Development of Information Communication Technologies in Construction Project Management

The relationship between theory and technology and its application to the construction industry, including a retrospective on the development of technology that demonstrates how theory was altered and how practice was influenced.

By

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ABSTRACT

Theory in IT is generally constrained by technology. Thus, if the theory is not applicable through the state of technology, the theory consequentially adapts or initiates new theories. The objective of this report is to analyse the relation between theory and technology, how the ideas in information communication technology (ICT) and their implementation in construction have evolved. The methodology reviews preceding theory of ICT in construction, compares it to the corresponding technological development and analyses eventual discrepancies between the theory and the practice, in order to identify the limits of progression of innovation and to assess the context of current research development. It is assumed that the theory of ICT has been around since the very beginning of electronic information processing and has not been dramatically influenced by the state of technology. The very few developments that have proven to be dead ends were assimilated or integrated within the general development of technology. Especially in construction, computing has yet changed life in so far, that it has replaced manual tasks. So on the one hand, the construction Industry relies on traditional, antiquated procedures, yet on the other hand with the increasing dependency on the flow of information, the radical spread and speed of telecommunication, the development of multimedia and interactive communication and integrative solutions, ICT has revolutionized communication and the way we live. The impact of the internet, connectivity and mobile technologies are considered, how together with innovative applications, the information flow in construction can be improved for a more reliable decision making process. Now that Internet and mobility is widely established in society and in the conscience of the users, construction is increasingly incorporating ICT. Issues such as information overflow, ownership, compatibility and technical integration remain to be resolved however, the construction industry and its productivity will inevitably benefit from the combined and integrative capabilities of ICT. So once hardware is in place and processing speed sufficient, the software available and interoperable, communication channels sophisticated and the data organized, what comes next?

Key words: Information Communication Technology (ICT), Theory, History, Construction Project Management, Collaboration Technology

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In order evaluate the findings and test the accuracy, semi structured interviews were conducted with leading professionals in the areas of research and practice to comment retrospectively upon their area of research. I would like to thank: Professor Rob Howard, the author of 'Computing in Construction' 1998 and co-author of 'IT in Constriction' 2004 for his advice on integration of systems and the development of theory and practice in construction. Professor Alan Penn, Director of the Virtual Reality Centre at University College London, whom I sought for advice concerning potentials and barriers of Virtual Reality, who introduced me to a different perspective on the construction industry. Professor Ghassan Aouad, Director of the Salford Centre for Research and Innovation for his opinion on nd Cad simulations and highlighting the importance of standards. Paul Wilkinson, author of 'Construction Collaboration Technologies' and head of corporate communications at BIW Technologies comments on collaborative technologies and changing attitudes in construction practice. Professor Martin Fischer, Director of the Center for Integrated Facility Engineering (CIFE) at Stanford University for his reflections on the development of CAD and gave me highly interesting insights into the future of CAD, especially concerning virtual building models in construction.

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1 INTRODUCTION

Technological innovation has come a long way in the built environment since the inception of digital information processing and commercialization of desktop computers. Initially the construction industry was very enthusiastic in its adoption of Information Technology (IT) in the early 1970s as a tool for design and construction. This excitement soon waned in the 1980s and turned into realism about the time needed to develop the computers' potential. Due to its caution for innovation, constrained investment in research and development and the reservation of its professional bodies, the construction industry lagged behind other industries in the development of IT. According to a DTI benchmarking study in 2004, the construction industry had one of the lowest levels of connectivity and network technology (Wilkinson 2005). However, the sophistication of technology, such as capacity of workstations, accessibility and proceeding advances in network and mobile technologies in recent years, have enabled a new drive for Information Communication Technology (ICT). This new excitement is increasingly transforming the business of construction practices (Sun and Howard 2005). Consequentially, there are downsides in the development, such as legal issues, interoperability and human acceptance.

The objective of this report is to analyse the relation between theory and technology, and how the ideas in information communication technology (ICT) and their implementation in construction have evolved. The methodology of the analysis is mainly based on available literature. Subsequently past and present theories in information technology and their implementation are reviewed. These developments are related to the current construction project environment and henceforth evaluated upon how they have changed the construction profession. Consequentially, current research areas and trends are considered and how ICT may develop in the future. The conclusion reflects on the accuracy of the initial hypothesis. The findings are tested and commented in semi structured interviews with experts from research and practice. The outcome provides a basis for discussion on the constraints of progression in ICT development and respectively implications for the industry. This in turn may influence the assessment of current research and development in terms of applicability and acceptability within the industry, as to what the limits to innovation are, if not technology and whether technological constraints have influenced the development and have changed the initial body of theory.

2 THEORY AND TECHNOLOGY

2.1 From IT to ICT

Our heavy reliance on technology would not have been feasible a decade ago. What was initially known as Information Technology (IT) has absorbed the communicative aspects of interaction and evolved to Information Communication Technology (ICT). This paramount development infers that IT is now effectively acting as an enabler of communication within modern society and consequently within organisations (Howard 1998). The contribution of networking technologies and the spread of the Internet have played a decisive role in creating innovative opportunities, which the computer on its own could not have achieved. Today it is commonplace to switch on the computer, communicate via e-mail and gather product information over the Internet. Always being available with a cellular phone and organizing the daily routine by writing with a digital pen on the display of a personal digital assistant, while listening to downloadable compressed digital music on a device smaller than a credit card and synchronising everything wireless with a portable laptop. Not too long ago, these obvious actions were any more than science fiction. Society's need for information, its flow and having it readily available, from every remote location is continuously increasing. In 1984 Kiesler et al. recognised this tendency: "...no one can predict in any detail the nature of the transformations that computers will bring... one aspect of life that will certainly be affected is communication" (Kiesler et al. 1984:1123). Communication is inevitably interlinked with IT and the effects on society are far beyond automation of routine tasks. ICT has fundamentally changed the way we live and the way business is conducted (Sun and Howard 2004). "The Information society is the latest of a series of cultural and technical changes; from the agricultural revolution to the industrial revolution, and now the electronic revolution which has resulted in cheap, reliable hardware and software. The next stage is the emergence of the information society when data and communications, and their integration with the needs of people, are the main focus of development. However, revolutions do not change society over night." (Howard 1998:15)

2.2 Theory

In the context of this report, theory is considered an idea of what might be in the future. Theory is defined as a proposed description, of the manner of interaction of a set of natural phenomena, capable of predicting future occurrences and capable of being tested through experiment or otherwise falsified through empirical observation (www.wikipedia.org accessed 05.08.06). Theory and fact do not stand in opposition. The importance of the availability of a theory is significantly important as it gives the direction for research. Vannever Bush emphasizes the necessity for theory and research to be available in order to innovate. In his introduction to 'As we may think' he reflects on history when a specific idea or innovation had been developed, but due to circumstances could not be delivered to those capable of extending it (Bush 1945).

2.3 Information

Information is the raw data, which needs to be possessed in order to become knowledge. Information is meaningless if it cannot be related to already existing knowledge. In the 'Post Capitalist Society', Drucker emphasises that knowledge is not just another resource alongside the traditional factors of production such as land, labour and capital, but is in fact the only meaningful resource (Drucker, 1993). Extensive research is being conducted to master implicit and explicit knowledge and how to transform information into knowledge and capture such. It is widely believed that besides tangible resources, such as physical assets, the intangible resources such as reputation, knowledge and of course information define the true wealth of an organisation (Bartholomew 2005). Hence, a general motivation is to create the means to capture and make information accessible in a comprehensive manner, to have the precise knowledge readily available. The discussion about the benefits of knowledge capture go beyond the purpose of this paper, yet the concept must be emphasized to facilitate the management of information through technology and to recognize that the "capacity of the firm to learn, is arguably, the most important determinant of its ability to innovate on projects" (Winch 1998:276). However, information is not always of benefit. It may induce psychological constraints and threats when inappropriately processed or wrongfully distributed. According to Winograd and Flores most knowledge comes from observation and is subject to individual interpretation of data (Winograd and Flores 1985). Consequentially at every time each individual has an idea in his mind. When he wishes to communicate this idea with another person, he cannot guarantee that the transferred idea corresponds with his original intention. As long as information is not made unarguably visible, it is subject to interpretation.

2.4 Communication

Generally, communication is the exchange of information. The ability to communicate is the essence of management, hence the ability to encode and decode information. For a project manager, communication consumes about 75-90% of his time (Alshawi and Ingirige 2003), and consequentially it is not surprising that communication has been cited the primary cause of project failure (Dainty et al. 2006).

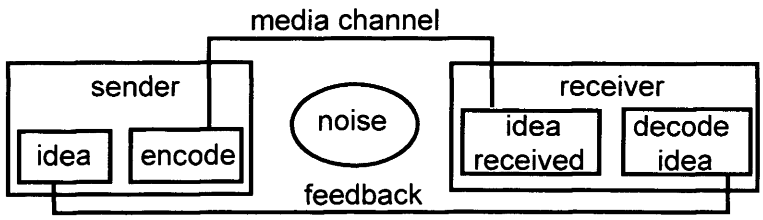


Figure 1: Communication Model

The body of theory of communication has evolved over the later half of the 20th century, through mathematical theories as well and social and psychological perspectives, by examining the processing and flow of information through channels and networks. In the 1970s focus was drawn towards organizations as processes, not as entities (Handy 1995). Communication in organizations enables the coordination of results, manages change and is necessary to motivate employees. Communication concepts have been identified as (Dainty et al. 2006:5):

- Transfer of information
- Bridge a distance
- Social skill involving effective interaction between people
- Convey facts, feelings, values and opinions
- Between groups or organizations
- Transactional process

Types of communication can be verbal, non-verbal, written, audiovisual or electronic. And consequentially, barriers to effective communication may be generally defined as 'noise' (Dainty et al. 2006:63):

- Individuals frame of reference and cognitive dissonance, to hear what you want to hear and ignore conflicting information
- Stereotyping, perceptions about communicator
- Influence of group dynamics
- Words meaning different things to different people

- Non verbal communication issues
- Emotions
- Acoustic noise
- Size and structure of organization

It has been perceived, that the reason why individuals exchange knowledge within a community is their desire to have access to that community hence, not using the forum for socializing, nor to develop interpersonal relationships, but value the community as an opportunity to exchange knowledge (Dainty et al. 2006). Communication may be classified by the extent to which feedback is permitted. A linear flow of information, from sender to receiver with no opportunity of feedback, is cheaper and more rapid, whereas a reciprocal flow of information with numerous of opportunities for feedback, secures trust, mutuality and spirit of cooperation.

2.5 Technology

"Technology is as old as humankind. It existed long before scientists began gathering the knowledge that could be used in shaping and controlling nature" (Basala 1988:27). It refers to the interaction of human to control nature through knowledge of tools, methods and materials. Technology can advance over time, as people improve upon or replace the technologies that came before, but it can regress when the infrastructure necessary for the support of the existing technology no longer exists. Basalla relates technological evolution to four basic concepts: diversity, continuity, novelty and selection (Basalla 1988). The subsequent development of ICT in all its consequences has enabled globalization of the economy, promoted democracy and brought competition beyond national borders (Sun and Howard 2004). Winograd and Flores prelude in 'Understanding computers and Cognition' with the question "Are computers merely giant adding machines or are they electronic brains?" (Winograd and Flores 1985:3). How far can technology go, does it help augment programed and routine tasks or can it learn and create and eventually replace human actions. This discourse may seem exaggerated, yet is a popular basis for discussion, especially in the late 1960s. Nevertheless technology, specifically ICT is not more than a tool or an aid to humans. The effectiveness of technological development is ultimately dependant upon the ways in which the information is encoded, transmitted, decoded and interpreted by the people involved (Dainty et al. 2006).

2.6 Collaboration

"Cooperation is everything: freckles would make a nice tan coat if they'd get together" (unknown, cited in Pinto and Millet 1999:119). Wilkinson defines collaboration as a "creative process undertaken by two or more interested individuals, sharing their collective skills, expertise, understanding and knowledge (information) in an atmosphere of openness, honesty, trust and mutual respect, to jointly deliver the best solution that meets their common goal" (Wilkinson 2005:3). Traditionally construction projects tend to be fragmented, complex and temporary, resulting in poor information, lack of collaboration and trust, create competitive and adversarial attitudes amongst participants of construction projects (Kelly et al. 2002). The industry has a legacy of mistrust and allocating blame when things go wrong especially in projects involving uncertainty, integration and urgency (Turner and Muller 2003). The more trades and contractual relationships are involved, the more intermediate stages exist between participants, increasing transaction costs and respectively the expenses that occur (compare Greenberg and Ive 2000). The whole contractual relationship system in construction hinders the flow of information. Each contract allocates risks, responsibilities, and defines the motivation of the contract parties. Therefore construction professionals engage in strategies to manage and minimize their own costs to the disadvantage of the value of the project as a whole (Kelly et al. 2002).

