Information and Knowledge for Building: A Role for Emerging Technology

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ABSTRACT

Advances in microelectronics and computer technology have had a major impact on quality and productivity in the commercial, institutional and manufacturing sectors. The building industry has taken only limited advantage of this technology. Technologies may be roughly divided into two classes: 'hard' and 'soft'. Hard technology includes CAD/CAM, robotics, monitoring, control and document preparation. Soft technology deals with the information and knowledge requirements of the industry. Some hard technologies have penetrated the design and building delivery process, but these automation technologies cannot substantially change the building cycle. Soft technologies have the potential to alter the building cycle because this cycle depends on communication. This paper discusses the need for reliable information flow and knowledge accessibility. Soft technologies are reviewed for potential application in design, construction, operation and maintenance of North American buildings. Of the soft technologies, knowledge-based expert systems promise greater information accessibility in the building cycle. An expert system can act as advisor, assistant, or diagnostician on a wide variety of building-related topics. Examples of existing expert systems are identified and potential future developments are postulated.

Information et connaissances dans le bâtiment : un rôle pour la nouvelle technologie

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MOTS CLÉS

Cycle du bâtiment, intelligence artificielle, systèmes experts.

RÉSUMÉ

Les progrès de la technologie informatique et de la microélectronique ont eu un impact considérable sur la qualité et la productivité dans les secteurs commercial, institutionnel et manufacturier. L'industrie de la construction n'a que très peu bénéficié de cette technologie. On pourrait classer les technologies en deux catégories : les technologies "dures" et les technologies "douces". La première catégorie comprend la CAO/FAO, la robotique, les activités d'analyse et de contrôle, et la préparation de documents. La deuxième inclut les technologies qui servent les besoins de l'industrie en matière d'information et de connaissances. Quelques-unes des technologies "dures" ont été introduites dans le processus de conception et de réalisation des projets de construction, mais elles ne peuvent à elles seules opérer des changements considérables dans le cycle du bâtiment. Les technologies "douces" ont la capacité de transformer le cycle du bâtiment parce que ce cycle repose sur la communication. Dans cet exposé, on discutera de la nécessité de créer une source d'information fiable et d'avoir accès aux connaissances. On examinera la possibilité d'appliquer les technologies "douces" à la conception, la construction, l'exploitation et l'entretien des bâtiments en Amérique du Nord. Des technologies "douces", ce sont les systèmes experts avec bases de connaissances qui offrent la plus grande accessibilité à l'information dans le cycle du bâtiment. Ces systèmes experts peuvent fournir des conseils, de l'aide et des diagnostics dans de nombreux domaines relatifs au bâtiment. Des exemples de systèmes experts existants seront cités et il sera également question des développements futurs dans cette sphère.

1. INTRODUCTION

Excitement about emerging technologies is a result of current advances in microelectronics and parallel improvements in software techniques. Product engineers have incorporated these advances to decrease costs, increase quality (and competitiveness) and decrease the time required for product delivery. Emerging technologies comprise a broad front of hardware and software innovations. The technology has evolved through phases. First, simple automation emulated purely physical tasks (e.g. word processing, computer-aided drafting). Second, the task was restructured for automated efficiency (e.g. database managers, communications systems). Now, the automaton (the hardware and software) is being restructured to emulate aspects of human intelligence.

The building industry has used some simple automation techniques in the design and construction of buildings. Although application in the building industry has been limited, there is considerable research in the use of artificial intelligence techniques for investment, design and construction decision making; robotics for construction; and advanced communications systems for building control.

This paper outlines Division of Building Research (DBR) interests in emerging technologies for the building industry in its broadest terms, and focuses on the current directions and developments in Knowledge Based Expert Systems (KBES) -- an applied area of artificial intelligence.

