DOI NUMBER: 10.19255/JMPM01208

KEYWORDS Innovation ▪ project management ▪ sustainable energy ▪ processuality ▪ client ▪ geothermal heating ▪ bio-climatic design

THE DYNAMICS OF INNOVATION DRIVERS: CLIENT REQUIREMENTS and sustainable energy innovation uptake

Satu Reijonen
Senior Adviser at The Nordic Council of Ministers
sare@norden.org

Rebecca Pinheiro-Croisel
Professor of Management at UQTR and Associate Professor at Sciences Po Rennes
rebecca.pinheiro@uqtr.ca

ABSTRACT

Despite growing interest, sustainable energy innovations encounter difficulties in attaining market success. This paper investigates the role of requirements set up by the clients in generating more conducive conditions for sustainable energy innovations in building projects. With the help of two case studies we identify three dynamics provoked by specific client objectives with a focus on sustainability: the dynamics of exploration beyond the habitual ways, the dynamics of future inclusion and the dynamics of verification. By provoking these dynamics, client requirements change the prevailing level of ambition of the project and the ways in which the benefits and costs are calculated. They thereby create a strong entanglement of the sustainable energy innovation and the design project. Furthermore, the dynamics tend to favour the uptake of existing innovations rather than generating completely novel solutions. The article concludes with a discussion on the possibilities of policy intervention for innovation supportive dynamics in construction projects.

Introduction

Sustainable energy innovation is a popular catchphrase in the construction sector today. While the integration of energy related considerations into the very early phases of the design process is commonly viewed as a prerequisite for sustainable energy solutions in building, building projects rarely succeed in doing this in practice. Client requirements as expressed in both competition and tender briefs and successive contracts include instructions to competitors and may define issues such as the responsibilities of the actors, the financial resources, time frame, functional criteria and the level of ambition related to the energy performance of the building to be designed. While not necessarily binding, briefs touch upon many issues that enable or prevent the integration of sustainable energy innovation from the very early phases of the design process. For instance, the objectives listed by the client may contribute to different circumstances that are commonly viewed as hindrances to innovation in the construction sector, including the project-based nature of the industry (Hardie, 2010; Jacobsson and Linderoth, 2010; Nam and Tatum, 1998; Winch, 1998) and overdependence on cost (Hardie, 2010). Early client requirements may thus be one of the elements that work towards bringing sustainable energy innovations into – or keeping them out of - construction.

Apart from a few exceptions, there is very little academic discussion about client requirements in construction, and even less in relation to the role of client demands in advancing sustainable energy innovation. In terms of other drivers and barriers for innovation in construction, however, the extant literature offers a wealth of readings. The influences mentioned can be divided into those addressing the capabilities of the firm (e.g. Lu and Sexton, 2006; Manley, 2008; Seaden et al., 2003), the firm's environment (e.g. Ivory, 2005; Manley, 2006, 2008; Winch, 1998), issues influencing its relationship with its environment (Winch, 1998) and the generic mode of work in the construction sector (e.g. Hardie, 2010; Koskela and Vrijhoef; 2010, Nam and Tatum, 1998; Reichstein et al., 2006). While this body of literature recognizes a wide range of different actors and contextual conditions in the construction industry, the drivers of, or hindrances to innovation are mainly dealt with as generic categories applying to the whole sector. Furthermore, very little attention is paid to the ways in which the drivers of innovation actually influence the actors in construction projects as these evolve over time. These two shortcomings lead to an overly generalized picture and understanding of how innovation is shaped in the construction sector. In order to add to the existing literature on these critical points, this study attempts to 1) contribute processual and contextual understanding of influences on innovation and 2) shed light on the role of explicit client requirements in innovation processes. In addition, we bring the findings of this article into the discussion about policy interventions for sustainable energy innovation. We claim that client relations hold a great potential in terms of promoting innovation, which makes this study especially interesting in terms of policies for environmentally sustainable construction.

This paper presents two empirical studies of innovation in the construction sector with a focus on a hitherto little studied type of influence on innovation uptake: client requirements. We follow the relationship between client requirements and the innovation, from the competition and tender phases to the design process under contract. Our interest lies in examining how client requirements shape the design work in ways that may affect uptake of sustainable energy innovations. Based on our empirical studies, we theorize about the relationship between an influence on innovation and the innovation itself, by highlighting the dynamics related to the ways in which the client requirements may promote the uptake of sustainable energy innovation during the course of a building project.

This article will begin with a review of the current literature on innovation and construction. We will then introduce an emerging approach to innovation in the construction sector (Harty, 2005, 2008, 2010; Schweber and Harty, 2010) and position our theoretical standpoint in relation to this. After a note on our research methods, we will introduce the results of two case studies on the role of client requirements in the uptake of sustainable energy innovations in France and in Denmark, respectively. We will proceed with a comparison of the different types of client requirements demonstrated by our case studies and their role in facilitating innovation. Finally, the findings will be discussed with respect to the possibilities of successful political intervention for sustainable energy innovations in construction.

Theoretical landscape: drivers for innovation in the construction sector

Innovation in the construction sector is not a simple matter (Tryggestad et al., 2010). The magnitude of the different possible influences and the complexity of their possible interactions underline the difficulty of successful regulative intervention. The influences mentioned in the extant literature can be put into three loose categories: 1) the generic characteristics of the sector, 2) the firm's resources and capabilities and 3) the firm's innovation environment. As for the general conditions in the construction sector, several authors suggest that the industry structure consisting of many small firms is a hindrance to innovation (Hardie, 2010; Nam and Tatum, 1998; Reichstein et al., 2006). The project-based mode of action with its temporary work coalitions is mentioned as another barrier to innovation (Hardie, 2010; Jacobsson and Linderoth, 2010; Nam and Tatum, 1998; Winch, 1998). In the same vein, the time frame of a construction project is seldom long enough for explorative innovation to be generated (see e.g. Hartmann 2006). Locality of markets (Reichstein et al., 2005), overdependence on cost (Hardie, 2010) and dependency on fixed capital investment decisions (Nam and Tatum, 1998), supply chain complexity (Hardie, 2010; Winch, 1998), the tacit nature of industry knowledge (Hardie 2010) and the separation of design and maintenance functions (Nam and Tatum, 1998), resistance to standardization (Hardie, 2010), the high level of in-situ production (Nam and Tatum, 1998), and so forth, are yet more industry-specific characteristics considered to work against novel thinking and technology uptake. Furthermore, Hardie (2010) and Koskela and Vrijhoef (2010) claim that the industry suffers from a peculiar self-perception: the inherent uncertainty and interdependence of operations are ignored.

