and directions. However, eventually the technology will take on a set of more definite character, shaped according to some industrial purposes rather than others. The cost of neglecting opportunities in this formative phase may thus be high.

Viewed as a Technological Innovations System (TIS) the construction industry is currently weak in recognizing and exploiting nano-technological possibilities. First of all the existing patterns of problem identification and learning is oriented towards incremental innovations, thus largely overlooking possibilities in R&D-dependent areas of innovation including nano-technology. Second, the industry is characterized by a marginal differentiation between the activities of production and development activities. Dedicated innovation networks are thus often too fragile for innovations to stabilize and diffuse. Such weak networks are a substantial challenge to nano-technology innovations which depends on long-term innovation horizons.

Recognizing the lengthy and stepwise character of the process it is argued that an alternative TIS needs to be established if the construction industry is to gain from the nanotechnological possibilities in any substantial way. A basic challenge to an alternative TIS is to establish mutual supportive links between the development, diffusion and use of new technology and the industrial organization and processes.

It suggested the identification and establishment of “incubation rooms” or marked niches is fundamental to supporting and developing the seven key processes identified by Jacobsson. An initial step could be visioning activities designed to balance openness and concreteness. While being open to new areas of application such initiative should identify in dept areas of concrete application of the technology. Identification and creation of markets potentials should be utilized to direct entrepreneurial activities and research and to attract further resources. Aside to support such marked formation the visioning should be concerned with the shaping of industrial processes in order to support the innovative capabilities of the new TIS. In the Danish case political network formations should be established in order to map construction in the political nano-strategy.

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