Traditional emphasizes the 'historical ways of thinking', as a pre-understanding of interactions concurring with those who share the same tradition (Winograd and Flores 1985). Kellogg identifies "the need for removing the legal, social, and labour restraints presently burdening the construction industry" (Kellogg 1971, cited in Tsao et al. 2004). Both Latham (1994) and Egan (1998) promote the concepts of partnering and strategic alliances. Information exchange relies on trust and on the necessity to behave in a cooperative manor, not opportunistically (Egan 1998). Through ICT and its effects on cultural commutability and globalization, certain traditions must be 'extended' to promote managerial efficiency. Once competitive and adversarial barriers are overcome, collaboration and trust can be established, the cognition of a common goal anticipated, and an effective information exchange process can evolve. Collaboration is essential in order to exploit the full benefit of ICT. The impact of ICT on collaboration is gaining in dominance, now extending and managing the information flow of activities across the whole supply chain (Alshawi and Ingirige 2003).

2.7 Hypothesis

Theory in IT is generally constrained by technology. Thus, if the theory is not applicable through the state of technology, the theory consequentially adapts or initiates new theories. Thereby, technology appears to be the main limiting factor in the implementation of theory. However, Winograd and Flores 1985, Pinto and Millet 1999, Dainty et al. 2006 and many others have identified behavioural aspects to be the more significant constraints in the convergence of technology to actual practice.

People are trying to keep up with the possibilities of technology (Howard 1998). Attitudes inevitably change over time. Respectively, in order for attitudes to change, alternatives to current practice have to be available and marketed. Certain developments however must be prerequisites in order to enable technology to advance and eventually define alternatives, or new theories. By relating current state of technology to the initial body of theory, patterns of how to asses the current technological development may be anticipated. These findings are relevant for current research, to understand the constraints on its progression. Specifically information technology, unlike other sciences, does not develop coincidentally; it requires a predefined body of theory. Howard coins the "Cyclic nature of invention", visions are created long before they can be realized (Howard 1998). In order for a theory to be implemented successfully and eventually meet the requirements of practice, a holistic approach towards the effects of the theory is inherently important (Winch 1998).

3 REVIEW OF ICT RELEVANT TO CONSTRUCTION

3.1 Availability of Theory

"Most of the applications of computers in construction were envisaged in the 1960's long before they could be delivered efficiently by the computers of the time" (Howard 1998:25). Accessibility to information from everywhere was perceived an early goal. In the 1940's Vannevar Bush introduced the concept of the 'Memex', "...a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory" (Bush 1945). This vision is believed to be the birth of the concept for the later Internet. Research at that time, was generally concentrating on face-to-face interaction.

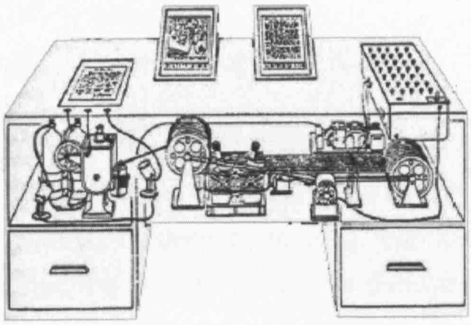


Figure 2: Memex (Bush 1945)

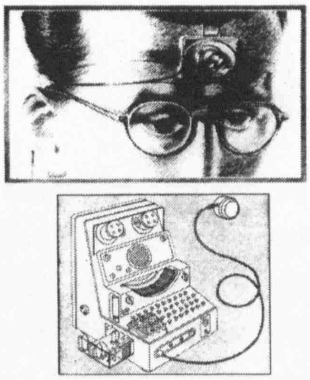


Figure 3: Thought transfer (Unknown)

The 1960's was the decade where concepts, visions and theories were initiated and demonstrated in rather primitive manners. In 1962 Douglas Englebart wrote his PHD thesis on 'Augmenting Human Intellect' that introduced the computer as a tool to increase the capability to approach complex problems, to gain comprehension and to suit particular needs (Englebart 1962). He committed his research to the human-computer interface, initiating developments such as the mouse, hypertext, network computing and graphic user interfaces (1968 "the mother of all demos", http://sloan.stanford.edu/). J.C.R. Licklider, introduced the view of computers as general tools, rather than simply devices for performing calculations. He conceptualized modern computer interaction and realized the potential for computers as channels for mass communication and enabler for the freedom of speech. Licklider is considered the father of Artificial Intelligence. Leonard Kleinrock established in the mid 1960's the framework theory on 'Hypertext' that enabled the Internet to be developed. Together with Englebart, he worked on the 'Advanced Research Projects Agency Network' (ARPANET) project in 1969, the world's first electronic computer network. Ivan Sutherland is a further pioneer in human computer interaction (figure 4). He developed the Sketchpad program in 1963, which is considered the first Computer Aided Design (CAD) application, conceptualized Virtual Reality (VR) and introduced the idea of a head mounted displays in 1968 (Sutherland 2003). Another decisive step in ICT and enabler of computer simulations was the conception of the object oriented modelling language by Kristen Nygaard, Ole-Johan Dahl and later Robert Bemer in the mid 1960's. Their approach link geometric objects to other assigned attributes, to generate virtual simulations (Froese 1992). Theodor Nelson predicted in 1974 at a fundamental level how computers would enable new generations of media (Nelson 1974). In the 1980's theoretical research focused on Computer Mediated Communication (CMC), possibilities of fast and precise information exchange such as e-mail, forums and simultaneous computer conferences were investigated.

3.2 Development of ICT

Early devices for the mechanical calculation and storage of data may be traced back to ancient devices such as the Abacus and the Antikythera mechanism. However, modern computing technology dates back to when John Napier invented the logarithms in 1614 (Howard 1998). From then on, continuous developments were introduced, until 1940 when computing became electronic. Known as the first generation computers based around wired circuits containing vacuum valves and used punched cards as the main storage medium (Shapere 1998). Tomas J. Watson, the Chairman of IBM coined in 1943 the legendary phrase "I think there is a world market for maybe five computers". In 1945, Vannevar Bush articulated his keen vision of having all human knowledge accessible through a single device (Bush 1945), and basically defined the culminating future of ICT. Nevertheless, computers available at that time were gigantic systems devoted to one single task. Mainly military and academic research programs initiated the subsequent conversion to commercial use. Most significantly to project management, the development of Project Evaluation Review Technique (PERT) and Critical Path Method (CPM) in the late 1950's simplified the planning and scheduling of large and detailed projects and managing plant maintenance (Morris 1997). The 1960's delivered concepts to most applications available today (Howard 1998). Not ideas of what to do, but the volume of data that could be processed and the hardware available were the limiting factors. Word processing was invented by IBM in late 1960's and electronic spreadsheet was conceptually outlined in 1961 (Eisenberg 1992). Papers were written and read enthusiastically around the world, but equipment was confined to very few research laboratories. One of the first commercial uses was in processing payrolls and other financial records (Power 2004). The use of computers involved highly complex operations which could only be performed by specialists. Hence the interaction of the user was the basis for substantial research.

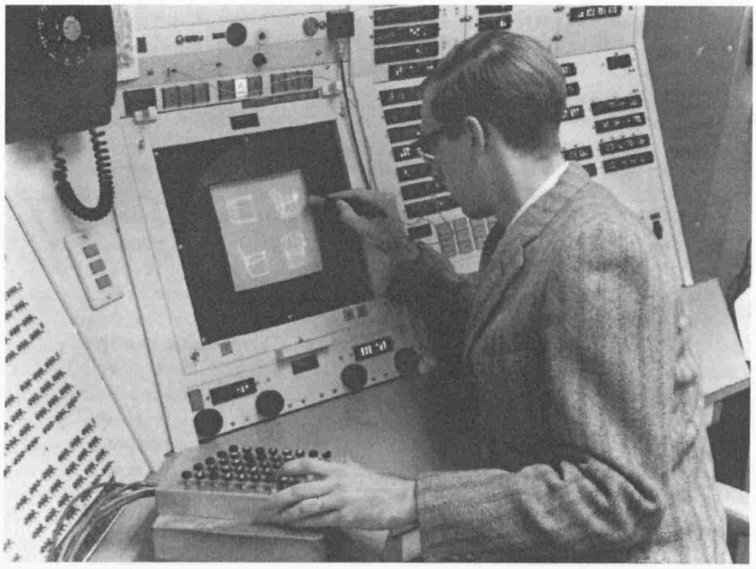


Figure 4: Ivan Sutherland's SKETCHPAD demonstration in 1968

Most early applications were purely for research purposes, to find out the potential users of computers and complement with human skills, the next decade developed this knowledge and related it to productivity. Howard characterized the 1970s as the decade of hardware, when timesharing mainframes slowly developed to separate, reliable and affordable minicomputers, to carry out routine structural calculations and subsequently to cheap single work stations with integrated processor chips, known as the microcomputers or Personal Computer (PC). The continuous improvement of Microcomputers in size, speed and reliability led effectively to a rapidly growing market (Howard 1998). In 1981, IMB introduced its first commercial version of the PC, which enabled the 1980 to be coined as the decade emphasizing software, with emergence of standard operating systems and availability of most software applications (Howard 1998). The former special mainframe systems soon disappeared and were replaced by desktop PCs with an increasing awareness of IT literacy for general staff. Specific programming languages developed to standard operating systems and to graphic user interfaces, enhancing usability. Standalone applications emerged with integrated administrative software suites. CAD software packages were becoming commercially available and affordable. The miniaturization and tendencies towards mobility evolved through the enhancement of data storage and transfer mediums in the mid 1980's (Siodmok 2005). CD ROMs were developed in 1985 (450 times the storage capacity of commonly available data storage devices), first laptops appeared in 1986 and consequentially, in 1989 the World Wide Web was invented at CERN (Conseil Européen pour la Recherche Nucléaire) using the Internet to link digital resources on different computers through hyperlinks (Berners-Lee 1996). The 1990s was the decade of communications. A new generation of researchers emerged, ignoring the experience of the pioneers and reinvented some early visions (Howard 1998). User friendliness advanced, improving IT literacy throughout society. Cellular telephones became widely available and the first Personal Digital Assistant (PDA) appeared in 1995 promoting the increasing strive for mobility (Kimoto et al. 2005). Connectivity was inexorably advancing and enabled the spread of the Internet. By the late 1990s applications were starting to be delivered over the Internet (Wilkinson 2005) via download. From conversion of analogue to digital via modem through traditional copper based telecommunication lines, being augmented by ISDN, ADSL, SDSL, fibre optic cables, wireless technologies, satellite, etc. With elements in place, the current decade is giving true value to data on which the systems depend (Howard 1998).

3.3 Influence of Internet

Today it is difficult to imagine working without the Internet. Its explosive growth since the 1990s coupled with the development of telecommunication has provided a platform for a new type of interaction. Whilst in the 1980s typical file transfer or exchange of project information meant physical transfer on a fixed media, such as tape of disk involving a courier (Wilkinson 2005). The Internet is effectively changing the way in which organizations and individuals communicate, providing cheap, interactive and multimedia opportunities. Howard ranks the Internet as the most prominent phenomenon of the information society, allowing the exchange of ideas irrespective of distance (Howard 1998). However, until mid 1990 the true potential of the internet had not been recognized to construction, although metropolitan networks had been foreseen, yet not worldwide (Interview with R. Howard 25.08.2006). Bill Gates, in the early years of the Internet, recognized its potential to construction: "The Internet has a huge potential as it relates to construction. This is an industry that continually moves information back and forth between offices and remote job sites. Pulling together even a simple straightforward project now requires the interaction of hundreds of people and thousands of documents. Today's communication challenges are incredible." (Gates 1996 cited in Wilkinson 2005:22)

One of the earliest applications of the Internet was FTP (File Transfer Protocol). Eventually being around since the late 1970's it enabled the exchange of files over a network, involving client and server computers (Fransman 2006). Collaboration applications were developed in the mid 1990s based on client-server networks. However alternative Internet based technologies soon followed, capable of being accessed over the Internet via any computer linked by any browser and not tying a user to specific networks (Wilkinson 2005). At that time, e-business was predicted to become a major economic sector, involving business- to-business and business-to-consumer activities. Dainty et al. 2006 defined three concepts of e-business relevant to construction:

- E-procurement, to facilitate the purchase of products of products and components;
- E-commerce, supporting transactions between the vendor and purchaser;
- E-collaboration, enabling communication amongst supply chain partners.

