DTU Library

# The challenge of a greener European construction sector: Views on technology-driven (eco)innovation

**Jofre, Sergio**

*Publication date:*
2011

*Document Version*
Publisher's PDF, also known as Version of record

# The Challenge of a Greener European Construction Sector:

## Views on Technology-Driven (Eco) Innovation

**Report 2.2011**

**DTU Management Engineering**

Sergio Jofre
February 2011

**DTU Management Engineering**
Department of Management Engineering

# Contents

## The Challenge of a Greener European Construction Sector: Views on Technology-Driven (Eco) Innovation

# Foreword

Part of this work is based on findings made by the *Green Nanotechnology in Nordic Construction project* (2007-2010), financed by the Nordic Innovation Centre, NORDEN, Norway. The project was lead by the Section of Innovation Systems and Foresight, Department of Management Engineering, Technical University of Demark.

The aim of this report is to disseminate crossdisciplinary knowledge regarding innovation in the European construction sector. The review focuses on the challenge of incrementing the productivity and competitiveness of the sector while increasing its environmental sustainability. In this context, particular emphasis is given to the description and discussion of technology-driven eco-innovation initiatives such us nanotechnologies for a greener construction. Although the scope of this report covers the European construction sector, most data presented is at an EU scale. In this context, particular emphasis is given to the discussion of the main topics from the perspective of Nordic countries.

*Author:*

Sergio Jofre, PhD

Researcher/Assistant Professor
Section of Innovation Systems and Foresight
Department of Engineering Management
Technical University of Denmark

*Contact information:*

Produktionstorvet
Building 426 Entrance A
2800 Kgs. Lyngby
Denmark

Phone: +45 4525 4534
Email: sejo@man.dtu.dk

# 1. Introduction

The European construction sector faces a great dilemma: increasing and sustaining production and global competitiveness while radically improving its environmental performance. Successfully overcoming this challenge is of a considerable strategic relevance to Europe's economy and environment.

In Europe, construction accounts for 10% of EU GDP and 7% of its workforce. Yet, construction consumes over 40% of Europe's energy and resources. In the environmental context only, construction has been indicated as a strategic sector to support the ambitious EU goals for CO2 emissions reduction by year 2020. Nevertheless, potential gains in resource and energy efficiency along building's life cycles can also have a considerable positive impact in public health, economy and environment.

Balancing economic, social, and environmental issues in the sector is a difficult task that resembles the challenge of achieving sustainable development. The need of a greener and yet competitive construction sector calls for a radical transformation in the way consumption and production systems are perceived, implemented and sustained over time. Furthermore, it remarks the strategic value of innovation as a pillar of change.

However, innovation in construction seems to occur and diffuse at a slower pace than in other sectors and industries. In comparison, construction – as an economic activity – also exhibits a lower productivity but a higher level of labour intensity. The difficulty of innovating in construction is often explained in terms of the sector's complexity. In Europe, SMEs and a small number of large – yet very influential – corporations drive the dynamics of a sector predominantly oriented to local markets and retrofitting activities. Indeed, construction of new buildings in Europe accounts for only 2% of activities in the sector. Therefore, construction is a highly fragmented industrial activity, with complex interactions, involving a large number of agents and one-end – large and long-lasting – products. In this context, the strategic management of firms – if any – broadly focuses on solving the particular problems arising from each project. Common problems to constructions projects regard constrains due to space, time and budged requirements, lack of skills and technologies, stringent regulations and norms, quality demands and complexity of logistics.

Paradoxically, in spite of the sector transcendental role in the economic growth of countries, construction tends to stagnate even in countries with a high innovation performance (e.g. Denmark and Sweden). Transforming construction into a *manufacturing* activity with proper management models for efficiency (e.g. *lean manufacturing*), is an ongoing task in Europe and other regions around the world. In this context, a higher efficiency in construction activities is not only seen as a requirement for better management, but also a strategy to reduce environmental burdens. Indeed, the so-called "green" or sustainable building approach is gradually gaining momentum in developed economies.

From this perspective, innovation in the construction sector is often linked to the development and diffusion of new technologies enabling for example the use of new materials or the establishment of new assembling processes. In this context, the potential exhibit by nanosciencies and nanotechnologies – particularly in the area of new materials – is considered by many as a revolutionary path to boundless innovation in the construction industry. Nanotechnology – or the "revolution of the small" – could open the doors to a promising future in architecture, allowing unseen forms of construction and living environments with higher standards of quality, attained with fewer resources and emissions. However, the potential of nanotechnology – and any other technology – as a driver of innovation and sustainability in the sector is debatable.

Although construction is strategically relevant to national and regional economies, cross-disciplinary research in the area is yet incipient. Indeed, recent studies suggest that measuring innovation in the sector is difficult due to the complexity of its operations and logistics, and the particularities of management systems. The missing information in the sector could account for a considerable amount of “hidden innovation”.  Therefore, whether the solution for an innovative sector should focus on the introduction and diffusion of new technologies (such as nanotechnologies) or the total redefinition of the activity itself, is yet a (necessary) conjecture.

# 2. Characteristics of the European construction Sector

## 2.1. Definitions

Construction can be understood as "a project-based activity engaged in the conception, design, building, maintenance, re-configuration and demolition of one-of-a-kind products" (BUILD-NOVA, 2006a), or simply as "all activities that contribute to the creation, maintenance and operation of the built environment" (E-CORE, 2005). The built environment "embraces the dwellings, offices, factories, leisure facilities, urban spaces, schools, hospitals and other buildings in which most of our lives are spent and economic activities take place, and the civil works – roads, dams, ports, airports, etc – that provide our energy and water services and our transport and communications networks". Yet, it is important to remark that construction does not entail mass production, and subsequently it does not constitute a manufacturing activity.

According to the Classification of Economic Activities in the European Community (NACE), construction (F 45) is a basic industry that entails a large number of activities and related industries (See Table 1).

Table 1. Diverse economic activities in the European construction sector

| Classification of Economic Activities in the European Community (NACE) | |
|---|---|
| Field | NACE Code (F) |
| *Construction* | 45 |
| *Site preparation* | 45.1 |
| Demolition and wrecking of buildings; earth moving | 45.11 |
| Test drilling and boring | 45.12 |
| *Building of complete constructions or parts thereof; civil engineering* | 45.2 |
| General construction of buildings and civil engineering works | 45.21 |
| Erection of roof covering and frames | 45.22 |
| Construction of motorways, roads, airfields and sport facilities | 45.23 |
| Construction of water projects | 45.24 |
| Other construction work involving special trades | 45.25 |
| *Building installation* | 45.3 |
| Installation of electrical wiring and fittings | 45.31 |
| Insulation work activities | 45.32 |
| Plumbing | 45.33 |
| Other building installation | 45.34 |
| *Building completion* | 45.4 |
| Plastering | 45.41 |
| Joinery installation | 45.42 |
| Floor and wall covering | 45.43 |
| Painting and glazing | 45.44 |
| Other building completion | 45.45 |
| *Renting of construction or demolition equipment with operator* | 45.5 |
| Renting of construction or demolition equipment with operator | 45.50 |
| | *Source: Eurostat, 2009* |

The sector embraces five sub-sectors such as *site preparation*, *civil engineering* (building of complete constructions or parts), *building construction*, and *building completion and renting of equipment*.

The organization and interaction between these sub-sectors is of a complex nature and remarks the fact that construction is different from other production systems in a number of important aspects. The resultant products of construction activities are commissioned projects

– thus with unique features – they are assembled at the point of consumption, they are physically unmovable, and present a long lifespan (CONSTRINNONET, 2004a). These imply that the agents engaged in a construction project will often interact during a fixed period determined by the project span. Hence, management and production will take place and last accordingly with the project requirements and length. Projects also take place within a specific socio-political context that affects production choices, procedures, and the way in which inter- and intra-organizational negotiations are conducted. This regards for example, urban planning concerns, professional and technical codes and certifications, material and products regulations, and any other domestic public ordinance with respect to health, safety and the environment. A basic typology of construction's agents according to CONSTRINNONET (2004a) is as follow:

*Building owner*:
Acting at the origin of a building project with a specific purpose office,
*Building user(s)*:
End or intermediate user(s) of built premises,
*Designer*:
Skilled professional in charge of architectural/technical design
*Contractor*:
Specialized firm in building construction and technical aspects of a building,
*Products manufacturer*:
Producer of building parts and components needed in construction,
*Products distributor*:
Commercial/technical intermediary between products manufacturers and contractors,
*Material supplier*:
Providers of materials to products manufacturers
*Service provider*:
Firm that is totally or partly in charge of the exploitation and/or maintenance of the building

Communication and coordination among these agents are often fragmented and therefore it is difficult to characterize a single production process. Manseau (1998) suggests a complementary perspective on construction that shows the main processes, subsystems and framework conditions of construction (See Figure 1).

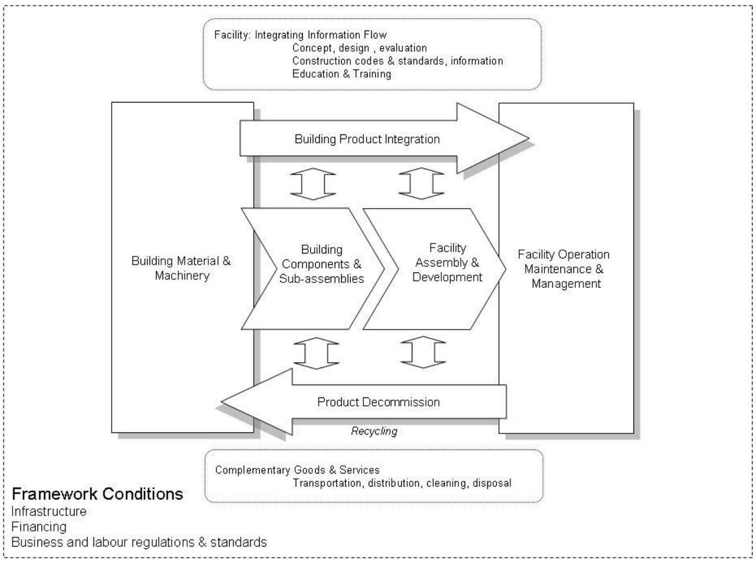


Figure 1. Generic representation of the construction process (Modified from Manseau, 1998).

As construction' projects emerge and reach their end, working teams, management and supply networks are rapidly created and dismantled. Therefore, supply and value chains are dynamically created and replaced fragmenting knowledge and information processes.

