
INNOVATION FOR A SUSTAINABLE BUILT ENVIRONMENT

Emilia L.C. van Egmond-de Wilde de Ligny
Faculty of Architecture, Building and Planning, Eindhoven University of
Technology
e-mail: e.v.egmond@tue.nl

ABSTRACT

Despite the indisputable contribution of innovations to socio-economic development, the world has realized that many innovations and technologies have been a major cause of climatic change and resource depletion. This research aimed to identify how and whether innovation in construction contributes to achieve a sustainable built environment. An analytical framework -derived from literature studies on evidence and theories on innovation in manufacturing-was applied in Dutch construction. The study underpinned that sustainable construction requires innovative solutions which go beyond the traditional and generally accepted way of building. Government support appeared necessary for a regime shift to stimulate innovation for a sustainable built environment. Policies thus should be directed to tackle a major bottleneck in construction: knowledge, expectations and beliefs concerning innovation for sustainable construction.

Keywords: *innovation, sustainable built environment, construction, technology regime*

ABSTRAK

Meskipun tidak dapat dipungkiri bahwa inovasi memberikan kontribusi terhadap pembangunan sosial-ekonomi, dunia telah menyadari bahwa banyak inovasi dan teknologi telah menjadi penyebab utama perubahan iklim dan berkurangnya sumber daya. Penelitian ini bertujuan untuk mengetahui bagaimana dan apakah inovasi dalam konstruksi memberikan kontribusi untuk mencapai arsitektur berkelanjutan. Sebuah kerangka kerja analitis yang diturunkan dari studi literatur tentang bukti dan teori mengenai inovasi di bidang manufaktur diterapkan untuk konstruksi di Belanda. Studi ini didukung dengan pembangunan berkelanjutan yang membutuhkan solusi inovatif yang melampaui cara tradisional dan yang berlaku umum pada bangunan. Dukungan pemerintah diperlukan untuk memunculkan pergeseran era untuk merangsang inovasi terhadap arsitektur berkelanjutan. Kebijakan demikian harus diarahkan untuk mengatasi hambatan utama dalam bidang konstruksi: penge-

tahuan, harapan dan keyakinan tentang inovasi untuk pembangunan yang berkelanjutan.

Kata kunci: *inovasi, Lingkungan terbangun yang berkelanjutan, pembangunan, era teknologi*

INTRODUCTION

This paper deals with research on innovation in construction i.e. the development, diffusion and deployment of building technologies related to the achievement of a sustainable built environment. Despite the indisputable contribution of new technologies to socio-economic development, the world has realized that many technologies and innovations applied in production and construction have been a major cause of climatic change and resource depletion. Construction has an important impact on the environment. In the next sections first a summary will be given of the literature studies on the current construction performance, as well as on empirical evidence and theories of the role of innovation in manufacturing. Thereafter the analytical framework derived from these studies is presented. The application of this framework to evaluate innovation in Dutch construction is described in the section that follows. Based on the conclusions recommendations are formulated to stimulate innovation to achieve a sustainable built environment.

Construction Industry

The role of construction in the development of national economies is important. Its contribution to GDP, fixed capital formation, government revenue and employment is significant (Egmond, 2007). It has a huge impact on people's way of living, working and recreating by providing shelter for all human activities. Yet construction everywhere faces problems and challenges.

The construction industry seemingly is not able to properly respond to the demand for shelter especially in urban areas with a growing population, whilst the prospects for 36% of the urban population particularly in developing countries still look depressing, lacking durable housing and adequate living space, improved sanitation and clean water (UN MDG Report, 2010). Moreover new demands for buildings became more diversified and complex due to globalization enhanced convergence in lifestyles. Besides the Construction Industry is a wasteful sector. It consumes large parts of world's natural resources, which is 3 billion tons of raw materials annually and about 40 %t of total global use (Roodman and Lenssen, 1995) and it heavily contributes to greenhouse gas emission and construction and demolition (C&D) waste generation (Muller, 2000; Macozoma, 2002).

An improved performance is thus essential if the construction industry is to move forward towards sustainability.

