BENEFITS OF ICT IN THE CONSTRUCTION INDUSTRY – CHARACTERIZATION OF THE PRESENT SITUATION IN HOUSE-BUILDING PROCESSES

Miklós Molnár, Ronny Andersson, Anders Ekholm
Lund University, Faculty of Engineering LTH, Sweden

ABSTRACT: Departing from the hypothesis that R&D within ICT plays an essential role in the transformation of the construction sector from a traditional to an industrialised process, a joint Swedish and French project has been carried out (to be completed in April 2007) to assess the short and medium term possibilities to improve efficiency and quality in multi-storey house-building. This paper describes today's use of ICT (situation as-is) in Swedish multi-storey house-building projects and identifies a number of key development areas. The research was carried out through steps including statistical analyses of market data, a case study, a survey with active developers working with R&D in the field of ICT and workshops with construction industry representatives and researchers.

Typically, Swedish multi-storey house-building projects are carried out as isolated projects, involving 15 designers, 20 subcontractors and 40 material suppliers. Relations between most of the project participants are ad-hoc. ICT-use is regulated by the architect's CAD manual regarding layer structures, routines for information exchange during design, use of a project network, hardware, software and filing. 2D CAD is the predominant design tool. ICT is widely used for administrative purposes, especially by the large contractors. Information transfer between participants in and between different stages of the project is inefficient and redundant information is created. Transfer of information is often carried out manually.

Computer aided design, interoperability, virtual reality, cooperation and ICT-policies, the product definition process, use of systems products, quantity take-off and reuse of experience are identified as development areas where ICT can play an important role to improve productivity and quality. Highest potential to achieve improvement by immediate uptake is attributed by the survey persons to computer aided design, interoperability and reuse of experience. A time span of 2 - 5 years is needed to obtain benefits by more efficient cooperation and ICT-policies and rational quantity take-off.

KEYWORDS: construction processes, house-building, industrialization, information and communication technology (ICT).

1 INTRODUCTION

The traditional construction sector is today rapidly moving towards industrialisation of the product and production processes. The aim is a more efficient process with products, production methods and organisations based on platform concepts. In Sweden, all large contractors, material suppliers, property managers and newly also consultant companies within architecture and engineering, are developing their own industrialized building concepts. In this perspective both industry representatives and R&D-actors agree that ICT has an important role to make the sector more efficient and customer oriented (Lessing, Stehn and Ekholm 2005).

In spite of international and national R&D programs (IT-BoF2002) which did contribute to improved efficiency in the traditional construction industry, actors have an hesitant attitude towards introduction of innovative ICT (Rivard 2000, Samuelson 2001). Hinders and drivers for implementation of ICT in the traditional construction industry have been investigated by (Stewart, Mohamed and Marosszeky 2004). Among others, they include business strategies where every project is seen unique, the fragmented character of the process with participants having divergent interests, low client involvement, etc. Also poor knowledge and underdeveloped practice concerning evaluation of the benefits of investments in construction ICT are identified as important hinders (Stewart and Mohamed 2003; Love, Irani and Edwards 2005). Among others, standardization of processes/outcomes and project alliances between key members are recommended as coping strategies (Peansup and Walker 2006).

ICT use in a less fragmented sector, the Swedish industrial timber building industry, has been investigated by (Johnsson et al. 2006). They find that successful implementation of IT-systems, which in the mechanical industry have contributed to substantial productivity and quality improvements, are inhibited by lack of machine interpretable product structures and design process outcomes which need manual transformation in order to be available for further use in the production processes. Improved productivity, flexibility and quality improvements have

been achieved in highly automated precast concrete industries (Persson 2006). However since this design and production is only a part of the whole process, manually transformations still have to be done in connection to the process. These findings indicate, that coping strategies within a traditional building industry moving towards industrialization must consider the design, production and business processes as a whole.