The firm's internal capacities, such as its marketing, human relations, technology and relationship strategies and capital (Lu and Sexton, 2006; Manley, 2008; Seaden et al., 2003), its ability to translate learnings between projects (Manley, 2008), structures for knowledge storage and transmission (Lu and Sexton, 2006), level of employee education (Bröchner, 2010), technological leadership and innovation-friendly leadership (Manley, 2008; Nam and Tatum, 1997) are often highlighted as relevant for innovative action in construction projects. The characteristics of the innovation also play a role in this respect: there has to be a good fit between the capabilities and resources of the firm and those required by the innovation itself (Manley, 2008).

In addition to the above-mentioned points, the firm's environment of interaction is another theme that is frequently depicted as decisive for innovation in the construction sector. Regulation (Manley, 2008; Gann, et al., 1998) and the role of other actors outside the construction project, such as independent brokers (Manley, 2008; Winch, 1998), are thought to play a role in enhancing or hindering innovation in firms. In terms of inter-firm relations, Winch (1998) highlights the importance of a system integrator (a kind of inter-organizational innovation champion) that organizes the relations between the project partners.

In relation to the environment of the firm, it is generally agreed that clients have a significant impact (see for example Manley 2006; Nam and Tatum 1997; Winch 1998) and the literature points towards a handful of issues that may explain client driven success in innovation. However, as Ivory (2005) points out, not all clients are interested, committed or competent and often the benefits have to be clearly demonstrated and the risks minimized for the client to become involved in innovation (Hartmann 2006). To further innovation, clients ought to be committed both financially and organizationally (Nam and Tatum 1997). The incentives for designers and constructors in innovation projects are increased when the clients are ready for risk- and gain-sharing; this, amongst other issues, is reflected in their procurement and tendering strategies (Manley 2008; Winch 1998) and inputs to R&D (Hartmann 2006; Manley 2008). According to studies made in small firms, client involvement in the project practice is seen as a factor that motivates designers to innovate (Lu and Sexton 2006). Advanced clients, who set challenging project demands, may also propel innovation (Manley 2008). Technical competency may be a key to both advanced client involvement and leadership but also to the ability to set high demands that trigger innovation (Nam and Tatum 1997; Winch 1998). In this article, we will further investigate the role of client demands in innovation.

Towards a new understanding of influences on innovation in construction

While scholars have recently successfully identified a host of different drivers and barriers for innovation in general, these are still portrayed in rather stable and universal terms. Influences are identified and listed without much discussion (let alone theorizing) about when, why and how these issues might influence the relationship between an innovation and its possible future users. The often mechanical and simplified understanding of innovation drivers and barriers is interlinked with the abstract, acontextual and descriptive models of innovation prevalent in many of the current theories of innovation, as noted by Schweber and Harty (2010: 673). These models of innovation are clearly distinguishable in the few texts that have attempted to capture the dynamics of innovation and innovation influences in the construction sector in more conceptual terms. These include the work of Slaughter (2000) who puts forward a rather mechanical understanding of innovation as consisting of different stages of implementation. A similar generic model is advocated by Sexton and Barret (2003) who depict innovation process as consisting of five parts: diagnosis, action plan, taking action, evaluation and specific learning. In the light of the generic nature of the extant research, it is hardly surprising that there has been a call for empirical studies on the process and trajectories of innovation (Reichstein et al,. 2005, Winch, 1998). Some exceptions to this can be found in recent studies that provide empirical accounts of building processes and study the role of innovation drivers (e.g. Harty, 2005; 2008; Ivory, 2005; Jacobsson and Linderoth, 2010; Manley, 2008; Schweber and Harty 2010).

While the majority of these readings focus on identifying crucial barriers and drivers for innovation in construction, some recent contributions predominantly inspired by Science and Technology Studies and especially Actor-Network Theory (Akrich, 1992; de Laet and Mol, 2000; Latour, 1996) have highlighted the benefits of examining innovation as a process taking place in the micropractices between different actors. These scholars advocate analytical approaches that pay attention to the distributed, on-going and negotiated nature of innovation, taking place across a variety of organizations and networks of actors (e.g. Harty, 2010; 2008; Schweber and Harty, 2010), rather than approaches that anticipate stability in the innovation and in the contexts of its development and implementation. We wish to build further on this emerging approach to innovation in the construction sector.

In this paper, we bring the emerging relational and processual approach to an investigation of the workings of influences on innovation in construction. In the realm of Actor-Network Theory (ANT), scholars have intensively studied the role of different non-human actors - for example marketing devices, management technologies and theories - in social life and, as relevant here, in shaping the ways innovations emerge and stabilize[1]. These studies show that while the influence of any thing, tool or device cannot be taken for granted, when supported by other socio-material elements they may nevertheless make the environment more or less suitable for innovation. Thus, the interesting question for ANT is not so much whether the devices have influence or agency but rather, how their influence comes about and what consequences this has. In this paper, we attempt to investigate how and by which means the client requirements listed in briefs and contracts can possibly reformulate architectural and engineering design practices in terms of innovation. We suggest that the ways in which client requirements may become influential in terms of innovation can be understood when investigating the ways in which they shape the calculative (Callon 1998) dimension of design work.