2. THE BUILDING DELIVERY SYSTEM AND INNOVATIVE TECHNOLOGY

The building industry is a large but subtle, fragmented, dynamic system. For each building, the formal building team and the sectors involved in the building cycle are structured as a system. Once the building is completed, the structure is dissolved. In this constant state of system flux, technological innovation comes slowly. Acceptance of innovation by the industry is affected by three factors:[1]

1. Technical feasibility - the hardware and software must be available, and the ability to apply technical knowledge to the building industry. Emerging technologies are being developed by the computer science sector, in conjunction with pure mathematics and applied psychology. Application of these technologies to buildings will depend on the building research community.

2. Economic impetus - the building industry is highly leveraged and sensitive to interest rates, building cycle fluctuations, and first-cost. Each of the under-capitalized sectors of the building industry has its own profit incentive. Because of this fragmentation, life-cycle costs have little meaning unless the building is delivered and operated by a single entity, as may be the case for government buildings. Clients and investors, designers, construction contractors, and building operators and managers will introduce innovation voluntarily only if the innovation will result in increase of profits, efficiency, or tangible market advantage.

3. Institutional and cultural acceptance - the technology must fit the existing styles of work and organization to some degree. Innovative robotic technology and prefabrication methods may not be acceptable to the strong trade-union building delivery organization. Codes and standards may work for the inclusion of technology, or work against it.

The above issues must be positively addressed for the building industry to incorporate software and hardware tools.

3. EMERGING TECHNOLOGIES

The potential technical changes for the building industry include:

1. automation of tedious or dangerous tasks,
2. restructuring of tasks to take advantage of automation,
3. applying intelligent automatons to the system.

The automation of some tasks has been accepted by the industry because the three governing principles of technical feasibility, economic incentive and cultural acceptance held true. For example, word processing, certain applications of computer-aided drafting, specification writing, cost estimation and project control are all being applied by the industry to the building delivery task.

Restructuring the task to take advantage of automation has occurred on a very limited scale in the building industry. Examples may be found where both the design and manufacture occur within the same sector. One such CAD system, SHOP (1), has special functions to lay out ductwork relative to the floorplan, generate bills of materials, create patterns for ductwork and duct fittings, and use these patterns to drive a cutting machine to form the parts. This integrated CAD/CAM concept works for the mechanical contractor, but is impractical to apply to the whole building delivery system. Whereas contractors benefit most from the efficiencies of a common building representation database, the capitalization costs are borne by the design sector. Large building industry organizations that are life-cycle cost sensitive will benefit most from integrated CAD development.

Restructuring the automaton to emulate human behaviour is still an embryonic technology. The most successful industrial advances have been in the application of artificial intelligence techniques to emulate human expert behaviour. These Knowledge Based Expert Systems (KBES) rely on modeling the heuristics used by an expert while solving a problem, diagnosing a situation, or giving advice. KBES techniques are being applied to investment decisions and project management. The same technology can be used in design for accessing technical information, and in the operation sector for maintaining buildings.

4. KNOWLEDGE BASED EXPERT SYSTEMS FOR THE BUILDING INDUSTRY

During the building cycle, the successful flow of information ultimately defines the building. Poor or uninformed decisions may lead to building

(1) SHOP is a product of Accugraph Corp., Ottawa, Ontario, Canada.

problems. Because buildings and the teams that construct them are unique assemblies, general research information, guidelines, or manuals contain a large proportion of irrelevant information. Knowledge Based Expert Systems are computer programs designed to draw inferences about specific problems based on a general knowledge base. These systems provide answers similar to those provided by human specialists in their field of expertise. The level of knowledge in a KBES determines whether it is characterized as an assistant, a colleague or an expert. KBES technology is suited to heuristic problems -- problems where naive physics, a large store of experiential knowledge, and specialized information are used in the solution. In the building delivery and operation process, these classes of problems are most prevalent. Rarely is there a need for detailed simulation or calculation (unless mandated), and mandated procedures are generally fairly simple algorithms.

Knowledge Based Expert Systems perform interpretation, prediction, diagnosis and prescription, design, planning, instruction and control. In the building sectors, problems arise in each of these areas.

