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# **Socio-Technical and Human Cognition Elements of Information Systems**

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## Chapter IV

# Information Technology in Construction: How to Realise the Benefits?

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### ABSTRACT

*Advancement in the utilisation of computers has, in recent years, become a major, even dominating research and development target in the architecture, engineering and construction industry. However, in empirical investigations, no major benefits accruing from construction IT have been found. Why do the many IT applications, which when separately analysed seem so well justified, fail to produce positive impacts when the totality of the construction project is analysed? The objective of this chapter is to find the explanation for this paradox and to provide initial guidelines as to what should be done to correct the situation.*

### INTRODUCTION

Advancement in the utilisation of computers in construction has in recent years become a major, even dominating research and development target. This is clearly reflected in the number of related research undertakings, published scientific papers and in educational curricula. There are numerous conferences specifically address-

ing construction computing and integration issues. This *Zeitgeist* may well be illustrated with the following quote from an editorial of the *ASCE Journal on Construction Engineering and Management* (Farid, 1993, p.195): "The productivity and competitiveness of the construction industry can only be improved with the transfer and implementation of computing and other advanced technologies."

Although the ground for this optimism is seldom explicitly stated, it is easy to understand it. We all are using software, for word-processing, spreadsheet calculation or drawing, that clearly makes us more productive. Sending a letter by e-mail is speedier and less costly than using conventional mail. Indeed, there are countless information technology (IT) applications which, when the task it supports is only considered, seem to be perfectly efficient and to promise a major productivity increase.

On the other hand, investigations into the actual impacts of IT in construction reveal a not very flattering picture. Especially regarding site construction, the use of information technology has not brought any major benefits—on the contrary, it is claimed that the impacts may have been negative. Thus, the rhetoric and visions associated with construction IT have turned out to be alarmingly distant from the reality of construction IT usage. Why do the many IT applications, which when separately analysed seem so well justified, fail to produce positive impacts when the totality of the project, firm or industry is analysed? The objective of this chapter is to find the explanation for this paradox and to provide initial guidelines as to what should be done to correct the situation.

## BACKGROUND

### The Baseline

It is interesting that communication in the construction industry has been analysed from a socio-technical angle before the wide introduction of computers into this industry. In a pioneering study carried out by the Tavistock Institute (1966), characteristics of the structure and functions of the industry were empirically analysed. The overall approach was to consider building from a communications point of view. Interdependence and uncertainty were found to be the two important characteristics of construction. It was found that the building industry depends to a large extent on the application of an informal system of behaviours and management to work adequately. As the root cause of problems, the disparity of the characteristics of the formal and informal systems in relation to the needs of the real task with which they are concerned is put forward. The formal system (contracts, plans, etc.) does not recognize the uncertainty of and interdependence between the operations of the building process. On the other hand, the informal system of management is geared towards handling uncertainty and interdepen-

dence, but it produces a climate of endemic crisis, which becomes self-perpetuating. Further research on designing organizational forms with less uncertainty and on tools for coping with interdependency, especially in design, was suggested (Tavistock, 1966). It is unfortunate that this research was not continued.

## **Use of Information Technology in Construction**

Mechanization of intellectual work by means of computers started in the 1960s (Grierson, 1998). Computers are now widely used for automating and supporting various tasks in construction. Increasingly, computers are also used for supporting and automating the information flows that integrate these tasks. However, as yet no real computer-integrated construction has evolved (Laitinen, 1998). This stems from the reality that the construction business in general involves the temporary convergence of core competencies from different players to deliver a unique product, the building. Each individual player uses his/her specific IT tools to facilitate his/her specific work objective. Consequently information sharing through IT between different players is in essence a nightmare (Kazi et al., 2001).

