The dynamics of innovation influents: contracts and sustainable energy innovation uptake

Satu Reijonen, Rebecca Pinheiro-Croisel

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Satu Reijonen, sr.ioa@cbs.dk

Rebecca Pinheiro-Croisel, Rebecca.croisel@mines-paristech.fr

Despite a growing interest, sustainable energy innovations encounter difficulties in attaining market success. This paper investigates the role of contracts, a hitherto understudied innovation influent, in generating more conducive conditions for sustainable energy innovations in building projects. With the help of two case studies we identify three dynamics evoked by specific types of building contracts with sustainability focus: the dynamics of thinking beyond the habitual, the dynamics of reverse calculation, and the dynamics of countability. These dynamics change the prevailing level of ambition of the project and the ways in which the benefits and costs are calculated and thereby create a strong entanglement of the sustainable energy innovation and the design project. Furthermore, the dynamics lead to favouring of uptake of existing innovations rather than generating completely novel solutions. The article concludes with a discussion about the possibilities of policy intervention for innovation supportive dynamics in construction projects.

Keywords: innovation; sustainable energy; processuality; geothermal heating; bio-climatic design

Introduction

Sustainable energy innovation is a popular catchword in the construction sector today. Despite of this, examples of successfully marketized sustainable energy innovations are rare. In a building project, contracts define the responsibilities of the actors, the financial resources, time frame and the level of ambition related to energy performance of the building to be designed. In doing so, they touch upon many issues that enable or disable innovation. Contracts 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). Contracts may thus be one of the elements that work towards bringing sustainable energy innovations into – or keeping them out of - construction.

While discussion about the elements for success for specifically environmentally relevant innovations is very limited, the extant literature on innovation in the construction sector offers a wealth of explanations for the success or failure of innovation. These influents 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 the 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 influents actually influence the actors in construction projects. These two shortcomings lead to an overly generalized picture and understanding of how and why innovation is shaped in the construction sector. It is therefore not surprising that empirical studies on the process and trajectories of innovation have been called for (Reichstein et al,. 2005, Winch, 1998).

This paper presents two empirical studies of innovation in the construction sector with a focus on a hitherto understudied innovation influent: the construction contract, including contractual elements such as requirements implied by the competition brief. We theorize about the relationship between an innovation influent and the innovation by highlighting the dynamics related to the ways in which the contract may promote the uptake of sustainable energy innovation during the course of a building project. This study thus contributes to the extant literature on innovations in the construction sector by 1) enhancing the understanding of the dynamics through which the influents for innovation work and 2) by shedding light on the role of contracts in innovation processes. In addition, we bring the findings of this article into the discussion about policy interventions for the promotion of innovation through building contracts in the field of sustainable energy. We claim that contractual relations in terms of promoting innovation, which makes this study especially interesting in terms of environmentally sustainable construction.

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 brief note on our research methods, we will introduce the results of two case studies about the role of contracts in the uptake of sustainable energy innovations in France and in Denmark, respectively. Finally, the findings will be discussed against 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 different possible influents and the complexity of their possible interactions underline the difficulty of successful regulative intervention. In this section, we sum up the discussion about drivers and influents of innovations in the extant literature. Following from this, we relate our approach to the existing research approaches and highlight the ways in which we augment the discussion of innovation influents in construction.

The influents mentioned in the literature can be put into three loose categories: 1) firm’s resources and capabilities, 2) firm’s innovation environment and 3) the generic characteristics of the sector. 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 friendliness of leadership (Manley, 2008; Nam and Tatum, 1997) are regularly highlighted as relevant. Innovation characteristics 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).

The firm's interaction environment is another theme that is frequently depicted as decisive for innovation in the construction sector. Clients (Lu and Sexton, 2006) and their innovation competency (Ivory, 2005; Manley, 2006, 2008; Winch, 1998), regulation (Manley, 2008; Gann, et al., 1998) and independent brokers (Manley, 2008; Winch, 1998) are emphasized by many scholars. In regard to the relationships between the firm and its environment, Winch (1998) highlights the significance of a system integrator (a kind of inter-organizational innovation champion) and incentive structures, such as contracts. Bröchner's (2010) empirical findings suggest that collaboration with different types of contractors enhances the innovation capability of a firm.