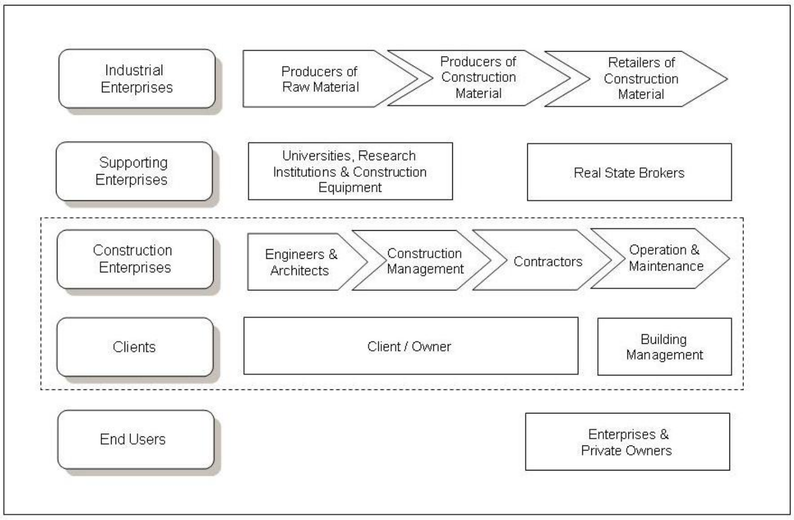


Figure 2. Simplified version of the construction supply chain and value chain (Modified from e-Business W@tch, 2006).

Karud (2007), argues "(…) there are significant inefficiencies in communications and collaboration systems in construction". Largely, these inefficiencies can be characterised by the fragmented communication through the value chain, in which output and input are managed individually at each segment. In addition, in the project-based working method, agents interact with and within different networks, and often belong to more than one value chain (Karud, 2007).

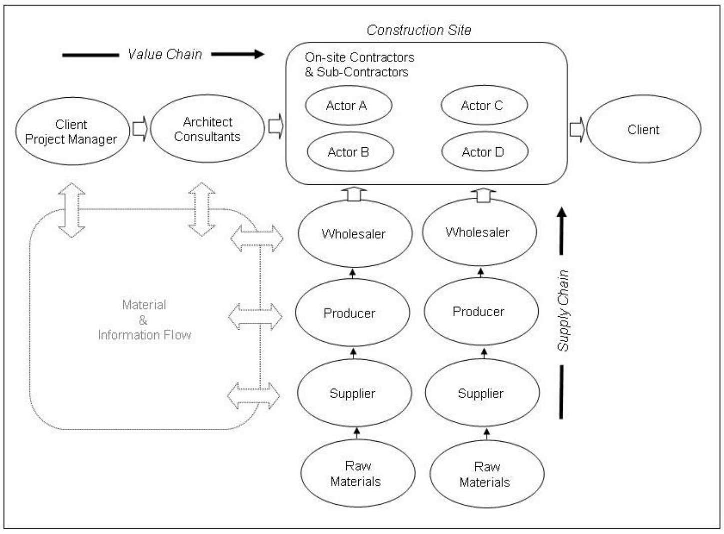


Figure 3. On-site construction working method and the flow of information, value and materials along stakeholders (Modified from Karud, 2007)

Figure 2 shows a generic representation of value and supply chain in construction. As the figure depicts, a large number of stakeholders within the construction industry and the local socio-economic infrastructure interact to create value and the required flow of resources (e-

Business W@tch, 2006). The vertical chain represents the value creation from industrial enterprises to end users. Horizontal arrows depict the supply flow among the different segments in the value chain. The area delimited by a dashed line represents the construction site on which value and supply chains converge.

Alternatively, Figure 3 shows an alternative representation of an on-site construction project. In this case, the construction process is also defined by the interaction and convergence of both the value and the supply chains. The flow of information and material between the chains define the resultant characteristics of the project such as cost, performance and span. The more information is share among the agents greater possibilities for improvements may arise (Karud, 2007).

## 2.2. Structure

The sector is distinctively built by a large number of micro, small and medium-sized enterprises (SMEs). The category of SMEs, by definition entails enterprises which employ less than 250 persons and which have an annual turnover not exceeding 50 million Euros, and/or an annual balance sheet total not exceeding 43 million (CONSTRINNONET, 2004a). Within this category, a micro enterprise employs fewer than 10 persons and presents an annual turnover and/or annual balance sheet that do not exceed 2 million Euros; a small enterprise, on the other hand, employs less than 50 persons and its turnover and/or annual balance sheet total does not exceed 10 million Euros.

Accordingly, the European construction sector is composed of approximately 2.37 million enterprises, 97% of which are SMEs. Micro enterprises account for 93% of this total (Dick and Payne, 2005). However, large-sized firms in construction have a significant market share and often, a notorious international profile. Overall, construction enterprises present a wide geographical dispersion and the primary focus of their activities is on their local environment. As a result, there is no significant interaction or networking between these companies beyond their common geographical boundaries. This in fact, implies a high fragmentation of activities and underlines the complexity of sectoral dynamics.

## 2.3. Economic aspects

Construction represents a strategically important sector for the European Union, providing building and infrastructure on which all sectors of the economy depend. The sector provides constructed assets representing 49.6% of the EU Gross Fixed Capital Formation – GFCF – (ETAP, 2007). The market for these activities is often classified into residential, non-residential, and infrastructure (EC, 2007).

Construction is one of Europe's largest industrial sectors with an annual turnover exceeding 1200 billion Euros, and activities that accounts for 10,4% of the EU GDP and employs 7,2% of its workforce (ETAP, 2007; BUILD-NOVA, 2006a). However, it has been estimated that construction-related economic activities directly or indirectly provides 22 million jobs (CONSTRINNONET, 2004b). By year 2001, 22.1% of the total labour employed in construction was self-employed (Eurostat, 2003 quoted by EF, 2005). This represents the labour market tendency in construction: a blooming creation of "one-man" firms in which the individual's skill is becomes the most valuable asset (Jørgensen, 2003 quoted by EF, 2005). At EU level, the civil engineering sub-sector has a slightly higher growth rate than building, emerging as the most important construction sub-sector, accounting for more than half of the employment and value added in 2000. Most of the remaining employment is in the building installation and completion sub-sectors (EF, 2005).

Although microenterprises are the dominant business operators in construction, the market share of medium and large-sized enterprises reaches a considerable 35%, representing only a

22% of the sector's workforce (CONSTRINNONET, 2004a). Germany, UK, Italy, France and Spain hold 74% of the total European construction market – (BUILD-NOVA, 2006a).

In Europe, production in the construction sector increased by 3% over the period 2000–2003, while the rest of the industry exhibited no growth over the period. As production and growth of the sector show positive trends, its overall productivity however is lower if compared to other European manufacturing sectors (EF, 2005; ETAP, 2007). Due to the nature of construction activities, the opportunities for mechanisation and automation of production – and therefore for capital-intensive production – is rather limited. Accordingly, the construction sector remains very labour-intensive (EF, 2005).

The particular structure of the sector implies a significant fragmentation of activities and a strong dependence on domestic market conditions. As a basic "national industry", construction is highly dependent on public regulations and public investments. Thus, policymakers frequently use the sector as a trend indicator - a cyclical stabiliser of macro-economic trends, restricted in periods with economic expansion and stimulated in periods of recession (EF, 2005).

In general, construction firms access different markets according to their size (BUILD-NOVA, 2008). Large companies and project developers dominate *global markets* trading specialized products such as industrial pre-fabricated products. In *regional markets*, highly qualified medium-sized companies and regionally based project developers are the dominants players. Finally, micro and small-sized companies exclusively operate in niches of *local markets*.

## 2.4. Competitiveness

Construction markets compete at local, national and/or global markets. These markets presents different institutional frameworks, while some companies traditionally operate almost only at local markets, others operate globally exhibiting a dynamic infrastructure and appropriate logistics (BUILD-NOVA, 2008).

In spite of the predominant role of SMEs in construction, a few European large-sized international companies have the largest combined share in the global construction market (EF, 2005). During the last years, this leading edge has weakened in favour of Asian competitors, notably Japanese transnational. By 2003, only four European companies remain between the top ten construction companies: Vinci (France), Bouygues (France), Skanska Ab (Sweden) and Hochtief AG (Germany).

The trade of construction services between the EU and the rest of the world is still positive, but relatively small and less competitive. Service in construction is mainly oriented to sales of expertise and civil engineering services to other countries (EC, 2007).

The lost competitive advantage of European construction companies has become an important driver in sectoral policies at EU level. The European commission has indicated that increasing and sustaining the global competitiveness of relevant economic areas such as construction is of strategic importance to Europe's ambitions of economic welfare (EC, 2007).

## 2.5. Research and Development

The construction sector presents a low level of R&D investment (EC, 2007). Consequently, R&D does not drive development in the sector that is mainly determined by on-site problem-solving routines (CONSTRINNONET, 2004a; Karud, 2007). By year 2001 the average EU investment in R&D accounted for only 0.01% of the total production value in the construction sector, being Finland the country with the highest R&D intensity (0.22%), followed by Sweden (0.11%). By the period, the average EU R&D intensity was significantly lower than the one exhibited by leading economies such as Japan and the US with 0.23% and 0.03% respectively (EC, 2007).

## 2.6. Norms and Regulations

Since construction is a basic and strategic industry oriented to national markets, fundamental regulatory frameworks for its activities remain almost completely within the national competences of Members States. However, the European Commission has been actively working on communitarian issues regarding construction.

In year 2006, the DG Enterprise conducted a study concerning the impact of EU policy instruments aiming at construction or being of any relevance to construction policies among Member States. The study not only focused on-site based activities of firms, but also on design and other related professional activities, specialised construction management functions, and on some aspects of the manufacture and supply of construction materials and components (DG, 2006). Table 2 shows some of these influencing regulations concerning the sector.

In this context, it is clear that construction has become a heavily regulated activity. This fact has implicit repercussions for business development in the sector. Although, the DG study revealed that construction agents have a general positive perception about this regulatory framework, notably among engineers and architects, there are some concerns about the real achievements in business competitiveness and gains on environmental performance.

In the context of research and innovation, the study revealed that there is optimism about the overall benefits of participation in research and innovation programmes such as gaining strategic advantages through knowledge creation and networking. These advantages seem to be more important than direct financial benefits. However, there is increasing concern about inadequate awareness of the programmes – particularly by SMEs – and about financial obstacles to participation.

On the other hand, the construction sector considers environmental regulations and policies to have had the greatest impact in reshaping the way firms conduct their business. However, environmental issues are not addressed in the same way in Member States. This situation is of concern to firms performing business across borders. There were concerns about differences in practice. Although environmental regulations have a positive impact in construction it was found they have a little influence in the overall competitiveness of the sector. Notable exceptions are firms specialising as developer or providers of environmental technologies and/or environmental consultancy.