Innovation in Manufacturing

The performance of the developed market economies over the last 150-200 years is characterized by the emergence and diffusion of fundamental technological advances linked with periods of economic expansion social and cultural changes (Kondratiev, 1925). This went along with extensive changes of production systems in manufacturing industries through new technologies and materials which enabled mechanization, systematization, standardization, automatization, flexibilization and diversification of production processes resulting in a shift from home-based manual production to large-scale factory production (Dicken, 2000). The production processes became more flexible with a movement towards reaching a higher quality of production output and the production of finished products of different kinds (Freeman 1989). The emerging variety of inter-firm relations and a stronger inter-connection between countries through the development of information & communication technologies stimulated a rapid expansion of cross-border trade, foreign investments and technology and knowledge transfers. This opened the possibilities for a fast extension of the technology and knowledge base leading to an improved production performance and economic growth in countries by just taking over new technologies and thereby omitting the burdens of high and un-certain investments for R&D. After all it became a conventional wisdom that the production performance of industries, competitiveness and socio-economic development in countries depends on innovation (Egmond, 2005).

However innovation does not always result in the expected effects and are not always as appropriate as desired. Innovation still takes in majority place in the advanced countries. Lately also China, India and Brazil are counted as innovating countries, where technological and socio-economic changes rapidly take place. Apparently only a small part of the world population could benefit from innovations. Moreover one can see that the way of life is often taken over from more advanced countries, thereby introducing a “MacDonaldized” culture. Traditional materials and techniques are abandoned. “Modern” materials and innovative techniques are introduced instead, just taken over from abroad, thereby introducing the negative environmental impacts of these practices as well (Egmond, 2007). It is thus a question what the precise role of innovation in a sustainable development of the production performance and competitiveness of industries could be.

Theoretic Views on Technology and Innovation

Various theories came into existence among which the neo-classical economic theories to understand the relation between innovation and change in social and economic environments highlighting aspects such as origins of invention and innovation, individual qualities, particularities of social environments, resources access and incentives for problem solving.. Neoclassical economic theories assume that change occurred due to the fact that motivated profit-maximizing, cost minimizing and output maximizing entrepreneurs make choices among various technologies in a

perfect competition environment (Schumpeter, 1934). However these theories could not offer a clear insight on the content and process of innovative activity or on the existence of persistent differences in the volume, scope and quality of innovations across firms, sectors or countries (Rosenberg, 1976).

The difficulties in addressing issues of technological change are due to the particular nature of technology. Technology is a complex concept that appears to convey different meanings and co-notations to different people and thus is defined as such differently (Egmond, 1999). It is a general wisdom that technologies have something to do with production processes, in which the production inputs (natural resources and/or intermediate products) are transformed into the desired production output (products and/or services) by means of technology. In this perspective technology is seen as a system of interrelated know-how, skills and knowledge (know-why, when, where and by whom) embodied in production processes and products.

Extensions of the neoclassical theory (e.g., new growth theory) as well as alternative approaches to technological change have emerged, including the broad field of evolutionary economics to explain innovation and its impacts. The core concepts in these theories are innovation and technological regimes.

Innovation refers to the total process from invention -i.e. the development of new technologies (products and production processes) and knowledge- and the diffusion, adoption and application of these in an innovation system (Rogers, 1995; Egmond 2005, 2009). Product innovations are seen as successfully developed, introduced, diffused and used product technologies. Process innovations can be defined as successfully developed, introduced, diffused and used production process technologies.

Diffusion is the rate at which (new) technologies -knowledge, a novel ideas or inventions- are adopted and applied in companies or institutions, or by people, causing the technology to spread in society (Rogers, 1995). Diffusion is accomplished through human interactions; communication between members of an innovation system (Rogers, 1995).

An innovation system is defined as a network of interrelated individuals, organizations and enterprises who share a common field of knowledge and interest regarding innovation (Malerba, 2002). The actors can be found at international-, national-, sector-, and company- or project level.

Innovation theories point at the technological regime in an innovation system that is determining for innovation volume, scope, quality and speed (Nelson & Winter 1982; Tidd, Bessant and Pavitt, 2006; Egmond, 2008).

Technological regime (TR) is seen as a social construct -a pattern- made of knowledge, rules, regulations conventions, consensual expectations, assumptions, or thinking shared by stakeholders in an innovation system, which characterize profes-

sional practice and which guide the design and further the development of innovations (Kuhn, 1962; Dosi, 1982; Nelson & Winter, 1982).