The development of such electronic marketplaces culminated in the late 1990s, where hundreds of businesses attempted to capitalize on e-business. The construction industry enthusiastically announced its involvement in e-procurement ventures to facilitate an electronic marketplace for building materials and services (Wilkinson 2005). During this boom providers flooded the market. However the initial strive soon collapsed when the 'dot.com' bubble burst in 2001, too many firms with too high expectations, deficient security standards, lacking trust and reliability. Uncertainty about financial stability and long term prospects of Internet firms was the result. On the one hand sellers were concerned that customers would aggregate buying power and drive down prices, on the other hand buyers were concerned that sensitive information on their buying habits being revealed to competitors. The initial over-ambitiousness turned to realism about the time necessary to establish standards and procedures for the Internet to regenerate and become a safe communication environment (Wilkinson 2005) which effectively has changed everyday life completely. Its growth is often attributed to the lack of central administration, which allows organic growth of the network, as well as its non-proprietary open nature, which encourages vendor interoperability and prevents any one company from exerting too much control over the network (Figure 5).

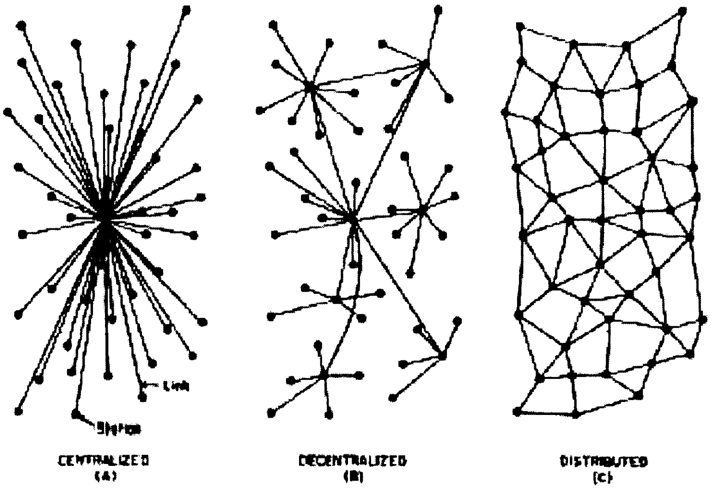


Figure 5: Network Structures

E-mail has established itself amongst the most popular forms of communication and multimedia advantages are increasingly deploying their potentials, ranging from user interactions, application services, file sharing networks, forums and information exchange and technologies such as audio/video on demand, etc. Provider attitudes have changed from a product orientated to a service orientated culture. Microsoft suggests "software is a service, not a product" (Wilkinson 2005:53). The Internet over the years has become an indispensable tool and created the demand for even more reliable, faster and higher capacity connections. Multimedia and interactive communication and integrated solutions have revolutionized communication. Retrospectively, life is not the same as before the Internet, and its influence is increasing.

WORLD INTERNET USAGE AND POPULATION STATISTICS

World Regions	Population (2006 Est.)	Population % of World	Internet Usage, Latest Data	% Population (Penetration)	Usage % of World	Usage Growth 2000-2005
Africa	915,210,928	14.1 %	**23,649,000**	2.6 %	2.3 %	423.9 %
Asia	3,667,774,066	56.4 %	**380,400,713**	10.4 %	36.5 %	232.8 %
Europe	807,289,020	12.4 %	**294,101,844**	36.4 %	28.2 %	179.8 %
Middle East	190,084,161	2.9 %	**18,203,500**	9.6 %	1.7 %	454.2 %
North America	331,473,276	5.1 %	**227,470,713**	68.6 %	21.8 %	110.4 %
Latin America/Caribbean	553,908,632	8.5 %	**79,962,809**	14.7 %	7.8 %	350.5 %
Oceania / Australia	33,956,977	0.5 %	**17,872,707**	52.6 %	1.7 %	134.6 %
WORLD TOTAL	6,499,697,060	100.0 %	**1,043,104,886**	16.0 %	100.0 %	189.0 %

NOTES: (1) Internet Usage and World Population Statistics were updated for June 30, 2006. (2) CLICK on each world region for detailed regional information. (3) Demographic (Population) numbers are based on data contained in the world-gazetteer website. (4) Internet usage information comes from data published by Nielsen//NetRatings, by the International Telecommunications Union, by local NICs, and other other reliable sources. (5) For definitions, disclaimer, and navigation help, see the Site Surfing Guide. (6) Information from this site may be cited, giving due credit and establishing an active link back to www.internetworldstats.com. ©Copyright 2006, Miniwatts Marketing Group. All rights reserved.

Figure 6:Internet usage Statistics (http://www.internetworldstats.com, accessed 07.09.06)

3.4 Mobile technologies

Science fiction identified mobile technologies rather early as an aspect of future development. The initially anticipated 'wrist communication terminal' are now available as cellular phones. The now common Laptop PCs were actually developed in the mid 1980s. The popularity and technological advancement are transforming mobile technologies to common tools (Bowden 2005). The surge for mobility has introduced a wide variety of hardware options such as personal digital assistants, pen tablets, mobile phones, with cameras, wireless LANs, terrestrial broadcast, low earth orbit and geostationary satellites and effectively integrating all functions in one device. A cellular phone with organizer, high resolution digital camera, voice recording and data storage and even GPS, navigation, television and internet access are increasingly common standard. The benefits of implementing electronic information capture systems in construction have been conceived to improve efficiency, through accessing the data at source, ensuring the integrity of the data and reducing errors though transfer. Information can be immediately fed into a collaboration tool available to all project participants, eliminating rework due to insufficient, inappropriate or conflicting information (Bowden and Thorpe 2002).

3.5 Present state of technology

Construction projects are becoming increasingly complex technically, environmentally, socially, legally, and culturally, with increasing economic pressures on facility owners, while at the same time shortening the schedules (Keegan and Turner 2002). The role of ICT in project management is to simulate, analyze, and evaluate expected performances of the facility design, the design of the facilities delivery process, and the design of the organization carrying out the process. The scope of ICT in project management is the multi-disciplinary integration of a broad range of information (Fischer and Kunz 2004). This consideration allows a more proactive management of the construction process rather than the reactive attempt to solve problems on site.

Measuring, working up and printing complex bills of quantities to standard databases were obvious applications for computers since the 1960s. Applications constipated for the space race, provide tools to control performance. Project management packages are shared with other industries. Being an early application however, the construction industry adopted them rather slowly. Constant progress bar charts and network analysis have been developed rather recently to meet client pressure and rapid inflation. Prior to the inception of network planning, construction planning and scheduling was based mainly on the intuition and expertise of experienced site personnel (Froese 1992). The initially large scale systems with independent, stand alone applications, relied on numerical analysis techniques of the 1960s were later developed to desktop computers with dramatic reduction of costs whilst improving reliability and processing power. The current development is progressing toward combined communication and information technologies, however still relying on independent resources and databases (Nitithamyong and Skibniewski 2004). Applications in project management cover the following tasks:

- project accounting
  - payroll
  - general ledger
  - accounts payable
  - accounts receivable
  - job cost accounting
- estimating
- scheduling
- resource allocation
- equipment management
- inventory control
- purchasing
- financial planning
- engineering and surveying support
- computer-aided design and drafting
- general management and administration

A single integrative application that manages and coordinates all project information remains to be developed (Sun and Aouad 2000). Three areas of application in project management have been identified: business and information management, process simulation and collaboration technologies.

3.5.1 Business and Information Management

Business and information management systems facilitate communication within an organization, ranging from simple correspondence to customer relationship management and sophisticated knowledge management systems (Sun and Howard 2004). These packages consist of:

3.5.1.1 Enterprise Resource Management

Dating back to the 1960s, initial Enterprise Resource Management (ERM) systems were mainly concerned with inventory control. In the 1970s the focus turned towards material requirement planning. In the 1980s, the optimization of the entire plant production process became the core function of ERM systems (Koch 2006). Modern ERP systems combine the data of formerly disparate applications systems covering the cross-functional coordination and integration in support of the production process, basically integrating the entire range of a company's activities. Areas of application are (Winch 2002:348):

- Manufacturing resource planning,
- Financial system,
- Human resource planning,
- Costumer relationship system,
- Supply chain management,
- Professional services administration.

However, despite the benefits, ERP systems are hugely complex, time consuming and expensive to implement and maintain. The adoption of such systems is not yet comprehensively available to the dynamic nature of the project environment (Sun and Howard 2004).

- SAP http://www.sap.com
- Oracle http://www.oracle.com
- Unisys http://www.unisys.com

3.5.1.2 Electronic Document and Record Management Systems

Initially Electronic Document Management System (EDMS) were used for managing electronic and paper-based documents and Record Management Systems (RMS) for classifying, archiving, preserving and destroying records in the long-term, were separate applications. However recently, EDRMS became one complete integrated system managing documents through their whole lifecycle, from creation till destruction. These automated systems support the creation, use and maintenance of paper or electronic documents for the purpose of an organisation's workflow and processes to preserve evidence of activities and preserve its knowledge (Johnston and Bowen 2005). Such applications are increasingly available as part of collaboration technologies accessible over the Internet.

- AcroSoft http://www.acrosoft.com
- Hummingbird http://www.hummingbird.com
- Lotus http://www.lotus.com
- BIW http://www.biwtech.com

3.5.1.3 Computer Aided Facility Management

This application manages the coordination of building operation and maintenance over the whole life cycle of a building, including CAD, database management system, graphic information systems and network administration. The facilitation ranges from a simple helpdesk to network infrastructure and integrated planning, analysis and forecasting tools and also including asset management, space management, building operation management, and even real estate and lease management (Sun and Howard 2004).

- ArchiBUS http://www.archibus.com
- CAFM Explorer http://www.cafmexplorer.com
- Serviceworks http://www.serviceworks.co.uk

3.5.1.4 Risk Management

Risk Management (RM) information systems are typically computerized systems that assist in consolidating property values, claims, policy, and exposure information and provide the tracking and management reporting capabilities to enable to monitor and control overall cost of risk. Since the 1960s RM application consisted of databases linking probabilities to cost as a by-product of insurance and accounting functions. In 1967 the first independent risk software programs became available to banks and insurance companies, yet it took until 1980 with the development of the PC, before these applications became widely available (Trutner 1996).

3.5.1.5 Cost Estimation

Accurate cost estimation and rigorous project accounting are the cornerstones of successful project management. Sophisticated cost estimation applications are capable of measuring, counting, computing and tabulating quantities. Most common are spreadsheet applications such as Microsoft Excel with scenario simulations, analysis and graphic documentation. Specific cost estimating software links the bill of quantities directly to cost libraries and provides a cost analysis by adjusting elements such as waste, contingencies and profit margins. Reports are automatically generated. Some software packages can link geometric CAD information to the bill of quantities. (Sun and Howard 2004)

- Conquest http://www.conquest.ltd.uk
- Masterbill http://www.masterbill.com
- Esit-Mate http://www.estimate.co.uk

3.5.1.6 Planning, scheduling and site management

Systems assist on- and off-site management to plan ahead, evaluate, adopt and execute the most efficient options. After identifying the tasks, applications produce programs, schedules, probabilities and allocate recourses. Most common techniques are PERT, CPM and Gantt-charts. Consequentially, site operation simulations can help optimize productivity and monitor site activities. Such systems use public access terminals to monitor the rate of productivity and analyze the effects and benefits on cost control, health and safety and supply chain management. (Sun and Howard 2004)

- Primavera http://www.primavera.com
- PERT Master http://www.pertmaster.com
- Asta Teamplan http://www.astadev.com

3.5.2 Process simulations

3.5.2.1 nD CAD

Computer Aided Design (CAD) is basically the way in which computers assist the design process. 'n' is a variable in which the dimension of the design is facilitated. Typically 2D CAD is a two directional drawing. When considering space, the third dimension is represented in the computer model. Additional features can consequentially be added to the second and third dimension to simulate a process, respectively 2D + time or 3D + time. Other factors, such as cost can be considered to simulate 'what if' scenarios. Summarizing, nD represents all possible dimensions, "an extension of the building information model, which incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility" (Lee et al. 2003:37).