## 2.7. Environmental issues

Construction is widely considered as an “environmental unfriendly” activity since it consumes large amounts of natural resources and energy, and generates a great amount of pollutants and wastes. indeed, it has been estimated that construction activities and the maintenance of our built environment alone consume over 40% of all resources and energy, and 16% of all the water worldwide (Chenga et al, 2006; WEC, 2004). The environmental impact of construction not only regards resource depletion but also biological diversity, global warming, and water and air quality. There are also growing concern about the implications to human health due to poor indoor-air quality. In this context, it has been estimated that over 30% of buildings presents a low air quality (Chenga et al, 2006). The World Energy Council has estimated that in spite all gains in efficiency, energy consumption in the built environment will continue to rise (WEC, 2004)

In Europe, construction also account for almost a half of total resources and energy consumed (ETAP, 2007). The energy consumed by heating and lighting of buildings account for around

42% of all energy consumed in Europe, while construction activities and associated transport account for an extra 5% (ECTP, 2005b). Furthermore, the overall energy consumption of the sector is expected to rise over 115-190% by year 2050 (WEC, 2004). IN terms of waste generation, construction and demolition waste represents about 22% of all generated waste measured by weight. On the other hand, by year 2001 buildings account for 18% of total CO2 emissions in Europe – not including electricity – becoming the third single source of greenhouse emissions, behind electric power and transport. Including the emissions generated by electricity, buildings become the first source of greenhouse emissions with a 36% total share. In a sectoral approach, this consumption is expected to increase in Europe within 115-190% of today's value by year 2050 (WEC, 2004).

Table 2. Relevant regulations (by category) regarding the construction sector in Europe by 2006

| Policy Area by Subject | Type and Number of Legal EU Instrument | | | | | Total |
|---|---|---|---|---|---|---|
| | Communication | Directive | Regulation | Decree | Resolution | |
| *Economy* | | 5 | | | | 5 |
| Regulation | 2 | | | | | 2 |
| Enterprise | | 1 | | 1 | 1 | 3 |
| Public Procurement | 2 | 2 | 1 | | | 5 |
| Community Assistance | | | 1 | 2 | | 4 |
| Taxation: VAT | | 1 | | 1 | | 2 |
| Internal Market | 4 | | | | | 4 |
| Standardization | | | 1 | | | 1 |
| Information Society | 1 | 1 | | 1 | | 3 |
| Electronic Commerce | | 1 | 1 | | | 2 |
| *Social* | 1 | | | | | 1 |
| Education | 1 | | | | | 1 |
| Employment and social affairs: Health, Hygiene and Safety at Work | 6 | 14 | 1 | 1 | | 22 |
| Employment (Mobility) | 3 | 3 | 1 | | | 7 |
| Employment (Rights) | 1 | 2 | 1 | | | 4 |
| Employment (Social Inclusion) | 1 | 2 | | | 1 | 5 |
| *Energy* | | | | | | |
| Energy Efficiency | 3 | 2 | | | | 5 |
| Renewable Energy | 1 | | | | | 1 |
| *Environment* | 3 | 5 | 4 | 2 | | 14 |
| Climate Change | 1 | | | | | 1 |
| Noise | | 1 | | | | 1 |
| Sustainable Development | 5 | | | | | 5 |
| Urban Environment | 1 | | | 1 | | 2 |
| Wastes | 3 | 5 | | 1 | | 9 |
| Water | 1 | 2 | | | | 3 |
| Research and Innovation | 2 | | 1 | 2 | | 5 |
| *Totals* | 42 | 47 | 12 | 12 | 2 | 115 |

*Source: DG Enterprise and Industry (2006)*

Consequently, construction could play an important strategic role in the EU plans to cut down CO2 emissions by 20% until year 2020, and its overall goal of improving resource and energy efficiency, and public health and quality of life (ETAP, 2007). From this perspective, improving the performance of construction activities might not only bring environmental benefits, but also positive effects to Europe's economy and society (EC, 2007; BUILD-NOVA, 2008; ETAP, 2007).

In the environmental context, there is large a regulatory framework on construction activities, products and practices, Table 3 depicts some of the policy areas that direct or indirectly influence construction.

It is clear that construction has become a heavily regulated activity. This fact has implicit repercussions for business development in the sector. Aware of these implications, in year 2006, the DG Enterprise conducted a study concerning the impact of EU policy instruments aimed at construction or had special relevance to construction policies among Member States. The study focused on site-based activities of firms, design and other professional activities, specialised construction management functions and on some aspects of the manufacture and supply of construction materials and components (DG, 2006). The study covered 115 regulations within the following policy areas: economy, social, energy, environment, and research and innovation. The DG study revealed that construction agents have a general positive perception about this regulatory framework, notably among engineers and architects, although there are some concerns about the real achievements in business competitiveness and gains on environmental performance.

In the context of research and innovation, the study revealed that there is optimism about the overall benefits of participation in research and innovation programmes, such as gaining strategic advantages through knowledge creation and networking. These advantages seem to be more important than direct financial benefits. However, there is increasing concern about inadequate awareness of the programmes – particularly by SMEs – and about financial obstacles to participation.  On the other hand, the construction sector considers environmental regulations and policies to have had the greatest impact in reshaping the way firms conduct their business. However, environmental issues are not addressed in the same way in Member States. This situation is of concern to firms performing business across borders since there are substantial differences in practice among States. Although environmental regulations have a positive impact in construction it was found that, they have little influence in the overall competitiveness of the sector. A notable exception is eco-innovative firms that have specialized their business activities as developer or providers of environmental technologies and environmental consultancy.

Table 3. Environmentally driven regulation on the European construction sector

| EU Regulation Relevant to Construction | | |
|---|---|---|
| Policy Area | Classification | Date |
| *General* | | |
| Effects of certain public and private projects | Dir 85/337/EEC | 27/06/1985 |
| Prevention and reduction of environmental pollution by asbestos | Dir 87/217/EEC | 19/03/1987 |
| Adaptation of asbestos regulation to technical progress | Dir 1999/7/EC | 26/07/1999 |
| Revised eco-label award scheme | Reg 2000/1980/EC | 12/07/2000 |
| Community eco-management and audit scheme (EMAS) | Reg 2001/761/EC | 12/02/2001 |
| Effects of certain plans and programmes on the environment | Dir 2001/42/EC | 21/07/2001 |
| Guidance for implementing EMAS | Reg 2001/680/EC | 17/09/2001 |
| Environmental aspects of standardisation | COM (2004) 130 | 25/02/2004 |
| Action Plan promoting NGOs | Dec 466/2002/EC | 01/03/2002 |
| Sixth Community Environmental Action Programme | Dec 1600/2002/EC | 10/09/2002 |
| Proposal for a Regulation concerning the Registration Evaluation, Authorisation and Restriction of Chemicals (REACH) | COM (2003) 644 | 29/10/2003 |
| Environmental Liability | Dir 2004/35/EC | 21/04/2004 |
| Timber licensing scheme | Reg 2173/2005 | 20/12/2005 |
| Working document: better regulation and the Thematic Strategies for the Environment | COM (2005) 466 | 28/09/2005 |
| *Climate change* | | |
| European Climate Change Programme (ECCP) | COM(2000)88 | 8/03/2000 |
| *Noise* | | |
| Noise emission by equipment used outdoors | Dir 2000/14/EC | 3/07/2001 |
| *Sustainable development* | | |
| Consolidating the environmental pillar of sustainable development | COM (2003) 745 | |
| Sustainable Development | COM (2003) 829 | 23/12/2003 |
| Draft declaration on guiding principles for sustainable development | COM (2005) 218 | 25/05/2005 |
| Review of the sustainable development strategy – a platform for action | COM (2005) 658 | 13/12/2005 |
| Thematic strategy on the sustainable use of natural resources | COM (2005) 670 | 21/12/2005 |
| *Urban environment* | | |
| Integrating the environmental dimension into the urban environment | Dec 1411/2001/EC | 27/06/2001 |
| Towards a thematic strategy on the urban environment | COM (2004) 60 | 11/02/2004 |
| *Wastes* | | |
| Framework Directive on waste (and subsequent amendments) | Dir 75/442/EEC | 15/07/1975 |
| Batteries and accumulators | Dir 91/157/EEC | 18/3/1991 |
| Hazardous waste | Dir 91/689/EEC | 12/12/1991 |
| Packaging and Packaging Waste | Dir 1994/62/EC | 20/12/1994 |
| Landfill of waste | Dir 99/31/EC | 26/04/1999 |
| Lists of waste and hazardous waste Lists of waste and hazardous waste, amending Directive 2000/535/EC | Dec 2000/532/EC | 3/5/2000 |
| Report on implementation of Community waste legislation 1998-2000 | COM (2003) 250 | 11/07/2003 |
| Proposal for a Directive on batteries and accumulators and spent batteries and accumulators | COM (2003) 723 | 21/11/2003 |
| Proposal for a Directive of the European Parliament and the Council on waste | COM (2005) 667 | 21/12/2005 |
| *water* | | |
| Protection of groundwater against pollution caused by certain dangerous substances | Dir 80/68/EC | 17/12/1979 |
| Framework Directive in the field of water policy | Dir 2000/60/EC | 23/10/2000 |
| Proposal for a Directive on the protection of groundwater against pollution | COM (2003) 550 | 19/09/2003 |
| *Energy* | | |
| Energy performance of buildings L 1, 2003 | Dir 2002/91/EC<br>92/42/EEC | 25/11/2002 |
| Proposal for a Directive establishing a framework for the setting of Eco-design requirements for energy-using products amending Council Directive | COM (2003) | 01/08/2003 |
| Energy Services Directive | COM(2003) 739 | 10/12/2003 |
| Promotion of combined heat and power | Dir 2004/8/EC | 21/02/2004 |
| Green paper on energy efficiency or doing more with less | COM (2005) 265 | 22/06/2005 |
| The support of electricity from renewable energy sources | COM (2005) 627 | 07/12/2005 |

*Source: DG Enterprise and Industry, 2006*

# 3. Trends, drivers and barriers of change in the sector

The European construction sector is undergoing important changes – notably the transformation in the framework conditions at EU level – such as the strengthening of the internal market by including service activities, the EU enlargement, and largely due to the market internationalization of construction materials (EF, 2005; BUILD-NOVA, 2008-2006b). The commission expects these external factors will induce important adjustments in the years to come, particularly in terms of inter-firms relationships, employment, sector organization and business models.

Firms within most sub-sectors in construction are challenged by highly competitive and fluctuating markets in their countries. In this context, the ongoing process of enlargement in the EU is opening new market opportunities meanwhile it is also changing the dynamics of competition towards globalization pressing firms to adapt and innovate quickly in order to survive. Demographic changes across Europe – notably the fast aging and declining of population – are also posing new challenges to firms (e.g. availability of human capital, skills and know-how). In spite of these trends, the construction sector does not yet reach considerable levels of activity beyond the national scope. Transnational activities are yet rare and mainly conducted by large-sized companies (CONSTRINONNET, 2004c).