The diffusion of an innovative technology will be successful when it fits in the prevailing technological regime that characterizes the professional practice of actors in an innovation system (Douthwaite, 2002). The diffusion of new knowledge and technologies might need a regime shift. A regime shift is a significant, profound and irreversible change from one fundamental view to another, a different model of behaviour or perception. A further elaboration of these views resulted in the assertion that technological regimes define an environment with a particular combination of four factors of innovativeness. It concerns an environment with (1) technological opportunities, has powerful incentives for innovative activities, thus potential innovators may come up with frequent and important technological innovations; (2) in which appropriability is high i.e. possibilities of protecting innovations from imitation and of reaping profits from innovative activities; (3) in which the properties of the knowledge base (nature of the knowledge that is available) supports innovative activities; (4) with cumulateness, which means the possibilities of diverse learning processes through which a stream of subsequent innovations can be generated that are incremental changes of the original one creating continuities in innovative activities and increasing returns. Experts indicated that the key-element for innovation is the knowledge base i.e. the interrelated system of know-how, skills and knowledge- available in the innovation system, which changes through learning mechanisms, thereby changing the Technological Regime as well (Malerba & Orsenigo, 1996; Breschi, Malerba & Orsenigo, 2000; Tidd c.s., 2006).

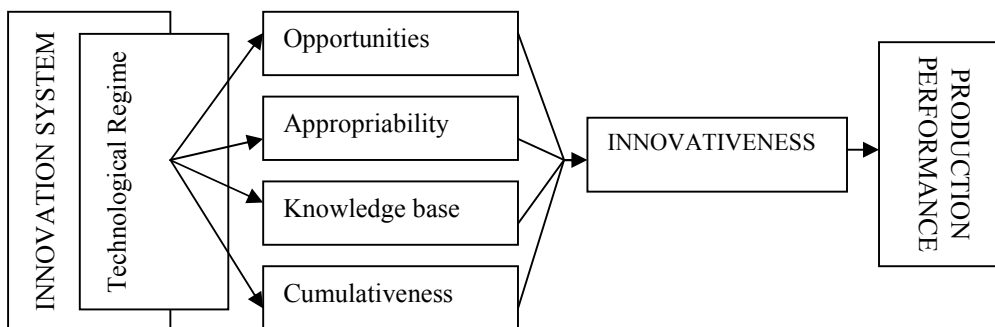


Figure 1. Analytical Framework

Empirical evidence in manufacturing underpin that what actually has happened in the course of time is that a convergence of technologies and knowledge from different areas and disciplines has taken place (Egmond 2005, 2009). Combinations of innovative solutions based on accumulated technological and knowledge advances were adopted in attempts to move from largely craft-based production to a systematic production process where resources are utilized efficiently and effectively to meet the customer's demands for a socio-economic value added. By means of this again new technologies could be developed to meet the ever increasing and faster changing demands of man. Whether innovation really leads to innovations for

sustainable development in all its dimensions depends on the Technological Regime as shown in figure 1.

RESULTS AND DISCUSSION

Innovation for Sustainability in Construction

In the course of time also in construction a sequence of innovations were developed by construction enterprises and organisations addressing new markets to withstand severe competition (Egmond, 2010). Mechanization in parts of the construction process on site and prefabrication of building materials and elements were the first phenomena of innovation in construction with the purpose to reduce costs of manpower and time-consuming activities.

The awareness amongst construction stakeholders regarding the importance of achieving a more sustainable built environment has been given a new boost during the last years in various countries. Increasing construction resource costs and a growing lack of on-site skilled labour-enhanced by a greying society, stimulated innovation in construction towards efforts to achieve an improved sustainability. Currently the focus is on the development of sustainable construction technologies and materials such as composite materials, recycled waste in new products, non-traditional materials that have less environmental impact, new construction techniques that reduce waste and innovations in the management and scheduling of projects (ECTP, 2007).

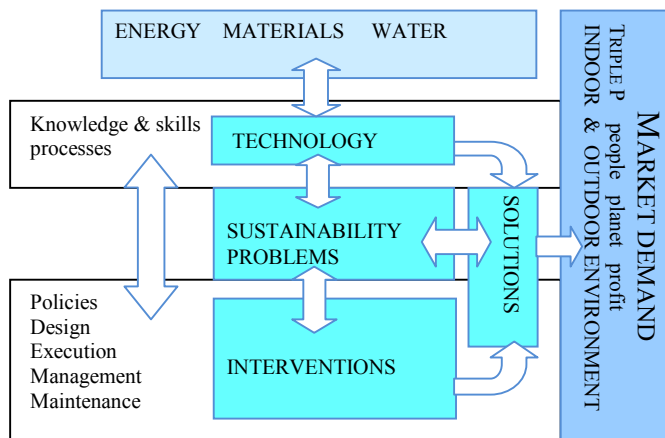


Figure 2. Sustainable Construction
Source: Egmond, 2008

Sustainable Construction encompasses the simultaneous pursuit of a balanced social equity, environmental quality and economic prosperity (people, planet and profit) in the built environment for the present generation without harming the opportunities

for future generations to respond to their demands for a sustainable built environment (Kibert, 2005). In fact it boils down to energy and resource efficient ways of construction to meet the specific demands for a sustainable indoor and outdoor environment (Stofberg and Duijvesteijn, 2006). Figure 2 illustrates this. It also shows the possible intervention mechanisms applicable to streamline the construction processes towards adequately meeting the market demands for sustainable construction.

