DETERMINANTS OF THE DEVELOPMENT OF COMPUTER INTEGRATED CONSTRUCTION

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SUMMARY

The status of advanced construction technology, like computer integrated construction and construction robotics, varies widely in different countries.

The goal of the paper is to find the determinants to the development of computer integrated construction. This is achieved by comparing the current status and development plans in two countries: France and Finland. The situation in Japan and the USA is also briefly commented.

The results of the feasibility studies on computer integrated construction which have been carried out in each of the two countries are presented as well as the major construction techniques in use, along with other determinants related to computer integrated construction and robotization.

As a synthesis, the general determinants of the development of computer integrated construction are sketched.

1 INTRODUCTION

The status of advanced construction technology, like computer integrated construction (CIC) and construction robotics, varies widely in different countries. Even if there has been several studies into this and related problems, the reasons to this situation are not obvious neither well known. The major findings hitherto are summarized in the following.

Brown (Brown 1989) analyzes causes for lagging in the development of construction robotics. He argues that the separation of design and construction, the relative lack of investment in R&D and the culture of the building site inhibit advanced technological development.

Tatum (Tatum 1989) analyzes design and construction automation from the point of view of competitive advantage for the firm. He concludes that one of the greatest management challenges is awareness that automation both improves operations and provides new sources of competitive advantage.

A further investigation at the Center for Integrated Facility Engineering (Mahoney & Tatum 1990) identifies and defines several types of barriers that prevent effective use of new computer technology for integration in construction:

- institutional barriers are characteristics of the construction industry that inhibit integration

- legal barriers are legal precedents and policies that inhibit integration
- organizational barriers are charateristics of particular companies that inhibit integration
- behavioral barriers are human reactions to integration of hardware and software systems into a new area of application.

The goal of this paper is to find the determinants to the development of computer integrated construction. This is achieved by comparing the current status and development plans in two countries: France and Finland. The situation in Japan and the USA is also briefly commented. The results of the feasibility studies on computer integrated construction which have been carried out in each of the two countries are presented as well as the major construction techniques in use, along with other determinants related to computer integrated construction and robotization. As a synthesis, the general determinants of the development of computer integrated construction are sketched.

2 THE STATUS OF COMPUTER INTEGRATED CONSTRUCTION AND CONSTRUCTION ROBOTICS IN CHOSEN COUNTRIES

2.1 Finland

During the 1980's, a cluster of development projects with wide participation have been initiated in Finland in order to create the necessary basis for a second wave of industrialization of construction. The targets include the creation of an open construction system based on prefabricated components and of a national framework for project wide computer aided design. On the other hand, measures towards creating the necessary national competence in computerization and robotization of construction has been launched.

The project "RATA 2000" (Construction Method 2000) is an umbrella project, by means of which a framework for component based industrialization will be set up. The project analyzes requirements for the construction process and for the project organization set by the utilization of prefabricated components. The leading ideas include:
- integration of design and manufacturing/site production
- performance based product specification
- establishment of such a competition structure, that various products, materials and technologies can compete with each others from their own starting points
- modification of the areas of responsibility of the parties in the construction process to correspond functional and integrated wholes.

On the basis of the results of the "RATA 2000", material specific development projects have been or will be initiated for precast concrete construction, masonry structures, steel frame construction and wood construction. The project for precast concrete component construction of housing and office buildings "TAT" started in 1986 and will be finished in 1991 (Sarja 1989). The project further develops the Finnish BES-system, an open concrete component system set up in the 1960's and 1970's. The following principles concretize the TAT targets:
- increase in the freedom of design and quality/cost management
- industrialized and mechanized manufacture of components
- compatability of various technical systems
- easy assembly and installation of structural components
- optimization and enhanced management of the design and production process.

The main aim of the RATAS project is to define the basic structure of the computing environment of the construction industry in the early 1990's. The first phase resulted in a visionary model of what the computer aided design and building process of the 1990's should look like. The second phase of RATAS was completed in the beginning of 1988. The work was carried out in four expert groups, which considered,

respectively,
- general data bases
- data exchange methods
- definition of a standard project data base structure
- new types of design documents and the design process.