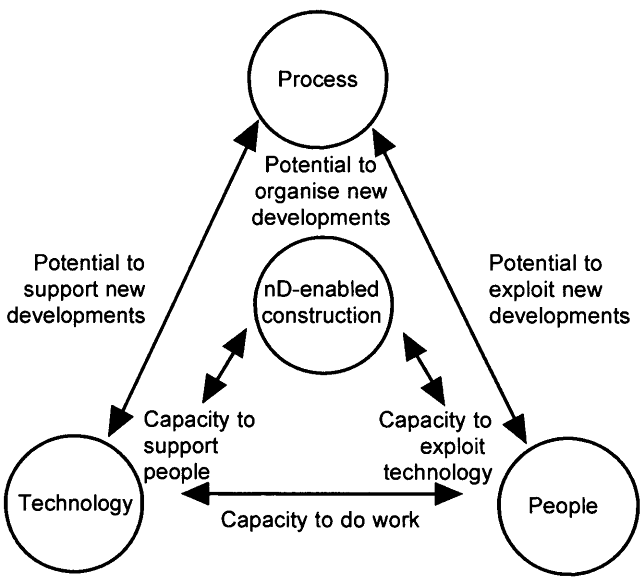


Figure 7: Concept of nD modelling in projects (Lee et al. 2005:7)

CAD has replaced the traditional drawing board with the primary advantage of allowing editing, referencing and integration of graphical libraries. Ivan Sutherland's initial SKETCHPAD project in 1963 is considered the first 2D CAD drawing system using terminals linked to large mainframe computers and CRT displays based on radar screens, to display patterns of lines using simple algorithms (Figure 4). The commercial availability started slowly with early systems designed for other industries, especially for manufacturing (Sun and Howard 2004). It took until the 1980s for CAD systems to become more reliable, more efficient and affordable. Since than the sophistication progressed and enabled 3D CAD to a more profound spatial analysis and visualization of the interior, exterior and the relation to the environment (Sun and Howard 2004).

- AutoCAD http://www.autocad.com
- Microstation http://www.bentley.com
- ArchiCAD http://www.graphisoft.com
- Nemetschek http://www.nemetschek.com

Currently the potential of 3D CAD model is being investigated by inserting further variables to serve process simulations. Effectively the nD model could provide the greatest value as a communication tool for the construction industry (Marshall Ponting and Aouad 2005). It incorporates the need to think more holistically about the other stakeholder requirements, demonstrates design issues, simulates scenarios, rates alternative process suggestions, identifies potential conflicts and consequentially aids the decision making process (Compare with Marshall Ponting and Aouad 2005 workshop findings). Applications of nD modelling attempt to simulate processes, visualize environments, assess behavioural issues and resolve conflicts in time and space.

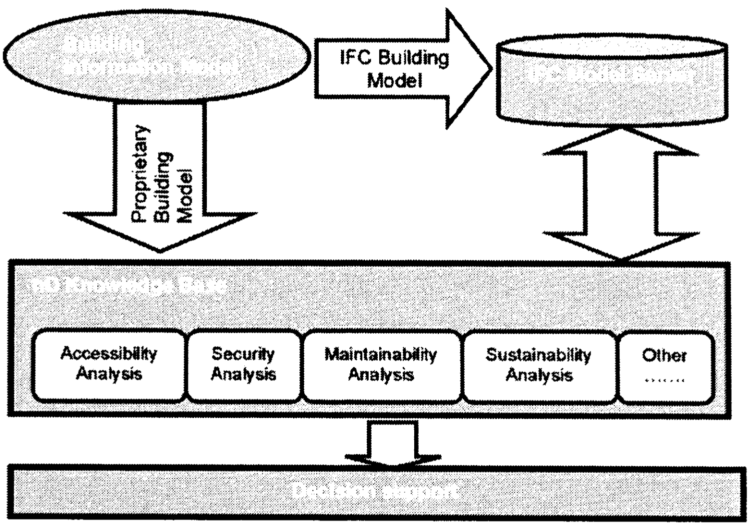


Figure 8: Architecture of nD modelling tool (Lee et al. 2006:19)

3.5.2.2 Visualisation and Virtual reality

Virtual Reality (VR) puts the user in control, it facilitates a direct interaction of a user with a computer generated environment, either relying merely on visual aspects such as computer screens, or including additional sensory information such as sound, smell, feel and tactical information. Users can interact with virtual environments either through standard input devices such as keyboards or mouse, or through more comprehensive systems such as head displays, wired gloves and suits and omni directional treadmills. The construction industry has had little impact on the development of VR. It evolved from concepts laid out by computer graphics programmers developing flight simulators and military applications where the attainment of realistic real-time interaction is critical. The most sophisticated systems that simulate the real world are used for pilots' combat training, or even in gaming technology. However, it is currently very difficult to create a realistic VR experience, mainly due to technical limitations on processing power, image resolution and communication bandwidth. These limitations are expected to be overcome eventually, as computers become more powerful and cost-effective. To construction, VR has the potential to improve visualization of building design and construction process, the implementation although has yet to reach maturity (Whyte et al. 2000). VR facilitates a natural medium for building design, providing 3D visualization that can be manipulated in real-time and can be used collaboratively to explore different stages of the construction process. Whyte et al. have characterised the transfer of geometrical data between CAD and VR systems as being the most critical factor for the implementation in construction, involving repetitive work processes. Eventually CAD models may be compatible with VR systems and could generate and print 2D CAD drawings directly from the system (Whyte et al. 2000).

3.5.2.3 Time Space Conflict

Conflicts in time and space are one of the major causes for productivity loss on construction sites. These could be prevented and managed, if identified prior to construction (Choo and Tommelein 1999, Heesom 2004). Such conflicts exist, when an activity's space requirements interfere with another activity's space requirements due to rework or schedule interferences. There is too little space, for too many activities, to be carried out simultaneously in too little time. This not only affects factors such as time and cost, but results in severe interventions in health and safety. Akinci et al. identified 6 types of spaces required by construction (Akinci et al. 2000):

1. Building component space,
2. Labour crew space,
3. Equipment space,
4. Hazard space,
5. Protected space,
6. Temporary structure space.

When considering each variable in relation to time, the evaluation process becomes highly complex and eventually improbable without computing technology. Systems assign volumes to procedures and calculate conflicting ratios considering (Staub and Fischer 1998):

- Spatial information, the location of a building component and the space it occupies;
- Temporal information, activity start and finish times and activity duration;
- Relational Information, logic information about an activity including preceding and succeeding activities, and the relationships between activities and 3D CAD objects;
- Geometric attributes, length, area, volume, etc., depending on the type of analysis;
- Component relationships and types of support.

There are numerous concepts to perform 'what if' scenarios and assess time-space-conflicts virtually before they occur in reality (Compare Winch and North 2006). Concepts range from site layout analysis (Tommelien et al. 1991), standard interview evaluations (Riley and Sanvido 1997), mark-up diagrams and possibilities of VR (Retik and Shapira 1999) and the use of geographic information systems (Cheng and O'Connor 1996). However, approaches to simulation and these consequentially manage the time-space-conflict are the focus of current research and shall be analysed at a later point in this report.

3.5.2.4 Building engineering applications

Since the 1970s, with the increasing number of specialist groups emerging in construction, the need has grown for new and sophisticated building engineering applications to simulate, analyse and assess building performance accurately. The variety of applications may be categorized in structural and service design.

Structural engineers were identified very early as users in the evolution of computing technology (Howard 1998). Since the mid 1960s, programs have been developed based on established calculation methods, relating geometric information to a materials and components database. Currently, structural engineering applications can perform static and dynamic analysis of 2D and 3D structures, for any material. The objective of the analysis is to optimise the structural design within the safety margins while avoiding waste of material.

Service-design applications coincide with the range of professions involved in the building process where typically each has an individual specialist application (Sun and Howard 2004). General environmental analysis and energy efficiency programs were stimulated by various energy concerns during the 1970 oil crises and awareness of global warming. Energy analysis systems and lighting analysis programs have increasingly been developed as necessary tools to improve a buildings performance. As energy consciousness and responsibility grows, such analysis programs eventually become bylaws and requirements by local authorities (http://europa.eu/pol/ener/index_en.htm accessed 04.08.2006). Mechanical and electrical design systems, heating, ventilating and general climate evaluation applications and so forth have become common practice to construction development.

- Energy analysis http://www.cymap.com
- Lighting analysis http://www.dialux.com
- Service design http://www.edsl.net
- Structural engineering http://www.cads.co.uk

3.5.3 Collaboration technologies

Traditional collaboration becomes difficult, due to the constraints and conflicts imposed upon practitioners by the numerous social, geographic, economic and legislative factors surrounding construction practice. Information Communication Technologies may help facilitate a solution. However, "Collaboration is an activity - not a piece of technology" (Bulter Group 2003 cited in Wilkinson 2005:5). The Internet provides a medium for project teams to communicate and exchange information, exceeding the project participants and supply chain and even organizational boundaries (Dainty et al. 2006). Wilkinson defines construction collaboration technologies as a "combination of technologies that together create a single shared interface between multiple interested individuals (people), enabling them to participate in creative processes in which they can openly share their collective skills, expertise, understanding and knowledge (information), and thereby jointly deliver the best solution that meets their common goal(s), while simultaneously creating an auditable electronic record of the people, processes and information employed in the delivery of the solution(s)" (Wilkinson 2005:7). He emphasizes the importance of the Internet to construction collaboration. In Egan's follow-up report 'accelerating change' reckons that "IT and E-business, as enablers, have already radically transformed many operations in the construction sector and there is still a vast potential for more. IT can deliver significant benefits for designers, constructors and building operators. Deriving the maximum benefit from introducing IT solutions will not, however, be easy. There is the potential to drastically reduce infrastructure cost behind the tendering side of the industry by adopting the wider use of the Internet and e-procurement specifically (...) Key barriers to this transformation include organisational and cultural inertia, scale, awareness of the potential and knowledge of the benefits, skills, perceptions of cost and risk, legal issues and standards." (Egan 2002:36)

Winch defines the application of the internet to construction as e-construction (Winch 2002:352) with e-resources and e-projects (Figure 9). The aim of the e-resources is to reduce transaction costs, facilitate e-portals and forums and enable e-auctions. A greater impact on construction project management and therefore the enhancement of efficiency has, according to Winch the e-project, consisting of supply chain management and project extranets. An intranet is an organizations internal, private and secure network. Once this network is connected and made accessible to the organisations customers, partners or suppliers, it extends to an extranet. "In particular, the development of project extranets since 2000 is probably the single most important development in IT tools in the history of project management, for it places the construction project manager as the key node in the project information flows, and hence in a much easier position to exert project leadership..." (Winch 2002:358)

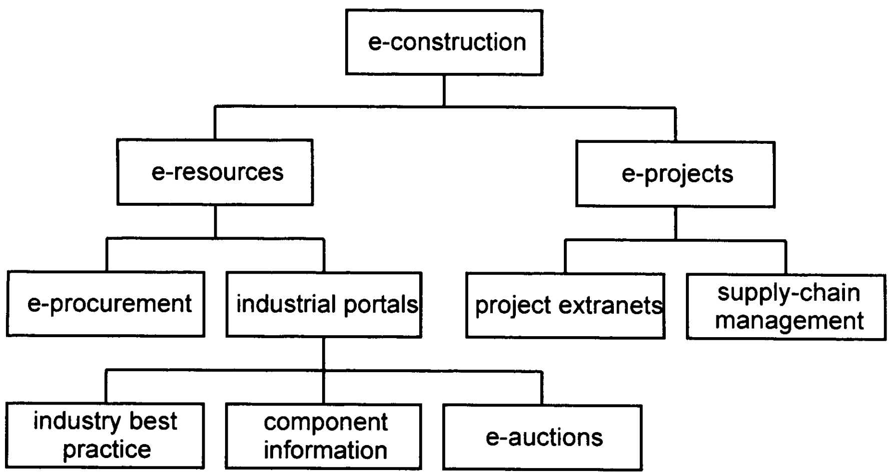


Figure 9: E-construction according to Winch 2002:352

Project extranets enable the facilitation of information exchange, evaluation of progress, review of project documentation, management and tracing of correspondences, monitoring of engineering change orders, data exchange formats for construction drawings, Internet chat enhanced with on-screen images, pictures and drawings, web-conferences and live video-cam function for site based data capture, up-to-date data collection, search engines, data storage and distribution and task management, schedules and coordination, etc (Powell et al. 2004).