On the other hand, the growing public awareness about sustainability issues is becoming an important factor of change in terms of framework conditions. As awareness rises, new demands are to be fulfilled trough market creation, not only for environmentally friendly products, but also for integral housing solutions (EF, 2005). Sustainability issues as well as health and safety concerns have also an important role in national and EU regulatory frameworks. Besides national regulations, construction activities are subject of a large number of regulations at EU level (see Table 3). These regulations are expected to push the sector to embrace change, improving process and opening new market opportunities (EF, 2005; DG 2006).

There are also internal forces driving change within the sector. These forces often focus on development of new technology and organizational arrangements to cope with external changes (EF, 2005). An important technology change in the construction sector has been driven by the adoption of Information and Communications Technology (ICT). The most important developments in the construction industry regarding ICT are in the areas of e-procurement, 3D technology, and project web. “These technologies carry significant economic potential for the industry, particularly with regard to process efficiency” (e-Business W@tch, 2006).

Hence, technology developments are expected to play an important role in the future competitiveness of the sector. Yet, there are considerable barriers to these potential developments – internal or external in nature – that must be overcome in order to gather a sustainable sectoral transformation. Table 4 outlines some of the relevant drivers and barriers regarding changes in the European construction sector.

Table 4. Drivers of and barriers to change in the European construction sector

| Characterization of the European Construction Sector | | | | |
|---|---|---|---|---|
| Drivers | Key Issues | Trends | Opportunities | Barriers |
| *Productivity* | Market orientation & competitiveness | Low productivity Domestic-oriented market | Market internationalization for product and services with increased productivity and competitiveness | products' nature (high size and weight) market conditions, business culture |
| *Demographics* | Recruitment, market opportunities | Fast aging of population & active immigration | New market opportunities (e.g. housing for elderly), assimilation of foreign skilled workforce | socio-economic adaptability, cultural divergences, business culture |
| *EU enlargement* | Market creation Labour & occupational safety | market growth | New markets and competitiveness – e.g. urban development and infrastructure | Market protectionism, Social inequality, lack of practice standardization |
| *Movement of Labour* | Recruitment, skills & labour conditions | Transnational flow of workers, low wages and safety conditions | Increased recruitment and skills diversification | unsatisfactory labour conditions, public acceptance |
| *Enlargement of the Market* | Demand for investment in infrastructure, energy, manufacturing, and processing | Inflow of labour, investment and technology in new Member States | Improved practices and quality standards in new Member States & business opportunities for old Member States | Sectors low productivity and market orientation |
| *Technological Developments* | Common technological platform, Use of ICT, e-business, Lean construction, R&D, industrialization of construction process, environmental sustainability | Slow pace of innovation, adoption and diffusion of new technologies, lack of strong and focused R&D investments | Increased innovation rate & technological development, Lean production, know-how, intensified servicing, customer satisfaction, environmental benefits | awareness, knowledge, competencies among construction companies and incentives |
| *Market Developments* | Globalisation of markets for building materials & knowledge-intensive services, complex supply chain solutions, new financial models and collaboration | Market enlargement, exportation of know-how rather than of products, fragmented supply chains, insufficient investment | exportation of knowledge-based products and services, networking, financial flow, global competitiveness, increased innovativeness by collaboration | sector composition and fragmentation, investment, regulations, business culture |
| *Regulations and Legislation* | Legislative pressure and regulations for trade, health and safety, environment, transportation, public procurement and labour | National policies and regulation with dominant weigh but increasing number of EU regulations on construction | Regulation and deregulation of activities with impact on national frameworks, fair trade, social equality and inclusion, enhanced safety and health, environmental protection, energy and resource efficiency | Risk of excessive regulation, national priorities, social inequality, informal work, business culture, complexity of sector structure, market conditions |
| *Labour Qualification* | Qualification needs, Awareness and action in relation to qualification needs, SME's awareness of the qualification problem Short-term contracts Financing of education and training | Shortage of qualified workers, high rate of informal employment, low investment in training, lack of certification of activities, short-term contacts, lack of lifelong learning approach | Increased qualification of labour, social equality, lifelong learning initiatives, increasing innovation rate in small firms, enhanced competitiveness | access to investment, access to qualified training, standardisation of procedures and practices, socio-economic divergences, business culture, regulations, market conditions |

*Source: European Foundation for the Improvement of Living and Working Conditions*

# 4. The traits of innovation in the construction sector

Construction remain a domestic-based economic activity of strategic importance, with predominant presence of MSEs, few but very large international companies with decreasing global competitiveness, low R&D investment, low productivity, and highly labour-intense. These characteristics are indicated – repeatedly – as important impediments to the required sectoral change. Without drastic changes, the European construction sectors is at risk of stagnation. In this context, the European Commission sees innovation as a driver of change and sustainable economic growth.

Indeed, innovation is at core of the current EU strategy to “enhance Europe’s global economic competitiveness” (EC, 2006). The European commission has acknowledged that “innovation in a broad sense is one of the main answers to citizens’ material concerns about their future” and that a broad strategy is required in order to translate efficiently, investments in knowledge into products and services (EC, 2006). This broad strategy recognizes that “all forms of innovation need to be promoted, for innovation comes in many forms other than technological innovation, including organisational innovation and innovation in services”. The Commission indicates that an “increased competition constitutes the most efficient instrument to stimulate innovation” although policy measures and innovation support mechanisms may also have an important role to play. Consequently, the EU’s innovation strategy focuses on key sectors for its economic competitiveness and the establishment of support mechanisms and policy measures to enhance and sustain their performance. Construction is one of those strategic sectors (EC, 2006; BUILD-NOVA, 2008; CONSTRINNONET, 2004a-2004b-2004c)

Innovation in construction takes many forms and it is therefore, difficult to measure (E-CORE, 2005; BUILD-NOVA 2008). Although, innovation in other industries often regards the creation of new products or technologies – at a rate measured in number of patents – in construction innovation is rather oriented to problem-solving routines for a particular project or task (CONSTRINNONET, 2004a; E-CORE 2005). These innovations often involve novel design concepts, use of new materials – generally developed by other industries – architectural improvements, or improved building processes driven by cost and time constrains (E-CORE 2005). Innovation here occurs at different stages of a project involving planning management, and logistic and communications processes. Often, these innovative developments are not translated into new products, technologies or processes measurable in term of intellectual property – patents – and consequently, they are not properly measured or accounted for (E-CORE, 2005). Hence, measurable innovation outputs in the construction sector remain weaker than in manufacturing industries.

Given the conservative nature of the sector – nurtured by strong craft-based traditions and cultural settings – technology adoption and diffusion tend to occur at a low pace. Notably, the adoption and diffusion of ICT in construction has been less intense than in technology-driven industries (e-Business W@tch, 2006; BUILD-NOVA 2008).

In the European market, small construction projects have a considerable weigh. They often regard retrofitting of existent building and involve the participation of micro-firms with a low investment capability. In general, SMEs tend to have a limited resource base that implies, for example, that small firms “do not have enough time or funds to develop their technological and organisational capabilities, even if they have the motivation to do so” (CONSTRINONNET, 2004a). Conversely, highly qualified medium and large-sized companies managing larger construction and infrastructure projects present higher risk investment and R&D capabilities (E-CORE, 2005). Building activities and infrastructure developments offer a wider ground for innovation than retrofitting and maintenance projects (BUILD-NOVA, 2008).

## 4.1. Sources of innovation

Some key sources of innovation in the construction sector – besides direct R&D efforts in large companies – include (E-CORE, 2005):

> *Product suppliers*: Creating market advantage through R&D focusing on new or improved products. Suppliers usually disseminate information and offer training as a part of their marketing strategies settling an important base for innovation particularly among small-sized firms,
>
> *Other industry sectors*: Many innovations in the construction sector are the result of R&D efforts conducted in other industries. These developments often involve materials that have a potential application in the built environment.
>
> *The creativity of individuals*: In construction, problem-solving routines are the main driver of innovation at on-site activities. Agents involved at different stages of a project become an important source of innovative solutions – e.g. clients, designers and planners introduce. The interaction between these agents determines the rise of new demands on material and design principles stimulating the search for new solutions. Although these ideas are not originated from research, they often require research and development prior implementation.
>
> *Research programmes*: Besides research in products and materials for direct or potential application in construction, funding in construction research generally comes from public sources and focuses on the development of design principles – for the introduction of codes, standards, and regulations – or on the exploration of organizational and communications issues. These research efforts are important to determine how new developments are to be implemented and what their overall implications to economy, environment and labour might be.

## 4.2. Barriers to innovation in construction

Since innovation in construction activities broadly focuses on problem solving at on-site developments, change has become traditionally local and incremental. Thus, groundbreaking innovations with higher potential to induce systemic changes are often limited. The main barriers to innovation are intrinsically rooted in the organisation of the construction practice itself and in the framework system in which their take place. These barriers are (ECTP, 2005a; E-CORE, 2005):

1. *The number and range of interests involved in a construction project*: a construction project – besides its size – demands a complex arrangement of inputs allowing ambiguity an uncertainty. Introduction of novelties in such a context implies risks that project managers and costumers prefer to avoid, particularly if the novelty to be introduce implies more resources, cost and time.

2. *The complexity of construction outputs*: since construction projects demands a considerable amount of inputs, reciprocally, their output complexity is large. Hence, resultant buildings and infrastructures constitute complex systems that must perform according to expectations for an unusual long span. Changes in the performance of one structural or functional component in the system may bring unexpected consequences at any time. This implies that concerns about the final product performance must be considered through the entire building life cycle accordingly extending the involvement of agents and their liability.

3. *Lack of performance-based competition*: the performance of construction outputs difficult to evaluate and competition is based on price alone rather than on a performance/price relationship. Projects are commissioned in order to fulfil specific requirements and comparison with alternatives is rather difficult until final design specifications are completed. In addition, comparison often involves subjective attributes such as aesthetics that are impossible to evaluate in objective terms. Thus, there is little incentive for agents to introduce novelties regarding performance that are not clearly advantageous, particularly in terms of cost reduction.

4. *Short-term relationships*: projects incidentally gather different agents or stakeholders on the base of a short-term contractual relationship. These imply that there are few opportunities for knowledge diffusion and learning from valuable experiences, and new ideas may be inhibited.

5. *Focus on initial costs*: construction projects respond to budgetary structures with capital expenditures and operational costs being subject to different procedures and controls. The resultant effect is that agents focus on initial cost rather than on long-term performance optimizations. As an example, the energy-efficiency performance of buildings is encouraged through regulations and not by market pressure.

6. *The dominance of small firms*: large firms have a higher resource capability than micro and small companies and therefore, they can easily overcome the risk associated with innovation. In the construction sector, the large number of micro and small firms is an important constrain to the innovation flow.

7. *Skills and training*: the aggregated effect of the precedent barriers is that investment in training and skills within the construction sector is inhibited.