Design practices are abundant with choices about design options and decisions about which ideas to develop further and which innovations to pursue. In this continuously developing design space, the design team assesses, evaluates, compares and differentiates between different possible paths forward. In these terms, design practice is – apart from being creative – also a calculative practice understood as including both quantitative but also calculative assessments (for more see Callon 1998; Cochoy 2008). The client requirements posed in the tender and competition briefs and contracts may be enrolled into these assessments of what design options may be most appropriate. Hence, the requirements may shape the calculative space within which the decision-making and creative work takes place. To use another term, the requirements may help frame (Callon 1998) the situation and the choices related to this in a particular fashion, making some of the design options – innovative or less innovative - more attractive than others. In order to better capture the processuality by which client requirements organize and transform the calculative dimension of the design space, we propose that these requirements provoke particular dynamics in design practice that may lead to the uptake or the generation of an innovation. These dynamics may, for instance, consist of specific ways of perceiving benefits and risks – or costs, as in our case – and the use of related tools and calculation programmes. In the following analysis, we will discuss the dynamics provoked by two different types of client requirements as posed in the project briefs.

1. Aramis, Market devices

2.Approaching the relationship between the influence on innovation, the innovation and the project through the notion of dynamics hinges on the approach advocated by Jacobsson and Linderoth (2010) in their recent study on the adoption and use of ICT in construction projects. Jacobsson and Linderoth claim that contextual elements of construction such as project organizing, influence actors' frames of reference and lead to specific interpretations of new technologies and solutions. These interpretations in turn influence the possibility of success for the uptake of these technologies.

3. Uni A and the related names of actors are pseudonyms for reasons of confidentiality.

Methods

The findings of this article are based on an analysis of two cases studies (Yin 1981) on the role of client requirements in promoting sustainable energy solutions in construction projects. The first case study took place in a design project of a university campus, Ecole Nationale Supérieure des Techniques Avancées (ENSTA), initiated as an open public tender process. The campus was designed and built in France in 2007-2012. The second case study, Uni A, concerns a project where a university college was designed as a result of an architectural competition in Denmark from 2009 onwards.

In both cases, a specific sustainable energy innovation was taken up. In ENSTA, geothermal heating technology was applied to the whole campus area. In essence, geothermal heating refers to a heat pump technology used to harvest heat from the ground. Geothermal heating technology is well known and increasingly used for heating private homes in countries such as Sweden and Finland, but its use is still somewhat limited in France. Furthermore, it is uncommon for it to be applied on a large scale. In Uni A, the design team adopted a bioclimatic design principle to design the building. The principle, which depicts architecture that relies on passive solar systems for heating, cooling and lighting the buildings, is well known in green architecture but the innovation has not been brought into wide use in conventional projects.

Client requirements for sustainable energy solutions

The focus of this article is on the potential role of client requirements in enhancing innovation uptake in construction. Our cases demonstrate two different, relatively unusual sets of objectives defined in the competition and tender briefs and contracts, which influenced the sustainable energy innovations in their own ways. Thus, our case studies offer an interesting opportunity not only to investigate the role of influences on innovation in design processes but also to investigate and compare the differences and similarities in the ways different 'disruptive' elements in the client requirements may work to foster and enhance innovation.

The influential elements in the client requirements in terms of the adoption of the respective sustainable energy innovations in our case studies are as follows. In the ENSTA case, the tender brief indicates a 30-year period allocating responsibility of the design, building and maintenance of the campus area, its buildings and the heating system and heat production to a design team. In addition to the 30-year financial and executive responsibility, the brief also specifies that 50% of the heating energy has to be obtained from renewable sources. Also, the heating costs need to be lower than those paid by the client in its current sites. As to the energy performance of the building, the regulations in force in France since 2005 were also valid for the project, setting the buildings' maximum consumption at 80 kWh/m2/year of primary energy.

In Uni A, the competition brief was slightly more conventional than the brief for ENSTA. In Uni A, the pivotal element in the brief was the requirement that the buildings meet the standard of Low Energy Class I, as defined by the Danish Building Code 2008. The low energy class was a voluntary standard which at that time set the maximum energy consumption of a building at 45 kWh/m2/year of primary energy, i.e. 50% lower than the norm. This reduction could be achieved by any possible means, including compensation by renewable energy sources located on the same building ground, or by using energy-saving building technologies and forms.

Data collection and analysis

In the case studies, our aim was to understand the influence of client requirements on decision-making, actions and explorations in the uptake of sustainable energy innovations. Both cases rely on interviews, documents such as technical studies, meeting notes, memos and e-mails, observations of meetings and, in the case of ENSTA, site visits with members of the design team during the construction phase. In addition, frequent observations of the architects' work were conducted in Uni A, often on a daily basis, during the three first months of the post-competition design phase in 2009. In both cases, the data regarding the competition and tender phases comprises documents and retrospective semi-structured interviews. While the design phases of both cases were followed in real time, retrospective interviews were also carried out after the design phase.

For ENSTA, a total of 12 semi-structured interviews were carried out with the design team. 11 of the interviews were with construction engineers and one with the energy services engineering company. For Uni A, four retrospective interviews took place with the leading architect, energy consultants in the architect firm and an energy engineer in the engineering firm. The design team in ENSTA consists of a private grouping comprising a company providing funding, an architecture firm, a construction-engineering firm (Vinci Construction) and an energy services thermal engineering company (Cofely). The construction engineering company was the leading partner of the grouping. Uni A was a design and build competition, meaning that a turnkey contractor assumed the final responsibility for the design and construction of the building. The design team consisted of an architecture firm and an engineering firm, both employed by the turnkey contractor.

In order to analyze the data, information related to either the uptake of the respective innovations or to the project brief and successive contract was extracted from the body of data. We proceeded by asking 1) how the respective innovations were stabilized and 2) what role the client requirements played in this process. Having identified the interfaces between innovation and the client requirements, we proceeded by studying which kind of dynamics the client requirements created in support of the innovation. Three categories emerged in the course of the data analysis, featuring the different dynamics through which the requirements transformed the design practice to accommodate for the sustainable energy innovation. These dynamics are discussed in the following section.