## **Impacts of Information Technology in Construction**

What, then, have been the impacts of IT in construction? A number of studies have been carried out recently in order to answer this question. Howard et al. (1998) found high levels of benefit from construction IT in design and administration in Scandinavia, while management applications have resulted in little change. Especially, contractors reported little change in productivity resulting from materials or site management. Similarly, in their study on construction IT in Finland, Enkovaara et al. (1998) found that for contractors, IT had not produced any benefits, whereas in subcontracting and client procurement activities, IT benefits were negative, i.e., the benefits accrued have not offset the costs. A similar study in Canada (Rivard, 2000) comes to largely similar results. According to it, most benefits have been in the areas of general administration, design and project management. These benefits accrue to the fact that the number of mistakes in documentation have decreased, and the quality of documents and the speed of work have both increased. On the other hand, the complexity of work, the administrative needs and the costs of doing business have increased. It is concluded that the benefits of information technology come at a cost. Also Gann (2000) observed that in many firms, IT-related investment and training costs had been higher than the expected benefits.

Perhaps the most systematic study into the benefits of IT in construction is that of Thomas (2000), where outcomes of 297 projects (primarily heavy industrial) were studied. The outcome variables addressed cost growth, duration, schedule growth, safety, field rework, changes and other issues. Project data originating from

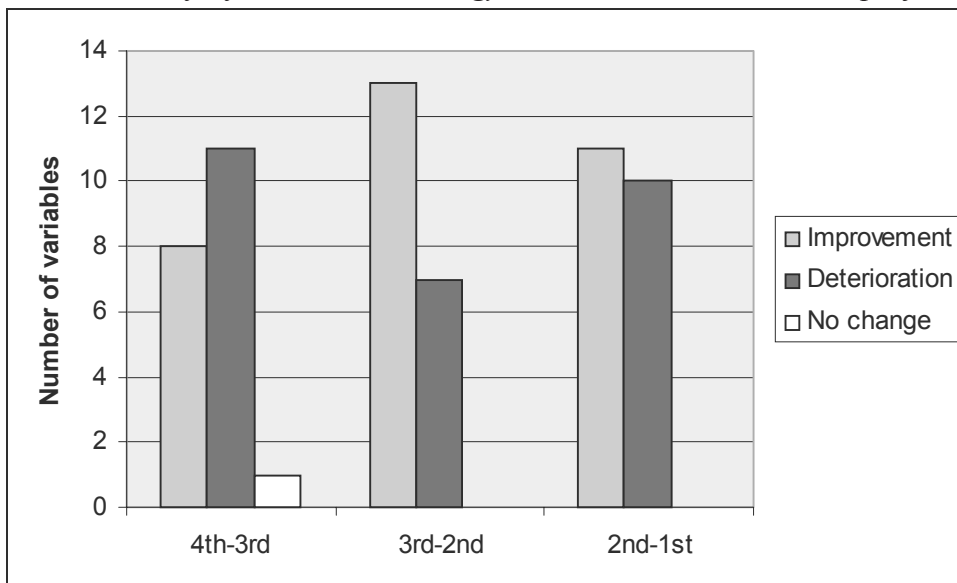
owners and contractors were analysed separately. Projects were divided into four classes according to the level of use of information technology, where the first represented the highest use and the fourth the lowest. It is concluded that both owners and contractors can expect overall project and construction cost savings. Let us consider in more detail the results for owners, who represented the largest category in the sample. For owners, the project cost savings due to moving from the fourth class to the first class are 0.8% and the construction cost savings correspondingly 3.9%. However, the results indicate a cost increase of 7.3% when proceeding from the fourth class to the third class. Also many other variables showed deterioration when the third class is compared to the fourth class. In fact, from the total 20 variables considered, 11 were worse after the introduction of information technology, while one remained the same (Figure 1). Thomas interpreted this as that the question is about performance penalty for the learning curve effect—cost and schedules are impacted when project team members experiment with new technologies.

Factually, Figure 1 reveals that a transition towards more use of information technology regularly leads to deterioration in a considerable number of variables, while remaining variables show improvement or no change. These results provide more evidence to the finding that information technology, while providing benefits, also has *detrimental impacts*. However, in contrast to Thomas' view, we contend that such detrimental impacts are not only related to the initial introduction of information technology. When variable values for the second and the first classes are compared, it turns out that only 11 variables improve, whereas 10 variables get worse when use of information technology increases. Thus, it must be added that a learning curve effect seems to operate also when advanced information technology is introduced, that is, in the opposite end of the IT usage scale. There seems to be a trough-shaped occurrence of IT penalties.