8. *The long-term consequences of failures*: failures in the built environment might not be evident during the span of a project. However, they can manifest themselves at any point afterwards with unforeseen consequences. Since construction activities are based on contractual relationships, it is difficult to delineate the liability of construction agents in the long-term run. Therefore, introduction of novelties and the resultant increasing risk of future liabilities are often avoided at early stages of planning and development, limiting the possibilities of radical innovations.

9. *Regulations and standards*: the resultant performance and implications of construction projects cannot be easily perceived by end-users. Hence, regulation plays an important role setting up the "minimum performance standards" to satisfy basic costumer and social requirements. However, regulation can inhibit innovation by demanding specific features and not allowing alternatives. Since construction activities and products imply a high level of complexity and risk, regulations on the sector tend to be restrictive, inhibiting the market for new products or concepts.

Overcoming these barriers is not an easy task. It implies the sector's transformation within a systemic change supporting innovation. In this context, the European Commission has indicated:

> “(…) *the EU can only become comprehensively innovative if all actors become involved and in particular if there is market demand for innovative products. This broad strategy needs to engage all parties – business, public sector and consumers. This is because the innovation process involves not only the business sector, but also public authorities at national, regional and local level, civil society organisations, trade unions and consumers*”
>
> *(EC, 2006)*

For the construction sector, the challenge of innovation has particular features, notably the need of overcoming cultural barriers within the supply and demand sides, balancing growth and environmental protection, and crucially, the transition from a project-based activity towards industrialization.

The European Construction Technology Platform has indicated that a R&D framework for the sector development should consider the barriers to innovation as a starting point (ECTP, 2005a). Overcoming these barriers demands a shift from “the individual project problem-solving approach to a more universal, sector-wide application” including the “creation of a positive innovation climate and strong, coherent innovation processes – including infrastructure, education and training – radically enhancing the number and quality of new products, processes and services being introduced” (ECTP, 2005a). Consequently, a construction sector open to innovation should exhibit the following features:

1. *Long-term relationships both within the supply side and between supply and client interests,*
2. *A focus on performance and costs over the life-cycle and away from initial costs,*
3. *Knowledge-based, with people at all levels able to assess and implement new concepts,*
4. *Widely accepted sets of performance indicators,*
5. *A network of information and knowledge services.*

## 4.3. New technology opportunities

As new technologies are being created and adopted within industries and sectors, construction also finds new and valuable opportunities for change. Possibilities are many but some technologies present greater potential for adoption and diffusion within the sector. New technologies may induce and support greater innovative and competitive capabilities, and more importantly, they can lead construction towards a knowledge-intensive industry. This can be achieved by (ECTP, 2005b):

1. *Introducing more human sciences in the development of new customer-oriented business models, and developing human-oriented innovative construction processes,*
2. *Introducing ICT at all stages of the construction process and through the buildings’ life cycle enabling a constant flow of information and knowledge within all stakeholders. Particular ICT applications regard advanced design based on modelling and simulation, automation of construction plant and equipment, advanced embedded electronics, wireless or mobile communication technology, advanced monitoring techniques and wireless intelligent sensors, and integrated demand and asset management,*

3. *Introducing both nanotechnology and biotechnologies in order to develop new and advanced multifunctional materials, components and processes,*
4. *Introducing remote sensing – satellite – technologies in services for construction equipment positioning, monitoring and evaluation of construction activities and their impact,*
5. *Adapting production and managerial concepts developed in other manufacturing industries such as for example "just-in-time production", "Design for Disassembly" and "Design for Recycling"*

## 4.4. EU innovation strategy: the lead market Initiative

The European Commission has acknowledged the important role of construction in the sustainable development of the European community and taken several actions to promote the sound development of building activities. A relevant step in this direction was the inclusion of the sector in a general innovation strategy for EU launched in September 2006 (EC, 2007). In the official communication "Putting Knowledge into Practice: A broad-based innovation strategy for the EU" the commission recognizes the relevance of EU research framework programmes for increasing the offer of new high-quality products and services while strengthening the demand-side of innovation. This initiative, often call "lead markets" is based on a "strategic and integrated approach to policy-making" to set the right conditions for innovation-driven lead markets to emerge and develop in Europe. Lead markets are innovation-friendly markets for creating new and innovative products and services in promising areas currently constrained by regulatory or other obstacles.

In the context of lead markets, "Sustainable construction can be defined as a dynamic of developers of new solutions, investors, the construction industry, professional services, industry suppliers and other relevant parties towards achieving sustainable development, taking into consideration environmental, socio-economic and cultural issues" (EC, 2007). This definition involves aspects such as the design and management of buildings and constructed assets, choice of materials, building performance and the interaction with urban and economic development and management. Since construction is an activity defined by national priorities, culture and traditions, different approaches to the lead market initiative can be followed – e.g. prioritizing energy and resource efficiency, land management or social inclusion. However, in general terms, the commission looks for the interaction and combined effect of two markets driving innovation such as "rational use of natural resources" and "user's convenience and welfare". The choice between the two set of drivers is to be guided by a number of general considerations on the future anticipated market requirements and trends. Table 5 depicts some of the relevant trends and drivers influencing the potential development of a lead market in construction (EC, 2007).

The European Commission has recently indicated that "insufficiently coordinated regulations, coupled with the predominantly local business structure, lead to considerable administrative burdens and to a high fragmentation of the sustainable construction market" (EC, 2008). The EC remarks "there is a lack of knowledge on possibilities within the existing legal framework for public procurement that could facilitate demand for innovation-oriented solutions". Potential solutions to this impasse a goal-oriented approach within the context of sustainable construction, better regulation policies, awareness campaigns among stakeholders, and standardization measures with focus on sustainable practice and concepts (EC, 2008).

Table 5. Trends and drivers in the Lead Market initiative for sustainable construction

| Variables in the development of a Lead Market for Sustainable Construction | |
|---|---|
| | Trends and Drivers |
| *Market segment* | |
| Residential | 1. Faster pace in changes of users' requirements demanding actions at early stages of design and construction processes<br>2. Increased need of accessibility and flexibility at all life cycle stages of dwellings to satisfy different types of users and ages<br>3. Increased consideration of energy and resource efficiency, environmental quality, health and safety issues in the selection of materials and structural components<br>4. Increased public acceptance and demand of "energy efficient solutions" such as the "passive house" and integration of renewable energies<br>5. Increasing technological capability to control indoor climate and increase comfort<br>6. Higher inclusion of ICT solutions for automated and integrated (remote) control of appliances, equipment and security systems<br>7. Increasing demand for more affordable and higher quality dwellings |
| Non-residential | 1. Increasing demand for energy efficiency and renewable energy will influence – and favour – alternative building structures and functionalities<br>2. Increasing role of indoor climate quality as a factor influencing comfort and work efficiency and as a driver of and functionality in design<br>3. Increasing demand of adaptability and flexibility of space and utilities to satisfy faster changes and rotation of businesses |
| Infrastructure | 1. Increasing strategic approach towards Investment will focus on long-term functional characteristics of the infrastructure and the associated life-cycle costs |
| *Innovation focus* | |
| construction industrialisation | 1. *Improvement of quality and productivity*: greater utilisation of prefabricated products and industrialisation of processes<br>2. *Partial transfer of on-site to off-site production activities*: process continuity, higher quality of products, and improved control of their environmental characteristics<br>3. *Facilitation of industrialisation of on-site activities*: by product model-based construction design, management of product information and e-business, on-site deployment of IT and standardization<br>4. *Industrialization*: potential to reduce volume of wastes and safety risk (potential logistic constraints due to heavy transport and impact on the European road infrastructure should be considered) |
| Networking in project implementation | 1. *Effective communication and collaboration in the supply chain*: increases productivity, greater innovativeness via economically viable life-cycle services, increasing knowledge flow via communication beyond the lifespan of the project |
| Life-cycle expertise | 1. *Development of skills and services to meet customer and occupants requirements in a life cycle perspective* |
| New services models | 1. *New service models to satisfy specific customer's needs* |
| | *Source: European Commission (See EC, 2007)* |

# 5. Eco-innovation

## 5.1. Definitions

As a term, eco-innovation involves any process, product or service that contributes – directly or indirectly – to sustainable development. The extend of this contribution varies accordingly, from improved industrial processes, enhanced performances of product and services, to new technological and social developments providing gains in resource efficiency and lessen environmental burden. However, eco-innovation implies value creation and novelty, and therefore it does remark the economic character of environmental innovation. Although eco-innovation is often used as a synonymous of *environmental innovation* – and it is linked to concepts such as *environmental technology, eco-efficiency, eco* or *environmental design* – its scope and implicitness go beyond the design and product development process, involving the societal and political aspects of innovation.

Since its rather recent conceptual introduction (See Fussler and James, 1996), eco-innovation has increasingly gain relevance, notably among policy makers and innovation scholars. On an early definition, eco-innovation was understood as "new products and processes which provide customer and business value but significantly decrease environmental impacts" (James, 1997). During the following years many other definitions has been proposed, focusing indistinctly on ether the environmental or innovation setting of the concept. Recently, two new definitions have been introduced in the context of a major EU involvement in the area of innovation, sustainability and economic competitiveness.

In essence, eco-innovation includes any novel or significantly improved solution introduced at any stage of a product/service lifecycle with a significant gain in resource productivity or a reduction of environmental impacts (Reid and Miedzinski, 2008). The overall understanding of eco-innovation requires of a systemic approach in which the implications of environmental innovations are analyzed at different organizational levels: at micro level (processes, products and services, and firms), at meso level (supply chain, industry, sector, region, and product/service systems), and at the macro level (economy, nations, global). While innovations focusing in products and their environmental performance do not necessarily bring absolute gains in resource efficiency, systemic innovations that are capable to reduce environmental burdens significantly, require of a series of innovations at micro and meso levels in order to occur. This paradox implies that if significant gains in resource and energy efficiency are to be achieve, innovation must be attained and sustain across all levels of organization (Reid and Miedzinski, 2008; Kemp R. and P. Pearson, 2008).

There are different definitions of eco-innovation, but in general, they look up to:

> *"…the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation – developing or adopting it – and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use – including energy use – compared to relevant alternatives"*
>
> *(Kemp and Pearson, 2008).*

Based on this definition, eco-innovation focuses on environmental performance rather than on environmental aim and it is not limited to new or better environmental technologies. Hence, it does not exclusively imply innovations aimed at reducing environmental harm but also any new resource-efficient process at firm or sector level. This implies in turn, that any eco-innovation must consider carefully an overall assessment of environmental effects and risks through entire life cycle of products, services and processes.