Although Sustainable construction has evolved as a dynamic, rapidly growing field it still is a relatively new concern for construction (Egmond, 2010). To increase awareness amongst construction practitioners and to standardize Sustainable construction practices, sustainability assessment tools were developed, such as the US LEED, UK BREEAM and the Dutch GPR.

In the meantime a number of innovative design concepts and principles for Sustainable Construction have been developed. The focus is mainly on the reduction of energy, materials and waste in construction and the built environment. Innovations that have taken place were mainly directed to the application of eco-technologies in traditional building practices. Most innovations took place in the residential sector. Various innovative industrially produced standardized building systems were developed based on the understanding of the important role which industrialised building can play in driving up quality, value and increase of the lifespan of the building and building parts while cutting resource utilization and construction costs. The common factors that supported the acceptance and implementation of these systems included in European countries such as Sweden and Belgium: Substantial off-site profit; Highly mechanized site distribution; Just-in-time delivery of material and components; Low load of material waste; Well-paid onsite workforce; Skilled and well-trained workforce; High level of R&D; Flexible relationship between design/architecture and contractors; Early influence of contractors in the design process; Use of liability insurance (Hamelin, 2007). Pre-fabricated housing units lead to at least 30% savings in steel and concrete in Europe (Goodall, 2007). By working along these lines the roles of the various stakeholders in the construction chain have to change drastically as well.

Despite these developments the construction industry still is commonly characterized as one that is labour intensive, with a low level of innovation, of technology diffusion, of technological advancement of on-site construction and thus a low level compared to manufacturing. The total construction process itself remained a rather traditional complex multi-stage production process. On-site construction practices involve shaping of building parts like facades, roof, services and infill in more or less parallel processes. There is a lack of alignment between the many parties working side by side on construction projects. This translates into dysfunctional teams, poor levels of cooperation, lots of overlap, inefficiency, failure costs, complex coordination, lack of mutual respect and lost opportunities for the optimum use of resources (Egmond, 1999, 2005; Lichtenberg, 2002, 2005).

Besides the relatively low level of innovation, most innovations at present are predominantly additions to technologies on component level. They offer only *partial solutions* that end up in also partially meeting the building project requirements. Evidence showed that construction is deeply embedded in local laws, regulations, and institutions and not in the least place in long established conservative professional practices, which enhances a reluctance to change enhanced by risks of unforeseen failure and damage during project execution and a marginality of profits (Ofori, 1990; Egmond, 2005).

Sustainable Built Environment by Innovation: the Dutch Case

The lines of thought of the theories that were discussed before were applied in the case study of innovation in Dutch construction. The theories tell that the speed at which a regime shift and adoption of innovative concepts for a sustainable built environment will occur highly depends on the features of current innovation system of construction.

The innovation system of construction in the Netherlands alike elsewhere in the world includes a variety of actors. A central lead and promotion of the common interests of the actors in the innovation system is lacking, which is detrimental to stimulate innovation.

The knowledge base is scattered amongst the distinct institutes, organisations and firms which is detrimental for innovation. There is a generally limited focus at sustainability requirements; limited communication, knowledge exchange and combination of different knowledge set e.g. marketing & engineering in firms and organizations in production chains. Much of the technology and knowledge at least in construction firms is tacit, not codified and project experiences are often not documented, which makes diffusion more problematic. Moreover the project based characteristic of construction forms a constraining factor for learning and the cumulativeness of technological advances. The relatively low appropriability in construction makes, that the industry has an extensive scope for diffusion of inventions and technological improvements from other projects and industries. Technological opportunities which stimulate innovation in construction are limited. The variety of contractual agreements, rigid specifications in traditional contracts and the separation of responsibilities among those involved in construction, enhance reluctance to change and a tendency to conservatism making that diffusion of technological developments generally faces quite some constraint (Nam & Tatum, 1988; Ofori, 1990).