Having the lowest levels of connectivity and networking technologies (DTI benchmarking study 2004), the construction industry has a lot of catching up to do. As a matter of fact, in contrast to manufacturing and retail industries, the overall construction industry has shown a relatively slow uptake of web technologies to improve its practices (Alshawi and Ingirige 2003). Nevertheless, the UK construction industry seems to be in the midst of technological revolution. Its penetration has gained pace in recent years, on the one hand due to collaborative ambitions within the industry fuelled by reports and on the other hand the rapid improvements in hardware and software (Goodwin 2001). "Internet based interactive business tools are now available which have the potential to significantly improve the ways in which project participants communicate" (Duyshart et al. cited in Dainty et al. 2006:199).

4 HOW ICT HAS CHANGED THE CONSTRUCTION INDUSTRY

4.1 Cycle of anticipation

In the last 100 years, the construction industry has evolved from a craft based to multifaceted service, production and manufacturing sector. Its basic unit of operation remains the project (Dainty et al. 2006). As a result of innovative materials, rational design styles and alternative procurement routes since the 1960s. However, coordination and management practice has not much changed much until the 1970s (Wilkinson 2005). Having standardization and prefabrication as legitimate approaches to design and construction, the adaptation of computers for repetitive and routine operations is quite obvious. However, it took until the mid 1970s for the production of working drawings to become an application of IT, mainly because the benefit was believed to be constrained to the re-use of tested details and, when considering every project to be unique, having a limited advantage to the dynamic nature of construction (Howard 1998). In 'The Automated Architect', Nigel Cross perceived in 1977, no particular advantages for the use of computer aids to solving building design problem (Cross 1977). Initial applications in the 1960s were concerned with accounting, processing data and consolidating results. The construction industry adapted tools and applications from other sectors were applicable, to meet their needs (Howard 1998). It must however be emphasized, that applications in the 1960s were not user friendly. In order to perform even the simplest operations, complex codes and specialised programmers were required.

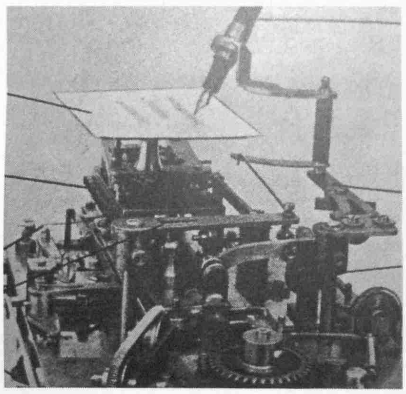


Figure 10: 1946 Writing Machine (Negroponte 1970:16)

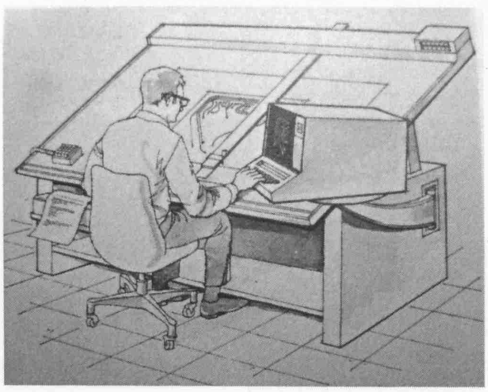


Figure 11: Computervision's CAD Terminal (Negroponte 1970:18)

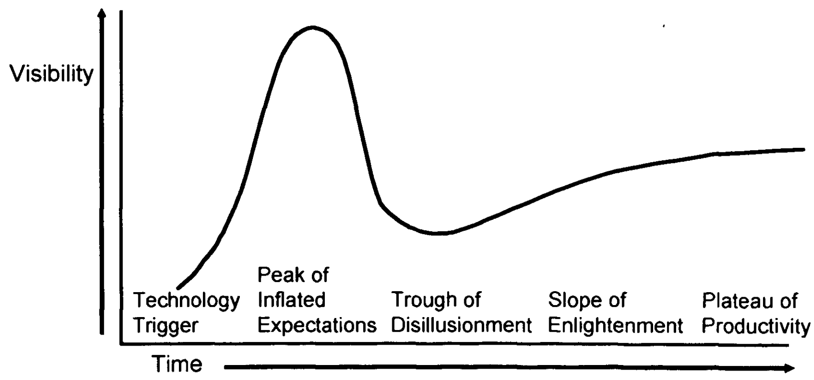
In 1967, the UK Minister of public buildings and works foresaw: "the time would come when design and construction information would be passed as readily between one group and another as a telephone conversation took place today" (Howard 1998:72). Even the concept of a single comprehensive building model was an early target, yet technology remained the limiting factor to research. With the enhancement of CAD systems, storage tubes for displaying graphics and pen plotter for printing, three applications were identified in the 1970s (Howard 1998):

- Drawing production, based on automated 2D manual drawing techniques. The Number of packages available grew through 1970s and 1980s. The applications seemed most realistic for architects and engineers;
- 3D modelling, 2D drawings and perspectives as forms of output, describing a building in attributes and performance, however initially only as basis for accurate manual rendering of presentation drawings
- Automated design, however computers are restricted to few factors necessary for design. This idea was initially subject of much academic research but did not meet the needs of architects and was abandoned

The emergence of CAD was initiated in other industries, and found its way into architectural offices in the 1980s together with the PC. Coincidentally, AutoCAD's breakthrough to replace the expensive systems although was not a technological but a marketing phenomenon (Sun and Howard 2004). Considering that projects were both manually drawn and by using CAD side by side, investment was perceived with scepticism. However, the increasing complexity of construction projects and growing project teams inevitably increased the dependency on the flow of information, from briefing through to operation. This enabled the uptake of computer applications. Winch characterizes fragmentation and adversarial attitudes as barriers to the effective implementation innovation (Winch 1998). Construction has a "tendency to want to keep its options open and to design every new building as if it were the first. This is a result of competitiveness and the higher profit margins enjoyed in the past" (Howard 1998:128). IT applications in construction remain standalone, independent substitutions of formerly manual tasks. Dainty et al. 2006 characterised the industry's reluctance to embrace ICT:

- Fragmentation: high level of specialist organisations;
- Limitation in bandwidth: necessity for significant computing power;
- Cost: high investment on relatively low profit margins and the indirect cost of learning what the technology will do and how to utilise its functionality effectively;
- Information overload: 'law of data' the more storage space, the more data will fill it, enabling those expected to respond to certain information.

The industries preference for paper is significant for its lagging behind other industries in implementing innovative IT solutions and latest management approaches (Wilkinson 2005:21). In Latham 1994 and four years later Egan 1998 pointed out the situation and demanded a change in behaviour, by advocating partnering, strategic alliances and collaboration, which in turn is necessary for the successful implementation of ICT.



Myth: The use of IFCs is not growing; it will wither and die
Reality: Customer enthusiasm is limited, but growing
Reality: Customers are confused about the actual offerings

Figure 12: Myth verse reality (Kiviniemi 2006)

The late 90s provided the technology necessary for partnering, a whole team could access common project data and could effectively reduce problems caused by poor communication. According to Dainty et al. 2006 the "construction industry is arguably in a period of irrevocable change, moving to a stage where adversarial working and poor relations between project participants will not be tolerated and where performance improvements are delivered through effective collaboration" (Dainty et al. 2006:227). Winch coined a shift in attitude, form a product to service orientation. He recognizes the necessity to 'deliver client satisfaction' rather than "allocating liability once the client is dissatisfied" (Winch et al. 1998:194). The design team can overcome communication problems by increasing ICT within project environments by efficiently facilitating non-verbal communication. As organizations have become geographically dispersed, working across different industries and over international boundaries, project teams are able to communicate more effectively. The role of the project manager is to facilitate the communication processes and methods. However, the mere availability of ICT does not guarantee a performance improvement to the project team. Currently, ICT "has had limited influence on efficiency of the process and quality of information exchange, the most common method to communicate remain traditional methods such as 2D drawings, face to face meetings, written statements, telephone and fax. This may be because of the slow uptake of new technologies within the industry and the continuing problems of compatibility between different systems" (Dainty et al. 2006:34).

4.2 From information restriction to information overflow

Before the spread of IT and ICT, information was a highly influential resource. The 'knowledge is power mentality' (McLure et al. 2000) existed between organizations and within society more general. The reluctance of an organization's members to exchange knowledge is originated in the incentive to maintain their status and influence upon others. Especially in fragmented industries such as construction, where adversarial attitudes prevail to minimize accountable risk, access to information is essential (Winch 2002). Receipts, counter signatures, witnesses and many other instances are common practice to secure the correct allocation of information (Alshawi and Ingirige 2003). Hence the flow is constrained by various obstacles.

This restricted attitude towards information has changed through ICT. Advantages are foremost the speed of access to information and products. Interactive communication and management systems such as the Internet have yielded tangible benefits to project performance, as they allow circumventing traditional chains of command, eliminating communication barriers (Dainty et al. 2006). However, despite the advantages, attitudes and cultures have significantly changed to an abundant and maybe excessive distribution of information. This 'information overflow' is mainly attributed to the vast amounts of information available through the Internet. Search engines are established to facilitate the allocation of the desired content. The search for 'ICT' has provided 120 million hits in 0.07 seconds, 'technology' has over 6 billion hits and aerated concrete still has over 110,000 hits. The variety of information is increasing and so is the variety of owners of information striving for publication. The allocation of the correct content and amount of information is highly time consuming, hence in order to save time, information is sent out in batches. The sending out of more information than necessary also secures one's position and may prevent later accusations. Email is probably synonymous with the success of the Internet. It is widely accepted as the Internets first 'killer application' (Wilkinson 2005). Yet beneficial implications quickly turn into abuse of networking systems as participants are added to distribution lists indiscriminately, leading to overloaded inboxes, requiring dispro-portionate management, and providing no easy way to centrally store, retrieve, manage or track the interaction between project members. Spam, the abuse of electronic messaging systems to send unsolicited advertisement, bulk messages known as junk mail, is a popular phenomenon of information overflow. In 2004 it was estimated that "70% of email was spam" (Wilkinson 2005:24). Viruses, Trojan horses, electronic worms and other illegitimate computer programs, are directed towards harming networks and workstations, and are additional indications that question the reliability of networking systems and are the nature of most fundamental problems resulting from ICT abuse. This excess of information can be considered the 'noise' of ICT. Ways in dealing with information overflow can be:

- ignore parts, maybe discarding the relevant information;
- distortion, passing on incomplete information;
- gatekeeper, to check information forehand;
- queuing, invest time to check information chronologically;
- repeat, eventually sending or checking important messages twice;
- verify, check with sender of information;
- feedback, once information has been received;
- erase, discard message completely.

All above considerations may be time consuming, costly or result in severe drawbacks. The installation of filter systems can take care of unwanted information and immediately categorize data. Even though filter systems are increasingly sophisticated, often one does not know what really lies behind the information before it is already too late. Information in our society needs champions (Bartholomew 2005), either individuals or applications with the skill to evaluate and assess data by granting certain competencies, applying set of rules and regulations to categorically integrate within an existing knowledge database.

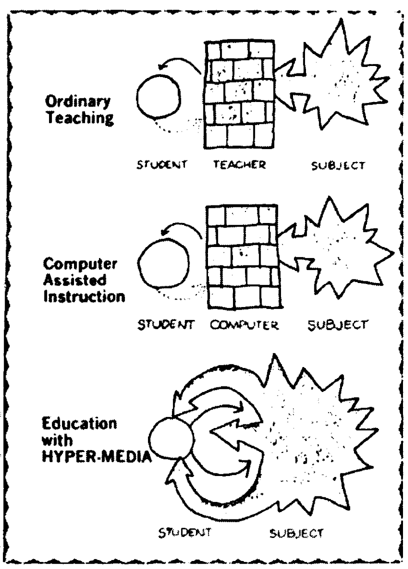


Figure 13: Teaching becomes scientific (Nelson 1974:21)

5 EVALUATION OF IMPLEMENTATION

5.1 Theoretical aspects

The implementation of ICT and realization of its potentials depends on changing attitudes, cultures, structures and processes. Currently there are numerous papers published dedicated to ICT, to identify the inherent constraints within the industry and contemporary practice to evaluate the necessity of ICT and why it is being embraced so hesitantly. Primarily research is lagging behind other industries and secondly, common practice has not yet perceived the benefits. Apparently technology makes a halt, when it reaches the construction site, hence where most monetary means are concentrated. Case studies reveal that ICT is inevitably important to improve construction practice. Research has identified opportunities; surveys conclude the willingness of practitioners; and the case studies show, that once a functioning system is in place, it would be gladly used. Even site staffs show their enthusiasm, being ready and willing to use communication devices (Bowden and Thorpe 2005, Dainty et al. 2006). This cognition requires theory and technology to extend its research from being initially restricted to office applications to purpose orientated, integrated systems involving on-site feedback.