Findings: the dynamics of influences on innovation

Drivers and barriers for innovation make the world around the novelty more conducive to innovation. We have argued for the benefits of a better understanding of the process through which the influences on innovation reconfigure the prevailing logics of action and socio-material entanglements that may be ignorant of or even hostile towards the ways in which the innovation works. The following analysis captures three specific dynamics provoked by client requirements, which shape the existing conditions for innovation: the dynamics of exploration beyond the habitual, the dynamics of future inclusion and the dynamics of verification.

Dynamics of exploration beyond the habitual

Dynamics of exploration beyond the habitual

In both the ENSTA and Uni A cases, the project briefs and the successive contracts include specific objectives related to energy sustainability that are not used in 'business as usual' projects. In ENSTA, the client demanded that 50% of the energy used in heating be produced from renewable energy sources. In Uni A, the competition brief stated an ambitious energy performance requirement for the building: the building should meet a voluntary Low Energy Class I requirement defined in the Danish Building Code 2008. In practice this meant that its maximum energy consumption should be 45 KwH/m2/year, i.e. 50 percent of the legal maximum. In the following, we discuss how these client requirements influenced the uptake of sustainable energy innovations in the respective cases.

In the Uni A case, the Low Energy Class I requirement was already effective very early on in the design phase. After studying the competition brief, the team that was later to be declared the winner of the competition conferred to discuss and define shared visions for their work. This meeting took the form of a brain storming session facilitated by an engineering PhD student, Charles, employed by the architecture firm at that time. In an interview, Charles explained that three main visions emerged in the discussions, one of these being: 'The house has to be a 'green' house that can accommodate future requirements.' During the brain storming, the design team decided between two approaches to meet the Low Energy Class I requirement, both of which would require an innovative approach to the design process: the bioclimatic design principle or compensating for the building's energy use by adopting technical innovations. A yellow Post It on the white board signalled that the design team preferred to focus on the passive elements of the building: 'No solar panels!' A few days later, the design team's decision to opt for a bioclimatic design strategy was communicated to an engineering student, Lucy, as a way for the architects to avoid technology such as solar panels, which would break the visual harmony of the façade. According to the head architect, Lone, the tight budget of the turnkey project also influenced the decision not to use technology that was deemed more expensive.

We argue that the level of ambition defined by the client's functional requirements provoked dynamics of exploration beyond the design team's habitual practices. The client's clearly stated ambition provided a framework in which more ambitious energy measures had to be taken into consideration. In practice, this meant that energy issues had to be integrated into the design or alternatively, that the energy target had to be attained through an ambitious, innovative technology strategy, for example by introducing solar panels to compensate for the electricity used.

In Uni A, the dynamics of exploring beyond the habitual ways continued throughout the competition phase. The bioclimatic design principle itself did not form a single predefined object whose effect could be calculated at once. In practice this meant that the design was gradually optimized, simultaneously to its development. As such, this is nothing new in design projects. Here, however, the energy consultants and the energy engineer continued to explore different possible designs in relation to their energy-related impacts on a remarkable scale. For instance, the in-house energy consultants delivered 12 different suggestions for a preliminary façade concept and investigated the impact of different types of glass and different floor materials on the amount of daylight in the rooms. The head architect, Lone, later described the amount of work carried out on the windows and façade as follows:

> '…so, in fact it is just a way to locate things rightly in terms of daylight. Because daylight is a primary source when we talk about energy, and the more there is, the more we can save when turning on the lights. We worked especially to make the daylight function. It was, in fact, daylight that was the primary thing here [in working on the building's shape and the concept of the façade].

Furthermore, the energy engineer was physically placed in the architecture firm during the design process, to enable close cooperation and immediate feedback to the emerging design ideas. While the scale of exploration related to the energy solution was clearly motivated by the client requirement, it cannot be concluded that this exceptionally strong effort by energy engineering professionals will be generated in every project aimed at achieving the Low Energy Class I.

Another example of the dynamics of exploration beyond the habitual ways is provided by the ENSTA case, where the client demanded that 50% of the energy used for heating the buildings should be covered by renewable energy sources. The major part of the turnover of Cofely, one of the engineering partners in the project group, came from the production and supply of natural gas[4] in France, an area in which it had acquired competencies through the acquisition of the oldest national gas company in France (GDF). While Cofely had also recently begun to offer bio-gas services, it still had most experience in the production and distribution of energy from natural gas. Accordingly, Cofely thermal engineers proposed a solution to power campus buildings with conventional gas. They were confident because they knew themselves to be the best designers, builders and managers of gas heating systems. However, as the head architect Domingos, from Vinci Design stated:

> 'To meet the requirement of using renewable energy, we had to eliminate the natural gas solution.'

The 50% requirement and the lack of a gas supply/distribution network on the campus site framed the design space in a manner that left the project partners with no other choice but to inquire into alternatives in the realm of renewable energy sources. Thus, the requirement forced the design team for ENSTA to move beyond their habitual resource base in gas-based heating. In this case, the engineers at Vinci and Cofely launched a joint exploration process that began by studying possible renewable energy solutions for the building project. Several potential solutions were studied by them, three of which - photovoltaic solar energy, biogas and geothermal energy - were submitted to detailed investigations regarding their applicability, the price of purchasing, installation and maintenance of the technology and the price of heating.

Dynamics of future inclusion

In addition to the requirement for 50% of the energy used in heating to be produced by renewable energy sources, the ENSTA brief also included other energy-related stipulations. According to the brief, the engineering firms Vinci Construction and Cofely were financially responsible for the construction of the technology for the production and distribution of heating energy in the campus area, and for the technical maintenance of these solutions during the 30 year contract period. Furthermore, while the actual energy bill was to be paid by the occupants, the design group was obliged to reduce the costs compared with those paid by the client on its current site[5]. These client requirements came to frame the calculative space of design practice in a very powerful manner.