To contribute to the maximization of the benefits of ICT in the process of industrialization of the building industry, the present paper reports results from a joint Swedish-French project named "Evaluation of benefits of ICT for the industrialization of project and product processes in the construction industry" (BICT). Within the BICT project use of ICT in multi-storey house-building is investigated concerning situation "as-is", development areas, possibilities for immediate uptake and medium term implementation, and issues for future research, development and education. The investigations include analyses of statistical data, a case study, a survey, workshops and a state-of-the-art study. This paper presents the situation "as-is" and identifies key development areas for immediate uptake and medium term implementation as found in the analysis of statistical data, the case study, the survey and workshops. In (Robertson et al 2007) possibilities for immediate uptake and medium term implementation and issues for future research, development and education are presented based on the state-of-the-art study and workshops.

2 METHOD

Today's use of ICT in Swedish house-building processes and the Swedish construction sector's priorities concerning the potentially most beneficial ICT-related development areas have been assessed through:

1. Workshops with a reference group, with members representing the construction industry and universities
2. A case study involving mapping of the design and production processes and ICT-use in a typical house-building project
3. Statistical analysis of projects launched during the year of 2005
4. Survey with active developers working with R&D in the field of ICT in the construction industry and universities

2.1 *Reference group workshops*

A reference group with ten persons, representing key players in the construction industry and ICT-related R&D at Swedish universities, has been established in order to validate the research. Three workshops (I-III) have been held to:

1. establish criteria for choice of case study object;
2. validate the results of the case study (2.2) and identify ICT development areas;
3. validate the results of the survey (2.4) with active developers and elaborate on plausible scenarios in a future with more industrialised multi-storey house-building.

2.2 *Case study*

During the period April – June 2006 semi-structured interviews have been carried out with the client's project manager, the architect, the structural and the pre-cast concrete engineer, the main contractor's design, purchase, site and project manager and finally the ventilation and the glazing subcontractors in an ongoing multi-storey house-building project identified as being representative according to the reference group (2.1/I). The interview persons answered questions related to their role in the design and/or production processes and the use of ICT. Questions concerning ICT covered, among others, use of ICT-tools, cooperation and work processes where ICT can play a role as a support. Based on the case study, eight ICT-related development areas were identified as being potentially beneficial for improved productivity and quality within multi-storey house-building. These development areas were further analysed in a survey and workshops, see sections 2.4.

2.3 *Statistical analysis*

In order to validate the case study (2.2), all multi-storey house-building projects in Sweden with production start during 2005, altogether 360 projects with 18 500 flats, have been analysed with respect to geographical distribution, form of tenure, procurement system, flat area, design and production costs and structural building system (Sverige Bygger 2006). The validity of the collected data was checked by telephone calls to every identified project, a work commissioned to the market research institute Gfk Sweden.

2.4 *Survey with active developers*

In order to validate the case study and valuate the potential of identified development areas, a survey involving 36 active developers, working in the construction industry and at universities, have been carried out. The survey participants were chosen from a total of 120 persons with ICT-related articles published during the period 2003-2005 in scientific or technical newspapers or with presentations held at professional seminars and conferences.

The survey was carried out in collaboration with the market research institute Gfk Sweden as follows: a) potential survey persons were asked by written mail and telephone calls to enrol in the survey; b) from persons interested in participation, 36 active developers representative for today's design and building processes in house-building were selected; c) selected participants were sent a written report with the results of the case study and requested to read the report and reflect on its content; d) after reading the report 28 of 36 persons answered the questionnaire. Six persons resigned from participation due to the large amount of work the survey required, whereas two persons reported illness.

Beyond personnel and professional data, the survey questions concerned a) the validity of the case study, b) today's ICT-use; c) valuation of the potential to improve productivity and quality of house-building of the ICT-related development areas identified in the case study.

3 TYPICAL MULTI-STOREY HOUSE-BUILDING PROJECTS IN SWEDEN YEAR 2005

Based on criteria established by the reference group, a multi-storey house-building project with the following typical features has been selected for a case study involving mapping of the design and production processes and use of ICT:

- Location: Malmoe/Lund, the third largest urban agglomeration in Sweden
- Form of tenure: tenant-owner association buys the property immediately after completion from a project developer belonging to one of the four dominating Swedish construction companies.
- Procurement system: design and build, with the main contractor belonging to the same group as the project developer.
- Purchase: the main contractor have group level purchase agreements with most of the material suppliers
- Participants: 15 designers, 20 subcontractors, 40 material suppliers.
- The project: third stage of four, totalling eight buildings
- The building: four storeys, 20 flats with an average flat area of 100 m^2
- Design and production cost: 1350 €/m^2
- Load bearing structure: concrete elements combined with in-situ concrete.

