Innovation and collaboration for embedded technologies in Danish construction - the role of the client

Storgaard, Kresten; Forman, Marianne

Published in:
Proceedings of the 5th Nordic Conference on Construction Economics and Organisation

Publication date:
2009

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

INNOVATION AND COLLABORATION FOR EMBEDDED TECHNOLOGIES IN DANISH CONSTRUCTION – THE ROLE OF THE CLIENT

Kresten Storgaard and Marianne Forman (Aalborg University)

ABSTRACT

In a Danish setting, clients are especially seen to have the potential to be the main drivers in the process of stimulating innovation and use of embedded technology in construction: the paper questions this. The paper presents the results of a study of embedded technology. The study revealed the needs and potentials of specific types of embedded technologies in different segments of the sector. The types of technology include especially (Radio Frequency Identification tags (RFIDs) and Micro-Mechanical Systems of sensors (MEMS)). The segments in the construction sector were clients, suppliers and contractors. The study also included Danish research institutions and teams in this field. The empirical data were based on desk studies and interviews with key persons in supply (R&D in embedded technology), in potential demand (clients, suppliers and contractors) and in regulation/government. The study revealed noteworthy potential for innovation in developing products with embedded technology for the construction sector. The study also analyses barriers for this R&D process. What are the barriers and their character – technical or social? Are there any indications of how these barriers may be overcome, and who are the main drivers?

1. INTRODUCTION

A study on embedded technology in Danish construction, which SBi conducted for the Danish Enterprise and Construction Authority[16], demonstrated that each link in the supply chain in the construction industry may profit by solutions provided by embedded technologies. The basic technologies are developed! But still there is gap between these visions and available solutions for the construction sector. A process is needed that adapts the technology to the specific needs in construction. There is, in other words, a challenge for innovation and development - both in the fields of ICT and in the construction sector itself. Theoretically, the conditions for innovation seem obvious. Needs in the construction sector – comprising all links from supplier and contractor, to client and users - seem to be asking for solutions from the ICT sector. And the ICT sector has products and capability for innovation, which seem adequately to deliver the requests. Yet, this analysis concludes that the mark*et al*one seems to be inadequate as a driver for this process of innovation; at least not in the short term.

This paper will focus especially on the role of the client in the process of developing adequate technologies. In Denmark as in most western countries the client is seen as an agent or facilitator for change. As the end-buyer – the client has the potential capability to make demands not only to the built solutions – but also to the building process itself (for example to demand partnering elements in design and process). Therefore the client is seen as an effective gateway for facilitating changes even in the construction sector. A gateway because it is a much more simple policy to facilitate change through demands by public clients in tenders, than through programmes for innovation including research, private firms in construction and supply, users and clients. Such a client focused centred policy is also much cheaper for the state, and seems much less complex to implement.

[16] Storgaard, K., M. Forman and T.V. Rasmussen, 2007: Indlejret teknologi i byggeriet. Potentialer og besparelsesmuligheder for offentlige bygherrer. Erhvervs- og Byggestyrelsen. (Title in English translation: *Embedded technology in construction. Potentials and savings for public clients.*)

But the study demonstrates that a strategy depending on only the client as the facilitator for change, does not work. If the process of developing embedded solutions is seen as a chain of communication and negotiations between the developers of technology and the supply chain, the client and the user, it becomes evident that it is a complex setting. To develop solutions adopted by the users requires development of methods that support a process of innovation, which in turn reflects the complexity both in the sector and in the products.

2. STATE-OF-THE-ART REVIEW

2.1 Embedded technologies in construction

ICT and construction has been on the agenda for several years. Concepts of the Intelligent House and the Smart House were established, as well as real-life experiments with smart technology in buildings, which took place in several projects (Moltke *et al*., 1997; Ambrose and Nielsen, 1997). Potential for increases accessibility for disabled people has often been in focus (Bendixen and Christiansen, 1999). The perspective in many of these projects has had a rather technological focus, often with an implicit assumption that the technology has the capability to develop smart solutions which would be implemented and dispersed through the marked, with a little help from the demonstration project themselves. But increasingly both user involvement and focus on the innovation process itself have been seen, as is the case with a project for stimulating the regional economy in the periphery of Denmark (Lindgren; Sarghaug, 2008).