The realized innovations to achieve sustainable construction in the Netherlands included Innovative energy technologies centered at (1) prevention of unnecessary use of energy; (2) the use of renewable (e.g. solar boilers); (3) the deliberate use of clean and high performance non-renewable (e.g. high performance boilers for central heating). However, so far many of these inventions are not yet completely cost-effective and thus are not really commercially appealing. Efforts to improve a

sustainable use of building materials in the Netherlands are focused at (1) dematerialization; (2) substitution; (3) increase of the lifespan of the building and building parts; (4) enhancement of the reuse and recycling of building parts and materials. The majority concerns substitution of the traditionally used building materials. Innovative products and eco-materials like FSC timber, water based acrylic binders, recycled PVC rainwater pipes, water saving toilets, water saving showers are for example used in more than 50% of the newly built houses (Klunder 2002). There is a relatively high percentage of recycling and reuse of construction & demolition (C&D) waste in the Netherlands. Today, 95% of total C&D stony material waste is reused as rubble concrete granules, replacing sand and gravel.

Various innovative industrially produced standardized flexible and demountable building systems were developed as a three-pronged strategy to achieve sustainable construction with the resulting benefits of (1) flexibility for the client, (2) industrial production to cut materials, costs and time for the manufacturer and increase output quality (3) demount ability to decrease waste for society (Hendriks, 1990).

Meanwhile it has been realized that the traditional parallel processes in construction form an important constraint for sustainable lean construction and thus should be transformed into a sequential process (Lichtenberg, 2006). Based on this view the so-called Slim-Bouwen concept (Dutch for Smart Building and a trademark) was developed. This concept asserts that the solution for Sustainable construction should be found in product innovations which are integrated in process and organizational innovations. Following this concept, the construction process should be transformed into a sequential process (Lichtenberg, 2006). To achieve this the building is subdivided into four main building parts which even can (should) be pre-fabricated to a large extent (a) Foundation, skeleton and floors; (b) Envelope (Outer walls + roof); (c) Services (vertical through shafts, horizontally through hollow floors); (d) In fill (floor finishing, partitions and ceilings). The idea is that separation of the services package from the main structure is a basis for obtaining flexibility and adaptability, which benefits the exploitation of a building.

The Slimbouwen concept forms a guiding framework for the development and production of innovative designs, products, building materials and construction practices in an integrated manner, whilst the functional and economic lifespan of the structures and the recycling and the deconstruction of the building components and materials are taken into account. As such the Slimbouwen innovations will contribute to reduce environmental impacts with the benefit of achieving more sustainable and cleaner industrialized construction, a higher quality of output against lower cost and a higher value added of the products for clients.

It has been recognized that the application and wider diffusion of an innovative construction concept like Slimbouwen requires an early strong cross-industrial collaboration between the stakeholders and a multidisciplinary approach during design and production, with changes in the traditional roles of the stakeholders. Moreover specific knowledge and skills are required for the organization and

facilitation of and participation in the design, production and construction process (Egmond, 2010). Therefore Slimbouwen also functions like a shareware platform. It provides a knowledge and information infrastructure for firms – joint together in the Slimbouwen foundation- and offers a basis for their development strategy. Through a close collaboration between the stakeholders in the innovation system of construction the basic concept can be further developed and translated into integrated innovative designs, building components and materials. The stakeholders include those involved in the production chain of buildings; knowledge institutions like universities, governmental organizations and end-users. As such it brings more coherence into the fragmented development efforts by several actors in construction (Lichtenberg, 2005). A number of firms – most of them Small and Medium scale firms- already have united with the objective to accomplish innovative designs, building components and materials following Slimbouwen and some have been realized already.

For example a building system that results in the fact that the materials used in a dwelling construction project in the Netherlands, weigh about 50% of comparable traditionally built houses of the same volume, which is about 70 ton less weight (Lichtenberg, 2005). The parts of the whole building are prefabricated and assembled on site on top of a light foundation. The main structure is composed of steel columns. The flooring system is composed of steel beams (normally IPE 160, for 5m span) embedded in a thin concrete layer which meets the requirements for strength and stiffness. Conducts and cables for the service installations are prefabricated as well and placed within the flooring system that is finished with thin flooring panels. These include hatches that can be opened to change or maintain the conducts and cables. The main structure is covered with prefab façade elements which are composed of masonry outside walls including the window frames, insulation and a concrete inner wall. On top a complete prefabricated roof is placed. Finally the inside partitions and vertical conduct system is placed. The assembly of the main structure of 36 houses took 3 weeks, while all houses were delivered within 5 months after the start of the construction (Deelen, 2001).