## 5.2. Eco-Innovation in the construction sector

In construction, eco-innovation focuses on developing “sustainable construction” a goal on line with current EU initiatives regarding the greening of the sector, notably the “Lead Market Initiative” (See EC, 2007). Lead markets are innovation-friendly markets for creating new and innovative products and services in promising areas currently constrained by regulatory or other obstacles. In the context of lead markets, “*sustainable construction* can be defined as a dynamic of developers of new solutions, investors, the construction industry, professional services, industry suppliers and other relevant parties towards achieving sustainable development, taking into consideration environmental, socio-economic and cultural issues” (EC, 2007). This involves aspects such as the design and management of buildings and constructed assets, choice of materials, building performance and the interaction with urban and economic development and management. Since construction is an activity defined by national priorities, culture and traditions, different approaches to the lead market initiative can be followed – e.g. prioritizing energy efficiency, land management or social inclusion.

The share market for sustainable building has rapidly increased during the last decade. Currently, in the US alone this niche represents about 9% of the entire construction market for an estimated 12 billion Dollars (Green Technology Forum, 2007). However, drivers, trends and barriers in eco-innovative activities in construction do not differ to those regarding innovation. Therefore, the challenge of greening construction activities and the built environment directly regard the sector capability to increase competitiveness and sustainability (ETAP, 2007).

The blooming market for sustainable or green buildings has been remarkably encouraged by developments in the energy-efficiency policy area (NORDEN, 2008). Stringent environmental policies adopted in the EU and Member States are influencing new dynamics within the construction industry and opening new opportunities for eco-innovation in light of the development of green markets. Since construction is the largest single consumer of energy and resources in the EU, “changes in the in the built environment in the form of solutions and measures promoting energy efficiency provide the largest single potential for reducing the total energy consumption” (NORDEN, 2008). It has been estimated that 40 Mtoe could be saved by year 2020, a number that represents one fifth of EU’s targets with regard to the Kyoto Protocol. Energy-efficiency demands in construction also have a potential impact on the development of wider variety of “Cleaner Technologies” among European developers, opening interesting business opportunities.

Energy efficiency in buildings has greatly improved since the first oil crisis in 1973, particularly in countries with high demand for heating (WEC, 2004). These improvements have been achieved thanks to the development of better insulation materials and advanced windows systems with double or triple glazing. Additionally, some considerable improvements are the result of retrofitting works particularly in residential buildings. Energy-efficiency in buildings is currently following two different directions: *Passive housing* and *intelligent housing*. The former refers to simple robust systems that allow exceptionally low energy consumption by integration of available efficient solutions. The later, requires of an ICT platform that integrates high-tech solutions for energy efficiency. Both ways present different innovation developments but they both focus on enhancing building insulation, Indoor climate control systems and energy recovery, and building automation systems.

The overall energy demand for heating and cooling of buildings can be reduced through improvements in the insulation capacity of structural and non-structural surfaces (e.g. walls and windows). Insulation on building is commonly achieved through the incorporation of insulating materials between layers of building materials. The performance of these materials not only depends on their thermal properties but also on indoor climate and design factors. As the insulation of buildings increases, the control of indoor climate conditions becomes necessary. Therefore, mechanical control systems have been developed to improve air circulation and quality. However, large airflows bring considerable energy losses through lost heat. Hence, heat recovery has become an important issue on energy innovations. Building automation on the other hand aims the integrated optimization of control and performance of building sub-systems such as ventilation, heating and cooling, lightning and electronic equipment. This integration of sub-systems allows buildings to “adapt” automatically to changing needs and conditions in response to internal or external environmental conditions. The response to changes in environmental conditions is attained through sensing and monitoring technologies.

Energy efficiency innovation in buildings has open new opportunities for technology development and integration, new materials, and design and engineering of indoor environments (NORDEN, 2008). Notable and promising developments in these areas are being conducted in high-tech research and developments notably ICT and enabling nanotechnologies.

## 5.3. Nanotechnology-based eco-innovation in the construction sector

### *5.3.1. Definition and dynamics of nanotechnology*

Nanotechnology can be defined as the “research and technology development at the atomic, molecular, or macromolecular levels using a length scale of approximately one to one hundred nanometers[1] in any dimension” (EPA, 2007). However, nanotechnology is a set of technologies on the nanometre scale and not a single technological field (OECD, 2007).

Nanosciences – the study – and nanotechnologies – the manipulation – of matter at nanoscale*, are the result of a convergence between the traditional fields of physics, biology and chemistry, and their development depend on contributions coming from a wide variety of disciplines.

Although the concept of nanotechnology is often associated with up-to-date developments in science and technology, the term was introduced back in the seventies (See Taniguchi 1974). By that time, nanotechnologies were initially used in the electronic industry in order to miniaturize components, notably in miniaturization of microchips. But the real capability to manipulate matter at the nanoscale is a more recent event linked to the invention of the Scanning Tunnelling Microscope (STM) in 1982, and the Atomic Force Microscope (AFM) in 1986 (OECD, 2007; The Royal Society, 2004).

Manipulating matter at the nanoscale allows the creation of particles, materials or structures with different properties. These distinguishing properties are the result of an increased relative surface area, and quantum effects (The Royal Society, 2004). These factors can enhance or even modify properties such as reactivity, strength and electrical characteristics. Bottom-up and top-down techniques are employed to manipulate matter at the nanometer scale. In the Bottom-up technique, materials and devices are built up from molecular or atomic components while in the top-down technique, nano-objects are designed from larger building blocks. By working at the atomic and molecular level, nanotechnology opens new possibilities in material design (Green Technology Forum, 2007). Currently, nanotechnology

[1] *A nanometre is one billionth of a meter ($10^{-9}$ m). As a reference, a human hair is approximately 80,000nm wide and a red blood cell is approximately 7000nm wide (Royal Society 2004).*

developments focus on the areas of *electronics*, *optoelectronics*, *medicine and biotechnology*, *measurements and manufacturing*, *environment and energy*, and *nanomaterials* (See OECD, 2007).

The enormous potential of nanotechnologies to revolutionise our material world and the economic implications on these promise, have produce a global race to lead the developments in the field. Over 30 nations are currently engaged on nanotechnology research and development with a global investment over 9 billion Dollars (EPA, 2007). In the international scenario, the United States, Japan and the EU leads nanotechnology developments. International organizations are also working in the field such as the OECD and ISO (EPA, 2007). Some important part of nanotechnology research and development funding is being directed to the study of environmental and health issues since uncertainties about occupational and environmental exposures to a limited number of engineered nanomaterials have been reported (EPA, 2007). These uncertainties might become important constrains to nanotechnology applications and public acceptance (Green Technology Forum, 2007). Nevertheless, products containing nanomaterials are available in markets worldwide, including computers, clothing, cosmetics, coatings, sports equipment and medical devices. In the American market alone, there are already approximately 80 consumer products, and over 600 raw materials, intermediate components and industrial equipment items that are used by manufacturers (EPA, 2007). As a result, is seems that economy will be increasingly affected by nanotechnology as more products containing nanomaterials move from R&D into production and commercialization. The future global market for these technologies by 2011–2015 is estimated around 1 trillion Dollars (The Royal Society, 2004).

Nanotechnology is an enabling technology expected to have a pervasive impact on existing industries and even lead to the creation of new ones (Risoe, 2007). This potential major industrial transition is likely to take 20–30 years if nanotechnology follows similar gestation times to those of other general-purpose technologies (Freeman and Loucã, 2001). Current nanotechnology development is at an early formative stage, characterised by high uncertainty and rapid and radical innovation, a situation that appears analogous to that exhibited decades ago by two other major general-purpose technologies such as biotechnology and ICT, (Freeman and Loucã, 2001). Although the technological development of nanotechnologies is fluid, it is difficult to characterize a patter since sub-areas are at different stages of development. However, the nanotechnology market by 2007 indicates that applications in the chemical and semiconductor sectors presents the largest combined share (87%), while applications in electronics, aerospace, pharmaceutical and health, and food industries presents is yet smaller (Green Technology Forum, 2007).

Innovation research on nanotechnology is also at an early stage and consequently the knowledge about industrial uptake is yet weak (Risoe, 2007). The level of commercialisation of these technologies varies considerably from country to country, and in many areas development is still experimental (EPA, 2007). In general, the involvement of industry in nanotechnology R&D is high but less dominant than in other fields due to the considerable involvement of government and academy (Zucker et al, 2007).

Although nanotechnologies are expected to have an impact across a wide range of sectors, experts in the field believe that the hype – or the misguided promises that nanotechnology can fix everything – will be the most important factor against its own development (The Royal Society, 2007).

### *5.3.2. Applications: Nanotechnologies for sustainable building*

Nanotechnologies present a great potential for application in sustainable building (Green Technology Forum, 2007). This potential is because nanotechnology can bring environmental benefits, through both direct and indirect applications (EPA, 2007). In general these environmentally-friendly applications focus on areas such electricity storage, engine efficiency, hydrogen economy, photovoltaics, insulation, thermovoltaics, fuel cells, lighting, light-weighting, water purification, environmental sensors, and land and air remediation (Technology Forum, 2007). Table 6 depicts some of the potential applications of nanotechnologies in the construction industry.

These applications present a great potential to reduce energy and resource intensity in the built environment while improving indoor quality conditions. Globally, nanotechnologies are expected to reduce carbon emissions in three main areas such as transportation, improved insulation in residential and commercial buildings, and generation of renewable photovoltaic energy (Green Technology Forum, 2007). Hence, the building industry has an implicit role on driving nano-related environmental initiatives. Many nano-engineered products are already on market and can help to create more sustainable buildings, providing materials that reduce waste and toxicity, and systems that can reduce energy consumption. Advances in nanotechnologies with focus on energy conservation in architecture include new materials like carbon nanotubes and insulating nanocoatings, as well as new processes including photocatalysis (Green Technology Forum, 2007). These material and processes can improve the strength, durability, and versatility of structural and non-structural materials, reduce material toxicity, and improve building insulation. However, the most significant activities in nanotechnology research within the industry still focus on understanding phenomena and improving performance of existing materials and products (Zhu et al, 2004). The wider application of nano-related products and processes in construction, although rising, is yet at a premature stage.