The Internet has opened up the perspectives for smart solutions both in the building and on the building site as well, combining net-based information or management systems with local devices. In 2002 the European Commission funded Roadmap projects including the ROADCON (Hannus *et al*., 2003), charged with the task of providing input for the RP 6, identifying key actors and preparing cooperation between them. Embedded and ambient technologies were seen as potential technological issues, and the construction sector should be involved in their development. ROADCON concludes that *the Challenge for RTD in Construction is to identify the opportunities to collaborate with and use results from other sectors while focussing its own resources on sector specific issues* (Hannus *et al*., 2003:3). But despite such advice for further investment for the IST programme, the construction sector did not play an important role in developing new technologies – neither in RP6 nor in RP7[17].

In 2005 the ECTP (European Construction Technology Platform) was formed to provide input to the RP7. Embedded and ambient technologies played a significant role in the recommendations by one of the subgroups[18]. And again strong recommendation for collaboration between the ICT sector and the construction sector was seen. Hitherto no major initiatives have been established in RP7.

The ERABUILD organisation[19] took a position where especially the RFID technologies[20] were seen as a major technological feature with potential importance for the construction

[17] The project ManuBuild (RP6) may be seen as a project that opens up for collaboration between ICT and the construction sector: *ManuBuild targets a radical breakthrough from the current 'craft and resource-based construction' to 'Open Building Manufacturing', combining ultra-efficient (ambient) manufacturing in factories and on sites with an open system for products and components offering diversity of supply in the market*. (Manubuild, 2005:1)

[18] PICT (Process and ICT) was Focus Area no 7 in ECTP; see http://www.ectp.org/fa_pict.asp

[19] ERABUILD (European Research Area in BUILDing) is an EU related strategic cooperation between national programmes promoting sustainable construction and operation of buildings between 8 EU countries, see http://www.erabuild.net/index.html

[20] RFID stands for Radio Frequency Identification. The technology consists of a tag that contains information and antenna or a radio-transponder and a reader, which can receive the radio signals

industry and for the built environment. A report[21] from an international consortium was published December 2006.

As early as 1995 Jaselskis *et al*. pointed out that the RFID technology was especially promising for the construction industry because it "*can be integrated into systems that can track materials, identify vehicles, and assist with cost controls*" (Jaselskis *et al*., 1995). The Era report was characterised by a rather technical view of the RFID subject, yet they "*acknowledge that there are also organizational and socio-political aspects of implementing RFID in an industry or organization*" (Erabuild, 2006:8). But they didn´t include these aspect in their analysis as they see such aspects as "*not a special RFID technology issue but more or less and issue that will be important for any technology and in any industry*" (op.cit, p8).

Two technologies are central when speaking of embedded technology: RFID and MEMS[22]. It is the combination of sensor technology (MEMS) connected to RFIDs and the access to the web that widened the perspectives much more than the perspective of use of RFID as a potent barcode technology, a function that hitherto has been in focus. The technology implies that data from a building material (e.g. a roof) or a building functional unit (e.g. a room) can be read and combined with information on the net, transferred to the reader. This will make it possible to get information about the situation on the building site (e.g. about the material (authenticity, condition/ moisture), instructions for the placing and handling of building elements, on Health and Security – or information about the building in use e.g. the roofs (e.g. leaking roofs, snow loads) or about temperature and ventilation in rooms. Information which typically requires response such as maintaining operations, alarms for pre-mould growth attack, removal of snow etc. or for automatic regulation of temperature and ventilation.

2.2 Client driven innovation

In recent years, the policy and research efforts in both Denmark and abroad have emphasised the role of the client as a driver for change in construction. This has been the case in the Danish policy on government building projects (Erhvervs- og Byggestyrelsen, 2002), it is seen in the proactive strategy of CIB on revaluing construction (Haugbølle og Sørensen, 2008), and it is seen in the establishment of an International Construction Clients' Forum (ICCF), (Haugbølle and Forman, 2006). However, little effort has been put into understanding how clients have in fact been a valuable contributor to reforms in construction. Thus a gap seems to exist between knowledge and policy on the role of the client as driver for change.

---

and thereby the information. The RFIDs can be either passive or active. In a passive tag, radio waves from the reader induce power in the tag, so radio-signals here can be transmitted and be readable by the reader. The distance between the tag and the receiver ranges from a few inches to 30 feet, depending on the frequency of the radio waves (ERABUILD, 2006:13).The amount of data has to be few; often only identification as an easy-to-read barcode, or an address on the internet. The price is low allowing the tags to be scattered widely e.g. in a building material – e.g. in concrete. The active RFID tag has access to power – a battery or a connection to the power supply – allowing transmission of signals over a longer distance, typically 60 to 300 ft. The amount of information can be high and prices are higher (ERABUILD, 2006:14; Bassi and Parand, 2002).