As mentioned before, Vinci and Cofely focused on three renewable heating solutions: heating by electricity from photovoltaic solar energy, biogas and geothermal energy. In order to choose between these options, the companies conducted extensive investigations and calculations to understand the long-term consequences of each alternative. The future impact of the technologies was embodied in the calculations as costs related to maintenance and renewal during the 30-year period, cost of raw materials over time, possible returns on investment (in the case of solar energy) and finally the risk of accidents related to the use of the technology.

As a result of their decision to include the future impact in the calculative frame, the project team rapidly ruled out the biogas option. Bio gas implied very high maintenance costs but, in addition, carried the uncertainty over the future price of the raw material required to produce it and the higher than normal risk of accidents involved. Comparative studies were launched for photovoltaic electricity and geothermal energy. A quote from an interview with Domingos, the head architect at Vinci Design, shows how the future was accounted for in the comparison between the solutions:

> 'We learned through our studies and explorations of solar solutions for example that in 20 years 80% of PV cells would have to be changed (…). For the geothermal solution, our study showed that one heat pump would have to be changed in 30 years.'

The inclusion of future costs showed the geothermal heating to be economically more favourable and the architects and engineers at Vinci, and thermal engineers at Cofely, therefore chose this solution. The 30 year responsibility for the maintenance and for the reduction in the heating costs framed the calculative assessments in a manner that led to dynamics of future inclusion in the design practice. Normally, the suitability of the energy production and delivery solutions would have been assessed against the up-front costs related to the purchase and installation of the technology whereas the operating costs and cost of energy would have been left out of the calculations. In this case, the extended financial responsibility called for a new framing of what was to be taken into account (Callon, 1998): the future. This led the actors to conduct extensive calculations based on totally different logics from the 'business as usual' situation.

How, then, did the future dynamics of future inclusion influence the uptake of a sustainable energy innovation in ENSTA? The use of a sustainable energy solution was already enforced because of the obligation of producing at least 50% of the energy for heating by renewables. However, the dynamics of future inclusion also made it possible to extend the use of geothermal technology to cover 100% of the energy for heating. Future costs calculations showed that in a long term, despite the technology's rather high up-front introduction costs, using geothermal heating alone would be cheaper than implementing two different heating technologies. The economic benefits revealed by these calculations were, indeed, so great that even though major technological challenges appeared, the interests of the actors remained unchanged. Engineers needed to come up with a new technology to be able to drill in extremely deep ground and to develop a novel, dispersed model for positioning the heat pumps to avoid collision with archaeological findings on the site. Thus, due to the long-term economic calculations implied by the client requirements, an energy source that probably would not even have been considered in a conventional building project suddenly proved to be highly competitive in comparison to the more established energy solutions.

Dynamics of verification

In the case of ENSTA, the 30 year financial responsibility for the heating production and distribution technology allocated to the engineering firms led to a situation where the emerging focus on long term calculations supported the adaptation of a sustainable energy innovation, the geothermal heating system. However, the 30-year responsibility paragraph in the brief also provoked other, closely related dynamics that influenced the relations between the innovation, the project and the design team: the dynamics of verification. Vinci ordered extremely detailed studies on the technical and financial aspects of the different solutions from high level expert consultancy firms. These studies, whose results were analyzed by the design team, were conducted to provide a sound basis for comparisons and successive decision making. During a quality control meeting, an engineer from a design team explained the significance of reliable information about the costs of the technologies as follows:

> "In addition to financial issues and responsibilities vis-à-vis the client set out in our contract, we had to be very careful about technical feasibility studies and the actual costs over the long term for the energy solutions. There were large risks involved for us. We doubled our efforts on studies, carried out internally and with external engineering firms."

The verification of the future costs was a complex process where different emerging concerns unexpectedly changed the view on the viability of the different technologies. The design team's view on photovoltaic technology changed drastically during the process of cost verification. To start with, PV promised quite remarkable returns on investment, which was not provided by the other technologies under consideration.

> Domingos, the head architect: 'The [photovoltaic] solution was so interesting that we conducted the study as a part of our 30-year contract to manage the site. We calculated that for an investment of 750 million Euros in PV our return on investment would be 15 million Euros per year.'

The expectation of the return of investment was based on the fact that in France, residual energy from photovoltaic systems can be sold by feeding it back to the grid, which converts the solutions into a potential source of income. The architects and engineers were enthusiastic about this aspect of photovoltaic cells - until they realised that the return on investment would be very low if the government redemption prices for solar energy fed into the grid continued the downward trend seen at that time. The uncertainty about the future redemption price made an exact verification of the future costs difficult and helped show that photovoltaic technology was inferior to geothermal heating.

The focus on the verification of outcomes is also visible in the Uni A case, albeit in a slightly different form. Low Energy Class I refers to a specific level of energy consumption for a building; compliance has to be documented using a specific calculation programme, Be06. By posing this requirement and related means of control, the client strongly prompted an emphasis on the countability and verifiability of the effect of the chosen technological and/or architectural solutions. The significance of verification in regard to the low energy standard was, indeed, clearly visible in the way the emerging object was continuously rendered calculable in its different instantiations through the use of Be06 and related daylight calculation programmes.

The impacts of the design option were subjected to frequent acts of verification through the energy performance calculations. Before the window concept was chosen, for instance, the in-house energy consultants provided calculations of seven different ways of allocating and placing the windows. Furthermore, daylight calculations were used later on to verify and optimize the chosen concept. Also, the energy engineer from the engineering firm carried out building energy performance calculations for the whole building several times during the competition period to ensure that the changes made in the design of the building would not have unexpected impacts on the energy economics.

Conducting detailed energy performance and daylight calculations is time and resource consuming - especially as the object of design is in an almost constant state of flux, especially during the early stages of the design process. Hence, energy consultants also employed alternate means of verifying the anticipated impacts of the possible design options. References to existing calculations of the effects of the compact building form and rules of thumb concerning the adequate window and window area/building depth ratio were used to communicate the benefits of different design strategies, especially in the early phases of the design process. Charles, for instance, told us that they initially chose to work with a 35% percent window area, as indicated in the reference literature.