Considering that most applications now available have been envisioned in the 1960s, theory is a path that technology subsequently follows. As a matter of fact, "information technologies do not often fail; they become assimilated within the general development of technology" (Howard 1998:89). One example of failed theory may be 'automated design', an early anticipation of CAD to generate dimensioned plans, ready for construction, by submitting a design brief with spatial requirements, relationships and environmental constraints to a computer (compare "Architecture without Architects" from Bernard Rudofsky 1972). Even though the general idea is discarded due to the complex nature of design, aspects of automated design are integrated in CAD applications.

There is a peril for defining theories well in advance of technological capabilities, as opposition may be sceptical and consider it unrealistic and over-ambitious. Yet the look into the future is necessary for theory, technology and society to progress. Theory must meet the needs of the market in which it is to be used and be fully understood and internalized by those developing and those supplying. By simply providing innovative hardware and software is not going to lead to success. "...an ICT oriented culture will only emerge when there is a sufficient critical mass of users for its use to become the norm within the industry (Dainty et al. 2006:206).

Construction "innovation depends upon the coincidence of the means, motive and opportunity to innovate" (Ive cited in Winch 1998:274). When analyzing applications used in construction, it becomes evident, that it is characteristic for the industry to introduce applications where appropriate, to satisfy specific needs. Theory is available, but when assessing its implementation in construction practice, not technological constraints seem to be the prime barriers to measure success upon, but behavioural factors such as organizational and managerial issues and acceptance within the broader industry (Goodwin 2001).

5.2 Human aspects

People are the actors in organization and only they can determine whether ICT will facilitate communication. According to Howard, the individual may be keen on innovation, yet people adopt new technology more slowly than technology develops, organizations change even more slowly, and whole industries again more slowly (Interview Howard 25.08.06). Pinto and Millet identified three main issues in the implementation of information technology (Pinto and Millet 1999).

- technical mastery
- behavioural
- managerial

Amongst these issues, behavioural is the most relevant. "We have failed and continue to fail because we insist on viewing the creation on new IS (information systems) as our ultimate goal rather than their successful introduction" (Pinto and Millet 1999:5). The introduction of communication technologies have been particularly successful and rapid because the communication process is known and technology provides advantages in the speed rate of speed of transactions, low cost and environmental impacts. However in the construction environment, personal interaction is the main form of communication and probably the most important (Dainty et al. 2006). Face-to-face interaction is ingrained in this traditional industry. Sending of drawings electronically between participants does not conform to these traditional practices and as such have not been well received in the industry (Alshawi and Ingirige 2003). The resistance to ICT in construction is rooted at higher levels than expected. Professional bodies defining codes of conduct (Winch 1998) and top management (Howard 1998) are at the forefront to change attitude and cultural barriers. Large firms tend to give the lead in innovation, but medium to small size firms, being characteristic for the industry, must abandon their hesitance towards ICT (Howard 2006).

Process and product improvements cannot enhance performance on their own, barriers engrained in existing cultures, reluctant to change must be overcome (Pinto and Millet 1999). A 'sink or swim' mentality is a one off antiquated approach of large companies striving for global competitiveness. Despite the massive investment in ICT in recent years, it is impossible to divorce personal communication from the construction process as it "is in these interactions that the success or failure of any project is rooted, and not the speed of an Internet connection or the compatibility of two Computer Aided Design (CAD) systems (...) it is essential that construction is viewed as a social activity within which communication plays a vital role." (Dainty et al. 2006:8). Awareness, consent and collaboration could enable change. Effectively ICT depends on how people use the technology that would enable revolutionary ways of working.

5.3 Technological aspects

The paradox is that the fundamental aim of technology is to make the user unaware of its presence (Penn 2005). Apparently technological constraints are most relevant to research and less to practice. The rate of development of technology is almost always underestimated, while that of human take-up is almost always over estimated (Howard 2006). The general problem with ICT is that some applications are consistently adopted, while others are not. The industries hesitant investment in innovative technologies can be related to the rather short sightedness of the industry, where strategic goals are set no longer than in a one to two year period (Smit et al. 2005). As a result, cautious investment leads to partial computerization, applications are not implemented in an integrative and interoperable manner such as in other industries and ICT cannot be utilized to its full potential (Green et al. 2004 and Duyshart et al. 2003). But the structure of the industry is its greatest constraint, "...innovation efforts in the industry are disproportionately orientated towards product enhancement rather than process improvement" (Winch 1998:269). Unlike centralized automotive or aerospace industries, construction is dispersed, agreeing on standards and processes is exceptionally more difficult. Apparently, technology even makes a halt when it reaches the site, yet the site is where most significant information is produced (Bowen and Thorpe 2002). Construction represents a vast market, its complexity needs to be understood by those developing technology, those supplying the technology and those applying it. It must be acknowledged that adapting complete packages and integrative tools require high initial research, investment and maintenance cost.

Aerospace – High trust economy	Construction - Low trust economy
Highly consolidated	Highly fragmented
Few customers	Many customers
High knowledge intensity	Low knowledge intensity
High barriers to entry	Low barriers to entry
Long time frames	Short time frames
Fixed locations	Transient locations
High inter-dependency	Low inter-dependency

Figure 14: Learning across Business Sectors (Green et al. 2004:29)

A common phenomenon of the information society is the 'digital divide'; some firms embrace ICT and the advantages it brings to managing processes and projects, other firms remain committed to traditional approaches to communication and information management (Dainty et al. 2006). This gap is not restricted to a fundamental attitude toward ICT, but rather concerning computing performance, connectivity, technical experience and access to subscriptions which strikes through the whole of society founded in economic, social, political and cultural conditions (Williams 2001). Overemphazising the role of technology can not make the overall construction process more effective and efficient (Alshawi and Ingirige 2003). In the direct comparison of ICT and traditional face-to-face decision making proved ICT to be more creative, had a higher degree of equal participation, with a bigger variety of options and use of some extreme positions although was slower than face to face meetings (Marshall Ponting and Aouad 2005). The "less paper office" replaces paper based correspondence electronically. This ambition of office automation however has yet failed according to Bowen and Thorpe, as the drawings are produced electronically, but are printed out for further use, "desks are now littered with computer printouts" (Bowen and Thorpe 2002:39). The advantages of electronic distribution and opportunities for effective feedback are evident, yet behavioural habits constrain the effectiveness.

5.4 Financial aspects

The cycle for replacement of technology is very fast. Hence, the most critical factor to investment in ICT is time, when benefits can be harnessed before the technology becomes obsolete (Howard 1998). The main reason for the implementation of technology is to gain competitive advantage. But how assess competitive advantage through ICT? An investment in the most sophisticated technology may create problems in compatibility, that no other application can communicate with the system or even worse, that standards become overruled by the market. Nevertheless, cost development of IT is synonymous for its success. In 1980 a single CAD workstation on a minicomputer cost roughly £ 100,000. By 1985, an IBM PC with a simple CAD application was available for £ 20,000 whereas in 2000, most powerful systems ranged from £ 3,000 - £ 5.000 (Sun and Howard 2004).

Financial benefits are extremely difficult to assess (Stewart and Mohamed 2003). According to Smit et al. construction organizations significantly invested large amounts in ICT with high expectations, in order to gain competitive advantage. Many of these anticipations ended up being dissatisfied, due to the difficulty in assessing the operational benefits (Smit et al. 2005). Appraisal techniques are insufficient and cannot be equally applied as the investment only takes tangible costs into account, which are only fraction of total costs experienced in the products lifecycle (Love et al. 2005). ICT investments may be evaluated under performance perspectives (Smit et al. 2005):

- operational benefits and impact on productivity
- performance perspective such as reliability, availability, security and suitability
- strategic competitiveness and long term strategic goals of the organization
- user orientation perspective.

Significantly to construction, there is a division between 'long termists' who see quality, collaboration and effective partnerships as primary drivers and 'short termists' who focus on cost and immediate return, with the later more common (Wilkinson 2005). Certain applications have inevitably become an obligatory resource, considering not to invest may have severe consequences to an organisation. Love concludes that a lack of strategic vision is a key factor inhibiting the uptake of ICT within construction organizations (Love et al. 2005).

6 CURRENT RESEARCH AND TRENDS

6.1 Integration and Interoperability

Technological improvements are increasingly available to meet each specific user needs. The focus of current research is integration and interoperability, or broadly how to get information from one system to another. Currently applications are generally independent from the management system and information from an individual application is treated as a distinct entity. With the possibility to transfer information across disciplines in a collaborative environment, construction productivity can be significantly improved by decreasing repetitive work processes, enhancing communication, improving process transparency and enabling knowledge based industry (Sun and Aouad 2000). There are three levels of integration:

1. Electronic Document Management Systems: the lowest level of integration, as the broad range of applications, were the system only manages 'documents' unaware of their contents;
2. Interoperating Autonomous Systems: exchange information through common interfaces, essentially through import/export;
3. Fully Integrated Systems: the system 'knows' what information it processes.

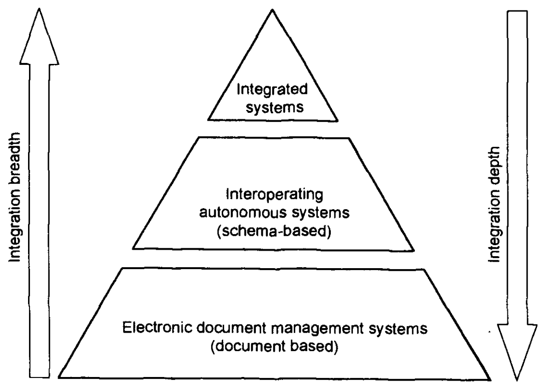


Figure 15: Integration Strategies (Sun and Aouad 2000:596)

Therefore effective integration can only take place in the upper two levels, through interoperability, based on standards legible by the integrated programs. By means of common software interfaces, 'standards' are agreed 'translators' linking the individual software systems. Such standards are mainly based on products of leading manufacturers as a result of market dominance. Yet each developer has a specific interest to not comply with standards, as these represent the lowest common denominator (Sun and Howard 2004). Developers generally offer standard interfaces, yet improve on them to the disadvantage of interoperability. One example is AutoCAD's data exchange format DXF, being a basic interface, accepted throughout the software community. Defining formal standards is out of touch with the fast changing need of ICT. Intentions are growing how to develop a relationship to integrate market standards into professional bodies (Howard 1998). The definition of standards requires the flexibility of regulatory bodies and the incentive of the developing industries to achieve an interoperable interface and cooperate with the professional bodies and their direct competition. Cooperation is the key and eventually surrendering the chance of achieving a possible competitive advantage maybe the price. In 1995 the Industry Alliance for Interoperability (IAI) was founded, whose members are willing to create such a set of standards (www.iai-international.org, accessed 08.08.06):

- Vision: Improving communication, productivity, delivery time, cost, and quality throughout the whole building life cycle.
- Mission: Provide a universal basis for process improvement and information sharing in construction and facilities management.
- Goal: Building on the collective knowledge of the global construction and facilities management industries to define Industry Foundation Classes.

Based upon such 'Industry Foundation Classes' (IFC) specifications, a further step toward total integration is possible, through a single point of responsibility. Several computers can communicate on the same level by sharing a common database, throughout the whole supply chain (Kiviniemi 2005). Project extranets and construction collaboration technologies can facilitate such integration. The platform for integration is not yet clear. On the one hand, geometric models containing additional non geometric attributes are perceived to be the basis for integration. Object oriented modelling links objects to specifications. This approach can be based on IFC standards, recognizing model attributes throughout the industry. On the other hand, money and time could just as well be the integrating factor.

