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# ICT DEVELOPMENT STRATEGIES FOR INDUSTRIALISATION OF THE BUILDING SECTOR

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***SUMMARY:*** *The article presents the main results of a joint investigation by Swedish researchers and industry representatives carried out during 2006-2007 concerning the benefits of modern object based information and communication technology, ICT, for industrialisation of the building industry. The background for the investigation was an experience by both parties of a lack of coherence between scientific results and practical needs of ICT, in spite of substantial contributions and positive evaluations of both Swedish and international R&D-programs.*

*In the manufacturing industry, ICT has proven to be a crucial factor in raising the industry's efficiency and quality. Even though R&D-projects have shown how modern object based ICT can be used in building and facilities management, such tools are largely missing in the sector.*

*The goal of the investigation was to answer the following research questions:*

- *How can a joint understanding be created between researchers and practitioners as a basis for continued R&D-efforts?*
- *What is the use of ICT like in a typical building project today?*
- *How can modern ICT be introduced to support both today's information flow, and create a foundation for development and increased effectiveness?*

*The first research question was addressed by carrying out the investigation in cooperation between researchers and practitioners. The second question was answered by mapping current ICT use in quantitative and qualitative investigations of traditional and industrialised house-building projects. The third research question was addressed in inquiries and State-of-the-Art investigations concerning software and standardised information structures.*

*Crucial focus areas for R&D to support the industrialisation of house-building were jointly identified by researchers and industry representatives, and a strategy in order to implement integrated and object based information management in the Swedish building sector was recommended.*

***KEYWORDS:*** *ICT, strategies, integrated, industrialisation.*

***REFERENCE:*** *Ekholm A, Molnár M (2009) ICT development strategies for industrialisation of the building sector, Journal of Information Technology in Construction (ITcon), Vol. 14, Special Issue Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning, pg. 429-444, http://www.itcon.org/2009/28*

# 1. BACKGROUND AND OBJECTIVES

## 1.1 Introduction

Industrialization of the construction process is by many actors within the sector regarded as the most feasible way to render construction more effective. Modern object oriented information and communication technology, ICT, can be used both to describe products and to link the processes together. The largest benefit of modern ICT will emerge when information can be exchanged without unnecessary manual adjustment. But to realise the full potential of ICT requires both that work is sufficiently structured and that the processes are integrated.

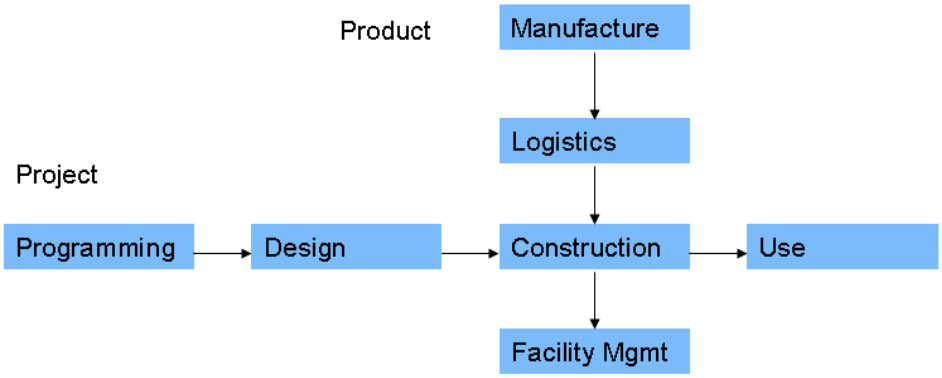


*FIG. 1: The project focus of traditional construction*

The construction sector traditionally has a strong singular projects focus, see Fig 1. Each separate construction project develops and produces its own unique end product, most often with new project participants each time. Compared with the manufacturing industry, the building industry internationally and in Sweden has for a long time had a weaker development of both quality and productivity (Egan 1998, Byggkommissionen 2002). Several investigations have shown that ”waste” within the construction sector is large (Josephson and Saukkoriipi 2005) and that many measures for rendering the processes more effective are possible (Byggkommittén 2004) and (Apleberger et al. 2007).

The backwardness of the construction sector is often explained by its strong project focus. Generally, the construction sector is very good at capturing different market needs, but the lack of continuity in product development and production seems to lead to recurring quality problems and low productivity. In later years though, the building industry has taken steps towards an increasing process focus and industrialisation (Lessing 2006).

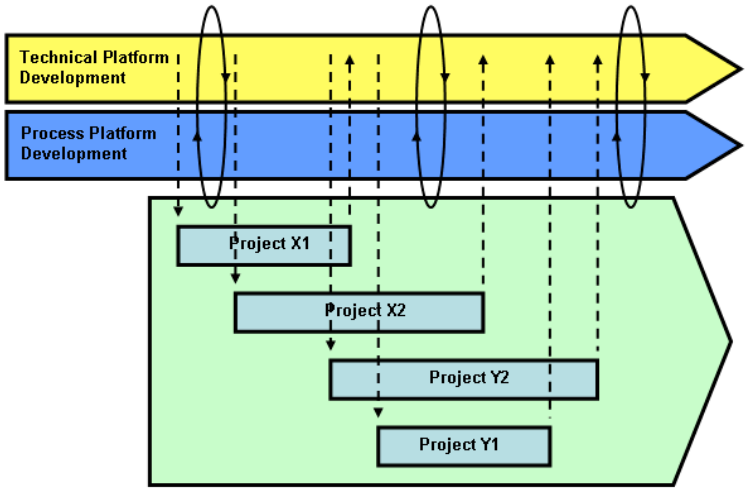


*FIG. 2: The industrialised building process, where product and process development are separate from the individual building projects (after Lessing 2006)*

The fundamental idea of an industrialised process is to separate the development of product and process platforms from the individual building projects, see Fig. 2. A long lasting experience from the manufacturing industry, e.g. the automotive industry, shows that a continuous and systematic product and process development is fundamental to improved productivity and quality. This is the starting point for the efforts currently made, among others by Swedish construction companies, within industrialised building. The product and systems manufacturers, e.g. for windows and concrete elements, already work according to industrial principles with a clear separation between product development and individual building projects.