In addition to the above mentioned, scholars have also actively pinpointed general conditions in the construction sector that influence the firm's ability to innovate. Several authors suggest that the industry structure consisting of several 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 named as another influent (Hardie, 2010; Jacobsson and Linderoth, 2010; Nam and Tatum, 1998; Winch, 1998). Locality of markets (Reichstein et al., 2005), overdependence on cost (Hardie, 2010) and dependency of 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) and 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. Hardie (2010) and Koskela and Vrijhoef (2010) furthermore claim that industry suffers from a peculiar self-perception: the inherent uncertainty and interdependence of operations are ignored.

While scholars have recently successfully identified a host of different drivers and influents for innovation, these are still portrayed in rather stable and universal terms. Influents are identified and enlisted without much discussion (let alone theorizing) about when, why and how these issues might influence the relationship between innovation and its possible future users. Some exceptions to this can be found in studies that yield empirical accounts about building processes and the role of influents in these (such as Ivory, 2005; Jacobsson and Linderoth, 2010; Manley, 2008; xxx). The often mechanical and simplified understanding of innovation influents is interlinked to 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). Indeed, these models of innovation are clearly distinguishable in those few texts that have attempt to capture the dynamics of innovation and innovation influents in construction sector in more conceptual terms. These include Slaughter (2000) who puts forward a rather mechanical understanding of innovation as consisting of different implementation stages. A similar generic model is advocated by Sexton and Barret (2003) that depict innovation process as consisting of five parts: diagnosis, action plan, taking action, evaluation and specific learning.

While the majority of these readings focus on identifying crucial influents and drivers for innovation in construction, some recent contributions predominantly inspired by Science and Technology Studies (Akrich, 1992; de Laet and Mol, 2000; Latour, 1996) have highlighted the benefits of interrogating 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.

Along the same lines as Harty (2010; 2008) and Schweber and Harty (2010), we claim that the extant literature on the influents of innovation would be greatly augmented by an approach designed to help us understand the processes of triggering and supporting innovation in more relational and processual terms. In this article, we conceptualize the processuality and relationality of innovation and innovation influents through the notion of dynamics. We suggest that innovation influents evoke specific dynamics in the socio-material environment of the construction project that may lead to an uptake of or generation of an innovation.[1] These dynamics may, for instance, entail changes in the ways of perceiving benefits and risks – or costs, as in our case – and changes in the materialities of design work, including tools and calculation programmes.

Methods (In progress)

The findings of this article are based on an analysis of two cases studies (Yin 1981) on the role of contracts in promoting sustainable energy solutions in construction projects. The first case study took place in a design project of a university campus, ENSTA, designed and built in France in 2007-2012. The second case study, Case B, regards a project where a university college was designed in Denmark in 2009.

In both cases, a specific sustainable energy innovation was taken up. In ENSTA, geothermal heating technology was applied to the whole campus area. In brief, geothermal heating refers to a heat pump technology with the help of which heat from ground and ground water can be harvested. Geothermal heating technology is well known and increasingly used for heating of 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 case B, the design team adopted a bioclimatic design principle in the design of the building. This principle depicts architecture that relies on passive solar systems for heating, cooling and lighting the building. While the principle is well known in green architecture, this innovation has not been brought into wide use in conventional projects.

The building contracts

[1] Approaching the relationship between the innovation influent, innovation and the project through the notion of dynamics hinges upon the approach advocated by Jacobsson and Linderoth (2010) in their recent study on adoption and use of ICT in construction projects. Jacobsson and Linderoth claim that contextual element 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.

The focus of this article is on the role of contracts in enhancing innovation in construction. Our cases demonstrate two different types of contracts that influence the innovations in hand in different ways. As both the building projects are based on competition, the contractual elements also include the non-negotiable requirements outlined in the competition brief and the contract itself.