Constant new visions and lack of implementation delay the development of common standards. The IAI provides basis for implementation, but is still in the midst of acceptance. Eventually IFC file formats can create a market and enable change in culture (Kiviniemi 2006). Challenges besides standards are ownership of information, as the data no longer relates to one individual workstation, and is accessible to all parties through an integrated project database. Primarily research has to tackle the soft and hardware problem to create a proper infrastructure for integrated systems. Secondly systems must be marketed in order to become available to common practice. ICT could provide a central storage of product information, standard solutions and best practice, and enable this data to be accessible and editable by all and on demand (Marshall-Ponting and Aouad 2005) and would enable an organized learning effect to all project participants. The ultimate goal in construction is to have all data needed interlinked. The role of project management may be to integrate the information and data and serve as a single point of responsibility (Sun and Howard 2004).

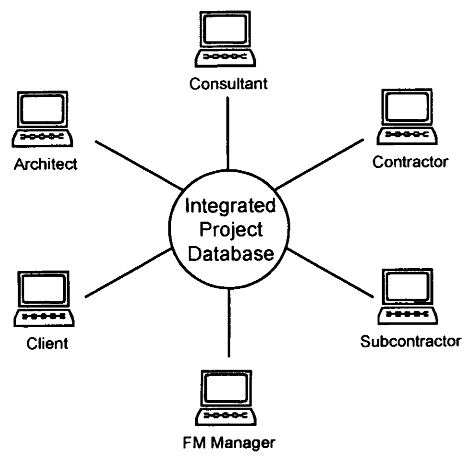


Figure 16: Single point of responsibility (Sun and Howard 2004:151)

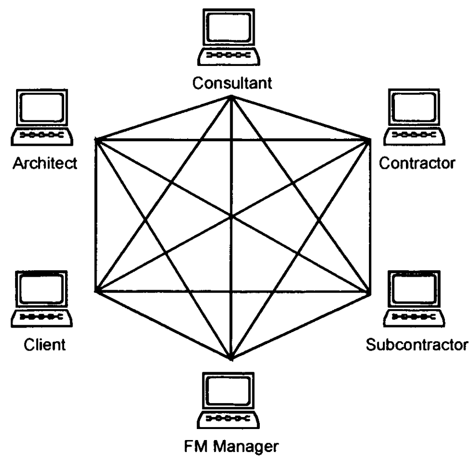


Figure 17: Interoperability by interface (Sun and Howard 2004:151)

6.2 The virtual construction site

Fisher and Kunz have identified that an organization's capacity to process information becomes the limiting factor in determining schedule, cost and quality performance and therefore, IT needs to support an organization's capacity to model, analyze, simulate, and predict a project's performance (Fischer and Kunz 2004). The virtual construction site relies on a collaborative environment, effective communication and flexibility. Considering the wide range of professions involved in the construction process, if each provides collaboratively the necessary information, a symbolic CAD model could generate an integrative solution that facilitates design issues, constructability, improving construction operations and decreasing project costs. This enables the rapid identification of potential conflicts in time and space. It allows improvements of the project executing strategy and eventually results in the corresponding gains of on-site productivity. Sequences can be simulated, workflow coordinated and site logistics more efficiently managed (Staub and Fischer 1998). The changing of the construction environment can be characterized through (Alshawi and Ingirige 2003):

- Globalisation of the marketplace;
- The economical forces;
- Increases in project complexity;
- The need to achieve faster results with the given resources;
- Rapid changes to project scope to expand benefits;
- New procurement practices;
- Client sophistication.

Integration and interoperability can evolve to a single comprehensive building model, as central data repository with access and editing rights to project participants. All project relevant information such as workflow, processes, material attributes, cost and schedule are linked to this initial model to efficiently improve the above performance aspects (Lee et al. 2003). Two approaches to evaluate the means of the building model in the conception of critical space analysis that enable integration and provide a platform as a collaborative virtual interactive environment are considered.

6.2.1 VIRCON Project

The Virtual Construction Site (VIRCON) is a decision-support tool for strategic construction project planning. The system integrates existing applications and methods currently used by planners. The VIRCON is effectively a 'hands on', hierarchical database, assessing geometric, method, resource and task specific information by checking and counterchecking data and providing an appropriate execution plan. The Program suggests a trade off between time, sequence and space. The particular feature of VIRCON is its immediate applicability to current practice (Dawood et al. 2003, Kelsey et al. 2001 and North et al. 2003). The space scheduling process is proposed on a 2D + time basis, discarding the vertical dimension, which makes the system concurrent to momentary construction procedures (Winch and North 2006). The system is designed to perform a weekly planning rehearsal.

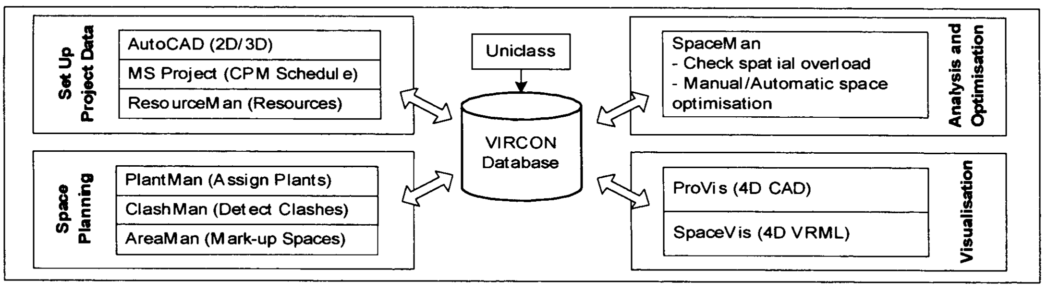


Figure 18: VIRCON tools (North et al. 2003:16)

6.2.2 4D modelling approach according to CIFE

Unarguably, graphic is the most effective method for human communication (Sun and Aouad 2000). Research at the 'Center for Integrated Facility Engineering' (CIFE) are developing a 4D CAD model by linking components in 3D CAD with activities from the design, procurement and construction schedules to facilitate and visualize a real time process simulation (Fischer and Kunz 2004). Not the integration of application and development of standards are considered, but the integration of data and processes into one comprehensive system. A point of criticism is the amount of information necessary for such a comprehensive 3D CAD model to be adequately displayed exceeds the current state of technology (Winch and North 2006). As 3D models are not entirely available at early stages of development, the types of operations and simulations must correspond to the level of detailing in order to provide the most benefit. Further sophistication of 4D applications can eventually learn from the 3D gaming industry, where predefined and mature algorithms are used to simulate logic processes in high detail (Bargstädt and Blickling 2005). However the model is a replication of real life, where buildings are in 4D, hence the more specific a simulation needs to be, and the more information need to be processed (Aouad et al. 2005)

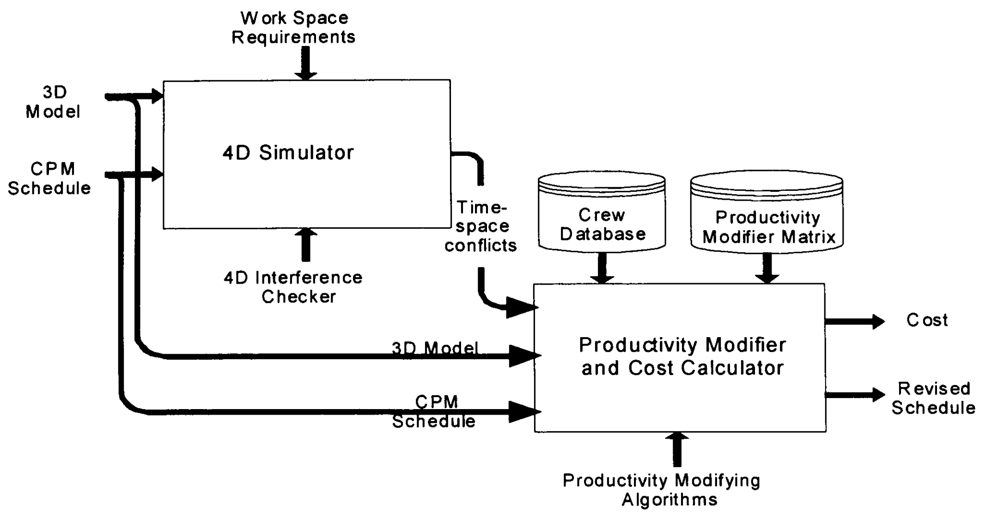


Figure 19: 4D Analysis of Cost and Productivity (Staub and Fischer 1998:6)

6.2.3 The Virtual Team

A virtual team is a group of people of geographic, organizational and temporal dispersed workers, relying on ICT to accomplish a common goal (Powell et al. 2004). With current development of mobile technologies and the spread of the internet, the construction project team is increasingly becoming a 'virtual team'. Combined with the potentials of process simulation, a comprehensive coordination model can provide continuous information and reference (Lee et al. 2003). The

BAA Genesis coordination model, attempted to assess the potentials of a comprehensive 3d CAD model in a pilot project in 1997, although was perceived as failure because the CAD model was not continuously updated (Williams et al. 1997). However, considering integrative approaches such as the VIRCON and CIFE project, together with hand held mobile computing hardware (Bowen and Thorpe 2002), processes may be updated and generated automatically and hence may extend the virtual team onto the construction site, where information is directly contributable.

6.3 Possible developments in the near future

General trends in construction are clearer than the future of specific products (Sun and Howard 2005). The aim of developments is always to enable change of some kind. To construction this change is essentially directed towards improving performance (Maas and Gassel 2005). This in turn could improve the delivery process and client satisfaction and effectively the general industry reputation for efficiency, reliability, safety and innovation. "...it is increasingly being realized that the effective use of ICT is necessary for delivering efficiency and improved project performance in the construction industry" (Howard 1998:191). There is a growing tendency in construction, and specifically for construction clients, who are less concerned with the size of the investment, but are becoming more and more interested in the total cost of ownership and life cycle cost, to look beyond the initial stages of design and building (Wilkinson 2005). Throughout the literature, the main area of achievements in technological improvements focuses on communication. "...an effective communication environment leads to a fairer, more open and inherently more satisfying workplace environment for all involved" (Dainty et al. 2006:228). According to Mass and Gassel, 'distributed' no longer means 'sent to many clients' but rather 'accessed at many providers'. Sharing distributed information resources has the potential to improve business processes in many ways (Mass and Gassel 2005):

- Avoiding unsolicited communication, the traffic of information is reduced, even if there is an increased amount of wanted traffic;
- It improves the validity of information, because it remains under control of the provider;
- It increases the quality of information, since it can answer a specific request or even result from a, possibly automated, dialogue;

Progress in collaboration attitudes amongst the project coalition coupled with enhancements in communication, connectivity and technological possibilities will produce totally integrated systems, interactive and interconnected, to enable mobile application operations, and immediate communication at every time, from everywhere. Five trends can be captured:

Integration	Synchronisation with back office and other systems and greater integration between design and construction people, processes and technology.
Collaboration	Enhancement of mobile connectivity to enable real time communication through Wireless LAN, general pocket radio services, broadband wireless applications and so forth to reduce reliance on slow, labour-intensive paper based processes to share project information when and where desirable.
Connectivity	More transparent, long-term commercial relationships to improve information flow among project coalition. Collaboration technologies and e-procurement and e-tendering will become widely used
Applications	Knowledge management to enable capture, retrieval and sharing on information, object orientated CAD systems, 4D modelling and performance simulation will become more sophisticated and improve the decision making process. Information flow will go beyond the office, linking the production directly with management. Systems for on-site project performance improvements through monitoring, inspection, positioning, checking and reference systems, through GPS and electronic ID, building information modelling and end user mobile computing system
Production	Highly interlinked with the above applications, production improvements to enhance the construction process will increasingly emerge. CAM for construction to enable prefabrication, reproduction and off-site manufacturing, hybrid pneumatic robots for dangerous and unreasonable heavy physical work to increase health and safety

Figure 20: Areas of development

However, it is widely believed that ICT is reaching the stage where engineering is rapidly approaching the limits of current materials (Dainty et al. 2006).

7 CONCLUSION

7.1 Reflection upon hypothesis

Apparently the theory of ICT has been around since the very beginning of electronic information processing and has not been dramatically influenced by the state of technology. In fact the theory is a path in which technology is subsequently following. Only very few developments have proven to be dead ends. Those that eventually failed or did not meet requirements of the market were assimilated or integrated within the general development of technology. Obviously the progress of the developments and the theory behind them becomes more precise and detailed; however the big picture remains the same. In 'Computing in Construction' Howard 1998 characterizes the 1970s as the decade of hardware, the 1980s emphasizing the development of software applications and standard operating systems, the 1990s as the decade of communications, and consequentially 2000 focuses on the data which is processed, concluding that general trends are clearer than the future of specific products. To my mind, this is a very accurate observation when considering the main focus of development and research. Most applications developed up to the present available on the market are more or less stand-alone applications, designed for specific tasks. Apparently, computing has changed life in so far, that it basically has replaced former manual tasks into electronic procedures. Even though considering more information and managing increasingly complex tasks more accurately, incredibly faster and more reliably, the process remains practically the same.