## 1.2 ICT has a significant role in the industrialisation of the building industry

Modern object oriented ICT with well defined information structures and efficient communication interfaces have in the manufacturing industry shown to be an efficient tool and supports the integration of processes for product development, production, materials supply and maintenance. ICT at this level of development is however missing in today's building processes.

Several national and European R&D-programs within construction ICT have made substantial contributions to making the construction sector more efficient, e.g. the Swedish IT Construction & Real Estate 2002 programme. In spite of positive evaluations, actors both in Sweden and internationally, experience a lack of coordination between the scientific results of the programs and the actual needs in the sector.

New initiatives within construction ICT must be oriented towards creating the best enterprise and societal benefit during the whole life-cycle of a construction project. One example is the North American FIATECH project, a broad industry initiative, which has developed a roadmap with the purpose to develop, demonstrate and implement fully integrated ICT for construction projects. The goal is to "create the foundation for a lifecycle data management and information integration environment of the future that is adopted throughout the capital projects and facilities industry" (www.fiatech.org/projects/roadmap/integrateddata.html).

The European construction industry has through the organisation ECTP, European Construction Technology Platform, in 2005 presented a plan with the objective to contribute to the development of a competitive building industry and a sustainable built environment. ICT is emphasised as an important means to reach these goals (http://www.ectp.org/fa_pict.asp). The EU-financed Strat-CON project has as its objective within ECTP to contribute by developing a R&D program for construction ICT (www.strat-con.org). However, Strat-CON mainly deals with technology development, and not the institutional, business related and geographical frameworks that in practice determine the use of the technology.

## 1.3 Objectives and research questions

The starting point of the project presented here is that R&D within construction ICT has an important role in the transition from a traditional to an industrialised construction sector. Therefore, it is urgent that a mutual understanding is developed between researchers and the industry about the possibilities of ICT to contribute to making the construction industry more efficient. This makes up a foundation for continued common investments in innovations within ICT for industrialised building.

The goal of the investigation was to answer the following research questions:

- How can a joint understanding be created between researchers and practitioners as a basis for continued R&D-efforts?
- What is the use of ICT like in a typical building project today?
- How can modern ICT be introduced so that it supports both today's information flow, and creates a foundation for development and increased effectiveness?

# 2. METHODOLOGY AND ORGANISATION

## 2.1 Methodology

The research questions have been answered through different procedures.

The research question: "How can a joint understanding be created between researchers and practitioners as a basis for continued R&D-efforts?" was approached through the overall design of the project. All phases of the project were planned and carried out by a working group consisting of both construction sector representatives and researchers. In order to strengthen the common understanding of the role of ICT for the development of the

construction industry, an analysis was made of earlier and ongoing Nordic programmes within the field. The objective was to analyse ambitions and results of the programmes in order to find possible reasons for the experienced gap between research results and implementation needs.

An additional objective with the retrospect analysis was to learn from earlier efforts and to identify success factors and pitfalls, in order to prepare for future R&D-programmes in the field. Industrialisation, which actively occupies both companies and researchers in the sector, was chosen as a paradigm for the continued effort of making the sector more efficient. In order to further balance between traditional priorities of industry and research representatives, business benefits and technology development were determined to be the two most important units of analysis in the investigations.

An important activity to reach consensus between industry and research representatives was a joint participation in workshops, seminars and conferences which had Construction ICT and Industrialisation as main themes. Further cross fertilisation has happened through the project members' participation in discussions of future R&D-programmes.

The research question: "What is the use of ICT like in a typical building project today?" was answered through a combination of quantitative and qualitative investigations. As a first step, a statistical investigation was carried out to characterise current house-building (Larsson 2006). Quantities, geographical distribution, technical and economic data, and form of disposal, were investigated for a one year production volume of multi-family houses. The results of the survey were among others used to identify typical house-building projects for deeper analyses. Multi-family houses produced by developers belonging to the four largest contractors to be sold to newly organised housing cooperatives were identified as typical for the period when the study was carried out.

An ongoing multi-family housing project with these characteristics was chosen for a case study where design and production processes and the use of ICT were investigated.

The investigation was carried out as semi structured interviews, one to two hours long, at the workplace of the respondents. These represented actors like the commissioner's project manager, the architect, the building and prefab structural engineer, the main contractor's engineering manager, the site manager, the purchasing manager, the work manager, the HVAC-designer and the window supplier.

The respondents were asked to describe their roles and main work tasks in the investigated building project. This was considered important in order to be able to position the role of ICT in the different phases of the construction process, and to avoid generalisations and one-sided focus of the technical aspects of ICT use. Detailed questions were asked about the development, exchange and storing of technical and economical-administrative information including economical aspects on these matters. The respondents were encouraged to reflect around the routines for ICT-use and evaluate its role for the economy of the multi-family housing project including its quality. The interviews were recorded on tape and afterwards written in an abridged format. Additional questions were asked on telephone in a few cases. Printed interviews were distributed to the respondents for control of facts. Different documentation was also collected, e.g. manuals for development, exchange and storing of information, architects and structural engineers drawings and sales material.

A specially formed group of eight experts comprised of both researchers and industry representatives have continuously analysed the project's results and contributed to identify the project's focus areas. The expert group used the material to compile a representative as-is documentation of the ICT use in traditional house-building projects and to identify development areas where modern ICT was considered to contribute to increased efficiency.