The case study project was considered representative by 22 of the 28 persons participating in the survey whereas the remaining 6 persons considered it only partially representative. The statistical analysis (2.3) also validated the case study object as being representative concerning location (10 % of all projects built in Malmoe/Lund), procurement system (57 % design and build), flat area (average area 91 m^2) and design and production cost (1350 €/m^2). However, concerning form of tenure flats built for tenant owner associations were in minority (47 % compared to 53 % for flats for rental).

4 TODAY'S USE OF ICT AND DEVELOPMENT AREAS– SELECTED RESULTS FROM THE CASE STUDY AND SURVEY

Information management in the case study project was regulated by the client's and the main contractor's requirements. Coordination of information in the project was commissioned to the architect. The architect's CAD manual contained regulations regarding the use of layer structures, routines for information exchange during design, use of a project network, hardware, software and filing.

In the main contractor's organisation, the use of following ICT-tools and -systems was compulsory: cost calculations, time scheduling and resource planning, tendering and purchase of materials, billing and economic reports and analyses and use of a project network. Besides participation in regular design and production meetings no further coordination of the information management was regulated in formal ways.

The 28 survey persons considered the use of ICT in the case study project being: representative – 24 persons, partially representative – 3 persons, not representative - 1 person.

Based on the case study, several development areas, where ICT could have a potential to improve productivity and quality, were identified. The survey participants were than asked to analyze hinders and possibilities connected to these development areas (4.1-4.2).

4.1 *ICT tools and cooperation*

Computer aided design (CAD)

2D AutoCAD was used by all designers in the case study project, excepting the pre-cast concrete engineer who, in order to transform design data into production files for the precast concrete manufacturer, used a soft-ware named FastCAD. The main contractor's design, purchase, site and project manager and the ventilation subcontractor, who also designed the ventilation system, could not handle CAD. Windows, stair cases and balconies were by the respective material supplier designed in object oriented 3D CAD. The architect used these 3D CAD objects for studies of connections details.

According to the survey persons the main reasons for the limited use of 3D CAD and building information models (BIM) in Swedish present multi-storey house-building projects are:

- House-building projects are not managed with the objective to achieve optimal results as a whole
- Limited knowledge to handle 3D CAD and BIM in the construction sector
- Low awareness concerning the economical and quality related potentials of 3D CAD and BIM

Virtual reality (VR)

VR was not used in the case study project. In the very first stage of the development project a VR model of one flat was used for marketing purposes. However, once the first building was completed, exhibition of the real flats was favoured instead of the VR model. The VR model was not either used in the building permit, design or production processes.

According to the survey persons the main reasons for not recycling information created in VR models in more processes of a building project are:

- Lack of coherent information structures able to store information for use by other players in subsequent processes
- Poor coordination between different stages of a project
- Low awareness concerning the potential of VR to improve efficiency

Interoperability

Re-creating information obtained from other players by hand was standard in the case study project. Considering that more than 18 different types of software have been used in the project, the amount of redundant information and manual transfer is estimated to be considerable. The

low degree of interoperability depends, according to the survey persons to:

- Lack of efficient standards and formats for information transfer. It is difficult to agree on common standards in issues affecting many players
- House-building projects are not managed with the objective to achieve optimal results as a whole
- There is a strategic, competition related interest in working with own, player specific information structures

Cooperation and ICT-policies

In the case study project a considerable amount of time was spent on design and production meetings. Typically, design meetings with up to 15 participants have been held every third week during the 4.5 month long design phase of the project. Many players regarded these meeting as inefficient and coordination, as a matter of fact, was achieved through informal communication. Yet, most critical towards these meetings were designers with least knowledge of CAD. Similar criticism was directed also towards the project network, which often was by-passed, much of the information being exchanged by telephone calls, e-mail messages and e-mail attachments.