A troubling finding in Thomas' (2000) study is that increased use of IT by contractors is associated with a clear decrease of safety. Also, increased IT use seems not to help contractors to speed up projects; in contrary, a minor slowing down can be perceived. For owners, change costs and field rework cost were negatively impacted when IT use increased. On the other hand, owners could achieve schedule compression through increased IT use.

The lack of impact of information technology on capital projects is also illuminated by a recent study of the Business Roundtable (1997), which defines the universal characteristics of best capital project systems, based on benchmarking a great number of projects. Whether these characteristics are used or not has a definite impact on the profitability of the project. The best company transforms a 15% return on investment (ROI) project, based on average performance, into a 22.5% ROI project, while the poorest performers corre-

*Figure 1: The number of improving, deteriorating and unchanged variables when the use of information technology is increased in construction projects*



The 4<sup>th</sup> quartile of projects is using information technology least and the 1<sup>st</sup> quartile most. The column title, say “4<sup>th</sup>-3<sup>rd</sup>”, refers to the differences in variable values when one quartile (the 4<sup>th</sup>) is compared to another quartile (the 3<sup>rd</sup>). The impacts were assessed by means of 21 variables. Original data, originating from owners, is from Thomas (2000).

spondingly end up at a 9% ROI. The characteristics were organisational or managerial; information technology was not among them. In other words, it seems that it has not been possible to create competitive advantages through IT utilization alone.

All in all, the empirical investigations give a confusing picture. Surely it is disappointing to find that considerable investments into the use of information technology have rendered only a cost reduction of 0.8%, especially when it is well known that the same impact—and actually considerably bigger—could be achieved through other, apparently less expensive means (as pinpointed in the study of the Business Roundtable, mentioned above). However, it has to be noted that the studies into IT impact in construction are still scarce, and there are considerable methodological problems related to them. Thus the results should be treated with caution. All told, there is yet no empirical justification that information technology would contribute to breakthrough changes in the performance of the AEC<sup>1</sup> sector, as has been suggested by the mainstream thinking.



### *Why Is the Impact of Information Technology so Lacking?*

Various reasons have been offered as an explanation for these disappointing results. Commonly presented reasons include the low maturity of organisations in construction regarding IT use (Enkovaara et al., 1998) and barriers provided by the peculiarities of construction, especially fragmentation (Brandon et al., 1998). However, we contend that there are deeper reasons for this lack of intended impact of information technology in construction. These reasons will be best presented when embedded in the historical development of the modes of thinking about computing in construction.

### *The Conventional View on Computing*

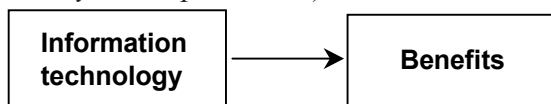
At the risk of oversimplification, it can be argued that the underlying conceptual framework (or mental model) of construction computing has been as shown in Figure 2. Information technology implementation leads directly to benefits and improvement in construction. This corresponds to the general approach to the use of information technology, largely prevalent still at the beginning of the 1990s. As formulated by Schrage (1997), the rationale of this thinking may be briefly crystallized as follows: if organizations only had greater quantities of cheaper, faster and more useful information, they could increase their profitability and enhance their competitive position. The underlying logic is that IT makes certain activities more cost effective, and—according to the logic of conventional accounting—the total costs are consequently reduced.

Unfortunately, it has been found that there is a productivity dilemma generally regarding IT investments: it has been difficult to find evidence for major productivity impacts contributed by the information technology (Gibbs, 1997). A new study by the McKinsey Global Institute (2001) gives further support to the belief that investments into information technology have not significantly contributed to productivity increase at the level of the national economy. There have been several explanations to this lack of economy-wide impact.

Firstly, Strassmann (1997) has provided extensive justification for the argument that IT investments have simply been poorly managed. Decisions on IT investments have factually been delegated to technical experts, and the level of scrutiny applied to other investments has not been applied.

Secondly, Davenport (1994) has argued that, in simple terms, the underlying view on information technology, as presented above, has developed to a bottleneck

*Figure 2: Underlying conceptual framework of construction information technology (inspired by Davenport, 1993)*



in itself due to its excessive focus on technology, rather than the context of its application. What is needed is better understanding of the organizations that use technology, rather than the understanding of information technology and its potential. Of course, this is the basic argument of the socio-technical approach: technical and social systems should be jointly optimised (Munkvold, 2000).