The research question: "How can modern ICT be introduced so that it supports both today's information flow, and creates a foundation for development and increased effectiveness?" was mainly answered through a written enquiry to 28 active developers extracted from 120 persons from the Swedish building industry or universities. Active developers where those that within the period 2003 – 2005 had published ICT-related articles in scientific or sector journals or had lectured in sector seminars respectively. During the selection procedure respondents were contacted firstly by mail and then on telephone and asked if they agreed to participate in the investigation.

The respondents were encouraged to validate the case study, and to evaluate the potential for improved productivity and quality in a selection of ICT related problem and development areas identified by the project's working group. They were asked to reflect on the reasons for the problems and suggest actions to achieve improvements within these areas. Additionally, they were asked to describe expected benefits and identify possible obstacles in their proposals. These questions were considered important in order to identify actors and drivers with real interest in sector common R&D-programmes within Construction ICT. The respondents were

also given the option to identify development areas on their own and propose measures of improvement. For each suggestion, both given and proposed the respondents were asked to judge on the expected time to practical implementation.

The results from the enquiry were evaluated in common by the working and expert groups. A number of scenarios were developed where ICT in a fundamental way was considered to contribute to the efficiency of house-building. Judgements were made of the prerequisites for implementation of the different scenarios, where the benefits and business strategy considerations for different actors were considered to be a critical parameter.

A separate study was made in order to map the information content in documents in today's construction process and their relation to an imagined information model based on object oriented ICT. Suggestions for guidelines, organisation and methodology were developed in order that the information exchange could be managed by object oriented ICT.

In another separate study, the application of ICT in off-site manufactured industrialised building was investigated in an enquiry to three leading Swedish companies in the field. The implementation of information systems in these companies were shown to be similar to that of the manufacturing industry, characterised by integrated information management for product development, manufacture and business processes.

With these investigations and analyses as a starting point recommendations for future R&D-programmes within Construction ICT were developed. The different investigations and their relations to the project's results are shown in Fig. 3.

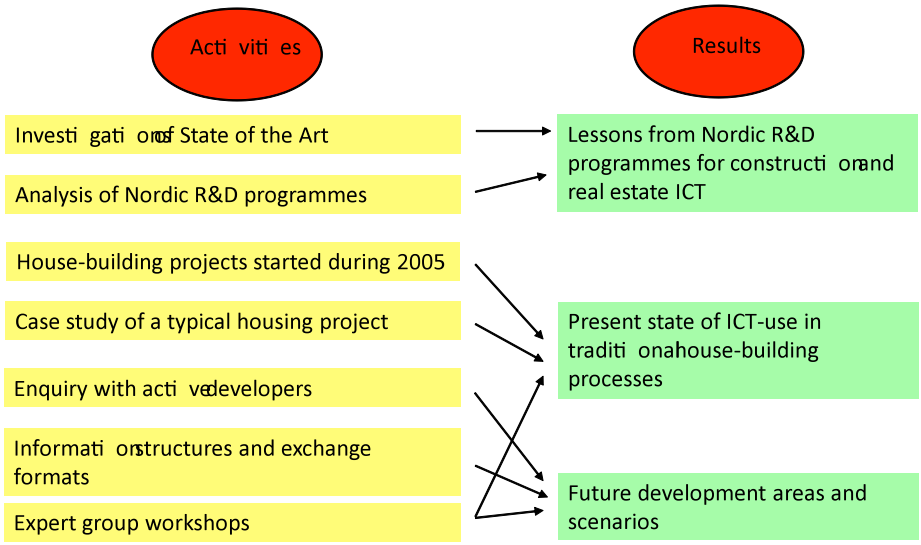


*FIG. 3: The project's investigations and their relations to the results.*

## 2.2 The project's organisation and financing

The project was carried out with financial support from among others the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS), the Building Cost Forum of the National Board of Housing (Boverkets Byggkostnadsforum), Building and Planning, Interreg IIIA and participating companies.

In total some 50 persons from Swedish universities and industry companies active within the Swedish construction sector have contributed through participating in interviews and answering questions in enquiries according to the objective to create a broad consensus between academy and industry.

In order to support the development of an international network within this field, the research was also made in cooperation between Swedish researchers and practitioners, and French researchers at CSTB (Zarli et al. 2006).

# 3. RESULTS

## 3.1 Lessons from Nordic programmes for construction and real estate ICT

In later years two Swedish R&D programmes within construction ICT have been carried out. The first, called IT-Build was running for 4 years 1991-94 (NUTEK 1995). The main objective for IT-Build was to increase the competitiveness of the Swedish construction sector by implementing and developing existing and future information technology. The programme stated that industry's capacity to use IT for increasing competitiveness was too low and that the academic research needed strengthening in order to be able to supply the industry's need for new knowledge.

The Swedish construction industry was in a severe crisis during the first years of the 90's, with a historically low rate of house-building, and there was a hope that IT could contribute to increasing productivity and competitiveness. Another objective was to establish research environments within the field at the three large universities of technology KTH, Chalmers and LTH. The programme was financed through a combination of public and private funding. The programme evaluation which was commissioned to Technopolis in London, recommended that a new program be initiated in cooperation with the industry taking their processes and problems as starting point (NUTEK 1995).

The subsequent R&D programme IT Build & Real Estate 2002, ITBoF, started in 1998. The complete budget amounted to 12 M€ financed to 40% by the public research funding agencies FORMAS and VINNOVA, and 60% by the industry equivalent SBUF and participating companies and organisations (IT Bygg&Fastighet 2003).

The main goal of ITBoF was to:

- Increase customer benefits, e.g. by developing the technology's ability to present products, services and processes with increased customer focus;
- Make the processes more efficient by development of standards for information management;
- Raise the sector's competence by distributing research results to basic and continuous education in cooperation between companies and universities.

The programme's focus was to support the sector's transition from manual to electronic information management; Electronic document management was an important area. It was an expressed ambition that the results should be directly applicable in the companies and answer to their needs.