[21] ERABUILD, 2006, RFID in Construction. Review of the current state of Radio Frequency Identification (RFID) Technology, its use and potential future use in construction.

[22] MEMS are sensor technology and it stands for Micro-Mechanical Systems. *A sensor is a device that provides information about the state of a physical system. A sensor is tailored to the physical system and operates on the premises of the system".* (http://www.sensortec.dk). The sensors might be reduced to a minuscule size where nano-technology meets sensor-technology, see fx the Smart Dust project at Berkeley (Pister, 2001), (Hsu *et al*, 1998). The sensors taste the molecules so to speak. The sensor measures the state of a functional condition (heat, moisture, ventilation, load, frequency of mould, etc) and may communicate this information to an actuator, e.g. through RFIDs, so a response to change the situation if needed, may be carried out.

According to the Swedish Academy of Engineering Science (Swedish Construction Client Forum, 2006) the client must maintain a broad spectrum of competences in order to manage planning, execution and operation of a building. Thus, focus must be on the client's ability to handle the relationship with all stakeholders of the building, be they the owner, the customer, society or the building industry.

The Danish Association of Construction Clients (DACC) focuses on client's line of action for purchase and tender. They propose that the action changes from being based on project-specific assumptions to be based on company and strategic discipline, and they propose clients to develop strategies for purchasing and supply of buildings (Bygherreforeningen og Konkurrencestyrelsen, 2008). This growing focus on clients as change agents is among other things inspired by the concept of lead users developed by Von Hippel. Von Hippel defines lead users as: "*Lead users are users whose present strong needs will become general in a marketplace months or years in the future. Since lead users are familiar with conditions which lie in the future for most others, they can serve as a need-forecasting laboratory for marketing research. Moreover, since lead users often attempt to fill the need they experience, they can provide new product concept and design data as well*." (von Hippel, 1986:791).

2.3 Public procurement and innovation

Edler and Georghiou argue that public procurement as an innovation policy has a major importance for the development, an argumentation that may enhance the interest of the public client as a main driver for innovation. In the 1970s empirical studies showed that over a prolonged period of time public procurements motivated to more innovation than R&D subsidies. They define demand-side innovation policies as "*all public measures to induce innovation and/or speed up diffusion of innovations through increasing the demand for innovations, defining new functional requirement for products and services or better articulating demand*" (Edler and Georghiou, 2007:952).

They point to the fact that public procurement has to play a different role depending on the stage the product has been developed to. They make a distinction between commercial procurement and pre-commercial procurement. Commercial procurement is when the products are already developed (the products are on the shelves) and the public clients just have to demand and buy the products. Pre-commercial procurement is the situation where the products are not ready for sale, but are still in a pre-commercial stage, and there is still a risk connected with the innovation of the products and services. The idea behind pre-commercial procurement is that the risk is shared between the potential producers and users, here represented by the public. There is still a need for R&D. Edler and Georghiou formulated it this way: "*In practical terms the procurement in fact is an R&D service contract, given to a future supplier in a multi-stage process, from exploration and feasibility to R&D up to prototyping, field tests with first batches and then, finally, commercialisation*." (Edler and Georghiou, 2007:954). They argue that the justification for this more flexible approach in the innovation process is that interaction is necessary between R&D activities and formulation of user demands. Three rationales for applying public procurement as innovation policy tool are identified: 1) Local demand, 2) market failures and 3) improvement of public infrastructure and service.

Local demand

Edler and Georghiou are inspired by the concept of lead-users developed by von Hippel. They extended the concept of lead-users to the concept of lead market. The rationale behind local demand is a situation where early users take a risk by using a technology that not finished and in return get access to a solution that can give competitive benefits or quicker access to a problem's solution. Lead market is when more users adapt an innovation long before the innovation is finished and contribute to products diffusion or when a single user like a public client constitutes a market by himself. The producers' advantage is a reduction in the investment-risk. Edler and Georghiou formulated the rationale for the public in the following way. "*The role of the state in creating or assisting in creating lead markets mainly lies in the provision of a means to combine supply and demand-side measures. This includes provision of appropriate framework conditions that include and enable innovative activity (infrastructure, sufficient R&D basis, support for co-operation, etc.)*" (Edler and Georghiou, 2007:956).