There are two significant developments of recent years, first the increasing tendency towards mobility and second the introduction of the Internet, changing everyday life completely and having the greatest impact and potential for the construction industry. With the increasing dependency on the flow of information, the radical spread and speed of telecommunication, the development of multimedia and interactive communication and integrated solutions, the Internet has revolutionized communication and the way we live. The Internet is obviously not the sole important development in ICT and a panacea for communication. Together with mobile technologies, information can be brought to every remote location. Eventually their introduction enables great potentials for new opportunities that computers on their own could not achieve. The communicative aspect of information technology has created new possibilities and effectively changed the way we work. Together they facilitate the management and coordination of the vast amounts of information, which a construction project is dependant upon for viable decision making. Theoretically, the more information becomes available, the more accurate the decision making and the more viable the planning could be. However this is dependent on the accuracy of the information inserted into the system and the interpretation capability of the users. The user must be aware of the potentials and recognize the benefits. Originally activities, costs and resources were monitored, evaluated and simulated independently. The continuous development and improvement of computing enables these factors to be integrated into one system. On the one hand, geometric models are perceived to be the basis for integration, on the other hand money and time could just as well be the integrating factor. No matter which will prevail, technologies that integrate communication systems, CAD, management applications, facilitation of information and promotion of interactivity are only achievable with the combined potential of computing and communication.

Hence, I believe my initial assumption as to how technology influences the theory of ICT in construction to be not quite correct. My findings have made me believe that the foresight, the theory and ideas on ICT were actually all along available since the 1960s. It was the introduction of the Internet that had the greatest influence on IT, which was consequentially transformed to ICT. Even though the ideas existed, the Internet proved to have changed current thinking most significantly. The way society interacts and the possibility to facilitate a radical change of the construction industry in the near future. Issues such as information overflow, ownership, compatibility and technical integration remain to be resolved however, the construction industry and its productivity will inevitably benefit from the combined and integrative capabilities of ICT. So once hardware is in place and processing speed sufficient, the software available and interoperable, communication channels sophisticated and the data organized, what comes next?

7.2 Implications

The major constraints on progression are apparently not theory or technology, but human reluctance to work in different ways. Farsighted or overambitious theories tend to be ridiculed and immediately dismissed. Even if technology proposes a trend, mindsets and habits restrain its efficient use, such as unnecessary prints in the 'less paper office'. Current challenges in legal and compatibility issues are mainly behavioural origins that now appear to be tackled due to tendencies of the industry to promote trust based relationships through partnerships and alliances. Hence, maybe people are getting innovation wrong; they rather stick to traditional methods of working and accept as little change as possible to maintain their status quo. Once a completely new approach is introduced, scepticism may restrain to grasp the maximum benefit of the innovation. It is eventually important to look well ahead and to anticipate possibilities, such as Vannever Bush's vision. Other industries may provide exemplary practice. The petrol-chemical industry may be perceived as being most similar to construction, yet aerospace and automotive industries may provide stimulations for increasing project performance, even though construction products are more dynamic. Consequentially keen visions can be turned into reality, after time reach the masses and change practice effectively. The construction industry may consider looking into the past and reflect on what possibilities it could engage to enhance current practice. Shakespeare coined "the past is prologue" yet one has to know what lies behind in order to advance. A goal to where development is heading is essential, even it the means are currently not available. When considering the sectors, some are more capable of adapting to new technologies, such as those involved at the front end as design and management functions whereas others, such as suppliers are less ambitious. However, a building exists in the 4th dimension. The logical consequence is to simulate the actual building in a virtual environment and to communicate, edit and reference necessary information from this one interactive media. The critical mass is important when striving for an ambitious goal, not only to current practice but also to research.

With the rising confidence in technology, ICT is gaining pace in the construction industry. Research is increasingly focusing on aspects of flexibility, mobility, connectivity and integration for the rapid and reliable exchange of information. This development is extending its area of influence on to the construction site. Through case studies, workshops and publications, practice is finally recognizing the possibilities of ICT and is increasingly investing in accordance to the spirit of competitiveness. The findings in this paper were consequentially tested and discussed in semi structured interviews. Wilkinson (Head of corporate communications at BIW technologies interview 21.08.2006), emphasises the increasing service orientation. Not individual products and the management of simple data, but rather the management of effective workflows are the essence of current developments. IT allows a holistic thinking of the whole life cycle of a building, and web services allow a combination of technologies. When considering integration, Howard (author of 'Computing in Construction' 1998 and 'Understanding IT in Construction' 2004, Interview 25.08.2006) and Aouad (Director of the Salford Centre for Research and Innovation, interview 04.09.2006) believe the development and agreement on industry standards, such as the IFC model to be the most important step towards the interoperability of applications.

The success of 2D was achieved through the .dxf format, 3D is lacking such a standard. According to Aouad, there is a generation gap within the industry and those currently involved in on-site activities have no incentive to promote 3D models. Fischer, from CIFE takes a slightly different approach, by focusing on the integration of procedures and data (Director of the Center for Integrated Facility Engineering at Stanford University, interview 30.08.2006). He thereby states that essentially standards are an excuse of practitioners to delay technological implementation. He emphasizes the potentials of 3D CAD and as Aouad, does not perceive any significant advantages of 2D CAD. Fischer consequentially assumes 3D to replace current 2D CAD practice through mobile technologies and the Internet. The industries current reluctance towards 3D CAD lies in the prevailing mindset of practitioners to work with 2D drawings. A completely different approach is taken by Penn (Director of the Virtual Reality Centre at University College London, Interview 06.09.2006), who assumes research does not consider, how time consuming and respectively expensive a 3D model is, and perceives no immediate benefit from such an integrated model. There are good reasons why things are done the way they are. The social networks are not as bad as assumed and the industry is not fragmented as proclaimed by Latham and Egan. The structure of the industry is appropriate for its cause. Penn doubts the potential of standards, as those who deciding upon them, are market leaders with the incentive to prohibit open standards. Penn highlighted three advantages of 3D CAD models, with CAM to develop customized elements for construction, test design development and for marketing purposes. Even though 3D may replace 2D, for the site there is no alternative for conventional 2D drawings. Despite different evaluations of current approaches, all interviewees recognise that the theory for the technology relates back to the 1960's, building on relational and mathematical theories. Behavioural issues were furthermore identified as the prime constraints on innovation.

7.3 Critical Comments

Computers are decision support systems. The actual process of decision making still lies in the responsibilities and the capabilities of the human administrating the system. However, for accurate decision making, accessibility and availability of information is decisive. Motivation for this thesis was my personal perception that innovative technologies, foremost possibilities of 3D/4D CAD are currently not used to their full potential. It has taken some time for 2D CAD to become common practice and 3D CAD is not yet widespread and remains mainly a tool for presentation, which seizes to exist once the project reaches construction stage.

Reflecting on interviews, articles published and through my own experience as an architect, it appears that 3D CAD models have not yet paid off! Innovation seems to be constrained by the mindset of practitioners to use 2D CAD as a primary source of reference, whereas the 3D CAD together with integration, mobility and connectivity could enable different types of interaction and provision of information.

There are countless discussions and publications on ICT throughout the history of computing, specialized for every need available on the market. This report focussed on past development, their relation to the body of theory and gave a brief introduction of current research. Innovation goes far beyond process simulation and integration, aspects influencing current research such as computer aided manufacturing and barcodes were not mentioned, yet have a great potential for the construction site of the future. Further, detailed research on the individual applications should be conducted. At this stage the story seems conclusive. By looking into the past, we can recognize patters of how our future may develop. However, the comparison between technology and theory should be repeated, as both are in a constant state of change. Especially when all visions of current research are in place, 4D CAD is common practice and construction projects are managed through a comprehensive, integrative and interactive reference model accessible through a project extranet.

7.4 Final Remarks

The development of ICT in the construction industry can be compared to the development of the automobile. At first, the car looked like a horse carriage but without the horse. Only when people became used to the 'car', did it become a distinguishable and individual type of transportation. The potential development could progress without the confines of resembling the former carriage. Similarly, the construction industry is hesitant in replacing current and traditional proceedings. ICT basically replaced manual tasks. Now people are getting used to ICT in their everyday life and are slowly accepting its influence and rethinking current construction practice. The full potential of ICT can now develop by loosening the confines of tradition.

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9 APPENDIX

9.1 Questionnaire CAD Process Simulations

1. The integration of applications is the focus of current research. Standards are being agreed (International Alliance for Interoperability), systems are becoming increasingly compatible and technology is being developed to create one interactive, integrative reference model for construction management. What are specifically the benefits of a 3d process simulation over a 2d approach (I am referring to the VIRCON project)?

2. The construction industry is perceived as being fragmented, traditional, adversarial and highly competitive. Despite recent ambitions to increase trust and partnerships, the industry remains grounded in traditional structures and attitudes (I am referring to practice in the UK). The acceptance of practitioners in adapting Information Communication Technologies is rather sceptical. It has taken some time for 2d CAD to become common practice and 3d CAD is not yet widespread and remains mainly a tool for presentation. Reflecting on interviews I conducted, articles published and through my own experience as an architect, I am assuming 3d CAD models have not yet paid off! However, the potentials of 3d + time and eventually + cost simulations are increasingly being recognized. Do you think 3d CAD has the potential to replace 2d CAD, and will at some time 4d applications be common practice?

3. For an adequate process simulation, a 3d CAD model of the building has to be available. Can process simulations effectively depend on preliminary design models or what level of detail is required for and appropriate 4d simulation? Can architects 3d models be linked to such simulations (exchange of CAD information and problems with layer structures) and at what stage in planning do you think process simulations are viable?

4. Is the development of a comprehensive IFC format and object oriented modelling the future of process simulations? Do 4d simulations depend on object oriented modelling and are such IFC standards necessary for 4d simulations to become accepted within the industry?

5. It appears as if technology and especially information communication technology stop when they reach the construction site. When considering the Internet and advances in mobile technologies, will process simulations have an

immediate impact on site activities (not referring to health and safety, rather to on-site applications) or do its potentials primarily relate to design and management of construction projects?

6. When considering theories in computer interaction, the timeline of Information Communication Technology suggest that most forms of application were envisioned in the 1960's (Please refer to attached letter). The object orientated approach to planning can be traced back to research conducted in Norway also in the 1960's. Is it true, that the theoretical framework of what is possible today relates to these developments?

9.2 Questionnaire Virtual Reality

1. The integration of applications is the focus of current research. Standards are being agreed (International Alliance for Interoperability), systems are becoming increasingly compatible and technology is being developed to create one interactive, integrative reference model for construction management. Does VR have its place in such a reference model?

2. The construction industry is perceived as being fragmented, traditional, adversarial and highly competitive. Despite recent ambitions to increase trust and partnerships, the industry remains grounded in traditional structures and attitudes. The acceptance of practitioners in adapting Information Communication Technologies is rather sceptical. It has taken some time for 2d CAD to become common practice and 3d CAD is not yet widespread and remains mainly a tool for presentation. Is VR underestimated and do you think VR has the potential at some time in the future to become common practice for supporting the decision making process, beyond visualisation aspects?

3. When considering theories in computer interaction, the timeline of VR suggests that VR was envisioned by Ivan Sutherland in the 1960's. The object orientated approach to planning can be traced back to research conducted in Norway also in the 1960's. Is it true, that the theoretical framework of what is possible today relates to these developments?

4. Currently research is conducted in 2d + time (VIRCON) and 3d + time simulations (Center for Integrated Facility Engineering). Even though it is perceived that 3d models have the greatest potential for the future, it is estimated

that at least 10 years are required till 3d technologies can become common practice. Is the development of a comprehensive IFC format and object oriented modelling the future of for process simulation and does VR depend on object oriented modelling?

5. It appears as if technology and especially information communication technology stop when they reach the construction site. When considering the Internet and advances in mobile technologies, will VR have an effect on site activities or do its potentials primarily relate to design and management of construction projects?