The influential part of the contracts in terms of the adoption of the respective sustainable energy innovations are as follows. In the ENSTA case, the contract covers a 30-year period allocating responsibility of the design, building and maintenance of the campus area and its buildings to a design team. The design team consists of a private grouping comprising an architect firm, two engineering firms (Vinci Construciotn and Cofely) and an external investment company (Société Générale). In addition to the 30-year financial and executive responsibility, the contract also specifies that 50% of the heating energy has to be obtained from renewable sources. Also, the costs of heating for the client need to be lower than in their current estate. As to the energy performance of the building, the usual 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 case B, the contract structure was somewhat more conventional compared to that of ENSTA. The design team, an architect firm and an engineering firm, hold responsibility for the design and construction of the building complex. In Case B, the pivotal contractual element was the requirement that the buildings meet Low Energy Class 1, 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 utilizing energy saving building technologies and forms.

Data collection and analysis

In the cases, our aim was to understand the influence of the contract on the decision-making, actions and explorations in the uptake of sustainable energy innovations. Both cases rely on interviews, documents such as technical studies, meeting notes and memos and e-mails, and observations of meetings. In addition, frequent observations of the architects' work were conducted in Case B, often on a daily basis, during the three four months of the post-competition design phase in 2009. In case B, the data regarding the competition phase is comprised of documents and x retrospective semi-structured interviews. For ENSTA, a total of 12 semi-structured interviews were carried out with the design team. x of the interviews were with Vinci Construction, a firm involved in the design, construction and management of the site. For ENSTA, furthermore, several visits were made to the construction site, accompanied by the designers, builders and managers, to monitor the construction of the campus and the interactions during the building works. This was crucial as several issues regarding the adoption of the geothermal heating technology only occurred on site.

In order to analyse the data, information related to either the uptake of the respective innovations or to the contract was extracted from the body of data. These extracts were then analysed while keeping the analytical focus on the question of the role of the contract in creating incentives for adopting or supporting conditions for innovation. During this process, questions arose regarding the influence and specifics of the contracts. We therefore returned to the interviewees and the documents in order to find detailed information about the ways in which the contracts intertwined into the design process. In the course of the analysis of the data, three categories emerged featuring the different dynamics through which the contract transformed the design practice to accommodate the sustainable energy innovation. These dynamics are discussed in the following section.

Findings: the dynamics of innovation influents

Innovation influents make the world around the novelty more conducive. We have argued for the benefits of a better understanding of the process through which the innovation influents 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 evoked by an innovation influent, the building contract, which shape the existing conditions for innovation: the dynamics of thinking beyond the habitual, the dynamics of reverse calculation and the dynamics of countability.

Dynamics of thinking beyond the habitual

In both the ENSTA case and the case B, the contracts include specific requirements related to energy sustainability. In ENSTA, the client demanded that 50% of the energy used in heating be produced from renewable energy sources. In case B, the competition brief stated an ambitious energy performance requirement for the building: the building should meet a voluntary Low Energy Class 1 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 contractual elements influenced the uptake of sustainable energy innovations in the respective cases.

In the case B, the workings of the Low Energy Class 1 were evident right from the beginning of the design process. 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 with the competition submission. This meeting took the form of a brain storming session facilitated by an engineering PhD student, Mike, employed by the architect firm at that time. In an interview, Mike 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, initial ideas of a compact building form and optimization of the building volume emerged. Furthermore, ideas for both low energy use and minimizing the need to cool the building were brought in. A yellow Post It put on the white board signalled further sympathy for the focus on the passive elements in the building as decisive for the low level of energy use: 'No solar panels!' The pictures and notes from the meeting clearly indicate that this vision was linked to the obtainment of the client requirement of Low Energy Class 1.

After the brain storming session the architects started to work towards visualizing the visions. Mike recalls a meeting in the very early phase of design activity where he and two other PhD students provided the architects with two rules of thumb, both of which are a pertinent part of the bio-climatic building design approach. One of the rules relates to the compact form and the other to the amount of daylight that can enter the building through the windows. According to Mike, a compact building design is necessary to obtain a low level of energy use, but this implies the challenge of deep buildings, which in turn reduce the amount of daylight and increase the amount of energy used for electric lighting. Hence, these two elements, the compact form and the window size, must be related to each other in each specific case.

After these initial meetings, the architects chose to work further on the compact building form and finally proposed a series of four cubic buildings. They came up with five different ways of positioning the buildings in the building ground, for which the PhD students conducted preliminary daylight calculations and an energy engineer made energy calculations. Based on these calculations, the design team was able to decide which way of organizing the building volume in the plot was the best in terms of daylight penetration into the buildings and also to have a preliminary idea of how much window area was to be allocated to the different walls with the underlying aim of meeting the Low Energy Class 1 requirements. This optimization of the relationship between the compact form and the daylight was needed in order to obtain the required reductions in the energy use of the building.