Table 6. Nanotechnologies applications in construction

| Focus | Potential Applications of Nanotechnologies in Construction<br>Properties | Commercial Products | Applications |
|---|---|---|---|
| *Insulation* | Efficient insulation due to extremely high surface-to-volume ratio, reduced toxicity and dependence on non-renewable resources. 30% more efficient than conventional materials | 1. Aerogel<br>2. Thin-film insulation<br>3. Insulating coatings | In structural and non-structural assembling |
| *Coatings* | Insulating nanoparticles can be applied to substrates using chemical vapour deposition, dip, meniscus, spray, and plasma coating to create a layer bound to the base material | 1. Self-cleaning coatings<br>2. Anti-stain coatings<br>3. Depolluting surfaces<br>4. Scratch-resistant coatings<br>5. Anti-fogging and anti-icing coatings<br>6. Antimicrobial coatings<br>7. UV protection<br>8. Anti-corrosion coatings<br>9. Moisture resistance | Windows and structural surfaces |
| *Adhesives* | Material with adhesive surfaces, replacing traditional chemical adhesives. Eliminates residues and increases adhesive force. | | Structural and non-structural assembling and sealing |
| *Lighting* | Increases lighting power while reduces energy and resource consumption. | 1. Light-emitting diodes (LEDs)<br>2. Organic light-emitting diodes (OLEDs)<br>3. Quantum dot lighting | Indoor and outdoor environments |
| *Solar energy* | Increases efficiency on energy generation while reduces cost and material intensity. | 1. Silicon solar enhancement<br>2. Thin-film solar nanotechnologies<br>3. Emerging solar nanotechnologies | Non-structural components |
| *Energy storage* | Improved efficiency for conventional rechargeable batteries, new super capacitors, advances in thermovoltaics for turning waste heat into electricity, improved materials for storing hydrogen, and more efficient hydrocarbon based fuel cells. | | Building and indoor systems |
| *Air purification* | filter particles, eliminate undesirable odours, and removal of airborne harmful elements | | Indoor system |
| *Water purification* | water decontamination, purification and desalinization, and providing improved detection of water-borne harmful substances | | Indoor system |
| *Structural materials* | Improving resistance, flexibility, strength and life spam while reducing deterioration rate, volume and weight | 1. Concrete<br>2. Steel<br>3. Wood<br>4. New structural materials | Structures |
| *Non-structural materials* | Increasing strength and durability while reducing heat losses | 1. Glass<br>2. Plastics and polymers<br>3. Drywall<br>4. Roofing | Window systems |

*Source: Green Technology Forum, 2009*

# 6. The Nordic construction sector: Patterns and trends on (eco) innovation and nanotechnology

## 6.1. The innovation performance

Nordic countries are among the most innovative nations worldwide. According to the European Innovation Scoreboard 2007 (See Pro Inno Europe, 2008; 2009), Sweden, Finland, and Denmark exhibit an innovation index of 0.73, 0.64, and 0.61 respectively, while the average EU innovation performance was 0.45. Notably, Sweden took the first place in this rank, ahead of countries such as US and Japan. Observed in the broader perspective, these results suggest that there is a favourable environment for (eco) innovation and technology development in the Nordic region. At national level, this observation may consider the disparities exhibited in terms of socio-economic capitals. Hence, technological uptakes among the countries may present different patterns and results.

## 6.2. Dynamics in the Nordic construction sector

In the context of construction, innovation in Nordic countries exhibit a high degree of "absorptive capacity" notably with regard to identification and utilization of new knowledge (NORDEN, 2008). Perhaps, this is due to the strong knowledge base on complementary areas such as material sciences, mechanical engineering, design and electronics, and availability of highly qualified personnel. However, the link between the industry and academy remain weak (NORDEN, 2008). On the other hand, the availability of human and financial resources in Nordic countries is following similar patterns than in the rest of EU; aging work force and lack of interest within young generations, and a cyclical market that discourage investment in new developments and innovation. Regarding market formation, in the Nordic markets building codes are the most influential instruments to create demand for energy efficiency in buildings but with a narrow scope mainly focused on insulation and heat recovery (NORDEN, 2008). This has important implications in the innovation trends in the Nordic construction sector, which tend to overemphasise *technical specifications* over *performance specifications* limiting the opportunity to radical innovations. Incentives to innovation, particularly on energy-efficiency have been focused on standard tax incentives and subsides (NORDEN, 2008; IEA, 2003). The result of such initiatives is considered to be unsuccessful across the region.

Construction employs approximately 6 to 8% of the total workforce of Nordic countries and is and activity of economic relevance in the region (NORDEN, 2008). Hence, the state has play a historical role in the development of the sector, particularly in Sweden and Denmark in which governments have a history of intervention in the residential sector. This interventionism has been conducted through commissioning of buildings and control of rents and subsidies to both companies and householders. Sweden and Denmark shows a large portion of their population leaving in rented or co-owned dwellings, while in Finland the rate of ownership is rather high. In Denmark, the level of ownership is greatly affected by the price of properties, 30% higher than in Sweden and Finland.

In the context of industrial dynamics, large-sized companies play a preponderant role in the Nordic construction market (NORDEN, 2008). These companies – the eventual developers of projects – have a large investment capability and therefore, a high incidence on economic decisions regarding the construction process. Three major companies based on Sweden have the most notorious role on construction developments across the Region (NORDEN, 2008). These developers often work with contractors belonging to their own companies. This tendency is becoming widespread across Nordic countries, emphasising the role of large-sized companies within the sector. This has become more conspicuous in Denmark and Sweden where companies are expanding their operations to a larger extension of the supply chain. In Denmark for instance, mayor contractors have purchased installation and material supply firms (NORDEN, 2008). Services are often provided by medium sized-companies while small firms predominantly conduct retrofitting activities following the overall EU trends (See EC, 2007). Construction – and related – policies and regulations in the region shows a similar pattern based on construction codes that greatly focus on energy specifications. The EU Directive on Energy Performance of Buildings enforced in 2003 influences the current policy framework for energy-efficiency (See Table 1). Energy savings in the Nordic construction sector have increased during the last 5 decades, due to more stringent norms notably in Denmark, though the development of specific codes for double glazing windows. These codes are expected to tighten even further by 2010 (NORDEN, 2008). Although, the energy-efficiency gains in the region are considerable, there is increasing criticism regarding the passive attitude to the sector with regard to innovation. Demonstration projects sponsored by Nordic governments proved that major efficiency gains are possible. However, companies are not yet fully considering such initiatives. This situation is often explained in terms of a weak collaboration within companies, government and academy.

Construction is one of the largest industries in Denmark, engaging one in four workers in the private sector (Ministry of Trade and Industry, 2000). This industry regards production of building materials, construction, consulting and the operation and maintenance buildings. As a sector, construction represents 10% of total Danish exports. In general, the competitiveness of the Danish construction sector has drastically decline during the last ten year. This implies that the overall efficiency of the sector is low carrying important implications for the internal market. Prices for new developments in Denmark are remarkably high in comparison to neighbouring countries at an average above 30%. Quality of constructed assets is also declining outlining service issues (Ministry of Trade and Industry, 2000). In Denmark, levels in the building trades are about 20 per cent below the OECD average measured by the overall share of R&D activities in the private sector, reflecting a decade of decline in investments and low innovative performance. However, several initiatives are being implemented in order to improve the sector competitiveness. These initiatives are online with current EU developments strategies. Hence, drivers and barriers to innovation in the sectors are not different to those addressed by the EU. Environment and construction are priority areas in the national innovation policy.

## 6.3. Developments in nanosciences and nanotechnologies

In the field of nanosciences Denmark, Finland and Sweden present a notable development while their nanotechnology uptake patters differs, notably in terms of organizational arrangements, industrial involvement and research and development focus. Although the R&D intensity of Nordic countries in the field is online with the EU average – and therefore lower than in US and Japan current leaders in the area – the scientific production of these countries is considerable (Cordis, 2005). In terms of nanotechnology EPO patents, Sweden shares 1% of total applications, Denmark 0,5%, and Finland 0,3% ( OECD, 2007). Nordic scientific production in the area is also relevant, with Sweden having a 2.05% share of the overall production, Finland 0.73, and Denmark 0.69% (Kostoff et al, 2007). In terms of most cited articles, the positions among the countries remain the same.

In Sweden, there is no formal national initiative on nanotechnology. However, a number of activities are being conducted in order to formalize a nanotechnology innovation system. There are approximately 500 active researchers in the field across 50 research groups and approximately 35 nanotech companies over 85 companies related in some way to the technology. Research and development concentrate around universities and industrial clusters. The focus of research is on Biotechnology, Electronics, Instruments and Equipment plus Materials and Surface Engineering (VINNOVA, 2008).

In Denmark, nanotechnology has become an important research and development area between academy and industry. Research in the field is conducted in all universities and there are an increasing number of research groups and centres of excellence being consolidated. Main areas of research include nano-architectures and structures, scanning probe techniques, optics and photonics, catalysts, and medical applications. There approximately 58 companies involve on research and development collaborations with academy (Risoe, 2007) and an estimated 14 nanotech firms (VINNOVA, 2008). Although developments in the area are of international relevance, there is yet a weak link between nanoscience advances and technology commercialization, particularly compared to developments in Sweden (Risoe, 2007).

In Finland, there are about 500 people working in the field of nanotechnology across 25 research groups and centres of excellence. (Lämsä et al., 2005). These groups concentrate on the Helsinki region, Tampere, Turku, Jyväskylä and Oulu. The focus of research and development is on nanostructured materials, new nanoelectronics solutions, and nanosensors and nanoactuators, while the main goal of the national research program is on strengthen existing research in the field, to accelerate the commercial development of nanotechnology and to support networking and researcher mobility. The current number of nanotech companies in Finland is about 19 (while the number of firms involved in some degree with nanotechnologies is larger). Funding to research and development in the field is supported by industry, academy and notably by government.

## 6.4. Nanoscience and nanotechnology in the Nordic construction sector

Direct applications of nanotechnologies in construction activities in Denmark are limited and broadly related to building materials. (Andersen et al., 2010). Therefore, innovation and eco-innovation – based on nanotechnology or driven by nanoscience – are at a very early stage of development in the Nordic construction sector. In this context, most of the focus of R&D – public and private – has been oriented towards medical, chemical, and energy applications. Andersen and collaborators (2010), suggests that in Denmark the interest of nanoscience is not in industrial applications whatsoever. Although R&D efforts are not focused on the construction sector currently, some of the ongoing innovation in nanosciences in Denmark might have potential applications in the construction sector, particularly in the area of sustainable building. In this context, the most advanced area is the application of nanotechnology in construction materials, notably, concrete and wood (Andersen et al., 2010).

In Finland, the scenario is not different. Only six firms working with nanotechnologies are – to some extent – related to construction activities (Andersen et al., 2010). In this country however, the potential application of nanotechnologies to well developed industries with incidence in construction, such as the case of wood production, might find favourable conditions (Palmberg and Nikulainen, 2008).

In Sweden, the development of nanotechnologies and nanoscience has focused on two sectors of strategic relevance to the countries' economic growth – electronics and bioscience. Direct R&D in construction applications is yet incipient as in the other Nordic countries. However, due to the higher development and interest on material sciences, Sweden exhibits a larger potential for development and application of nanotechnologies in building technologies (Andersen et al., 2010).

