Defining Characteristics of the Technological Innovation System for Zero Emission Buildings

Abstract

There is an apparent disconnect in the building industry between availability of technical know-how and materials on one hand and their uptake into building practices on the other (Brown and Vergragt 2008). Feasibility of zero-energy buildings has been repeatedly demonstrated by high profile prestige projects, but in the day-to-day reality of the building industry - with competitive tendering, project organization and predominance of small firms – sustainable measures are expensive and probably neither easy nor effortless to apply.

The bulk of research on zero energy buildings is technical. In the social sciences realm, specific policy measures such as energy labelling have been studied, as has end-user behaviour and satisfaction. A few studies address innovation. Slow diffusion of innovations in construction is often said to be because the construction sector is adversarial to change, conservative and not very innovative (Barlow 2000; Ryghaug and Sørensen 2009). Alternative explanations are explored here by asking:

Are there defining characteristics in the construction industry that can help explain why seemingly simple energy measures are difficult to do?

The construction industry has been largely absent from systemic innovation research. Applying a system of innovation approach to the analysis construction can provide new explanations for slow diffusion of zero energy buildings. As a means of structuring the discussion, the scheme of analysis from the literature on *technological innovation systems* (TIS) is applied. TIS analysis is twofold – there are structural elements and functions (activities). Since this is meant as a preliminary analysis and due to time and space constraints – the paper is limited to the structure, or basic building blocks of the system – the actors, institutions, networks and technology.

Introduction

This section introduces the analytical framework of Technological innovation systems.

Traditionally innovation has been thought of as a purely economic phenomenon. Increasingly - innovation and technological development are being upheld as solutions to societal issues such as mitigation of the current climate crisis. Diffusion of sustainable building techniques fits within that broader goal. It is notable because it means that the motivation to innovate lies not in the potential economic benefits. The lack of obvious economic incentives magnifies the importance of institutions and understanding the industry context.

Understanding industry context is at the core of the systemic approach to innovation. The idea of a system of innovation surfaced with the concept of a national innovation system (Freeman 1987; Lundvall 1992) which was quickly followed up with, regional innovation systems (Asheim and Isaksen 1997; Cooke, Gomez Uranga et al. 1997). A more conceptual delineation of system specified around an industrial sector was introduced by Malerba (2002). He emphasizes that a sectorial system should not be thought of as static, which is often done in the field of industrial economics, but as dynamic and in transformation.

A closely related concept is a system defined around specific technologies as introduced by Carlsson and Stankiewicz (1991). They define a technological innovation system as: *…networks of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing, and utilizing technology (Carlsson and Stankiewicz 1991) p.111.* From this approach the more recent, functionally oriented technological innovation systems approach developed. A TIS may be defined as a subsystem of a sectorial system, or around one technology transcending industry limits. The central proposition of TIS is that just as the market or the actors may obstruct its development, so can institutions and networks. Weaknesses in structure can lead to system failures (Bergek, Jacobsson et al. 2008). A TIS may have geographical dimension, but location is not used as instrument of delineation.

The main difference between the systems approaches comes down to level of analysis, and method of delineation. A sectorial systems approach could possibly have captured much of the same actors, institutions and relationships. We choose to apply the technological innovation systems approach because it is a subset of a sector, not the whole we want to examine.

In a much cited article, Bergek, Jacobsson et al. (2008) lay out a scheme of analysis for TIS. The first step of which is defining the TIS in focus. That means deciding if the object of study is a specific technology or an artefact, or if the focus of the study is a knowledge field or a set of related technologies. In this paper the starting point and level of the analysis is that of a product. Step two is about the more or less stable structural components of a system. The structural components are actors, institutions and networks. Actors can be firms in the value chain, financiers, supportive organizations, government bodies etc. Institutions are often understood as rules. Networks are the links and relationships between the components (Hekkert, Suurs et al. 2007; Bergek, Jacobsson et al. 2008; Jacobsson and Bergek 2011). Step three is considered the main advantage of the approach as it concerns the processes, what actually goes on in a technological system.[1]

This paper, being a preliminary study, explicitly focuses on the first two steps of the TIS analysis. The analysis will point to system functions, but the full potential of a functional TIS study is not reached, as this is meant as a pilot study to gain overview, not policy advice. And that is, defining the focus and on the structure of the system. The structure is a relatively stable configuration of elements. Noting that the system is understood as fluid and emergent, the goal is to identify actors, describe structure and understanding the field and its institutional set-up. And perhaps this effort can point to clues about how to explain the slow diffusion of innovative building concepts and perceived lack of change in the field.

Methods

The study is qualitative. Research methods include: A review of relevant literature as well as policy documents. 7 semi-structured interviews with industry experts were conducted. Interviews were recorded and transcribed. I have attended industry events

[1] There are six steps in total – assesing functions or activities in the system is the star attraction.

such as breakfast meetings, industry fairs and seminars and courses, from which I have written field notes.

Defining the system in question

This section provides a clarification of what we mean by zero-energy building, and a discussion of what kind of an innovation it might be. In the scheme of analysis outlined above, the first step is to define the system in focus. (Carlsson, Jacobsson et al. 2002).