Market failures

Edler and Georghiou point out two aspects concerning market failures. Firstly, customers often do not know what there is on the market. There is a lack of information and traditional distribution channels are insufficient for spreading the information to the users. Secondly, the user-producer interaction and communication is often poor. The users do not voice their demands loudly enough for the producers to hear them (Lundvall, 1990; von Hippel, 1986). The result is a marked where demand and supply do not meet. Edler and Georghiou argue that public procurement can be a part of the solution of these market failures. Public procurement can reach critical mass and shape the incentive for the producers to innovate and to produce products that especially the public buyer demands.

Public procurement to improve other public policy and services

The rationale is that through public procurement the state can shape the direction for innovation and support certain policy goals such as sustainability, energy efficiency, e.g. In the case of embedded technology it could be goals as reduction of building damage or a more general a wish to maintaining buildings in a better way. It is argued that, it is shown that the state often is more demanding than private consumers in satisfying new societal needs and providing infrastructure and public service. The state will in this role often act as a lead user (Edler and Georghiou, 2007).

Implementation

Edler and Georghiou point out that a necessary condition for promoting public procurement is governmental management and coordination across the public sector. Simultaneously the suppliers have to realize the economic benefit they can achieve through this cooperation. They formulate the challenge in following way: "*The major requirement for a strategy procurement policy thus is to bring future needs and future supply together at an early stage*" (Edler and Georghiou, 2007:959). They point to the use of strategic forecasts as a way to develop common visions between producers and users.

This also shows the weakness in public procurement as a main driver for innovation on a national (European) scene. What was seen as a fruitful strategy for innovation is today more or less impossible – or at least difficult - to carry out, due to international agreements and regulations on competition and collaboration. In EU no major public procurement is allowed without tendering (EU, 2004/18/EF), which impedes strategic collaboration for innovation between public procurement agents and private firms. In DK and in many other western countries it is also the experience that management across governmental bodies seems simple but is a huge challenge in itself. These few empirical based facts weaken the assumption that the public body in collaboration with the industry in *an (politically) easy way* will be allowed to be agents for innovation in direct collaboration on innovation through purchasing.

2.4 Embedded technology in construction: a complex system

Buildings are often characterised as complex products and the production and supply system as a complex production systems (Gann and Salter, 2000). In this sense development and implementing of embedded technology in buildings and in the construction system may be perceived within the frame of innovation in complex production systems. Gann and Salter point to different central aspects that characterise innovation in complex production systems. In contrast to traditional industrial networks, the construction sector is project-organised. As a consequence of this, Gann and Salter point to the fact that: "*The project-based nature of work implies that firms have to manage networks with complex interfaces. Delivery of products and services requires collaboration between firms. Performance and competitiveness depends not solely on the single firm, but on the efficient functioning of the entire network*" (op.cit. p959). The created value and profits is in this way not connected to a single company but rather "*generated by project groups that tend to operate at the boundaries of the firm* (op.cit. p957)".

Often complex products and systems must be integrated in existing systems to function in the context. Gann and Salter point out that it appears that the level of technical complexity increases when new generations of technology must be integrated with older systems. Therefore the need arises for new specialisations to support system integration, which can be placed in different locations within companies or between companies in new firms (op.cit. p959). Furthermore project-based firms can position themselves in the role of system integrators. The development and placement of these new specialisations may have an impact on the production and use of complex products and systems itself. A key question concerning the development and implementation of embedded technology is how the system integration can be done? Which actors can be system integrators or develop into it, and what kind of framework has to be developed for this to happen?

For Gann and Salter not only clients and the regulation system are important single drivers; they add "*Governments and international agencies, financial institutions and insurance organisations are creating a new framework for the governance of technology in construction*" (op.cit. p960). Each stakeholder in the process might play an important role. And so must stakeholders in new businesses which may stem from the new solutions/ technologies, such as new services, financing bodies, insurances companies, etc.

Project-based innovation across organisations has at least two implications for the involved firms, customers and institutions e.g. first, innovation projects are characterised by having a lot of non-routine features. Second, *there is a need for integrity of information between suppliers, designers, systems integrators, engineers, contractors, clients and end-users* (op.cit. p961). Gann and Salter point to the fact that there is a growing need for developing services to support the owners and users of complex products and systems; both in relation to the management servicing and the maintenance of building systems. Services include financing, planning and design, consulting, customer support and training, supplier coordination, marketing and risk management, together with benefits in relation to facilities management. They conclude that "*Growing demand for packaged product and service delivery is blurring the traditional boundaries between manufacturing, design, construction and service sectors*" (op.cit. p962). Moreover a characteristic of complex products and systems is that the artefact generates added services and these companies earned money on the services instead of only on the artefact.