According to the survey persons, the main reasons for the shortcomings afflicted with today's forms of cooperation are:

- Poor knowledge concerning efficient cooperation methods and ICT-policies
- Organisations are under severe time press and have no possibility to introduce new cooperation methods or ICT-policies
- Many of today's ICT-tools, like project networks, do not support efficient cooperation

4.2 *Work processes in design and production*

Fragmentary product definition

Building components in the case study project were defined in subsequent stages of the project. Typically, in order to define an inner load bearing wall decisions and analyses were required from the architect, acoustics, structural, electrical and pre-cast concrete engineer, pre-cast concrete manufacturer, main contractor and the flat owner.

Asked to comment on the main negative consequences of a split-up product definition process, the survey persons pointed at:

- Increased number of mistakes
- Limited opportunities to standard solutions
- Lengthy and time consuming processes

Production management – systems products

In the case study project, goods and services were purchased from 40 suppliers and 20 subcontractors. Given the large number of players involved the process, planning and coordination of production was managed by a loosely coordinated master schedule. For example, the coordination with the HVAC subcontractors required large time slacks in order to avoid collisions. Also logistics planning was carried out ad-hoc, requiring a considerable amount of e-mail messages and telephone calls between the site manager and the suppliers.

The survey persons were asked whether introduction of systems products would improve efficiency and quality by reduction of the number of players on the production site. Only 12 of the 28 survey persons believed it would. As 11 persons could or did not answer this question, no further analyses are presented on this subject.

Quantity take-off

In the case study project quantities were calculated for cost estimation, material procurement, production planning, etc., in most cases by hand. Every player carried out his own quantity take-off at least once. Mistakes still occurred, e.g. the number and packaging of the windows was erroneous, with considerable extra work and financial losses for the glazing subcontractor.

The survey persons gave the following explanations concerning the large number of quantity take-offs:

- Large risks make players to rely only on take-offs carried out by themselves (large responsibilities to carry out supplementary ones)
- Lack of coordination between information sources

Reuse of experience

As the building in the case study was number five of a total of eight to be erected, positive repetition effects were observed by both the architect and the site manager. In the design stage the improvements were attributed to the repeated use of the same product structure, feed-back from the production site and smoother collaboration between a stable design team. In the production stage better established working routines and schedule optimisation gave improved productivity and fewer mistakes. Unfortunately, business secrecy policies hindered the main contractor from quantifying the achieved improvements to our research.

In spite of consensus concerning its positive effects, reuse of experience is limited to isolated projects also in large construction companies present on the entire Swedish market. The survey persons gave the following explanations concerning the limited reuse of experience in multi-storey house-building projects:

- Lack of distinct product and process ownership in construction companies
- Poor knowledge when it comes to a structured description of building systems and processes
- Fragmentary process, often with new teams in every project

5 THE SURVEY PERSONS' VALUATION OF THE POTENTIAL OF ICT-CONNECTED DEVELOPMENT AREAS

5.1 *Improved productivity and quality*

In order to maximize the practical benefits of the present research, the survey persons where asked to valuate the potential to improve productivity and quality of the development areas analysed in chapter 4. The development

areas were to be valuated on a scale with five grades, with grade 1 representing low potential and grade 5 high potential. The priorities of the survey persons are presented in Figure 1.

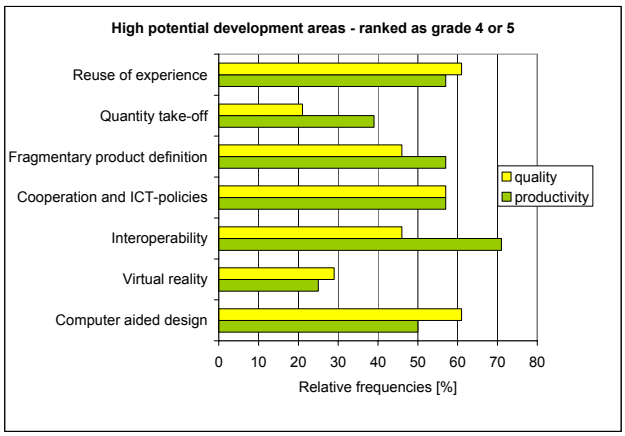

Figure 1. The survey persons' valuation of development areas. Areas ranked as grade 4 or 5 on a scale 1 to 5 are considered to have high potential to improve productivity and quality. Potential expressed as relative frequencies [%].