> Charles: [35%] draws on some analysis presented in a book… It is a book called 'Architecture and Energy'…

What kind of consequencesdo verification dynamics spark off in the relations between the innovation, the project and the design team? While the focus on the verification of solutions does not directly promote or disqualify sustainable energy solutions in construction in itself, we argue that its influence on innovation is nevertheless worth discussing. The emphasis on verification frames the horizon of possible solutions towards those that are well known, to such an extent that technologies which are so novel that their impacts cannot be calculated with a plausible certainty are ruled out. Resulting from this, the design team is most likely to adopt innovations, not to generate them itself. This is clearly visible in both of our building projects where the innovations adopted the bioclimatic design and the geothermal heating technology - are known, albeit seldom used solutions in construction. Elements that provoke these types of verification dynamics are widespread in the construction sector, which might partly explain the claims that the sector is neither innovative in general, nor in terms of sustainable solutions (e.g. Peuportier, 2008). However, innovations can be taken up in building projects if the calculative framing of the building project is construed in such a way as to acknowledge their benefits, and as long as their functionality can be made countable in this respect.

Different but similar

ENSTA and Uni A include elements that provoke innovation promoting dynamics in similar and in different ways. The performance-related objectives, the Low Energy 1 requirement in Uni A and the 50% renewable energy requirement for heating in ENSTA, both contribute to encouraging explorations beyond existing, well known solutions. The underlying reason is quite simple: they frame the design space in such a way that the clients' objectives cannot be met by purely 'business as usual' design strategies. The dynamics of future inclusion, evident in the case of ENSTA, strengthen this incentive to explore more ambitious and innovative solutions. They widen the area of responsibility of the design team, thus giving an explorative dimension to the design work in a manner that is not prevalent in the case of Uni A. Although compliance with the Low Energy Class I requirement is, to a certain extent, based on the calculations of the building's anticipated future energy use in the Uni A case, the future is reduced to a proxy of energy use, identical for all the upcoming years. In practice, this means that once the design team has demonstrated computational compliance with the required level of energy performance, their responsibility is lessened.

The client requirements both in ENSTA and Uni A led to a greater focus on verification of the energy related impacts of the proposed architectural or technical solutions. However, the two cases also differ from each other in this respect. In the case of the long-term financial responsibility in ENSTA, the design team itself is able to independently define the form and the scope of verification for the technology performance: it is up to the design team to decide which future costs will be taken into account when the alternative technologies are compared with each other. In the case of the performance related objective, the Danish Low Energy Class I, the parameters of verification are created outside the project team. The Danish Low Energy Class I can only be attained with reference to a set of detailed calculations, whose content is pre-defined by the public authorities. Here, verification serves to create legitimacy in the eyes of the client rather than internally in the project organization.

ENSTA offers an intriguing example of how two different requirements complement each other in promoting innovation. It can be speculated whether any one of these requirements alone would have led to the use of geothermal heating technology partially or on a full scale, as is currently the case at ENSTA. When we follow the design process it becomes evident that the geothermal heating solution was initially introduced to fulfill the requirement that 50% of the energy used in heating be covered by renewable energy. It was not until the financial calculations for the construction and maintenance of the heating solution supported the use of a single technology instead of a 50/50 solution that they decided to use

	ENSTA: 50% requirement for renewable energy for heating	ENSTA: 30-year responsibility for the heating solution (reallocation of long term financial responsibility)	Case A: Low Energy Class I (performance requirement)
Dynamics of exploring beyond the habitual way	The requirement forced the design team to explore renewable energy sources. The geothermal heating solution was favoured by this, but also by the 30 year responsibility for maintenance (cheap maintenance) and by the costs of other energy infrastructures.	Any saving will benefit the design team, thus strengthening the dynamics of exploring beyond the habitual ways.	The objective forced the design team out of 'business as usual' – the objective could not be obtained without exploring more ambitious design or technical solutions
Dynamics of future inclusion	-	Once the option of a renewable energy source was initiated, the allocation of long term responsibility favored geothermal heating and concentrating on one heating solution only. See above left.	-
Dynamics of verification	Verification requirement forced the design team to lean towards countable solutions.	The financial interest made the design team lean towards 'secure', countable solutions.	The performance requirement and the related control mechanism, Be06, enforced the idea of the verifiability of the effects of design/technical solutions. Together with the project time line, there was no way of controlling whether the objective could be met.

FIGURE 01. *Number of Indian Construction Companies surveyed*

4. Despite its name, natural gas is not renewable. It is found in deep underground natural rock formations or associated with other hydrocarbon reservoirs.

5. The contract is rather unclear about whether this is to be achieved by bringing down the energy consumption of the building or by achieving a more favorable price for the energy produced.

6. While the dominant form of innovation was that of uptake in both cases, this does not mean that the innovations were accepted as they were. In the case of ENSTA, archeological excavations forced the design team to abandon an idea of a single sounding and heat pump and to develop a strategy of a network of several dispersed heat pumps. In Uni A, the bio-climatic design principle was continuously exercised with an emerging building plan, which acquired new dimensions as the design work proceeded. These observations support the point made by Akrich, Callon and Latour (1988, 2002) according to which the success of an innovation should not be approached as a simple game of adoption or implementation but rather as an outcome of a process during which both the innovation and its environment may change. For the first, the innovation may be reconfigured or be subject to further innovations from its users. For the second, to uptake an innovation, does not mean mechanically fitting it in to an already existing fertile context. Rather, the world around the innovation also has to change in order for the innovation to succeed.

the geothermal heating technology on a full scale. The 30-year maintenance responsibility thus confirmed the attractiveness of the geothermal heating solutions, given its low maintenance costs in comparison to any of the other renewable energy sources considered. These observations indicate that the two objectives stated in the brief have sequentially reinforced the dynamics of exploration beyond habitual practices that would not necessarily have found place in the absence of neither or.