Figure 3. A+ Floor and Building System

Source: Deelen 2001 and www.woonen/woon_7

Most of the innovations were brought about by organizations which had a certain relation to universities and research centres. Demonstration projects were financed by the government, to increase the adoption of the new sustainable technologies and

to use the gained knowledge and experience from these projects to further develop and improve design tools for materials, energy, buildings and the built environment (Anink and Mak, 1993; Haas, 1992; Stofberg and Duijvesteijn, 2006).

Research on innovation for a sustainable built environment in the Netherlands showed that the driving factors for firms to employ them were cost reduction, profit and output maximization. Building regulations appeared to be the most important reason to apply energy saving innovations in the Netherlands, although getting a green image by energy saving is often mentioned as an important motive by major clients. Subsidies are considered as an important stimulation measure. Regarding the construction activities in general should be stated that despite some successful pilot projects, demonstration projects, innovative technologies and financial schemes there still is no success in terms of absolute reduction of resource use (Klunder, 2002). A full and successful diffusion of innovative solutions requires a process innovation and regime shift. This will take time and efforts to alleviate the constraining factors as was indicated by empirical evidence in manufacturing as well. Thus far government support was an absolute condition to create loyalty to sustainable construction and to change current reluctance, beliefs, expectations and standards.

CONCLUSIONS

Innovations in construction could develop by accumulation and convergence of technologies and knowledge from various areas and different parties in the course of time. Despite this the technological regime and the innovation system seems to adversely affect innovation.

The Construction Industry is challenged to change their practices in order to achieve the targets for a sustainable built environment. Strategies have primarily focused on innovations for material and energy saving in buildings and waste reduction during traditional construction processes. Yet the achievement of a sustainable built environment requires designers, building material producers and contractors to bring about design concepts, building elements and components as well as adaptations in the building processes by innovation and integrating these in construction projects in order to achieve the optimum application of sustainability principles during all stages of the life cycle of buildings. Hence there is a need for innovative solutions in construction which go beyond the traditional and generally accepted way of building. Besides for the adoption of measures and innovations on a large scale it is essential to accompany environmental gains with gains in building-economic terms. However innovative sustainable solutions for design, building materials and processes require investment in time and research costs, whilst such efforts are risky and their results cannot always be predicted to turn out positively. This boosts the perception of high investment costs of sustainable construction. Moreover life cycle thinking implies additional costs that occur on top of the initial investments. This enforces the reluctance amongst the various stakeholders in construction to be individually

responsible in risky endeavours. A regime shift is thus needed to change the traditional way of construction to bring about innovations for sustainable construction.

Relying on evidence in manufacturing can be stated that sustainability and continuity in construction can be achieved by means of strong relations and long term collaborations and contractual agreements between the production chain actors in a sequence of construction projects. This will stimulate learning effects, innovativeness and a resulting improved operational performance, which will be beneficial for both clients and the whole Construction Industry. Thus innovation for a sustainable built environment calls for the formation of building teams with long term collaborations in the production chain based on common interest and improvement targets as well as transparent performance measurement. Although in any case firms are likely to have differing motives, the major incentives for collaborations will be reduction of costs for R&D and market entry as well as reduction of time and risks of commercialization of the invention. Trust amongst the collaborating parties, complementarities of knowledge and skills, sustainability of operations, economies of scale are important aspects to be taken into consideration in the transitions in the innovation system from project towards strategic portfolio procurement by long term collaborating teams that include clients.

The Dutch experience learned that government support is imperative for a regime shift to stimulate innovation for a sustainable built environment. Thanks to the increased awareness for the need to change the construction practices in many countries measures are taken and policies, strategies and regulations are developed to stimulate innovation for sustainable construction. Both theories and empirical evidence point at the technology and knowledge base as important component in innovation systems for successful innovation and competitiveness. It thus has been stressed that policies and strategies in countries and industries should focus on knowledge and innovation based development to achieve sustainable built environment, economic and social well-being. This means that policies should be directed to change construction practices to tackle a major bottleneck in the innovation system of construction: the knowledge, expectations and beliefs concerning innovation for sustainable construction.

Strategies to improve the knowledge, expectations and beliefs concerning innovation for sustainable construction should then involve (a) voicing and shaping of expectations about the new technologies and knowledge e.g. through demonstration projects; and (b) stimulation of active technology and knowledge exchange amongst the actors in the innovation systems. As such these strategies will also create an increased awareness of the potential of novel technologies in the market to achieve a sustainable built environment, thereby increasing the market needs for innovation.

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