# 7. Concluding remarks

The construction sector in Europe is both, part of the problem and the solution in the challenge to achieve sustainable growth and competitiveness with less impact in the environment. Innovation is a key process in the search of higher efficiency and sustainability. Although the EU has already implemented several initiatives regarding innovation in the construction sector, the general indexes of innovativeness and productivity remain low if compared to other sectors. Based on the observations of current trends, this situation seems far from any considerable improvement. The review suggests that particularly strong barriers to innovation in the sector regard:

1. *Entangled cultural and organizational issues such as the nationally-oriented nature of the construction work,*
2. *The weight of tradition in building techniques and methods,*
3. *The political relevance of the sector in the national economy,*
4. *The increasing number and role of Small and Medium-sized enterprises within the sector and,*
5. *The project-oriented nature of the construction work*

In general, construction in the EU regards retrofitting of existing built infrastructure rather that of new and large-scale urban developments. This last issue suggests a particular feature of the EU if compared to regions – notably America and Asia – in which new developments and large-scale projects are the predominant drivers of innovation and knowledge creation in the construction sector. In Europe, although construction is strategically relevant to national and regional economies, cross-disciplinary research in the area is yet incipient. Indeed, recent studies suggest that measuring innovation in the sector is difficult due to the complexity of its operations and logistics, and the particularities of management systems. The missing information in the sector could account for a considerable amount of "hidden innovation". Therefore, whether the solution for an innovative sector should focus on the introduction and diffusion of new technologies (such as nanotechnologies) or the total redefinition of the activity itself, is yet a (necessary) conjecture.

Today, environmentally oriented innovation in the European construction sector seems to focus on particular stages and processes within the building cycle. Much focus is on materials, energy consumption and waste management. In this context, nanotechnologies find particular application niches, notably in the field of new materials. However, in spite that the potential application of these technologies is described as revolutionary, the sector has not adopted them thoroughly. No trends in the sector indicating an imminent change of attitude towards the applications of nanotechnologies were found by this review. In particular, the Nordic region – that currently exhibits one of the highest innovation indexes worldwide, and an adequate environment for eco-innovation and the development and application of nanotechnologies –exhibit similar trends observed in the rest of Europe. This suggests that in general, the performance and behaviour of the construction sector across Europe – in terms of innovation and technology-driven eco-innovation – is not significantly influenced by the innovation capability of countries, or their openness to eco-innovation.

In the global context, several initiatives are being implemented in order to promote and demonstrate the application of high-tech greener solutions – such as nanotechnologies – in the construction industry. However, in the context of this review, observed trends suggest that the current use of nano-engineered products in construction do not respond – in particular – to any environmentally driven strategy or motive. This might suggest in turns that eco-innovation in the construction industry is rather based on the incremental adoption (sometimes adaptation) and diffusion of technologies broadly developed – and successfully proven – in other productive sectors.

Eventually, the report concludes that although new technologies and/or new technological regimes are important innovation drivers – in any economic activity– the sound development of the European construction sector might also depend on non-technological innovation. This might imply a profound organizational and functional transformation of the sector, in line with the dynamics of national innovation systems. An important first step towards this change would be the systematic development of crossdisciplinary research in the area of construction and the built environment. In this context, the current lack of information and scientific evidence is unnecessarily hindering actions aiming to solve the many difficulties the sector faces today.

# 7. References


1. Andersen M., Sandén B. and Palmberg Ch. (2010) "Green Nanotechnology in Nordic Construction: Eco-innovation Strategies and Dynamics in Nordic Window Value Chains". Report, Nordic Innovation Center (Norden), Oslo, Norway, 90 p. June 2010
2. BUILD-NOVA. (2006a) "Characteristics of the construction sector – technology and market tendencies" Europe INNOVA, 93p.
3. BUILD-NOVA. (2006b) "Building Innovation in the European Construction" Europe INNOVA, 93p.
4. BUILD-NOVA. (2008) "Set of Policy Recommendations" D11, Europe INNOVA, 24p.
5. Chenga E., Hung Y. and Sin Tang B. (2006) "Exploring the economic impact of construction pollution by disaggregating the construction sector of the input–output table" *Building and Environment,* 41:1940–1951
6. CONSTRINNONET. (2004a) "Promoting Innovation in Construction Industry SMEs" Report on Regional Innovation & Technology Transfer Initiatives and Support for Small and Mediums Enterprises across the EU, 78 p.
7. CONSTRINNONET. (2004b ) "Innovation Issues, Successful Practice and Improvements" Report on Promoting Innovation in Construction Industry SMEs, 33p.
8. CONSTRINNONET. (2004c) "Regional Sectoral Support" Annex 3, Report on Regional Innovation & Technology Transfer Initiatives and Support for Small and Mediums Enterprises across the EU, 78p.
9. Cordis. (2005) "Some Figures about Nanotechnology R&D in Europe and Beyond" Unit G4 Nanosciences and Nanotechnologies European Commission, Research DG, Brussels
10. DG Enterprise and Industry. (2006) "Analysis and Assessment of the Elements of Certain Community Policies that Impact on the Competitiveness of the Construction Sector" Final Report, 258p.
11. Dick J. and Payne D. (2005) "Regional Sectoral Support: A Review of the Construction Industry, SMEs and Regional Innovation Strategies across Europe" *International Journal of Strategic Property Management* 9: 55-63
12. e-Business W@tch. (2006) "ICT and e-Business in the Construction Industry: ICT adoption and e-business activity in 2006" European Commission, Enterprise & Industry Directorate General, Brussels, Report No 7, 182 p.
13. E-CORE. (2005) "E-CORE Strategy for Construction RTD", ECCREDI, Brussels, 78p.
14. EC. (2008) "Coordinated action to accelerate the development of innovative markets of high value for Europe – the Lead Markets Initiative" MEMO/08/5, Brussels
15. EC. (2007) "Accelerating the Development of the Sustainable Construction Market in Europe" COM (2007) 860 final, Brussels
16. EC. (2006) "Putting knowledge into practice: A broad-based innovation strategy for the EU" COM (2006) 502 final, Brussels
17. ECTP. (2005a) "Challenging and Changing Europe's Built Environment: A vision for a sustainable and competitive construction sector by 2030" European Construction Technology Platform, EC, Brussels, 15p.
18. ECTP. (2005b) "Strategic Research Agenda for the European Construction Sector: Achieving a sustainable and competitive construction sector by 2030 " European Construction Technology Platform, EC, Brussels, 50p.
19. EF. (2005) "Trends and drivers of change in the European construction sector: Mapping report" European Foundation for the Improvement of Living and Working Conditions, 33 p.
20. EPA. (2007) "Nanotechnology White Paper" Science Policy Council, U.S. Environmental Protection Agency (EPA), Washington DC, 136p.
21. ETAP. (2007) "European Forum on Eco-Innovation: Markets for Sustainable Construction" Brussels, 20 p.
22. Freeman, C and Loucâ, F (2001): "*As times goes by. From the Industrial Revolutions to the Information Revolution*". Oxford: Oxford University Press.

23. Green Technology Forum. (2007) "*Nanotechnology for Green Building*" Indianapolis, 96 p. 2007
24. Karud O. (2007) "Defining the Value Chain" SINTEF Report on the Project STAND-INN (Integration of performance based building standards into business processes using IFC standards to enhance innovation and sustainable development), SINTEF, 41p.
25. Kemp R. and Pearson P. (2008) "Meassuring Eco-Innovation" Final Report MEI Project, Maastricht, The Netherlands, 122 p.
26. Lämsä M., Koponen P., Juvonen L. and Myllymäki V. (2005). "Nanotechnology a Priority Area" *Kemia-Kemi* Vol. 32 (6): 41-43
27. Manseau A. (1998) "Who Cares About Overall Industry Innovativeness?" *Building Research and Information*, 26 (4): 241-245
28. Ministry of Trade and Industry. (2000) "The Danish Construction Sector in the Future - from Tradition to Innovation" Building Policy Task Force, Ministry of Housing and Urban Affairs, Ministry of Trade and Industry, Denmark
29. NORDEN. (2008) "The Challenges of Energy Efficiency Innovations in the Nordic Building Sector" Greener Markets and Cleaner Technologies (GMCT), TemaNord 2008:566, Nordic Council of Ministers NORDEN, Copenhagen, 41p.
30. OECD. (2007) "Capturing Nanotechnology's Current State of Development via Analysis of Patents", DSTI/DOC (2007) 4, OECD, 52p.
31. Palmberg C. and Nikulainen T. (2008). *Nanotechnology and industrial renew-al in Finland*. ETLA B234.
32. PRO INNO EUROPE. (2008) "European Innovation Scoreboard 2007: Comparative Analysis of Innovation Performance" Inno Metrics Report, Belgium, 52p.
33. PRO INNO EUROPE (2010) "European Innovation Scoreboard (EIS) 2009. PRO INNO EUROPE Paper N°15, Belgium, 76p.
34. Reid A. and Miedzinski M. (2008) "Eco-Innovation: Final Report for Sectoral Innovation Watch" SYSTEMATIC Eco-Innovation Report 2008, Technopolis Group, 96 p.
35. Risoe. (2007) "Bridging nanotechnological opportunities and construction needs: NanoByg a survey of nanoinnovation in Danish Construction" Report, Risø National Laboratory, Technical University of Denmark Roskilde, 73 p.
36. The Royal Society. (2004) "*Nanoscience and nanotechnologies*", The Royal Society, London, 127p.
37. VINNOVA (2008) "Nanotechnology in Sweden- an Innovation System Approach to an Emerging Area", Verket för Innovationssystem, Swedish Governmental Agency for Innovation Systems, 100p.
38. WEC (2004) "*Energy End-Use Technologies for the 21st Century*" World Energy Council, WEC, London, 125p.
39. Wernerfelt, B. (1984) "The Resource-Based View of the Firm" *Strategic Management Journal*, 5 (2):171-180
40. Wernerfelt, B. (1995) "The Resource-Based View of the Firm: Ten Years After" *Strategic Management Journal*, 16 (3):171-174
41. Zhu W, Bartos P. and Porro A. (2004) "Application of nanotechnology in construction: Summary of a State-of-the-art Report" *Materials and Structures*, 37: 649-658
42. Zucker L., Darby M., Furner J., Liu R. and Ma H. (2007) "Minerva unbound: Knowledge Stocks, Knowledge Flows and New Knowledge Production" *Research Policy*, 36: 850-863

The aim of this report is to disseminate crossdisciplinary knowledge regarding innovation in the European construction sector. The review focuses on the challenge of incrementing the productivity and competitiveness of the sector while increasing its environmental sustainability. In this context, particular emphasis is given to the description and discussion of technology-driven eco-innovation initiatives such us nanotechnologies for a greener construction. Although the scope of this report covers the European construction sector, most data presented is at an EU scale. In this context, particular emphasis is given to the discussion of the main topics from the perspective of Nordic countries.

ISBN 978-87-92706-19-5

**DTU Management Engineering**
**Department of Management Engineering**
Technical University of Denmark

Produktionstorvet
Building 424
DK-2800 Kongens Lyngby
Denmark
Tel. +45 45 25 48 00
Fax +45 45 93 34 35

www.man.dtu.dk