A third explanation is related to the situation, typical in the sphere of production, where the majority of costs have their origin in physical processes, rather than information processes. By improving information processes, we hope to improve the physical processes. Unfortunately the impact on physical processes is indirect only, and strong causal mechanisms leading to benefits are not necessarily present. If the physical process is in a constant chaos, information technology as such rarely helps. In fact, in the context of manufacturing, it has been observed that Computer Integrated Manufacturing acts as a magnifying glass: it makes the good production system much better and it makes the poor system much worse (Melnik & Narasimhan, 1992).

A fourth explanation is related to the way we have been thinking about costs. As Johnson and Kaplan (1987) have shown, the traditional way of thinking has been that costs are caused by direct work. Thus, by providing IT that helps employees to carry out their work activities, we can reduce costs. However, as activity-based cost accounting has shown, overhead costs especially are caused also by many other cost drivers than direct work, and if information technology is not addressing the cost drivers in question, the impact of IT at least cost-wise will fall short.

Let us investigate whether it is possible to find indications about the occurrence of these explanative mechanisms in construction. Firstly, like in general business, construction IT investments have not been based on careful calculations. In a study on American AEC firms, it turned out that 75% of the firms had never tried to figure out the return on investment for information technology spending (Engineering News Record, 1997). Similarly, a British study concluded that formal cost benefit analyses are not widely used to assess possible investments in information technology (Churcher et al., 1996). The findings of Enkovaara et al. (1998), that in many cases the level of personnel competence or the degree of structured data have not corresponded to those required by an IT application, also pinpoint to managerial problems.

Secondly, Gann (2000) lists a number of reasons that are related to the arguments provided by Davenport. In most cases, systems were introduced into traditional organizational structures that hindered the ability to achieve widespread benefits. Incomplete and inconsistent datasets and a lack of explicit, codified knowledge hampered the development of IT systems. Often, the low level of trust between organizations prevented the use of inter-organizational IT networks.

Thirdly, the fact that benefits have been very modest in contracting, whereas more substantial benefits have been achieved in such information-related areas as

design and administration, point to the explanation that it is not necessarily easy to influence physical processes, such as work flows or material flows, by means of information processes. Applebaum (1982) provides an interesting analysis of the introduction of up-to-date computer methods and a large, bureaucratically organised management team to the construction project. He describes the resulting situation as follows: "...we have virtually two separate organizations; one for the management function and one for getting the work done. The two organizations do not coordinate their work, and they are characterized by different goals and viewpoints" (p. 229). Pietroforte (1997) also finds that the demands of fast-tracking further increases the dislocation between the pattern of roles and rules predicted by standard contracts and the one that emerges from practice. In other words, the observations made by the researchers of the Tavistock Institute, referred above, have not lost their validity. It is easy to conclude that the use of computers in formal management is bound to be of little value for informal management, which actually gets the work done.

Fourthly, it is widely known that a substantial share of costs and time in construction are contributed by non-value-adding activities (Koskela, 2000), caused primarily by poor coordination of tasks. Information technology that has been primarily addressing individual tasks cannot influence these costs substantially. In contrary, information technology may even increase non-value adding activities. Indeed, giving us a rare glimpse on what actually is happening in design, Sverlinger (1996) observed that half of the disturbances in design are due to design organizations themselves, rather than the design process in question. Furthermore, he found that design tools are the most frequent cause of internal disturbances in design firms. Most design tools were computer-based.

Thus, the generic mechanisms that have diminished the impact of the use of information technology in general seem to have operated also in construction. The conceptual model of IT implementation has simply been too shallow and insufficient, leading to several kinds of misplaced conduct.