Today, the first building of our case B, a new university college campus, is ready to be occupied. It is compact and cubic, and meets the strict energy requirements demanded by the client. The influence of the Low Energy Class 1 requirement imposed by the client is not only clearly visible in the process through which the design team chose and implemented the bio-climatic building design but also in the building itself. We argue that the level of ambition defined by the client's functional requirements evoked a dynamics of thinking beyond the habitual in the design team. The client's outspoken ambition did not leave room for 'design as usual' where the energy performance of the building is mostly a question of altering the already existing architectural design. Instead, the requirement of Low Energy Class 1 was so ambitious that it made energy related issues appear amongst the three key visions for the building and came to dominate the architects' quest for finding the most ample design and orientation for the building.

Another example of the dynamics of thinking beyond the habitual 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. As the major part of the turnover of Cofely, one of the engineering partners in the project group, came from the production and supply of gas in France, this would seem to have been an easy choice for the design team. However, with the 50% requirement, the project partners were left with no other choice but to inquire into other alternatives in the realm of renewable energy sources. In this case, the project partners launched a joint exploration process that began by studying possible renewable energy solutions for the building project. Several potential solutions were studied, three of which - photovoltaic solar energy, biogas and geothermal energy - were subjected to detailed investigations regarding their applicability, the price of purchasing, installation and maintenance of the technology and the price of heating. Thus, the requirement of 50% renewable energy for heating forced the design team for ENSTA to move beyond their habitual resource base in gas based heating.

Dynamics of reverse calculation

In addition to the requirement for 50% of the energy used in heating to be produced by renewable energy sources, the ENSTA contract also included other energy related stipulations. According to the contract, the engineer firms Vinci Construction and Cofely were financially responsible for the construction of the technology for 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[2]. Accordingly, when Vinci Construction and Cofely embarked on a comparative study of different alternative renewable energy production methods, issues related to the cost of technology, its implementation and maintenance as well as to the cost of energy production formed a crucial dimension of these investigations.

[2] 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 favourable price for the energy produced.

As mentioned before, Vinci and Cofely focused on three renewable heating solutions: heating by electricity from photovoltaic solar energy, biogas and geothermal energy. Biogas was rapidly ruled out because it implied very high maintenance costs but also because of the uncertainty of the future price of the raw material necessary for the production of biogas and because of the risks of accidents. In the end, photovoltaic electricity and geothermal energy solutions were deemed more suitable from the economic and the environmental standpoints and comparative studies were therefore launched for these two solutions.

The energy source for geothermal heating and heating based on photovoltaic cells is free. However, in France, residual energy from photovoltaic systems may be sold by feeding it back to the grid, which converts the solutions into a potential source of income. The designers were enthusiastic about this dimension of the photovoltaic cells - until they realised that the return on investment would be very low if sales prices continued the downward trend seen at that time. For the 750,000 Euros invested in the installation of the technology, returns on the sales of energy would only amount to 15,000 euros per year. While the income opportunities related to photovoltaic solar energy did not prove remarkable, the geothermal technology and its installation was still far more expensive than that of solar panels. Yet, the choice fell on the geothermal technology. The reason for this was that the technology for production of geothermal heating proved to be remarkably cheaper in terms of maintenance. Whereas in-depth studies showed that 80% of the solar cells would need to be replaced after twenty years, only one geothermal pump would need to be replaced during the thirty years of maintenance responsibility. Due to the low maintenance, the geothermal energy also reduced the heating bills, representing a third of the cost of gas and half the cost of photovoltaic energy solutions.

The contractual 30 year responsibility for the maintenance and for the reduction in the heating costs elicited a dynamics of reverse calculation. 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 while the operating costs and cost of energy would have been left out of the calculations. In this case, the extended financial responsibility resulted in the actors conducting extensive calculations based on totally different logics from the business as usual situation. The use of a sustainable energy solution was already enforced because of the contractual obligation of producing at least 50% of the energy for heating by renewables. Now, the dynamics of reverse calculations further supported the uptake of the green solution: the design team extended the use of geothermal heating to cover 100 % instead of the intended 50% coverage of heating energy. This was due to the results of the long term calculations that portrayed the geothermal heating as so cheap that no other energy source could compete with it in price.