Computer aided design, interoperability, cooperation and ICT-policies, product definition and reuse of experience are valued as high potential areas to improve productivity and quality. Low rank areas are virtual reality, quantity take-off and systems products. Due to the limited number of answers conclusions regarding systems products are uncertain.

5.2 *Implementation*

In order to gain as quick benefits as possible the survey persons were asked to rank the high potential areas identified in section 5.1 with respect to the time needed for practical implementation in the construction industry. The time perspective was set to immediate uptake (less than 2 years) and medium term (2 - 5 years).

Computer aided design, interoperability and reuse of experience are due to the survey persons development areas for immediate uptake, whereas new cooperation forms and ICT-policies and more efficient product definition require a medium term time perspective to be implemented.

6 ANALYSES AND CONCLUSIONS

Both in the case study project and in general, ICT coordination is commissioned to the architect. Typically for Swedish multi-storey house-building projects, neither the project developer nor the main contractor takes control of the ICT coordination. One explanation might be the expansive market situation, where the easiest way for project developers and contractors to earn money might be by maximizing incomes rather than by cutting expenses. On the contrary, in recessions there is a larger interest in cutting expenses. Another hinder is poor knowledge concerning benefits of investments in construction IT (Love, Irani and Edwards 2005). Project developers and professional clients have probably the most realistic incentives and also possibilities to take resolute action in this field. Appointment of a project information officer in house-building projects, PIO, might be another concrete step towards improving ICT coordination (Froese 2004; Robertson et al 2007).

Traditional cooperation forms in a split-up process, with many designers, subcontractors and material suppliers have in both the case study and survey been identified as a source of inefficiency. Still, inefficient design and production meetings or poorly configured project networks are tolerated by designers and subcontractors as long as they get paid for the time spent. Increased competition in the future, mainly in the form of project developers and concept owners not connected to the established construction companies, might exert the necessary pressure to rationalize cooperation forms and ICT-policies.

Low degree of interoperability between applications, players and stages of the design and production process makes project participants create redundant information. Splitting and special interests of the players appear to hinder the market from taking resolute action towards standards and rational exchange formats. Sector-level agreements or regulations introduced by the state, lines of action adopted e.g. in Denmark (Digital Construction 2007) and Finland, might be the solution for the Swedish building sector. However this type of measures take time and the survey persons' conclusion concerning the potential of this area as being for immediate uptake must be regarded as too optimistic.

Well structured products and processes are a prerequisite to obtain further benefits from ICT (Johnsson et al 2006). Several actors in the construction industry already cooperate on a large scale with researchers (CITS 2005) and work actively with these topics. Also, attitudes considering these topics as theoretical need to be changed, which might be the easiest to achieve through reformed education at technical universities. New specialisations for architecture and engineering students, such as industrial building, can play an important role.

Object oriented CAD has, at the present time, a very limited use among Swedish designers. According to the survey persons the main reason for not using object oriented CAD is that house building projects are not managed to achieve optimal results as a whole. This is confirmed by an interview research carried out with structural designers. More than 90 % of the structural engineers ignore to take responsibility for object oriented CAD since they (39 %) consider it not beneficial for their own work (GfK 2006). The situation might improve if, building material suppliers, large contractors or consultants companies, etc., succeed in taking substantial market shares with concepts based on industrial house-building. Object oriented design is per default an essential link between product configuration and production in such industrial house-building concepts.

Most design tools are developed by international players for international markets which in some cases inhibit sound national systems to be put into practice. For instance, the Swedish system for information structures in the building, facilities management and civil engineering sectors (BSAB 1999) could, by means of suitable design

tools, be used for generation of draft, principal and production information. Further links could be created towards other vital parts of industrial building concepts such as enterprise resource planning (ERP) and product data management (PDM) systems. Whether adaptation of information systems from the engineering industry or development of new ones tailored for the construction industry is the most adequate strategy for industrialization of the house-building industry is an R&D question under investigation (CITS, 2005; Andreasson and Pärnaste 2006).

Results regarding the potentials for use of system products were not analysed due to few answers. However the case study shows that several suppliers already deliver system products based on structured information management systems.