Zero energy buildings are a category of product found in a specific sector. There are different names and meanings given to this type of building. First od all because there are various meanings of sustainability, and secondly because several similar competing design concepts exist. In this paper sustainability is understood to be about mainly energy use, and climate change. And the buildings are taken to mean what Guy and Farmer (2001) called an eco-technic approach to architecture. It is essentially to plan and construct buildings that consume very little or no energy, or consume very little and produces energy in addition[2].

Within this understanding, there are specific product innovations, for example new building materials, new more effective heat pumps, very low u-value windows etc. the point here though is not to talk only of specific components, because single artefacts cannot mirror the complexity and integration issues relevant in building processes. The interesting innovations here are conceptual or architectural. For example passive buildings, plus energy houses, net zero-energy building, zero-emission building solar buildings or houses built according to strict standards such as BREEAM or LEED.

It is helpful to clarify what kind of products buildings are to understand what kind of innovations we are studying. According to Winch (1998) all constructed products are complex product systems in line with Miller, Hobday et al. (1995) where complex systems products are characterized as: highly customized, large scale and engineering intensive (Winch 1998; Gann and Salter 2000). Almost all buildings must also be integrated in infrastructures such as electricity grid, district heating, communication etc. These are infrastructures that carry with them constraints of the technologies they are designed for. So buildings are complex systems within complex systems (Gann and Salter 2000).

Innovation in complex systems products comprises components, product architecture and process. Planning and building new varieties of buildings may require process–innovations. That is innovations in organizational form or organization of process (Henderson and Clark 1990).

Structural configuration

In this section, actors, institutions, networks are discussed. The configuration of the system is described in an effort to explore why innovation in this respect is not a simple case of "rolling out" or implementing known technologies. This is not meant as a complete list of all actors, institutions or networks. The intention is to highlight some elements especially relevant for zero-energy buildings.

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[2] As opposed to other approaches to building that are concerned with natural materials without chemicals, or alternative materials like hemp or rubbish. Also not included are approaches that are about removing oneself from consumption altogether like "autonomous" homes aim to do.

Actors

Actors are organizations or individuals contributing to a technology. Adopting it, developing it, or influencing it through regulation. Actors are not necessarily firms, just as often they are other organizations or individuals - but they posses agency and ability to influence and change institutions. Some actors are more able to influence development and direction of system than other actors (Musiolik and Markard 2011). Hughes (1983) called them system builders. They can create political forces to lobby on behalf of their preferred technology or solution. There is considerable variety of potential actors. The following actor categories are discussed: Firm, project and industry actors, knowledge and educational actors, and finally government and supportive organizations.

Firms, project and industry actors

Starting with firms it is relevant to mention that the pattern of firms in the construction industry is dominated by rather small businesses and a few very large firms (Espelien and Reve 2007). Industry associations and unions are significant actors in the system because they influence working conditions, and importantly they are a significant source of continued education and updated learning for their members. For example the Norwegian association of Architects (NAL) provide extensive courses on for example sustainable building or HVAC planning relevant for architects. The builders association offers courses relevant for energy rehabilitation[3]. Another significant industry actor is the Norwegian Green Building Council, who owns the BREEAM-NOR certification tool. The council is non-commercial and consists 170 members along the whole value chain. They accredit professional surveyors in BREEAM-NOR to enforce the standard and they have extensive course activities in the whole country

An important trait of the construction industry is the organization of work in projects. Organizing around projects has several implications for the possibilities of firm level innovation. First because there may be broken learning and feedback loops between project and firm level. The uniqueness of each project - in team composition, location and product - invariably leads to a degree of "reinventing the wheel" in every project. The discontinuity of project work is not conducive to the formation of routines. Routines cumulate to enhance an organization's skills and increase firm's incremental innovation opportunities (Nelson and Winter 1982; Fagerberg, Mowery et al. 2005).

Project level actors need to be considered, and building projects tends to be split in two project organizations. One for planning and one for production (Winch 1998) On the project level the two organizations may partially overlap both in time and in participants. The design organization is established when a building project starts, land use planning, applying for permits and designing the building is initiated.

A typical design organization assemblage would be client, architect, contractor, HVAC designer, structural engineer, geological engineer, and electrical engineer. The architect usually manages the integration of other specialists input in the designs as they develop. Normally the architect also mediates the relationship between municipal actors and the client by applying for relevant permits etc. The production organization on the other hand, is established when the actual construction starts. The main actors are client,

[3] See: http://www.arkitektur.no/?nid=241917 for NAL course on HVAC , or http://www.arkitektur.no/?nid=242262 for NAL course on sustainability. For builders association see: http://www.byggmesterforbundet.no/kurskatalog/2012/#/10/zoomed

contractor, who is now project manager, and architect and various subcontractors and suppliers and installers. Subcontracting is very common in construction projects. Depending on contract type, a general contractor or the client divides the project into smaller contracts and awards to lowest bidder. Subcontractors also employ their own subcontractors and their own suppliers.