Following the argumentation of Gann and Salter we will conclude that in complex systems of innovation a single stakeholder is seldom seen as the main driver for innovation. If innovation has to be stimulated an innovation progressive policy must reflex the complexity among the stakeholders that must constitute the future technological solutions – that is stakeholders from ICT, from construction, from client, facilities management (FM) operators, users of the building, and even from the regulative bodies, financing bodies and future service providers.

3. RESEARCH PROJECT

3.1 Project description and objectives

The objective of the research project was to investigate the potential of embedded technology in the Danish construction sector. It was carried out for the Danish Enterprise and Construction Authority. In a key report for the Danish construction industry published in 2006 a central scenario was that *Major developers should require the use of embedded ICT in building materials and construction. Smart building materials can enhance the construction process, helping to meet users' needs and manage the building business.* (Erhvervs- og Byggestyrelsen, 2006:11)

The research team at SBi was given the task of investigating how close the vision was to the actual state of the use of embedded technology in the sector. The analysis was carried out and in August 2007 the results were published (Storgaard, Forman and Rasmussen, 2007). The task included a definition of terms and concepts and a clarification of the future and current market for embedded technologies in the construction sector, an overview of research in the field and a clarification of the need to stimulate development in relation to public buildings and embedded technologies.

3.2 Research methodology

The project was carried out in five phases[23]. The empirical data was based on desk studies and interviews with key persons in supply (R&D in embedded technology), in potential demand (clients, suppliers, contractors) and in regulation/government. Qualitative interviews with key persons were choosen as the main method for getting information on experiences from stakeholders. Surveys would add only little to the *understanding* of the use of the technology or of the process (or potential) for innovation and collaboration on R&D between the construction and the ICT sectors; although surveys may be suited for *mapping* the frequencies of use of embedded technology in construction and of frequencies of collaboration on innovation in the sector. Case studies would have been an option, which might have given a good understanding of how well the technology worked in the construction sector – and about the problems of daily use. But case studies would have brought only little experience to the explanation of processes that do not in fact take place – like for example the lack of collaboration on R&D, which, as mentioned in the introduction, was the assumption of the project from the beginning. Our conclusion is that the chosen methods are appropriate for outlining the patterns of use, potential use and potential savings as well as to give some indications to the understanding of the process of innovation. A total of 23 key persons were contacted and interviewed. All were stakeholders in the potential industrial complex between ICT, contractor and suppliers in the construction process, clients, research and

[23] Phase 1 - Conceptual Clarifications – based on desk studies. Phase 2 - Research into embedded technologies and construction. Desk studies, interviews with key players in research and research foundations. Emphasis was on identifying the Danish research, but also the EU research is described.
Phase 3 - Applications and saving potentials. Interviews with stakeholders in the construction value chain.
Phase 4 - Public clients and embedded technology. Special interviews with this type of user.
Phase 5 – Analysis of barriers and opportunities for the development of embedded technology.

consultancy and governmental bodies. The method used for finding the relevant people for interviewing was by the snowball method. Starting with a core group, then asking each person interviewed, whether they knew other people with experience in the area that it would be appropriate to interview.

4. RESEARCH RESULTS AND INDUSTRIAL IMPACT

4.1 Quantification of results

The analysis showed a construction sector with substantial potential for embedded technology that could contribute to solving its needs and an ITC sector with potential for delivering the wanted solutions. But the analysis also demonstrated solid barriers, which prevented demand and supply to meet.

Table 1 summarises the results. For each type of use, the state of use of embedded technology, the potential for further use and for possible savings are stated. The table shows that *clients* can benefit from embedded technologies especially through better FM functionalities for example improved energy management and operation, just-in-time repairs, warning against moisture and moulds, warning against break down of materials. Type of use that also the *end-user* (tenants, employees in factories and offices) may benefit from for example enhanced comfort and cost reduction of energy. In the building process as such, the *contractors* may benefit from better logistics, improved instructions concerning production and health and safety, information and management on logistics, condition and authenticity of delivered materials. The *distribution sector* may benefit from improved logistics that allows them to deliver just–in-time to their customers, i.e. the contractors. The *suppliers* may not only be the stakeholder that should embed the new technology in their products – to deliver products with higher value for their customers (clients, contractors, distributors) – they themselves can also benefit from added information to the single items (on RFIDs) with individual customer data, allowing a mass-customized automated production.