Three fields of activity were identified: R&D, Standardisation and Implementation. For research the objective was set to "carry out the necessary inventory and systematization of among others information activities and documents". The importance of standardised common concepts and process models is specifically mentioned. But standardisation of information for different processes and results, and the relations of these to product models, e.g. the levels of detail were not clarified or on the agenda. There was no mentioning of object oriented information management to be a goal for the development. The implementation strategy was loosely expressed and not explicitly coupled to expected R&D results.

The level of ambition of the program was high, expressed as Sweden after the finalised program would belong to the European leaders of IT for Construction and Facilities Management. IT Construction & Real Estate 2002 carried out 70 different projects within research, standardisation and implementation. The research produced 6 licentiate and 5 PhD theses in areas like standardisation of product information, knowledge management in large construction projects, process modelling, and use of VR. In the field of standardisation, the relations between IFC and the established Swedish building classification BSAB was investigated and a new classification of buildings and spaces was developed.

At half time, two evaluations were made that concluded that there were an overweight of research projects at the expense of practical implementation projects (Ekholm 2000, Aronsson and Hauch 2000). The programme board decided that the rest of the program should focus on practical applications of IT in companies. Four large implementation projects were carried out:

- Product model server and IFC-based information flow;
- Meta data standard for electronic document management;
- Project network with IT-support for better information exchange and;
- Standardisation of Facilities Management information.

In the Facilities Management project, a common process model was implemented including a clarification of the information content in different documents. The result has established a solid ground for continued development that still is based on this work. This focus was lost in the Product model server and IFC project, which would have needed a process model and information standardisation as a starting point. A probable reason for this deficiency is that sector common standardisation work came to a halt due to lack of funding in the second half of the programme (Johannesson et al. 2003:76). Instead, the Product model project was directed towards demonstrating how different applications could exchange information in IFC format with a model server, and thus contribute to a continuous information flow between stages in the processes.

The programme was considered highly successful by the evaluators of the ITBoF programme, and many projects were mentioned to have provided excellent results. The main criticism concerned a lack of business process focus (ibid:14) which meant that the implementation objective of the programme hardly was met (ibid:19). It could be argued that these deficiencies are the reasons that industry representatives have questioned the value of the results and talk of a gap between the programme and real needs of the industry.

To conclude, the Swedish R&D-programmes have defined crucial key questions, but they have not developed results that are immediately applicable in practice. One reason could be that the programmes have not conducted deeper stakeholder analyses to identify drivers and obstacles for development and implementation of the results. The programmes have partly had a bias towards medium and long term research and standardisation with the effect that the sector has not been able to see any immediate benefit.

In Finland, a sequence of large R&D-programmes has been carried out starting with the Ratas-programme 1985-1995 (Andersson et al. 2008). The programme identified for the first time the vision of a standardised object oriented product model as an integrating platform for the sector's different IT-applications. The project was carried out by the Foundation for Building Information, RTS. Within VTT another programme "RTA, Information and Automation Systems in Construction" was conducted during 1988-1991. The objective here was to closer investigate the applicability of new information technology in the construction sector, focussing on product modelling, expert systems and robotics. The Vera-programme 1997-2002 was a comprehensive R&D-programme with the objective to raise the level of IT-use in the construction and real estate sector. The total budget was 47 M€ of which the public innovation agency TEKES contributed with 22 M€. The programme strongly supported the development of the IFC-standard and Finnish software developers who implemented this in their applications. The most important results of the Vera-programme can be described as (www.cic.vtt.fi/vera):

- Wide adoption of Product Model Concept as a part of AEC/FM industry's processes and strategy;
- International networks;
- New software products.

Questions of implementation of a product model based planning and construction process were dealt with in the subsequent ProIT-project, (http://virtual.vtt.fi/virtual/proj6/proit_eng/indexe.htm). Here, a process model identifying the information requirements in the processes was developed. The starting point was the requirement to use the product model as a common source of information for the various parties involved in the process. The scope of the project covered modelling the product model-based process and its data exchange, compiling the design guidelines needed in product modelling, and creating product structure libraries. Industry-wide product modelling procedures and guidelines have been created as a result.

Overall the Finnish R&D-work in Construction ICT has reached an internationally high level. The Finnish construction industry, e.g. the larger contractors and material producers are active in promoting the use of building product models, now under the new name of Building Information Models, BIM. This development is also supported by the national public real estate owner Senaatti.

In Denmark, several coordinated projects were carried out during 1988 – 1995, dealing with CAD-use, e.g. cad-layers, data exchange, cad-manuals, EDI and GIS. In a governmental report from the year 2000, the sector's quality deficiencies were discussed, and concrete proposals to raise the industry's productivity, quality and innovation capability were made. For example, an effort to promote the development of IT is suggested (Erhvervs- og Boligstyrelsen 2003).

"The Digital Construction" programme was carried out during 2003 – 2007 with a combined budget of 9 M€, of which 50% were public funding (http://digitalconstruction.dk/home). The focus of the programme was application of existing object oriented technology and establishing fundamental communication standards for the

actors. The starting point was that the barriers for IT in the sector rather are cultural than technological. The focus was on implementation in companies.

An important incentive in the Danish programme was that the results were to be manifested in new legislation concerning digital information management in construction projects. The legislation is intended to be implemented gradually during 2007 – 2009, (Økonomi- og Erhvervsministeriet 2006). It means, among others, demands to use project networks and 3D digital building models in publicly financed projects with a contract sum above 5 M€. The work also includes the development of a new building classification system according to the international standard ISO12006-2.

The Danish work to a substantial extent builds on results achieved in other countries, especially Sweden and Finland. In one important aspect it is different from these and has carried the development further through its focus on information exchange in company processes. Special studies have focussed on the information needs of the processes, thereby enabling a specification of information contents of the models in different phases. This has allowed the Danish development to go a step further than in the other more technology focussed Nordic neighbours.