Knowledge and educational actors

It is not possible to review all educational actors here. Participants in building projects are diverse and represent almost all parts of the educational system. Builders, carpenters, plumbers, plasterers, electricians, painters, engineers, geologists, physicists, architects and a myriad of consultants all bring their expertise and know-how to projects. The level of energy and environmental awareness in the relevant educations is interesting, but has not been considered here. In industry R&D there is one very influencial actor. It is *Sintef Building and Infrastructure*. Sintef BI is a private (historically public) research institute devoted to the needs of the construction industry. They play many important roles. One such role is as information repository, by maintaining a large depot of "design details" available to architects and planners. These details include for example designs to avoid thermal bridges. Sintef BI also offers certification and technical documentation of products and materials. They offer specialist consultancy to projects on energy issues. And of course they conduct the vast majority of research activities pertaining to sustainability in construction[4]. Sintef BI has close ties to the Norwegian University of Science and technology in Trondheim and together they are home to the Zero emission buildings research centre, which is The Research Centre is one of eleven national Centres for Environment-friendly Energy Research (FME) establish by The Research Council of Norway[5].

Government and supportive organizations

National government shape focus of policy and give direction to other public organizations. The building codes are national, while municipal government is responsible for planning and zoning. We will come back to the regulation aspect in the section on Institutions. Two organizations are worth mentioning here. Enova are a public enterprise that is owned by the Ministry of Petroleum and Energy. They support energy measures in buildings by stimulating demand. It is debateable whether stimulating close to market technologies is the most conducive policy for innovation. The Norwegian state housing bank (NSHB) is also a public financing actor; they offer inexpensive loans and project-development subsidies to building projects that display particular sustainability ambitions. They can make demands on energy performance beyond what is specified in the building codes in exchange for financing.

Institutions

Institutional structures are at the heart of the systems approach. The TIS perspective does not offer much nuanced when it comes to the account of institutions. In the TIS literature institutions are often described as "rules of the game", the definition given by North (1990). Regulative institutions are laws and regulations – these are based on a cohesive logic, which means they are backed up by a system of sanctions. The most important regulative institution in relation to energy use can be found in the Norwegian building codes called TEK 10. The TEK specifies minimum u-values for building

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[4] See Sintef hompage for all activities: http://www.sintef.no/home/Building-and-Infrastructure/Buildings/

components such as roof, wall and windows, if all are made according to specification the building is in compliance. Also specified in TEK is maximum energy for space heating etc. The building codes are meant as a minimum standard, but there is very little incentive to go beyond their ambitions.

Also in the regulative realm - Standard Norway is the national standardization organization. National standards are developed as well as "translations" of EU and ISO standards. Standards play an important role in the regulation of construction activities because they are incorporated and referred to in the building codes. In relation to sustainability there are three relevant standards. They describe energy calculation methods for whole buildings such as passive houses and low energy buildings, one standard for commercial buildings (NS3701), and one for residential (NS3700). There is standard that relates directly to the building codes (NS3031). The process of creating the first passive-house standard for residential buildings was delayed several times. Several interviewees have pointed out that it was a turbulent process with a high level of discussions and disagreements. The creation of standards illustrates how firms compete not only in the market, but also in the institutional context to gain legitimacy. (Van de Ven and Garud 1993; Musiolik, Markard et al. 2012)

Both regulation and industry standards can act as a source of innovation, but they can just as easily become conservative forces. It has been argued that stringent policy demands can trigger innovation, but the stringency does have a sell-by date (Porter and Linde 1995; Dewick and Miozzo 2002). Another relevant institution is the procurement practices are important. Public actors are required by law to invite tenders and award contracts to lowest bidders. Most building projects are subject to contract bidding even if not legally required to do so.

Networks

The relationships between actors and institutions are formed in networks. Some of these are formalized, but many are informal. Three formal network spaces dedicated to environmental issues are identified here. The NGBC is provides a network frame for its members. The "low-energy programme" includes municipal and state organizations, firms and professional organizations. The architect's professional organization (NAL) provide a network called Ecobox, which includes a project database, they arrange courses and continued education, and monthly breakfast meetings about sustainable architecture. Membership or association with these networks may be overlapping as participants in one is likely to also participate in others.

Summary

Buildings, and particularly zero energy buildings must be understood as a specific type of *product*. If we view buildings as complex systems products in line with Miller, Hobday et al. (1995) – we see they are unique or highly customized one-off projects. Buildings are bound to location, which has implications for production. Buildings generally last for a long time (more than 50 years), which underscores how important decisions about energy use today are for the buildings performance in the future.

The *process* of building also displays distinctive characteristics. Not only are buildings complex systems products, but also the process of building is equally complex (Ørstavik and Pedersen 2011) which means uncertainty, lacking information, and many unknown dependencies. Contracts are won by competitive tendering, which means price is the major concern. Because work in construction is always project-based, relevant organizations are temporal. The discontinuousness has consequences for learning and may cause broken feedback cycles and little opportunity for the creation of organizational routines. Procurement practices – competitive tendering and extensive subcontracting cause fragmentation. Temporary organizations are held together by legal contracts, since contracts already specify the work to be done – it is easier to do just what the contract specifies instead of what might be best for the project as a whole.

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