## **Re-Engineering View on Computing**

Next, it is necessary to discuss re-engineering, which has been proposed as a solution to at least some of the problems of the use of information technology, as treated above. The idea of business process re-engineering (or redesign) was developed during the study of the impact of IT on organizations by MIT. Business process redesign was defined as one of five levels of IT-induced reconfiguration of organizations (Venkatraman, 1991). It was stated that our current principles of organization are geared towards exploiting the capabilities offered by the Industrial Revolution. It was argued that the IT revolution could alter some of these principles. Another article by participants in the study mentioned (Davenport & Short, 1990)

illuminates which kind of new principles were thinkable. However, it was only the article of Hammer (1990) and the subsequent book (Hammer & Champy, 1993) that sparked the interest in reengineering. Business process reengineering (BPR) was developed into a consulting package and became a buzzword. The first examples of BPR were from administration and services, and this focus prevailed, but also manufacturing companies started their re-engineering initiatives. However, towards the end of the 1990s, the fashionability of re-engineering waned, and it was increasingly discussed critically (Mumford & Hendricks, 1997).

In re-engineering, it is acknowledged that information technology applications do not directly contribute to benefits, but through the intermediation of information processes (Figure 3). Information (or material) processes may restrain or amplify the effect of information technology. In re-engineering, the interest is especially focused on the cases where information technology enables a new, widely superior process design (for example Hammer, 1990; Davenport & Short, 1990; Rockart & Short, 1989). According to Hammer, recognizing and breaking away from outdated rules and fundamental assumptions is the key issue in re-engineering.

The approach of re-engineering solves at least part of the shortcomings of the conventional view on information technology, as discussed in the previous section. The focus is turned from information technology as such, to changing information processes. However, one cannot be fully satisfied with re-engineering as a foundation: it is rather a management recipe (Earl, 1994), lacking an explicit theory. One critical shortcoming is that the concept of process, central in the reengineering rhetoric, has not been precisely defined. Koskela (2000) has argued that the term of process has been interpreted in three different ways, each leading to a different set of principles and practices. Historically, the first interpretation was that the question is of a *transformation* process. Actually, this has been the definition of the term process in reengineering literature (Garvin, 1998). However, the prescription of reengineering has been more focused on a second interpretation, where one holds process as a *flow*. Indeed, close reading of the seminal re-engineering articles and books reveals that what were considered as problems to be addressed were dysfunctions caused by the transformation concept, like excessive buffers, fragmentation and inadequate feedback along chains. What was recommended as a solution were process design principles or solutions emanating from the flow concept, augmented with IT capabilities. The third interpretation views a process

Figure 3: Underlying framework of re-engineering (Davenport, 1993)



as *value generation*. Although not systematically applied, even this interpretation is frequently mentioned in the rhetoric of re-engineering.

The other critical shortcoming of re-engineering is that it addresses only the *design* of processes. Instead, how the re-engineered process should be *controlled* and *improved* is largely left outside the focus. If the improvement potential lies in the ways control and improvement is carried out, it will remain untapped in a re-engineering initiative.

Interest in re-engineering has rapidly increased in construction research and practice (Betts & Wood-Harper, 1994; Ibbs, 1994). Indeed, re-engineering has to some extent shown the way towards a more effective approach to information technology. However, the interest in construction reengineering waned towards the end of the 1990s, as it did in other industries. On the other hand, similar initiatives are being carried out, but under different banners.

One of the most popular ways of re-engineering construction has been the design-build (DB) mode of realizing a construction project. Even if information technology does not necessarily play any prominent role in the execution of a DB project, it is interesting to consider this initiative for the sake of comparison. In a DB project, the client gives, in a single contract, the execution of both design and construction to one company (usually contractor) that has the freedom to integrate design and construction in a suitable way. The performance of the design-build delivery system in comparison to other major delivery systems has been studied in two recent studies in the U.S. and UK (Konchar & Sanvido, 1998; Bennett, Potheary & Robinson, 1996). The results indicate that statistically, the design-build process outperforms the traditional design-bid-build (DBB) process in several respects; however, the differences are not great. The U.S. study finds DB to be 6% less costly than DBB, whereas the UK study estimates that DB is 13-32% less costly than DBB (however, these figures have been calculated in incompatible ways and it is difficult to draw general conclusions from them). It can be noted that such an impact of an organizational solution outweighs the impacts of the use of information technology, discussed above.