The economic benefits revealed by the calculations were, indeed, so great that even though major technological challenges appeared, the interests of the actors remained unchanged. One of the challenges that measured the stability of the geothermic solutions in the work of the design team occured as the engineering firm needed to develop a new drilling technology in order to be able to drill extremely deep ground. In addition, during the first drilling operations, archaeological findings were discovered, requiring them to develop a novel, more dispersed model of positioning the heat pumps instead of one centralized geothermic well. Hence, due to the long term economic calculations, 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 countability

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 contract also evoked another, parallel dynamics that influenced the relations between the innovation, the project and the design team: the dynamics of countability. In the ENSTA case, extremely detailed comparative studies were made of the different solutions at a level not found in traditional projects with standard contracts. Calculation of the future costs related to the maintenance of the energy solutions dominated the decision-making process. In agreement with this, the design team only considered technological innovations the economic costs of which could be calculated, assessed and thereby compared.

The focus on the countability of outcomes is also visible in the case B, albeit in a slightly different form. Compliance with the Low Energy Class 1 is demonstrated through calculations of the energy performance of the building which is compiled of many different parameters. By posing this requirement, the competition brief simultaneously prompted an anticipation of the calculability of the effect of the chosen technological or architectural solution that would be used to achieve the reduced level of energy use. Bioclimatic design is not a standard design that creates a similar building in different projects. Thus, it is not an easy object for calculation. Even though the bioclimatic design principle itself did not form a single object whose effect could be calculated, such as that of geothermal heating, the practice of bioclimatic design in case B was, however, thoroughly calculative. References to calculations of the benefits of the compact building form and rules of thumbs based on generic calculations about the adequate window area were used to communicate the benefits of this design strategy. Mike, the PhD student working on energy and daylight issues, referred to several of these calculations and personally took part in work aimed at producing such. Furthermore, the practice of bioclimatic design included frequent acts of calculation in order to find out the optimal building form and orientation as well as an adequate window area and orientation. Building energy performance calculations were carried out several times in the competition period but were also used later to check that the detailed design of the building had not brought about unexpected impacts on the energy economy of the building. Thus, the impacts of the bioclimatic design were constantly made calculable in the energy performance calculations.

What kind of dynamics in the relations between the innovation, the project and the design team does this focus on calculability spark off? While the focus on countability of solutions itself does not directly promote or disqualify sustainable energy solutions in construction, their influence on innovation is nevertheless, we argue, worth discussing. The emphasis on countability frames the horizon of possible solutions towards those that are well known to an extent that technologies so novel that their impacts cannot be calculated with certainty are ruled out. Resulting from this, the design team is most likely to adopt innovations, not to generate these themselves. This is clearly visible in both of our building projects where both the innovations adopted, the bioclimatic design and the geothermal heating technology, are known yet seldom used solutions in construction.[3] Elements evoking these types of countability dynamics are widespread in the construction sector, which might partly explain the claims that the sector is not innovative in general, but also in terms of sustainable solutions (see e.g. Peuportier, 2010). Innovations, however, can be taken up in building projects if the calculative frame of the building project is construed to acknowledge their benefits and as long as their functionality in these terms can be made countable.

Discussion: policy implications

The contracts can, we claim, not only enhance specific innovation-promoting dynamics but may also accomplish this by skillfully riding on tendencies that are often described as hostile to innovation. The dynamics of reverse calculation change the way costs are calculated while simultaneously relying on the design team's focus on budget. The time frame of a construction project is seldom long enough for explorative innovation to be generated. However, innovations whose effects can be demonstrated and calculated may find their way to the building once the design team's methods of assessment of are geared to acknowledge their benefits. Unknowledgeable clients may be equipped to promote ambitious visions despite their lack of understanding of the issues involved. Our case studies have shown the role of contracts in making this happen. Indeed, the contracts can do remarkable work in turning hostile conditions into something fruitful in terms of innovation! In the following, we will elaborate upon these reverse dynamics in order to pinpoint and discuss potential entry points for the reformulation of policy design and intervention.