4.1 What Has Been Done?

Examples of KBES systems for the building industry include building code analysis systems, diagnosis of fungi and rot in walls, structural framing advisors, and generative design algorithms. Small systems are being built to address a variety of applications in the building industry.[2] At DBR we are developing a system for diagnosing window problems and choosing new windows. This is typical of the empirical experimentation with KBES systems. Most of these systems are quite small, and have no knowledge beyond their limited application. The knowledge bases have generally been built with information from manuals or references, as opposed to information elicited from domain experts. Researchers build systems with limited knowledge, and discard the structure when developing KBES for larger domains, or different applications. Theoretical foundations are being sought for the representation of knowledge, its structure, and its acquisition by machines.

4.2 What Could be Done?

Considerable development work has been done in financial planning and project management. This is directly transferrable to the investment and construction sectors of the building industry. KBES developments in other fields[3] can be used as models for application to the building industry. KBES developments in oil and mineral exploration (interpretation) have parallel applications to site selection and zoning law interpretation. Computer hardware manufacturers use KBES profitably to configure and specify large systems. Similar configuration problems in buildings could benefit from these approaches. Medical diagnosis systems, always at the forefront of KBES application, have been used as examples for building diagnosis problems. KBES for the design sector are being researched by the building research community, both government-based and academic. Research by the building research community has traditionally been aimed at the design sector, and the KBES developments now emerging reflect this tendency.

An array of possible applications is shown in Table 1. Because of the rapid changes in this field, many of the empty cells in the table have been or are being filled. Small systems could be built to address a variety of applications in the building industry. This will lead to a large number of limited KBES, each doing a small piece of the job -- but not sharing the knowledge with other systems.

4.3 What Should be Done?

Building knowledge based systems for the building design sector indicates a need to:

1. structure the knowledge base within each sector, and throughout the industry. Building science is not structured on the premise of understanding the building or its delivery process; rather it is fragmented in its technical evaluation of components. Bijl[4] has pointed to this critical problem within the design sector.
2. determine formalized methods for knowledge elicitation from experts who have an underlying understanding of the whole industry. "Gut feelings" for successful decisions must be formalized.
3. agree about the taxonomy of the building. User interfaces may be personalized to each designer's or contractor's vocabulary, but the symbolic terms used in the knowledge bases must be standardized if larger, more able systems are to be configured and if knowledge is to be shared.
4. define qualitative factors and through Delphi (or other concensus procedures) come to agreements about building method. Because knowledge bases are heuristic, some agreement must be reached if the knowledge base is to grow, without being continually questioned.
5. continue research on developing user interfaces that fit into building practice. This must include a thorough understanding of the use of knowledge by the industry and its impact on practice.

Although these issues are not as seductive to researchers as solving a specific KBES programming puzzle, they are critical to providing an acceptable stable technology within an existing professional practice context. Research done to increase the efficiency of the design sector and increase the quality of the building is justifiable only if it provides the economic incentives to the sectors that are to use the technology.

5. CONCLUSIONS

Emerging technologies provide a mechanism for increasing both productivity (and hence profitability) and the quality of decisions made during the building delivery and operation cycle. Application of simple automation is being accepted by the industry as a tool for productivity enhancement. Those whose primary justification is quality improvement without increase in productivity need to overcome inherent disincentives in the building delivery process. This might be achieved by mandated codes and standards, restructuring of the industry and formalizing the knowledge required to deliver and operate buildings.

Research and development into new applications of technology to the building industry should consider not only technical feasibility but also the needs of the industry and the realities of the marketplace. Knowledge based systems can have a significant impact on virtually every aspect of the building delivery and operation process.

REFERENCES

1. R. Schoen, A.S. Hirshberg and J.M. Weingant, New Energy Technologies for Buildings, edited by J. Stein (Ballinger, Cambridge, Mass., 1975) pp. 49-65.

2. D.M. Wagner, Expert Systems in the Construction Industry, (Construction Industry Computing Association, Cambridge, UK, Oct., 1984.)