Just as in Sweden, Finland and Denmark, it was the low productivity of the Norwegian building and real estate sector that motivated the public funding of the "Building Cost Programme" (Andersson et al. 2008). This was initiated in 2003 and has started two development areas, "IFC in the construction sector – Norwegian Building blocks" and "buildingSMART – the new electronic way of working". In Norway, the largest public building commissioner "Statsbygg" (StateBuild) is the driving force in applying IT in construction projects. They have engaged in the transfer to object based information management and see a large savings potential in the new technology. The same basic issues as in the other Nordic countries are raised in the Norwegian programmes. The objectives are to achieve:

- A common format for information exchange. The concentration is on IFC;
- A specification of what information that shall be exchanged and when. This is specified in an Information Delivery Manual;
- A common understanding of the meaning of the information. To reach this, a common classification is developed.

Accordingly, a common background for the Nordic contributions to R&D-programs in ICT for the Construction and Real Estate sector is the understanding that ICT in a substantial way can contribute to improving the productivity of the sector. The use of ICT increases the requirements for standardised information management in the sector and at the same time enables new processes and business opportunities.

Even though large programs have been carried out, change proceeds slowly, partly because of the specific technology focus of the programmes with a lesser emphasis on business processes and needs. In order to reach a deep, broad and open development, it is important that leading actors, like the largest public commissioners lead the way.

## 3.2 Today's use of ICT in a typical house-building project

The Swedish house-building market is characterised by large fluctuations in demand, mainly attributed to business cycle up- and downturns and housing politics. The market for multi-dwelling blocks experienced a business upturn during the last decade. During 2005 a number of 360 multi-dwelling block projects, with 18 000 flats were initiated, which corresponds to 2 flats per 1000 inhabitants and year. Approximately half (53%) of the flats were built as blocks of flats for renting whereas the other half for tenant-owners' associations. Typically, tenant owner associations are started by project developers belonging to the four largest Swedish construction companies (60%), and handed over to consumers who buy the flats. Building of multi-dwelling flats is concentrated to the three largest metropolitan areas (60%). Design and build is the most frequently used form of procurement (57%).

The present study focuses on the use of ICT in the design and production stages of typical house-building projects. Information management during the design stage is often regulated by the commissioner's and main contractor's legal documents which aim at coordination of the ICT use. Project developers and main contractors consider at the same time that the benefits with a coordinated use of ICT are limited and thus transfer this task to the project's architect. There is a wide-spread apprehension among actors in the sector that there is a lack of methods and tools to quantify the possible benefits of a coordinated construction ICT.

Most of the technical documentation during the design stage consists of drawings and specifications concerning technical characteristics of the buildings, building parts and products. Particular actors, such as window and prefab stair-case or balcony manufacturers are able to deliver object oriented models of their products. These models are occasionally used by architects to verify connection details and to avoid geometrical collisions. Generally, the utilization of 3D-based tools is limited.

Technical documentation produced in the projects is usually exchanged through web-based project networks. Nevertheless, many technical designers consider that project networks are not sufficiently user-friendly. Much irritation is generated when irrelevant information is received through the project network. The project networks are therefore often bypassed and drawings are instead exchanged as e-mail attachments.

In the production stage, purchase of materials and contracting of subcontractors are important activities for the profitability of the project and the quality of the end result. Quantity take-offs are carried out individually by all involved material suppliers and subcontractors from drawings. In this way, redundant, ambiguous and, quite often, erroneous information is created. Purchase of bulk products is often regulated through long term agreements at company level, which minimize information exchange. Also e-commerce is becoming more frequent.

Time schedules for work planning and deliveries are usually made using commercially available software. Time schedules for the main contractor's activities are relatively detailed. Yet, time schedules for subcontractors are only rough estimates and there is no real coordination between activities. Lack of coordination increases the demand for communication through e-mail, phone calls and site visits. Different ICT-tools are widely used in project administration and in making economic forecasts.

Communication with presumptive flat buyers is a prioritized activity for the project developer. Usually, flat buyers have the possibility to choose interior furnishing but can also change the layout of the flat. Systems for product configuration, widely used in the automotive industry, are not available in house-building. Customers' options and changes are registered and introduced in drawings manually. The economical effects of having this type of flexibility in customer relations are not fully clarified.

The investigations confirm the split-up nature of the traditional, project based building process. A large number of actors try to fulfil their obligations by acting in a way which is rational for their own organisations. Drivers to achieve holistic benefits are weak, resulting in a poor development of processes depending on coordination. Construction ICT is an illustrative example in the mentioned sense. In absence of correlated information structures and interfaces for information exchange, actors still work with their own models and exchange information as drawings. Redundant information is created in several steps with obvious risk for mistakes. Improvements seem to be possible by development of common information structures and tools that better accommodate the actors' work processes.

## 3.3 The building sector's view in ICT development

Departing from the present state concerning use of ICT in house-building, a group of active developers within construction ICT identified eight development areas with high potential for improved productivity and quality through application of modern ICT:

- 3D-CAD and building information models;
- Information structures and exchange formats;
- ICT policies for project cooperation;
- Virtual reality;
- Integrated design processes;
- Reuse of experience;
- Purchase and deliveries of systems products;
- Quantity take-off.

The active developers carried out a valuation of the identified development areas' potential to improve effectiveness of house building. The results of the valuation are presented in Figure 4.