[3] While the dominant form of innovation is that of uptake in both cases at hand, this does not mean that the innovations were accepted as they are. In the case of ENSTA, archeological excavations forced the design team to abandon an idea of a single sounding and heat pump and develop a strategy of a network of several dispersed heat pumps. In the case B, 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 (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 innovated on further by 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.

Policy measures in support of giving the design team the financial responsibility for the use phase

In the case of the French university campus, 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. The dynamics of reverse calculation that reflected the extended responsibility profoundy reformatted the actors' approach to alternative technologies.

Even though the use of this incentive structure is well discussed in the energy efficiency literature (Lienau, 1997; Rybach, 2000; Hepbasli, 2000), it is nevertheless seldom used in practice. When so efficient, how could its use be supported by adequate policy structures? We suggest that regulations could be introduced either enforcing the allocation of this type of responsibility or the client's compliance to long term energy performance goals.

The implications of project organization on policies for innovation

Project organization is a pertinent feature of the construction sector. In practice this means frequently-changing project coalitions (xxx) and short term management horizons (Jacobsson and Linderoth, 2010). This is bound to gear the sector towards an uptake of innovation rather than innovation generation as the latter generally takes more time than that allocated to a normal construction design project. Furthermore, the liabilities of construction projects suggest that unfinished or unverified solutions pose a risk to the design team and may therefore be ruled out of considerations. Indeed, this tendency towards favouring already existing innovations is also visible in the statistics that reveal the strongest innovation intensity at the supplier end of the construction sector value chain (e.g. Manley, 2006).

The dynamics of countability are strongly related to both the project-based nature of the construction, the avoidance of liabilities on the part of the design team and the favoring of already existing innovations. These dynamics offer an interesting insight into the promotion of sustainable energy solutions. Our case studies show that geothermal heating was adopted despite its high up-front costs due to 1) the changed framing of costs, and 2) the calculability and the certainty of calculations related to the price of the energy, including the costs of maintenance, in a long term. In other words, when the metrics of cost calculation are aligned with the benefits of the sustainable technology and the implications of the technology are calculable, uptake of such an innovation becomes possible even in a project-based enterprise.

This has implications for future policy design issues. First, we should distinguish between drivers and related policies to support innovation uptake, on one hand, and the generation of innovation, on the other. Of these two, innovation uptake carries major potential in 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, for example, 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. Furthermore, tax reductions can be claimed for the solar technology In Denmark. Second, in terms of policy intervention, acknowledging the blurring of boundaries between innovation and its implementation has consequences too. Thus, as innovation implementation may require hard work on altering the innovation 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 case, voluntary standards for more ambitious energy performance for buildings can also be useful, albeit not only way to support uptake of sustainable energy innovations. In the case of the Danish university college building complex, the voluntary Low Energy Class 1 standard defined in the Danish building regulation offered a legitimate external reference point for the client and the design team. After the client had included the standard in the contract through the competition brief, the level indicated in the standard became a non-negotiable and non-malleable goal 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, it is the standard that embodies this assessment, on the balance between novelty and feasibility. In the case of the Danish higher level education complex, the client may have been competent in sustainable energy innovations. This competency, however, did not need to materialize 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 1 standard. The absence of manifestations of the client's (possible) innovation competency did not lead to non-innovation due to the enforcement of the very standard. Thus, the contract 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 1 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 contract, the design team worked relentlessly towards finding the innovations that would enable them to meet the required performance level.

Conclusion

Building contracts influence the process of sustainable energy innovation in various ways by evoking dynamics through which an innovation, the project and the design team become increasingly entangled with each other. When they set ambitious energy requirements, contracts force the design teams to abandon their usual design practices and force them to explore alternative ways of organizing energy related solutions in the building. Building contracts that allocate responsibility for the maintenance of the energy supply and production technology to the design team over an extended time period reformat the benefit calculations in favour of energy sources that generate lower maintenance and raw material costs. Contracts 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 contracts are driven by 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 depictions of different innovation drivers. We have argued that the current literature would benefit from an increased understanding of the dynamics evoked by innovation influents and of the resources they draw upon to make innovation happen. Highlighting the dynamics that have followed from the use of particular types of building contracts emphasizes innovation as processual; it calls for thinking of innovation 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 of innovation promotion.

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