Discussion: policy implications

Short-timelines, focus on costs and clients without continuous engagement and leadership in innovation are often mentioned as barriers for innovation. Our case studies have shown how, despite of these factors, novelties can be adopted in construction projects. We claim that client requirements can not only enhance specific innovation-promoting dynamics but may also accomplish this by skillfully allying themselves with industry features that are often described as hostile to innovation. Based on the leanings from our case studies, we will now deliver some tentative openings for a discussion on what policy implications the identified dynamics and the insights they give to the calculative dimension of construction design may have.

Budgeting for sustainable innovations

While focus on budget (Jacobsson and Linderoth, 2010) is often put forward as an explanation of not including sustainable innovations in construction projects, our case studies show results that question this idea. The ways in which the client requirements framed the calculative space of design practices in our two cases demonstrate that innovations can be taken up in project environments despite tight budgets. In the case of the French university campus, for instance, the 30-year financial responsibility for the maintenance costs allocated to the design team proved to be decisive in terms of furthering the use of an innovative technology, geothermal heating, known for its high up-front costs. The dynamics of future inclusion that reflected the extended responsibility radically changed the actors' approach to alternative technologies. This in turn created favourable conditions for employment of innovations where both the energy and the maintenance costs were low. In other words, when the metrics of cost calculation were aligned with the benefits of the sustainable technology, uptake of such an innovation became possible even in a project-based enterprise.

Even though the use of this incentive structure is well discussed in the energy efficiency literature, it is nevertheless seldom used in practice. As it is so efficient, what policy structures could be devised to encourage its use? We suggest that regulations could be introduced either enforcing the allocation of this type of responsibility into project briefs and building contracts or the client's compliance to long-term energy performance goals.

Project organization and policies for innovation

Project organization is a pertinent feature of the construction sector. In practice this means frequently changing project coalitions (Hardie, 2010; Nam and Tatum, 1998; Winch, 1998) and short-term management horizons (Jacobsson and Linderoth, 2010). Short time-lines may be seen as hindrances to sustainable energy innovations, as the generation of novelties and the further development of ideas can often not be included in the horizon of the project. Contrary to the views that short timelines are hostile to innovation in general, our case studies suggest that, when combined with a calculative space geared towards favouring sustainability, they should be seen as drivers for the inclusion of known and verifiable innovations. Indeed, statistics reveal the strongest level of innovation intensity at the supplier end of the construction sector value chain (e.g. Manley, 2006; Pries and Dorée, 2005), which seems to confirm our argument.

This has implications for future policy design issues. We should distinguish between drivers and related policies to support innovation uptake, on the one hand, and the generation of innovation, on the other. Of the two, innovation uptake carries major potential in the everyday practices of a project-based environment such as the construction sector. In this process, policies can definitely play a remarkable role in transforming construction projects into markets for existing innovations through influencing the criteria on which the benefits of adequate solutions are assessed. This can happen, for instance, by integrating requirements for best available technology in building permission procedures or by providing financial incentives for investment in better technological solutions. An example of the latter is the obligation of the electricity providers to buy the residual electricity produced by private and public buildings for a set price in both Denmark and France. In addition, tax reductions can be claimed for solar technology in Denmark. When formulating policies for innovation uptake, it might also be useful to acknowledge the blurring of boundaries between innovation and its implementation in terms of policy intervention. Thus, as the implementation of innovation may require hard work on altering it to fit into the existing structures in its environment of use or vice versa, policy support for re-innovation and alterations may also be required.

Voluntary standards and the delegation of innovation competency

In the light of our cases, voluntary standards for more ambitious energy performance for buildings can be a useful, although not necessarily the only way to support uptake of sustainable energy innovations. In the case of the Danish university college building complex, the voluntary Low Energy Class I standard defined in the Danish building regulations offered a legitimate external reference point for the client and the design team. After the client had included the standard in the competition brief the level indicated in the standard was treated as a strong indication of the client requirements, which could not be fulfilled without a certain amount of innovation.

These types of standards offer the client the possibility of demonstrating a requirement for an ambitious energy performance level that may trigger the uptake of innovations. This is possible even though the competencies of the client alone would otherwise not be enough to define a doable, realistic level of ambition. Instead of the client itself, it is the standard that imposes an assessment for the balance between novelty and feasibility. In this way, the standard takes over authority for reformatting the calculative space of the design practice from the possibly unknowledgeable client. In the case of the Danish higher-level education complex, the client may have been competent in sustainable energy innovations. However, this competency did not need to be used in the relations between the client and the design team. The level of innovation was more or less implied by the introduction of the ambitious Low Energy Class I standard. The absence of manifestations of the client's (possible) innovation competency did not lead to non-innovation, due to the enforcement of the standard in question. Thus, the brief specifying the standard offered a solution to the dilemma pointed out by Ivory (2005): the qualified client and building owner may act as a driver for innovation, yet many clients may not have the capacities and/or competencies to do so.

Besides delegating the innovation competency outside the realm of the client (at least partially), voluntary standards such as the Low Energy Class I standard offer the client, the building owner and the design team predefined, visible and acknowledged means of communicating their expectations and values to each other and to the public. The potential of standards in simplifying communications relating to the project between the different actors should not be underestimated. Our observations show that once the performance standard had been rendered authoritative by the brief, the design team worked relentlessly towards finding the innovations that would enable them to meet the required performance level. There were no negotiations about the parameters or the level of energy performance.