The third phase of RATAS, now underway, covers
- product classification (from a EDI point of view)
- directory data base for construction data bases
- specification of a limited building product model (containing the information needed by the main contractor in order to make a bill of quantities and a cost estimate)

It is the aim to define the common RATAS framework in sufficient detail to allow software developers to create commercial products based on it.

Even before the above described initiatives, a de facto standard was developed for the communication between general purpose CAD systems (Hannus 1990). A neutral transfer file format called BEC is now widely used in integrated building design projects. Primarily for component manufacturers, a receiving software system for CAD-files has been developed.

The research programme "Information and Automation Systems in Construction" is concerned with the applications of knowledge engineering, robotics and integrated information systems in construction. The programme has been initiated by the Technical Research Centre of Finland, which also provides two thirds of the funds. It is more basic research and long term oriented than the projects mentioned above. The programme consists of three major projects, which consider computer integrated construction, construction management systems and construction robotics. Product modelling of constructed facilities is one key area in the programme (Björk 1989).

Research and development of on-site construction robotics is in an introductory phase in Finland. In the above mentioned research programme, a prototype tiling robot is under development. However, on the related field of tunnelling, a number of automated drilling and spraying machines have been developed and commercialized. Automation concepts have also been applied in prefabrication of concrete components. Actually, the research and development volume is quite large here. Development targets include
- machine tooled wax moulds from a digital 3-D model for prefabricated facade components
- facade components produced by the spraying method, without a mould.

2.2 France

The integration of the construction process is an ultimate goal. Referring to previous technical development and to the present situation, it is not easy to draw out the main lines of this future situation.

During the 1960's, with a very high demand for dwellings, a great number of prefabricated construction systems have been developed. Concrete was the predominant material. The technologies used were efficient but not flexible. People remember these huge parallelepipedic buildings, which are now being blasted because they do not meet today's requirements. Prefabrication was associated with design rigidity.

For individual houses, the demand of which strongly increased during the early 1970's, bricks or concrete blocks brought in flexibility but with a high rate of manpower.

These two basic technologies (concrete panels and (concrete) blocks) are now three:

the concrete cast in situ is presently predominant for small multifamily buildings (three to five story buildings) and small commercial buildings.

During the 1980's, a special emphasis was put on the increase of flexibility of construction systems with concrete panels.

The PIP national program aimed at designing open construction systems with a high degree of compatibility for components made by various manufacturers. A software, named G5, which is still being perfected, allows the design of a building with a concrete structure. The components are chosen from a set of available panels by manufacturers. The optimum solution can then be described.

The future of such a software is the communication of the information to manufacturers in order to produce the required components. The automated machines or "robots" will use these data automatically.

Such an automated process is already a reality for manufacturers producing for instance:

- prestressed concrete floor panels
- wooden or metallic frames (windows, doors, structures)
- energy network (electrical, hot water heating systems)
- reinforcements.

This trend for local automation is clear for nearly all the components likely to be used in the construction process. These locally integrated production processes are the roots of the future fully integrated process. The difference between now and the future is communication.

During the 1990's, the general trend will be the development of a better communication between participants in the construction process, between technical software, between actors and the technical literature, between the design stage and the site. Some significant projects are already underway to reach such goals.

The FARTEC project aims at digitizing about twenty thousand pages of technical regulation (texts, drawings, tables) and at developing intelligent systems to make easier the access to the relevant information. The project is carried out by the CSTB and professional partners with a political support from the ministry in charge of construction (Delcambre 1989).

The CIBAO project and related projects (COMBINE, CICERO...) aim to make easier the communication between technical actors who have necessarily different points of view. The data structures, the communication protocols, have to be precisely designed in order to reach such a goal. The CSTB and professional partners carry out these projects either with governmental support and within European research programs (Dubois 1989).

The EDICONSTRUCT association gathers members which want to promote the use of data exchange with informatics.

Other actions which cannot be presented in detail in this paper aim at a better communication through the different phases of a construction process.

Robots will probably be the "end users" of these structured data. A national program supported by the ministry in charge of construction, allowed to carry out studies and experiments in this field between 1985 and 1989.