## **A Suggested View on Construction Computing**

With which conceptual framework, then, should we equip ourselves when wanting to use IT in construction? An interesting direction is given by Fenves (1996). He calls for a science base of application of information technologies in civil and structural engineering. According to Fenves, one component of this science base would deal with the understanding of the processes of planning, design, management, etc., that engineers use:

“... we need to agree on an intellectual framework, in order to create a scientific understanding or abstraction of engineering processes in practice.” (p. 5)

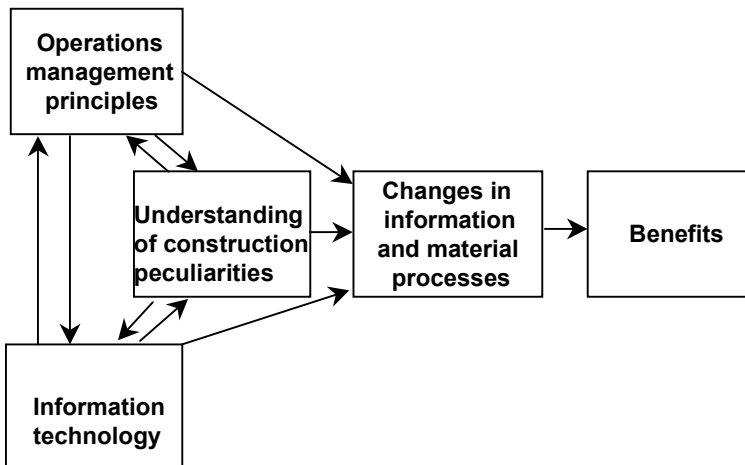
This can be interpreted as follows: the bottleneck in construction computing is not due to a deficiency in information technology in general or its specific applications, but to a deficient understanding of construction. Thus, what Fenves wants to add to construction computing research is an understanding of operations in general and of construction specifically. Information technology solely cannot cure the fundamental problems of construction—only better theories and concepts can, and support can be given by information technology. It is proposed to structure this issue as illustrated in Figure 4.

Here it is explicitly acknowledged that all three factors—(emerging) generic operations management principles, understanding of construction peculiarities (and their implications, such as decentralized organization and informal decision-making)—and information technology—may bring about changes in information and material processes. These three approaches interact with each other, and they may amplify or restrain each other's influences to information and material processes. In other words, the introduction of computers to construction does not qualitatively provide anything new from the point of view of the theoretical analysis of production systems: computing is worthwhile only as far as it can contribute—better than alternative means—to the realization of the principles of production.

The way changes and benefits emerge in construction is dependent on the fit between interventions emanating from these three fields as depicted in Figure 4. Let us illustrate this through examples.

There are three channels through which information technology can contribute to changes in information and material processes in construction. Firstly, information technology may directly change processes, by mechanising or supporting tasks carried out by people. Secondly, information technology may contribute to the

*Figure 4: The interrelationships between operations management, understanding of construction and information technology*



realization of a certain operations management principle. A central theme in modern operations management is that variability should be reduced in production (Hopp & Spearman, 1996). Excessive variability is a chronic problem of construction. Thus, it is required to search for computer-based means for the reduction of variability. One example is provided by three-dimensional CAD design, where possible geometric interference of components designed by different designers—a problem stemming from construction peculiarities—is automatically avoided. Thirdly, information technology may be used for eliminating the problems associated with construction peculiarities. One such problem is the scarcity of learning based on repetition in construction—practically all buildings are one-of-a-kind. However, this problem can at least partially be remedied through computer simulation and visualization of the product and process of construction.

On the other hand, the principles of operations management and the construction peculiarities provide a constraint for information technology. Firstly, information technology should not deteriorate the realization of operations management principles. For example, variability should not be increased by the introduction of information technology. Unfortunately, evidence shows that the various IT problems, like machine, software and communications breakdowns, and deficient skills, are a considerable source of variability. Thus, the background variability of the IT infrastructure should be reduced. Secondly, the peculiarities of construction, such as one-of-a-kind product, site production and temporary organization, and their implications, provide a challenging environment for information technology, and solutions fit to this environment should be aimed for. This means, among other things, that IT applications should support the communication of uncertain and qualitative information that characterises the design process (Pietroforte, 1997).