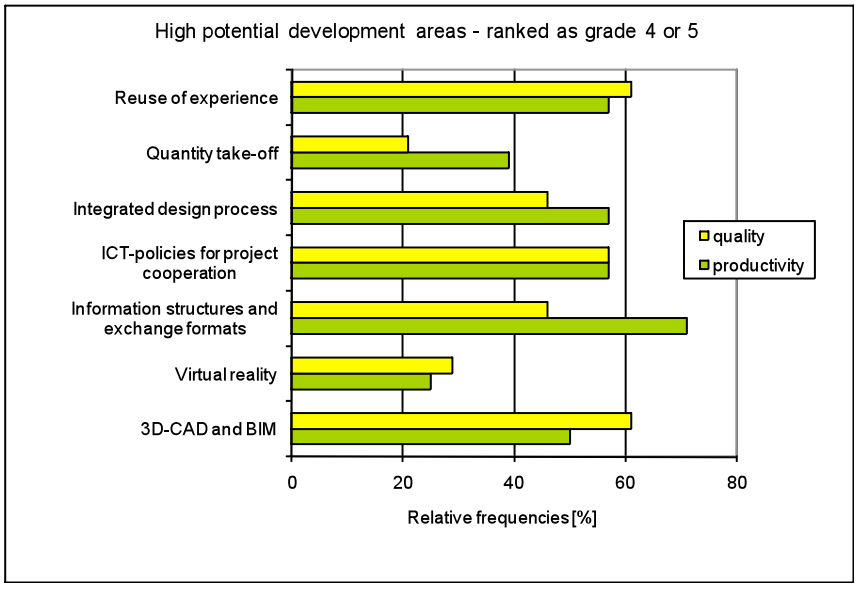


*FIG. 4: Valuation of development areas. Areas ranked as grade 4 or 5 on a scale 1 to 5 are considered to have high potential to improve productivity and quality. Potential expressed as relative frequencies [%].*

Furthermore, the active developers identified drivers for a continued ICT-development, necessary measures, possible opportunities and finally the sector's expected benefits provided that proposed measures are implemented within a time range of two (short-term perspective) to five (medium-term perspective) years, see summary below in Figure 5.

### 3.3.1 Drivers for use of modern ICT and new ways of cooperation

The house-building sector is characterised by increasing market dependency, customer focus, environmental considerations and international competition. Through requirements on profitability, companies become more flexible and are pushed towards new ways of cooperation such as strategic partnering encompassing actors throughout the entire value chain. In this new situation, cooperation between designers and constructors becomes a necessity. A more industrial construction process, through e.g. increasing use of complex systems products, such as prefab bathroom volumes, also requires long-term cooperation and investments in modern ICT.

Requirements on improved effectiveness call for a house-building process with distinct process ownership and responsibilities for the end product. The overall competence of the sector will improve, not least through a higher influx of personnel with research background. Leading actors in the process, such as developers, constructors and designers will develop better knowledge of efficient forms for cooperation and gain deeper understanding of modern ICT's potential to improve economical outturn and quality.

Modern construction ICT requires coordinated information structures and exchange interfaces. Long term cooperation throughout the value chain makes development of isolated information structures less interesting as a strategic instrument. A new information infrastructure with documented building systems and processes will develop and will facilitate reuse of experience. Project networks will work as an essential platform for digital information management in house-building projects.

### 3.3.2 Measures taken by companies to introduce modern ICT and new ways of cooperation

Developers and facility owners have a key role in development of more efficient processes and introduction of modern ICT. To achieve efficiency, an increasing number of facility owners will require information in form of building information models, BIM. This will force actors in the building process to work with object oriented 3D-CAD to an increasing extent.

Industrialisation of the house-building sector will support long term investments at the expense of short term thinking. With extended use of complex systems products, investments in product development, including object oriented 3D-CAD and BIM, are supported by the system development budget, not the individual projects. Product development as a process is introduced not only by material suppliers but also by contractors and designers with ambitions to posses own brands. Implementation will take place in individual projects and reuse of experience is systematically carried out to improve results in the future. Product development and design can more easily be carried out in integrated teams using information systems supporting concurrent engineering.

New business models, such as strategic partnering will stimulate communication and cooperation in product development. New business opportunities will arise for companies working with innovative information management solutions.

### 3.3.3 Measures taken by the sector to introduce modern ICT and new ways of cooperation

More efficient forms for information exchange must be created, with a continuous development of 3D-methodologies, classification and information formats, e.g. according to a model provided by the Danish "The Digital Construction" programme. A council for digital construction should be established with the main task to develop standard information formats for exchange of information between the actors in the process. The work shall be carried out in parallel, by both developing standards and testing the concepts in pilot projects. The objective shall be that all involved actors use compatible information systems.

The ICT-sector must gain a deeper understanding of the building sector's information systems and join the sector's work with development of standards. Standardisation shall be carried out on both national and international level. Software products with adaptable modularised components and neutral interfaces can facilitate development of applications in collaboration with the construction sector. These measures also will promote competition on the ICT-market.

### 3.3.4 Benefits of modern ICT such as 3D-CAD and building information models

Use of model based information with standardised information structures and interfaces imply that less redundant information is created. The over-all quality of information improves and mistakes are avoided or discovered earlier. Relevant information is identified more quickly, with time savings during data exchange. All these factors improve the sector's productivity and enable companies to compete through higher quality, extended customer involvement, more added value and creativity.

3D-CAD and information models with standardised information structures and interfaces enhance both quality and sustainability of information, facilitate reuse of experience, stimulate innovations and perpetual development and facilitate integration of information flows throughout the value chain.

| | |
|---|---|
| Drivers for modern ICT | Increasing market dependency, customer focus, environmental considerations, requirements on profitability, and improved effectiveness |
| Measures by companies | Information required as BIM and object-oriented 3D, industrialisation, use of systems products, product development, reuse of experience, concurrent engineering, startegic partnering |
| Measures by the sector | Council for digital construction, development of 3D-methodologies, national and int.national classification and exchange formats, pilot projects, ICT-sector engagement in construction issues |
| Benefits of modern ICT | Information quality improvement, relevant and non-redundant information, time savings, information sustainability, reuse of experience, integrated information flow, customer involvement |

*FIG. 5: Drivers, measures and benefits of modern ICT*

## 3.4 Strategy for sector level development

Departing from the studies presented in Section 3.1-3.3, the following strategy is recommended for future Swedish R&D actions within construction ICT:

### 3.4.1 Council for Digital Construction

Increased interoperability within the building process requires coordination and commitment from actors representing the entire sector. A "Council for Digital Construction" should be established. The Council's main tasks should be to facilitate a common transition to digital construction, with establishment of an object oriented information management and the integration of this with the traditional document based information management as the main target. Action should be taken to initiate R&D projects, to improve education of company and university personnel and to implement results through pilot projects.