Reuse of experience is considered one of the most powerful means to improve both productivity and quality. The main reasons why experience in traditional house-building is actually not reused are lack of distinct product and process ownership and poor knowledge when it comes to structured description of building systems and processes. As industrialization of the house-building processes implies development of ready to use/customise concepts, present development trends seem promising. It is especially interesting that ICT facilitates development of virtual technical platforms and thus increase the number of potential concept owners. However, in order to exploit this potential, product structures and processes have to be described and documented in a systematic manner. More R&D needs to be carried out in joint projects between industry and academia.

ACKNOWLEDGEMENTS

The authors would like to thank: a) The Swedish Research Council Formas-BIC, The National Board of Housing, Building and Planning – Byggkostnadsforum and ICT 2008 for their financial support; b) Mr. Christer Karström, NCC Construction Sweden for active participation in the research team; c) all interview persons in the case study and survey participants for their patience with lengthy interviews and questionnaires; d) the members of the reference group for the expertise they shared with us during intensive and stimulating workshops.

REFERENCES

Andreasson, S., Pärnaste, H. (2006). “Construction and engineering industry in symbiosis” (in Swedish). Vbyggaren, No 5, 2006.

BSAB 96, (1999). *BSAB 96. The Swedish construction industry classification system*. The Swedish Building Centre, Stockholm.

Centre for Information Technology in Construction and Facility managent, CITS (2005), Web presentation, accessed February 26th, 2007 at http://www.lth.se/index.php?id=8961

Digital Construction (2007). Web presentation, accessed February 26th, 2007 at http://www.detdigitalebyggeri.dk/english/0/10.

Froese, T.M. (2004) "Help wanted: project information officer." In A. Dikbas, Scherer, R. (eds) *ECPPM 2004 - eWork and eBusiness in Architecture, Engineering and Construction*, Istanbul, Turkey, pp. 19-24.

GfK (2006). “Interviews with structural designers”. Report 060560, 33 p. GfK Sverige AB, Lund, Sweden.

ITBoF 2002. Web presentation, accesses February 26th, 2007 at http://www.itbof.com.

Johnsson, H. et al. (2006). “IT-support for industrial timber building” (in Swedish). Technical report 2006:19, Luleå University of Technology, Luleå, Sweden, 62 pp.

Lessing, J., Stehn, L. and Ekholm, A. (2005). “Industrialised housing – definition and categorization of the concept”. In Proceedings for IGLC-13, Sydney, Australia 2005.

Love, P.E.D., Irani, Z., Edwards, D.J. (2005). “Researching the investment of information technology in construction: an examination of evaluation practices”. Automation in Construction 14 (2005) 569-582.

Peansupap, V. and Walker, D.H.T. (2006). “Information communication technology (ICT) implementation constraints. A construction industry perspective”. Engineering, Construction and Architectural Management, Vol. 13, No. 4, pp. 364-379.

Persson, S. (2006) “Information management regarding the production of precast concrete structures”. Proceedings of the Joint International Conference on Computing and Decision Making in Civil and Building Engineering. June 14-16, Montreal, Canada.

Rivard, H. (2000). “Survey on the impact of information technology on the Canadian architecture, engineering and construction industry”. ITcon Vol 5 (2000), Rivard, pg.37.

Robertson A., Jongeling R., Ekholm A., Olofsson T., and Zarli A. (2007), “Investigation of State-of-the-Art ICT for industrialization of house-building processes”. In Proceedings of CIB W78 conference 2007 in Maribor.

Samuelson, O. (2002). “IT-barometer 2002 – the use of IT in the Nordic construction industry”. ITcon, Vol. 7. Available at http://www.itcon.org/2002/1/paper.pdf .

Stewart, R. and Mohamed, S. (2003). “Evaluating the value IT adds to the process of project information management in construction”. Automation in Construction 12 (2003) 4007-417.

Stewart, R., Mohamed, S., and Marosszeky, M. (2004). “An empirical investigation into the link between information technology implementation barriers and coping strategies in the Australian construction industry”. Construction Innovation 2004; 4: 155-171.

Sverige Bygger (2006), Hudiksvall, Sweden. Available at http://www.sverigebygger.nu/.