Conclusion

Client requirements embodied in competition and tender briefs influence the process of sustainable energy innovation in various ways by provoking dynamics through which an innovation, the project and the design team become increasingly entangled with each other. When they set ambitious energy objectives, these types of pre-contractual arrangements may force the design teams to abandon their usual design practices and to explore alternative ways of organizing energy related solutions in the building. Briefs that allocate responsibility for the maintenance of the energy supply and production technology to the design team over an extended period of time reformat the benefit calculations in favour of energy sources that generate lower maintenance and raw material costs. Briefs that specify an ambitious energy performance target call for security in terms of the solutions' ability to produce the expected outcome. Thus, they promote innovation uptake rather than innovation generation. These influences on innovation work with existing logics of economic calculation and countability but reverse the incentives towards creating common standpoints for economy, accountability and sustainability.

The extant academic literature on innovation in construction is rife with descriptions of different innovation drivers. We have argued that the current literature would benefit from an increased understanding of the dynamics provoked by influences on innovation and the resources they draw on to make innovation happen. Highlighting the dynamics resulting from the use of particular types of client requirements has shown innovation to be processual; it suggests that innovation should be thought of as a process where different actors and issues need to be associated with each other in order for the innovation to become successful. In terms of policy development, understanding the dynamics through which innovation is supported and promoted is crucial. Only then will the policy makers be able to design policies that support existing and well-targeted drivers of innovation and policies that trigger the emergence of novel dynamics for promoting innovation.

authors


Rebecca Pinheiro is a Professor of Management at the Université du Quebec à Trois Rivières and Associate Professor at Sciences Po Rennes. Her research is at the crossroads of Public Management (Health and Safety) and Management of Innovation. His latest book, Piloting Innovation Collectives, focuses on the management of major public infrastructure projects. rebecca.pinheiro@uqtr.ca


Satu Reijonen is senior adviser on environment at the Nordic Council of Ministers. This paper presents results from her PostDoctoral studies at Copenhagen Business School financed by the Danish Council of Independent Research.

references

Akrich, M. (1992) The De-Scription of Technical Objects, in Shaping Technology / Building Society. Studies in Sociotechnical Change, eds. W.E. Bijker and J. Law, The MIT Press, Cambridge, Massachusetts, pp. 205-224.

Akrich, M., Callon, M. and Latour, B. June (1988 in French) (2002) The key to success in innovation part II: the art of choosing good spokespersons. International Journal of Innovation Management, 6(2) 207-225.

Bröchner, J. (2010) Construction contractors as service innovators. Building Research and Information, 38(3) 235-246.

Callon, M. 1998. An essay on framing and overflowing: economic externalities revisited by sociology. In M. Callon (ed.) The Laws of the Markets. Oxford: Blackwell Publishers/The Sociological Review. pp. 244-269.

Cochoy, F. (2008). Calculation, qualculation, calqulation: shopping cart arithmetic, equipped cognition and the clustered consumer. Marketing Theory, 8(1) 15-44.

de Laet, M. and Mol, A. April (2000) The Zimbabwe Bush Pump: Mechanics of a Fluid Technology. Social Studies of Science, 30(2) 225--263.

Gann, D.M., Wang, Y. and Hawkins, R. (1998) Do regulations encourage innovation? - the case of energy efficiency in housing. Building Research and Information, 26(5) 280-296.

Hardie, M. (2010) Influences on innovation in small Australian construction businesses. Journal of Small Business and Enterprise Development, 17(3) 387-402.

Hartman, A. (2006) The context of innovation management in construction firms. Construction Management and Economics, 24(6) 567-578.

Harty, C. (2010) Implementing innovation: designers, users and actor-networks. Technology Analysis and Strategic Management, 22(3) 297-315.

Harty, C. (2008) Implementing innovation in construction: contexts, relative boundedness and actor-network theory. Construction Management and Economics, 26(10) 1029-1041.

Harty, C. (2005) Innovation in construction: a sociology of technology approach. Building Research and Information, 33(6) 512-522.

Ivory, C. (2005) The cult of customer responsiveness: is design innovation the price of a client focused construction industry? Construction Management and Economics, 23(8) 861-870.

Jacobsson, M. and Linderoth, H.C.J. (2010) The influence of contextual elements, actors' frames of reference, and technology on the adoption and use of ICT in construction projects: a Swedish case study. Construction Management and Economics, 28(1) 13-23.

Koskela, L. and Vrijhoef, R. (2001) Is the current theory of construction a hindrance to innovation? Building Research and Information, 29(3) 197-207.

Latour, B. (1996) Aramis or the Love of Technology, Harvard University Press, Massachutes.

Manley, K. (2008) Against the odds: Small firms in Australia successfully introducing new technology on construction projects. Research Policy, 37(10) 1751-1764.

Manley, K. (2006) The innovation competence of repeat public sector clients in the Australian construction industry. Construction Management and Economics, 24(12) 1295-1304.

Nam, C.H. and Tatum, C.B. (1988) Major characteristics of constructed products and resulting limitations of construction technology, Construction Management and Economics, 6(2) 133.

Peuportier, Bruno (2008), Éco-conception des bâtiments et des quartiers , Presses de l'École des Mines, Paris.

Pries, F. and Dorée, A. (2005) A century of innovation in the Dutch construction industry. Construction Management and Economics, 23(6) 561-564.

Reichstein, T., Salter, A.J. and Gann, D.M. (2005) Last among equals: a comparison of innovation in construction, services and manufacturing in the UK. Construction Management and Economics, 23 (6) 631-644.

Schweber, L. and Harty, C. (2010) Actors and objects: a socio-technical networks approach to technology uptake in the construction sector. Construction Management and Economics, 28(6) 657-674.

Seaden, G., Guolla, M., Doutriaux, J. and Nash, J. (2003) Strategic decisions and innovation in construction firms. Construction Management and Economics, 21(6) 603-612.

Shu-Ling Lu and Sexton, M. (2006) Innovation in small construction knowledge intensive professional service firms: a case study of an architectural practice. Construction Management and Economics, 24(12) 1269-1282.

Winch, G. (1998) Zephyrs of creative destruction: understanding the management of innovation in construction. Building Research and Information, 26(5) 268-279.

Yin, R. K. (1981). The case study crisis: some answers. Administrative Science Quarterly, 26 58-65.