In spite of some successful projects such as the SOFFITO project (Salagnac 1989), robotisation looks to be a goal far ahead. Nevertheless, technical projects such as the tower crane automation carried out by the crane manufacturer POTAIN and the contractor SOGEA show which technical problems are to be solved shortly (Joly 1986). Again the communication between the design stage and the machine on site is a key point.

The sensing capacity of construction robots will have to be increased for them to communicate directly with other participants. French laboratories in robotics and specialized companies present a high potential in this field. The leadership of French in the robotisation of industrial cleaning is also an asset.

Specific problems of civil engineering have also been considered within the frame of a four year national program supported by the Ministry of research. Road works look to be a promising domain but time is needed to develop an integrated process (Le Corre 1990).

2.3 Other countries

From other countries we consider briefly the leading developers of construction automation: Japan and USA.

As for Japan, the leading position in construction robotics is well known and requires no elaboration. In other areas of computer integrated construction, the big contractors have also progressed rapidly. The major ACT project (Advanced Construction Technology) created a framework for further integration efforts (Terai 1988).

In the USA, the fundamental research into computer integrated construction and construction robotics is on a high level (Atkin 1989). The leading AEC firms have aggressively created integrated systems in recent years. As for construction robotics, there are more practically oriented development efforts in major AEC firms or machinery manufacturers (Killen 1989), but not as numerous as in Japan.

3 ANALYSIS OF THE DETERMINANTS

3.1 Finland

Factors which have influenced the Finnish situation include a high degree of prefabrication, a consensus culture, based on earlier succesful national systems, and the governmental technology policy.

Industrialization of construction has been a leading idea in Finland already from the sixties. The degree of prefabrication is among the highest in the world. Thus, it is not surprising to find major development efforts focused on concrete component manufacturing and related information transfer.

The Finnish construction industry represents a consensus culture, rooted maybe in the difficult rebuilding period after the war. The industry has been able to agree on a common construction system (BES) already in the 1960's. A similar cooperative effort towards a common informational infrastructure has been easily accepted.

The governmental technology policy has been activated during the 1980's. In the framework of it, national techonology programmes have been started. The programme focusing on construction has been directed to renew the industrial structure in construction, in order to achieve greater efficiency.

3.2 France

Even if it is not explicit, it is clear that the traditional construction techniques and processes deeply influence the development towards an integrated construction process.

The numerous participants in a construction project are in contact for this particular project and are not likely to work together for another project. The emphasis on communication problems is thus justified.

The tower crane is the most commonly used machine on sites. It is then consistent to improve the performance of this machine. It is used for very different tasks such as panel manipulations or concrete bucket handling.

We can hardly imagine that an integrated process will only use one construction technique. The competition between prefabrication and operations on site will be one of the challenges of the trend towards integration.

Apart from technical and economical factors, social parameters will have to be taken into account. The demand for a great architectural variety is strong. An integrated process is likely to be successful when it meets such a requirement.

3.3 Other countries

As for Japan, we find the following determinants:
- Several big, integrated construction companies, which invest vigorously in R&D
- The construction output includes difficult projects: tunneling, dams, bridges, skyscrapers
- The great weight given to long term considerations
- The national tendency towards solutions related to information technology
- There is a serious concern on the problems of labor shortage and industrial accidents in construction
- The degree of prefabrication is not especially high, which explains the focus on on-site robotics.

For the USA, we come to the following conclusions:
- The R&D into construction is considered to be low in general
- The competitive university system assures a high level of fundamental research in the leading universities; however, the university-industry links have not been especially strong
- The industry structure is maybe more fragmented than in Japan, with less major AEC companies
- Due to the continuous migration, there is no major shortage of labor force

3.4 Comparison and synthesis

We structure the determinants of the development of computer integrated construction as follows:
- The perceived need. This includes the much repeated triple "low productivity, high rate of accidents, shortage of labor", as well as the considerations for productivity and competitivity.
- The structure of the output of the industry, and the major techniques in use.
- The degree of anticipatory action in the construction industry. This includes the strategies of major firms in the industry and governmental policies.
- The overall organization of R&D in construction. This includes the links between fundamental research, applied research and development, as well as the general level of R&D, and the degree of industry-wide, common efforts. The number of major firms (design, contracting and materials manufacturing), capable of investing into R&D, is relevant as well.