It follows that understanding and utilization of the interactions among the generic operations management theory, construction peculiarities and capabilities of computing are most important in the successful advancement of IT in construction.

## CONCLUSIONS

Unfortunately, the analyses made indicate that there are no quick fixes regarding the possibilities for increasing the benefits accruing from the use of information technology in construction. Increased understanding leads to the conclusion that the use of information technology is an extremely complicated issue that we have only started to grasp. However, five areas of improvement become apparent. Firstly, we, both as practitioners and researchers, have to reject the deeply ingrained notion that information technology in itself brings about benefits in construction. Rather, the effects of information technology are intermediated

through information and material process, which can—and should—be improved also by other means. Secondly, the firms in the AEC sector should try to get their IT investments into control. Sound managerial principles should be used along all life cycle phases of an IT project. Especially the implementation phase has to be emphasized, for avoiding detrimental impacts. Joint consideration of the technical and human part of an information system is one important precondition for success. Thirdly, in the development of new information systems for construction, more emphasis should be placed on how organizational and managerial changes can effectively be supported by information technology, rather than only holding IT as the major driving force that necessitates organizational changes. Fourthly, regarding scientific research, there is a need for a reintegration of research addressing construction computing with advanced construction management research focusing on new organizational and managerial solutions. Recently, the research on construction computing has increasingly emerged as a discipline in its own—somewhat untimely, as integration to related fields would rather be needed. Fifthly, construction computing research, addressing up till now mostly the development of new concepts, methods and tools, should adopt empirical research into its methodical arsenal. How are information systems developed and implemented in practice? What actually happens when people are using information technology in construction?

## ENDNOTES

- 1 Architecture, Engineering and Construction

## REFERENCES

- Applebaum, H. A. (1982). Construction management: Traditional versus bureaucratic methods. *Anthropological Quarterly*, 55(4), 224-234.
- Bennett, J., Potheary, E. and Robinson, G. (1996). *Designing and Building a World-Class Industry*, 91. Reading, MA: University of Reading.
- Betts, M. and Wood-Harper, T. (1994). Reengineering construction: A new management research agenda. *Journal of Construction Management and Economics*, 12, 551-556.
- Brandon, P., Betts, M. and Wamelink, H. (1998). Information technology support to construction design and production. *Computers in Industry*, 35, 1-12.
- Churcher, D. W., Johnson, S. T., Howard, R. W. and Wager, D. M. (1996). IT in construction—Quantifying the benefits. *CIRIA Report 160*.
- Davenport, T. (1993). *Process Innovation—Re-Engineering Work Through Information Technology*, 336. Boston, MA: Harvard Business School Press.



- Davenport, T. (1994). Saving IT's soul: Human-centered information management. *Harvard Business Review*, (March-April), 119-131.
- Davenport, T. H. and Short, J. E. (1990). The new industrial engineering: Information technology and business process redesign. *Sloan Management Review*, (Summer), 11-27.
- Earl, M. J. (1994). The new and the old of business process redesign. *Journal of Strategic Information Systems*, 3(1), 5-22.
- Engineering News Record*. (1997). Design firms spend 3% of revenue on technology. October 6, 7.
- Enkovaara, E., Heikkonen, A. and Taiponen, T. (1998). *Rakennusalan Informaatioteknologian Kypsyys- Ja Hyötytason Mittaus* (In Finnish: *Measurement of Maturity and Benefits of Construction Information Technology*). Mimeo, Finland.
- Farid, F. (1993). Editorial for special issue: Applications of microcomputers and workstations in construction. *Journal of Construction Engineering and Management*, 119(2), 193-195.
- Fenves, S. J. (1996). The penetration of information technologies into civil and structural engineering design: State-of-the-art and directions toward the future. In Kumar, B. and Retik, A. (Eds.), *Information Representation and Delivery in Civil and Structural Engineering Design*, 1-5. Edinburgh: Civil Comp Press.
- Gann, D. (2000). *Building Innovation: Complex Constructs in a Changing World*. London: Thomas Telford.
- Garvin, D. A. (1998). The processes of organization and management. *Sloan Management Review*, 39(4), 33-50.
- Gibbs, W. W. (1997). Taking computers to task. *Scientific American*, (July), 64-71.
- Grierson, D. E. (1998). Information technology in civil and structural engineering design in the twentieth century. *Computers and Structures*, 67, 291-298.
- Hammer, M. (1990). Reengineering work: Don't automate, obliterate. *Harvard Business Review*, (July-August), 104.
- Hammer, M. and Champy, J. (1993). *Reengineering the Corporation*, 223. London: Nicholas Brealey.
- Hopp, W. and Spearman, M. (1996). *Factory Physics: Foundations of Manufacturing Management*, 668. Boston, MA: Irwin/McGraw-Hill.
- Howard, R., Kiviniemi, A. and Samuelson, O. (1998). Surveys of IT in the construction industry and experience of the IT barometer in Scandinavia. *Itcon*, 3, 45-56.
- Ibbs, C. W. (1994). Reengineering construction work processes. *The International Journal of Construction Information Technology*, 2(4), 27-47.