3. D.A. Waterman, A Guide to Expert Systems (Addison Wesley, Reading, Mass., 1986) Chap. 25.

4. Bijl, A., Designing with Words and Pictures in a Logic Modelling Environment, CAAD Futures, Proc. Int. Conf. Computer Aided Architectural Design (Technical University of Delft, Netherlands, 1985).

5. A. Ishigami, Automated Drawing and Cost Estimation Program for Platform Frame Construction: House 24, CAD 84. 6th Int. Conf. Computers in Design Engineering (Sussex, UK, 3-5 April, 1984), pp. 38-47.

6. F.I. Stahl, Common Format for the Model Building Codes: An Application of Advanced Techinques for Standards Analysis, Synthesis and Expression, Research and Innovation in the Building Regulatory Process, Proc. NBS/NCSBCS 6th Conference, Denver, Colo. (National Conference of States on Building Codes and Standards, Va., 1984), pp. 3-28.

7. G. Carrara and G. Novembri, Constraint Bounded Design Search, CAAD Futures, Proc. Int. Conf. Computer Aided Architectural Design (Technical University of Delft, Netherlands, Sept. 1985).

8. E. Gullichsen and E. Chang, An Expert System for Generative Architectural Design, Design Methods and Theories 4(2), pp. 253-267 (1985).

9. M.L. Maher, Hi-Rise: A Knowledge-Based Expert System for the Preliminary Structural Design of High Rise Buildings, (Department of Civil Engineering, Carnegie Institute of Technology, Pittsburgh, Pa., 1985) R-85-146.

10. V.E. Wright, Expert Systems in HVAC Design, Heating, Piping and Air Conditioning 57(1), pp. 125-131 (1985).

11. J. Lansdown, Expert Systems; Their Impact on the Construction Industry, (Royal Institute of British Architects, London, UK, 1982).

12. N. Cato, Developing Automated Specifications, The Construction Specifier 38(8), pp. 28-34 (1985).

13. J. Gero, Future Uses of Computers in Architecture, CAAD Futures, Proc. Int. Conf. Computer Aided Architectural Design (Technical University of Delft, Netherlands, 1985).

14. D.R. Rehak, Expert Systems for Construction Project Monitoring, The Use of Computers in the Construction Industry - Experiences in the USA and Hungary (Inst. for Building Economy and Organization, Budapest, 1985).

15. B.C. Paulson, Automation and Robotics for Construction, J. Construction Engineering and Management 3(3), pp. 190-207 (1985).

16. A. Warszawski and D.A. Sangrey, Robotics in Building Construction, J. Construction Engineering and Management 3(3), pp. 308-323 (1985).

17. J.F. Marney and D.J. Foord, A Practical Expert System in Fault Diagnosis, BSRIA Computer Newsletter (12) (1984).

18. G. Trimble, Expert Systems in Construction, Building Research and Practice, CIB 13(14) (International Council for Building Research, Studies and Documentation, Paris, 1985), pp. 231-233.

19. R. Sharpe, Building Research and the Microcomputer, Proceedings of Construction 86, Perth (1986).

TABLE I. Potential application of knowledge based expert systems by the building industry

SECTOR	PROBLEM	REF
Investor	Plan investments	
Client	Plan project cash flow and monitor progress	
Architect/	Interpret user needs with client for program	
Engineer	Interpret applicable codes and regulations for building type	6
	Interpret legal/professional responsibilities	
	Design building with respect to constraints	7,8
	Design structure	9
	Configure mechanical system	10
	Configure electrical system	
	Evaluate building against (heuristic) objectives	11
	Specify products related to constraints, plans	12
	Predict building physical behaviour and user response	13
Contractor	Estimate cost of building during design phases	
	Manage cash flow, labour, contracts	14
	Give knowledge to construction robots	15,16
	Check building against checklist before client acceptance	
Owner/	Instruct building operator on use of equipment	
	Manage office layout and work patterns	
Operator	Find building problems (qualitative, quantitative)	17,18
	Suggest options for prescriptive remedies	19
	Predict and control traffic and communication systems	
Maintenance	Schedule cleaning and maintenance	
	Control robotic or manual operations	
User	Instruct about building emergency procedures	