So far the construction sector has not shown any great willingness to use the new technology or to participate in the process of needed R&D to form the technology in accordance with their demands. This also applies the supplying industries. They were uncertain of how much demand there would be, and uncertain of the benefits, if any. It applies to the distribution and marketing stakeholders as well, reported to be on a stand-by, despite the benefits reported and documented by other industries. The picture seemed clear. Solutions to cover specific needs were developed – or could be delivered. In this way there was a potential for solutions to meet needs. But the technology has not fully matured yet – for commercial solutions. This means that specific solutions have to be designed for each customer. Volume in production is low, and prices high.

Table 1. Use of embedded technology in the construction sector and the potential types of savings.

		State of use today	Future use and potentials for savings and cost-reduction
Building materials		RFID for production management Prefabricated smart HVACs	RFID for the management of production RFID for warehouse management. Cost savings: Optimising logistics
Distribution		RFID for supporting logistic	RFID and sensors for supporting logistic, waste and the destruction of materials used for transportation and storage, and guarantee of authenticity. Cost savings: Optimising logistics.
Process of construction		RFID for the marking of construction equipment, etc.	RFID and sensors to support logistics, including losses of construction and destruction of building materials for the transportation and storage. RFID to support the building process itself with instructions, etc. for example with links to the websites of construction material manufacturers. The link between Digital Construction tools, the on-site digital hut, and tags on building materials. Cost savings: Reduction of waste. Increase of productivity. Reduction of industrial accidents
Use – Client, FM and residents	Operation	Local CTS building management system for managing energy	CTS – building management system for control of energy production and energy coupled to energy system. Using RFID to ensure proper cleaning through links to web based services managed by producer or service provider. Prevention of moulds, etc. through monitoring with sensors, etc. Cost savings: Optimising management of energy and ventilation
	Maintenance	Use of sensors for assessment of condition of concrete on bridges. Assessment of monitoring of moisture	Using RFID to ensure proper maintenance through links to the homepage of the producer. Using the wireless system (RFID and sensors) to the assessment of the condition of buildings. Cost savings: Optimising renewal - just in time.
	Use	Management of matters relating to comfort (light, temperature, humidity)	The use of embedded technology to support operations and new forms of cooperation. Control of lighting, heating, ventilation, humidity, etc. with CTS, sensors and RFID. Cost savings: Increase in the value of the buildings - enhanced comfort, improved energy balance.

4.2 Barriers and drivers

The overall picture of the innovation process was that many persons involved in the construction industry were reluctant and hesitant to implement embedded technology, due to uncertainty about it, and lack of clarity about its impact on their market potential. The study also pointed out a general type of problems concerning the *standardisation* in relation to RFID. This has to do with identification of frequency ranges and power. The standards that are currently developed are the passive tags for use in logistics, where the sole aim is to identify the manufacturer and the product.

A *gap between the speed of development of ICT and in technical/physical elements* was mentioned as a barrier as well. Buildings etc. are characterized by having a long life, while ICT equipment is characterised by rapid development and rapid transitions to new generations. Uncertainty as to whether one *generation* of embedded technology would be able to communicate with the next generation also weakened the motivation for the construction sector to invest in the new technology. Furthermore *security* was seen as a barrier. Would it be possible for competitors to "read" the tags and view a company's purchases and investments, and in this way get information about some of its key parameters of competition? Investments in embedded technology in buildings may be seen as a minor investment in a *total economic perspective*. Even if cost saving on FM is judged to make a profit of the extra costs in investment, the client is reluctant to take on the role of facilitator for innovation in this field. That the tenants often directly pay the FM expenditures only weaken the motivation for client-driven innovation even more. The analysis showed clearly that the level of readiness and awareness of the new technology was low at the time of the study, and that the level of uncertainty concerning the impact on the user of the built environment was high. The clients believed that other parts in the supply chain, especially the contractors, might benefit more than the client. And therefore the clients were not motivated for being prime drivers. Our research also demonstrated that insurance organisations might play an important role in the innovation of embedded technology. Not only as a part of the framework condition but rather as an active part of either the supplier and service system or as a part of the market system.