- Johnson, H. T. and Kaplan, R. S. (1987). *Relevance Lost—The Rise and Fall of Management Accounting*, 269. Boston, MA: Harvard Business School Press.
- Kazi, A. S., Hannus, M. and Laitinen, J. (2001). ICT support for distributed engineering in construction. In Stanford-Smith, B. and Chiozza, E. (Eds.), *E-Work and E-Commerce: Novel Solutions and Practices for a Global Networked Economy*, 909-915. Amsterdam: IOS Press.
- Konchar, M. and Sanvido, V. (1998). Comparison of U.S. project delivery systems. *Journal of Construction Engineering and Management*, 124(6), 435-444.
- Koskela, L. (2000). An exploration towards a production theory and its application to construction. *Espoo, VTT Building Technology*, 296. VTT Publications; 408. ISBN 951-38-5565-1; 951-38-5566-X. WWW: <http://www.inf.vtt.fi/pdf/publications/2000/P408.pdf>.
- Laitinen, J. (1998). *Model Based Construction Process Management*, 136. Stockholm: Royal Institute of Technology, Construction Management and Economics.
- McKinsey Global Institute. (2001). *US Productivity Growth, 1995-2000*.
- Melnyk, S. A. and Narasimhan, R. (1992). *Computer Integrated Manufacturing*. Homewood, IL: Business One Irwin.
- Mumford, E. and Hendricks, R. (1997). *Reengineering Rhetoric and Reality: The Rise and Fall of a Management Fashion*. <http://bprc.warwick.ac.uk/rc-repb-6.html>.
- Munkvold, B. E. (2000). Tracing the roots: The influence of socio-technical principles on modern organisational change practices. In Coakes, E., Willis, D. and Lloyd-Jones, R. (Eds.), *The New SocioTech: Graffiti on the Long Wall*, 13-25. London: Springer.
- Pietroforte, R. (1997). Communication and governance in the building process. *Construction Management and Economics*, 15, 71-82.
- Rivard, H. (2000). A survey on the impact of information technology on the Canadian architecture, engineering and construction industry. *ITCon*, 5, 37-56.
- Rockart, J. F. and Short, J. E. (1989). IT in the 1990s: Managing organizational interdependence. *Sloan Management Review*, (Winter), 7-17.
- Schrage, M. (1997). The real problem with computers. *Harvard Business Review*, (September-October), 178, 183-188.
- Strassmann, P. A. (1997). *The Squandered Computer*, 426. New Canaan, CT: The Information Economics Press.
- Sverlinger, P.-O. (1996). Organisatorisk samordning vid projektering. *Report 44*. Institutionen för byggnadsekonomi och byggnadsorganisation. Chalmers tekniska högskola. 118p. (Organizational Coordination in the Design Phase.)

- Tavistock Institute. (1966). *Interdependence and Uncertainty*, 83. London: Tavistock Publications.
- The Business Roundtable. (1997). *The Business Stake in Effective Project Systems*. Washington, DC.
- Thomas, S. R. (2000). *Impacts of Design/Information Technology on Project Outcomes*, 39. National Institute of Standards and Technology.
- Venkatraman, N. (1991). IT-induced business reconfiguration. In Scott Morton, M. (Ed.), *The Corporation of the 1990s*, 122-158. New York: Oxford University Press.