Before a "Council for Digital Construction" is established, business and requirements analyses should be carried out to illustrate the impact of modern ICT on the various parts of the building process. The analyses should identify development areas of high priority. This preparatory work should also clarify the mandate of the Council and the scope of its mission. Departing from the results of these initial analyses, the Council should:

- Carry out a state-of-the-art study concerning ongoing international and especially Nordic initiatives within the field. It is important to clarify what activities should be carried out on a national, Nordic or international level and to initiate collaboration;
- Elaborate a master plan for development of the sector's joint information structures. The plan should comprise tangible instructions concerning what is to be developed (formats, objects, properties, etc.) and in which order. The plan should also propose a strategy for implementation and for dissemination of the results to a broad range of possible users.

### 3.4.2 Short-term implementation activities

Pilot projects addressing development, adaptation and testing of information structures and new cooperation methods should be started in companies. Special activities improving competence in the field of digital construction should be directed towards actors in the building process, schools of vocational training and universities. The educational activities should be initiated in parallel to the pilot projects.

### 3.4.3 Medium-term implementation activities

Harmonisation of information management, systems for information exchange, modularisation, systems for reuse of experience, efficiency indicators, etc., should be promoted by initiation of R&D programmes within the field of international standardisation of products and processes. These programmes should start immediately and carried on during a foreseeable time range. As needs concerning rational efficiency indicators are urgent and R&D activities are expected to be comprehensive, work in this field should have highest priority.

Projects should be started in companies to benefit from the developed information structures and processes. Applications of special interest, e.g. 3D-CAD and BIM, quantity take-off, new ways of cooperation, systems for reuse of experience, have been identified in this paper.

## 4. ANALYSES AND CONCLUSIONS

Information management is, in conformity with other processes in house-building, pronouncedly split up. Information between actors is delivered with no further consideration to efficient handling in the subsequent work processes. Traditions and legal considerations come first and optimisation from a holistic point of view has low priority. Traditional constructions projects are not managed to maximize common benefits.

Actors in the construction process identify project developers and facility owners as having a key role in creating efficient construction and information processes. Quite right, project developers, especially those representing large construction companies, are also in a formal sense responsible for coordination of information management in house-building projects. This opportunity to control the information process is nevertheless seldom used in practice, as the task in the design stage is often transferred to other actors.

One explanation of project developers' reluctance to shoulder the responsibility for information coordination is attributed to the relatively low economic exchange obtained from construction activities. A larger part of the project developers' profit arises from providing the land. Another explanation for project developers' limited interest for ICT might be the large fluctuations that characterise the demand on the housing market. As long term investments in integrated information systems generate fixed costs, such investments are considered hazardous for companies acting on a fluctuating market.

During the post-war decades, when the Swedish housing market was characterised by heavy state subsidies and regulations, large commissioners used to have organisations with own design and production management resources. After the deregulation of the housing market in the beginning of the 1990-ies, these structures were wound up and project developers resigned from the role as process integrators. On a deregulated housing market, the most efficient means for project developers' competitiveness appears to be a flexible organisation able to identify market needs. Access to land with development rights is another important success factor.

*Conclusion 1: Within the current business model for house-building, project developers have neither drivers nor instruments to create a coordinated information process.*

There are indications that project developers' role as process integrators in today's house-building process is increasingly taken over by suppliers of systems products (ready-to-connect bathrooms, staircases, balconies, etc). This category of suppliers has to document their systems and products in a way similar to that of the manufacturing industry. Increasing degree of industrialisation of the production processes requires integration of the information processes. In the prefab concrete element industry for instance, information needed for steering of the robotised production line is translated and imported automatically from CAD-files delivered by structural

engineers. Also planning of deliveries, invoicing and purchase are integrated in the same information system. According to prefab manufacturers, investments of this type generally have a pay-back time of two to three years. Integration of the architects' and HVAC consultants' design tools is planned as the next step in the development. Beyond improved efficiency, it is expected that integration of the information management in the early stages of the construction process will generate strategic advantages to the prefab concrete element industry.

It is often stated that the construction sector during the past decades have exhibited a lower increase in productivity compared to the manufacturing industry. Official statistics show that during the period 1964 to 2004 the manufacturing industry have doubled its productivity whereas the productivity of the construction industry nearly stagnated or even decreased (Eastman and Sacks 2008). The statistical indicators are however partly misleading, mainly due to the fact that vital parts of the construction industry are classified as off site manufacturing. Eastman and Sacks assert that, inclusive of manufacturing of systems products, the productivity of the construction industry exhibit similar development as the manufacturing industry. These authors consider that modern information technology constitute an important reason for the increasing use of systems products and that this trend will accelerate with increasing use of object oriented ICT (ibid).

*Conclusion 2: Modern ICT has, by more rapid and reliable information transfer, improved profitability for manufacturers of systems products. This gives, together with other factors, incentives to integrate information systems also in the traditional, project based building process.*

The ongoing development of process and product platforms in larger Swedish construction companies can also indicate a shift in how production of dwellings is approached. If housing platform owners in the future will establish own brands, there will also arise a need to take a more comprehensive responsibility for the products. Further, there might occur a shift from today's project based ad-hoc organisation towards more stabile organisations where products are designed and produced according to standardised processes. Modern ICT constitutes a necessary tool to keep together processes in organisations of this character. In companies involved in industrial construction, information systems have already been integrated according to a pattern known from the manufacturing industry.