The study demonstrated that each link in the supply chain in construction may profit from solutions delivered by embedded technologies. However, the technological solutions differ in accordance with the type of need of each link in the demand chain. If the process of developing embedded solutions is seen as a chain of communication and negotiations between the developers of technology and the supply chain, the client and the user, it becomes evident that it is a complex setting. In this way embedded technology in the construction sector has to be interpreted as integrated complex products that must interact, if high effects are to be achieved. But that requires development of methods that support a process of innovation, which reflects the complexity both in the sector and in the products.

Although the construction sector is known for a certain restraint concerning investing in strategic innovative activities themselves, the interview nevertheless revealed a growing readiness to participate in R&D activities concerning use of the new technology in the sector. The study point out that in collaboration with the technology sector (researchers, developers and producers of devices for this new technology), the construction sector has the potential to be a major partner in further innovation in the ICT sector on a national and international scene. It can be noted that there is a gap between the current R&D in embedded technology and R&D in construction.

Coupled with R&D traditions in ICT and high-tech funding bodies that do not give priority to collaborative innovation projects between the ICT sector and industries, which are certainly not perceived as high-tech, the construction sector's traditional inertia to invest in development can be a significant barrier. In settings where the user of buildings may be seen as advanced users[24], there will be a potential for strategic collaboration between the construction sector and R&D in embedded technology for developing solutions that

[24] Advanced users are users, who embody the need of tomorrow, e.g. families who want careers, children and lot of leisure time – a cocktail that today's everyday life, often cannot fit in.

are suited for future demands in other markets as well. This may be the case in a Scandinavian context, where dwellings and homes are very highly valued, and there are high demands for functional everyday dwellings, as well as for architectural performance. The same applies to non-residential buildings, where Scandinavian companies are inclined to invest in the building part of their production system. Architecture is not only symbolic capital, but real estate as well. In addition, the construction sector represents a potentially significant demand itself. The turnover in the building set-up is large in the national economy and a small additional cost for technology investment, may seem modest in the overall construction project. If the new technology can increase internal functionality in buildings while at the same time contributing to a better performance in the process of construction and even improve the quality of the finished construction, there should be opportunities to develop solutions that have great potential for marketing in the international market.

5. CONCLUSIONS

Innovative processes in which technologies mature and develop are characterised by a high degree of uncertainty about the outcome. Through a process of negotiations between stakeholders the span decreases – the new technologies (including the use of the technology) crystallise and the scope of future influence is dramatically reduced. In the case of embedded technology there still seems to be opportunities for stakeholders to participate in forming the technology in these years. The study clearly demonstrated that in the field of embedded technology, the client alone is not capable of assuming the role of the leading facilitator of innovation. The connection between extra investment and a direct pay-off in higher value is judged to be too weak and uncertain, even by public clients. The study also demonstrated that the different stakeholders in the construction sector – or links in the chain of delivery - have different demands to what the technology should deliver. This puts focus on the need for a dialogue with these actors across the construction segment to developers and producers of the embedded technology. While clients may not be the main driver for innovation, they will be an important part in the dialogue in the complex network for innovation. Such a network should include stakeholders from the embedded technology (e.g. RFID, MEMS) who deliver the technology, the building materials industry, which produces the elements where the technology is built in (or attached), the client, operators (FM) and users of the buildings. Also the constructors, designers/architects and consultants are significant contributors to a dialogue-based innovation process. And so is finance and assurance which may develop new budget models if higher quality in the produced buildings with fewer failures and insurance costs.

It is the conclusion of the analysis that a wide diffusion of the use of the embedded technology depends on the establishment of a process of communication and negotiations between the developers of technology and a complex of the stakeholders in the construction value chain. A (re)configuration of actors has to take place. A client-driven process alone will not stimulate the process of innovation.

6. ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support of the Danish Enterprise and Construction Authority in sponsoring the project, "Embedded technology in construction".

7. REFERENCES

Ambrose, I. and Nielsen, J.S.R. (1997) *Informations- og kommunikations-teknologi i fremtidens boliger* (SBI-rapport 284). Hørsholm: Statens Byggeforskningsinstitut, 78pp.

Bassi, R. and Parand, F. (2002) *Electronic tagging and wireless technologies: Application in the construction industry* (Information Paper IP 16/02, Part 1). Garston: BRE & Department of Trade and Industry, 5pp.

Bendixen, K. and Christiansen, P. (1999) *Fokus på Smart Home teknologi.* Taastrup: Teknologisk Institut, 41pp.

Bygherreforeningen and Konkurrencestyrelsen (2008) *Guide, Bygherrens indkøbs- og udbudsstrategier – for bedre konkurrence i bygge- og anlægssektoren*. København, 39pp.

Edler, J. and Georghiou, L. (2007) Public procurement and innovation: Resurrecting the demand side, *Research Policy*, **36**(7), 949-63.

ERABUILD, http://www.erabuild.net/index.html

ERABuild (2006), *Review of the current state of Radio Frequency Identification (RFID) Technology, its use and potential future use in construction*. København: National Agency for Entreprise and Construction, Tekes, Formas, and Teknologisk Institut, 100pp.

Erhvervs- og Boligstyrelsen (2002) *Staten som bygherre – vækst og effektivisering i byggeriet*. København: http://www.oem.dk/publikationer/html/bygherre/index.htm

Erhvervs- og Byggestyrelsen. (2006) *Vision 2020 – byggeri med mening*. København, 28pp.

EU (2004) Udbudsdirektivet: 2004/18/EF, in http://www.eu-oplysningen.dk/dokumenter/retsakter/pop/32004L0018/

Gann, D.M. and Salter, A.S. (2000) Innovation in project-based, service-enchanced firms: The construction of complex products and systems, *Research Policy*, **29**(7/8), 955-72.

Hannus, M. *et al*. (2003) *Construction ICT Roadmap*. ROADCON: IST–2001–37278, http://cic.vtt.fi/projects/roadcon/docs/roadcon_d52.pdf.

Haugbølle, K. and Forman, M. (2006) The co-construction of clients, concepts and companies, in Pietroforte, R., De Angelis, E. and Polverion, F. (eds.), *Proceedings of the Joint International CIB WO55/WO65/WO86 Symposium Construction in the 21st century*. Napoli: Edizioni Scientifiche Italiane.

Haugbølle, K. and Sørensen, L.M. (2008) New CIB priority theme on 'Clients and Users', in www.cibworld.nl/website/0803/ clients.pdf

Hippel, von E. (1986) Lead Users: A source of novel product concepts*, Management Science*, **32**(7), 791-805.

Hsu, V.S., Kahn, J.M. and Pister, K.S.J (1998) Wireless Communications for Smart Dust. Electronics Research Laboratory Memonradum Number M98/2. Berkeley.

International Construction Clients' Forum (ICCF) (2005) An Update on the Activities of the International Construction Clients Forum (ICCF), in http://cibworld.xs4all.nl/dl/ib/0501/ICCFProposal.html

Jaselskis, E.J., Anderson, M.R., Jahren, C.T., Rodriguez, Y. and Njos, S. (1995) Radio-frequency identification applications in industry*, Journal of Construction Engineering and Management*, **121**(2), 189-96.

Lindgren, P. and Saghaug, K.M. (2008) *Realisering af Smart City/Smart House i Nordjylland*, in Lindgaard Christensen, J., Nielsen, T. and Tved Linde, L. (eds.): *Hvad skal Nordjylland leve af?* Aalborg: Institut for Økonomi, Politik og Forvaltning, Aalborg Universitet.

Lundval, B.-Å. (1990) Innovation as an interactive process: From user-producer interaction to the national system of innovation*,* in Dosi, G. *et al*. (eds.) *Technical change and economic theory*. London: Pinter, 349-69.

Manubuild (2005) Newsletter 1, in http://www.manubuild.org/downloads/ManuBuild-Newsletter01_2005-04-30.pdf.

Moltke, I, Andersen, H.H.K. and Honoré, C. (1997) *Villa VISION erfaringer*. Taastrup: Teknologisk Institut, 59pp.
PICT (2006), http://www.ectp.org/fa_pict.asp
Pister, K. (2001) Smart Dust. Autonomous sensing and communication in a cubic milimeter. http://robotics.eecs.berkeley.edu/~pister/SmartDust/
Storgaard, K., Forman, M. and Rasmussen, T.V. (2007) *Indlejret teknologi i byggeriet: Potentialer og besparelsesmuligheder for offentlige bygherrer.* København: Erhvervs- og Byggestyrelsen, 65pp.
Swedish Construction Clients Forum (2006) *The role and mission of the construction client*. Stockholm: BygherreForum, 24pp.