*Conclusion 3: Development of process and product platforms in construction companies calls for use of modern ICT as an integrating tool in a new type of house-building process.*

An inhibiting factor to investments in ICT, both in the construction sector and elsewhere, is the difficulty to measure its benefits (Love et al. 2005). A possible explanation of these difficulties might be that ICT constitutes a support system to product development, production, material supply and administrative processes. To measure the impact of ICT, outcomes from supported processes have to be quantifiable with e.g. use of efficiency indicators. This is seldom the case in the construction industry. A study concerning introduction of modern ICT-support in Swedish timber building companies show that lack of documentation of processes and products make an integration of the companies' information systems difficult to realize in the nearest future (Johnsson et al. 2006). Thus, a lack of systematic documentation of products and processes in the construction industry hinders investments in modern ICT.

*Conclusion 4: A documentation of processes and products using quantifiable indicators is a prerequisite for rational decision making support concerning investments in ICT.*

With a few exceptions, companies in the construction sector are today not prepared to carry out a documentation of their processes and products. As an IT-consultant expressed it in one of the surveys, "Actors in the building sector have difficulties in thinking in the abstract, such as processes and information structures". Much of the sector's knowledge of processes and products is accumulated as individual, non-formal knowledge and practical experience. In itself this is not only a drawback – knowledge carried by humans rather than in machines is probably easier to apply flexibly and to renew. This is probably why prefab concrete element manufacturers still keep personnel able to transfer information from drawings to automatic production lines. In-house technical competence is considered to be a strategic asset. On the whole however, lack of documented processes and products constitutes an obstacle to introduction of more advanced and resource efficient production.

As leading personnel in construction companies are educated in schools of civil engineering and architecture, process modelling should be included in the curriculum at universities. Further, the competence of researchers' and teachers' in this area should be improved by involving them in relevant R&D projects. Besides improving education in process modelling it is also important that a change in attitudes takes place within the building sector – today there is a bias towards practical skills and "quick fix at the site" at the expense of abstract knowledge.

*Conclusion 5: The building sector's over-all competence to work with processes and products in a structured way is insufficient. Education in this field needs to be improved, e.g. by involving researchers and university staff in R&D projects.*

The documents produced in different stages of the building process are interlinked in a logical chain. To achieve a smooth and efficient work flow throughout the processes, involved actors need to have control of the information content in the documents as well as the way the information is transferred between actors. Today's documents and transfer formats exhibit large variability concerning the level of structuring, established structures are seldom adhered to completely and information exchange interfaces between different processes are not fully developed. This results in poor reliability and usability of the information created by other parts. "Restarts" are common, because information cannot be used in the subsequent stage or its quality is questionable. As different actors use different documents and formats, every "restart" increases the risk that the created information is ambiguous or incorrect.

*Conclusion 6: To assure the reliability of information, this must be in agreement with formats and handling processes accepted by all actors in the building process. It must be possible to transfer information throughout the process without re-creating it, yet still meeting requirements put by the actors' work processes and product structures.*

A challenging question is whether there are drivers connected to business opportunities that can stimulate creation of a framework for integrated information management spanning over the entire or a large part of the building process. As creation of a framework of this nature requires economic means as well as long-term commitment, the absence of dominant product- and process owners makes it less likely that such drivers do exist in the traditional building process. On the contrary, stakeholders in de facto information standards can constitute a real obstacle to far-reaching integration.

Sharing possible benefits proportionally to investments in development is also considered difficult – many actors feel an apprehension about stowaways. Consequently, there is need for a joint, sector level action to promote ICT development in the traditional building process. A joint action could also counteract different stakeholders' negative influence on a future framework for integrated information management.

*Conclusion 7: A joint, sector level action is needed to create a framework for integrated information management in the traditional building process.*

Actors participating in the surveys presented in this paper identified a series of development areas with potential to improve as well efficiency as quality in the building process. At the same time, it is also obvious that actors give priority to issues serving their own business interests. Further, it can be observed that actors consider changes associated with new business models as threats against their own company's or trade's strategic interests. Accordingly, there is also a risk that a joint, sector level action on ICT development will be counteracted by many actors. To assure that a sector level action does not fail for this reason, business and requirements analyses should be carried out before the action get an institutional frame. The analyses should focus on connections between business processes and ICT and thus provide individual companies with rational support for decision making in the issue of joining a sector level action. If the business and requirements analyses succeed in arousing an interest among a large number of actors with a wide spectrum regarding their size, trade affiliation, geographic location, etc., the odds that the action will get enough support will be good.

*Conclusion 8: As a preparatory step to a joint, sector level action, business and requirements analyses should be carried out to illustrate the strategic importance of ICT for a wide spectrum of actors in the building process.*

The conclusions of the study are summarised in Figure 6.

| | |
|---|---|
| Conclusion 1 | *The current business model for house-building gives neither drivers nor instruments to create a coordinated information process.* |
| Conclusion 2 | *Modern ICT gives incentives to integrate information systems in the traditional, project based building process.* |
| Conclusion 3 | *Process and product platforms in construction calls for use of modern ICT as an integrating tool in new house-building processes.* |
| Conclusion 4 | *Documentation of processes and products using quantifiable indicators is a prerequisite for investments in ICT.* |
| Conclusion 5 | *The building sector's competence to work in a structured way is insufficient. Education in this field needs to be improved.* |
| Conclusion 6 | *Reliability of information transfer throughout the processes require agreements accepted by all actors in the building process.* |
| Conclusion 7 | *A joint, sector level action is needed to create a framework for integrated information management in the traditional process.* |
| Conclusion 8 | *As a preparatory step business and requirements analyses should be carried out to illustrate the strategic importance of ICT.* |

*FIG. 6: Conclusions of the study*

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