Beyond these technical aspects, the development of computer integrated construction will also have to take into account the affective link between the owner and his building. This is particularly true in Europe where structures are traditionally built to last during generations.

The trend towards CIC is certainly irreversible but techniques may progress more rapidly than the acceptance by end users.

4 CONCLUSIONS AND RECOMMENDATIONS

We have endeavoured to show that the status of computer integrated construction reflects certain determinants in each country. In the framework of these determinants, both barriers and incentives to integration can be found.

Even on the basis of this analysis, certain recommendations, related to the determinants found, can be presented for the advancement of CIC in national context:
- Consider the needs for CIC, if no other, competitivity surely counts
- Focus efforts on projects and construction techniques with sufficient potential for value added by advanced technology
- Plan for the long term success (or survival) of the national construction industry
- Pool industry resources for R&D, create links between construction industry, research institutes/universities and information/automation system suppliers.

These recommendations must of course be discussed. We feel that stronger links between the main outlines of CIC in different countries and the characteristics of local construction activities have to be found. It would be important at such a precompetitive stage to go further on in order to give guidelines to international cooperation for the development of CIC.

References

Atkin, B., Bridgewater, C. & Ibanez-Guzman, J., 1989, Investigation of Construction Robotics Research in the United States. Department of Construction Management, University of Reading.

Björk, B.-C., 1989, Basic Structure of a Proposed Building Product Model. Computer Aided Design Journal, vol. 21/2, March 1989, p. 71 - 78.

Brown, M., 1989, Barriers to the application of robotics and high level automation within the United Kingdom construction industry. Proceedings of the Sixth International Symposium on Automation and Robotics in Construction. June 6-8, 1989, San Francisco.

Delcambre, B., 1989, "FARTEC: Faciliter l'Accés aux Régles Techniques du Batiment", in: CIB 89, "La Qualité pour les usagers des batiments á travers le monde", PARIS, 1989 06 19 - 23, PARIS, DIB, 1989, p. 531 - 537.

Dubois, A-M, 1989, Model-based computer aided modelling: an approach for building energy simulation improvement". Communication á "CLIMA 2000", SARAJEVO, 1989 8 - 9 27 - 01. MGL 1048, SARAJEVO, JUKO KGH, p. 279 - 284.

Hannus, M., 1990, Computer aided design of component based buildings. 9 p. Open industrialization: A solution for Building Modernization. Conference proceedings. Stuttgart, February 21 - 23, 1990.

Joly, J-M, 1986, "Vers l'automatisation des opérations de manutention sur les chantiers de construction", in: Colloque CAO et Robotique en Architecture et BTP, CSTB, GAMSAU, IIRIAM, Marseille, 25 - 27 June 1986. Paris, Hermés.

Killen, T., 1989, The cutting edge in North America. Proceedings of the Sixth International Symposium on Automation and Robotics in Construction. June 6-8, 1989, San Francisco.

Le Corre, J.J & Peyret F., 1990, "SIREM: the absolute location of civil engineering equipment", in: 7th ISARC, BRISTOL. 5 - 7 June 1990.

Mahoney, J. & Tatum, B., 1990, Barriers to CADD in the AEC Industry, Center for Integrated Facility Engineering, Stanford University, Technical Report No. 23, January.

Salagnac, J-L, Giraud Ch., 1989, "SOFFITO: un robot mobile expérimental pour les travaux de second-oeuvre de batiment, in: CIB 89, "La qualité pour les usagers des batiments á travers le monde", PARIS, 1989 06 19 - 23. PARIS, CIB, p. 575 - 584.

Sarja, A., 1989, Principles and solutions of the new system building technology (TAT). Espoo 1989. Technical Research Centre of Finland, Research Reports 662. 61 p.

Tatum, C., 1989, Design and construction automation: competitive advantages and management challenges. Proceedings of the Sixth International Symposium on Automation and Robotics in Construction. June 6-8, 1989, San Francisco.

Terai, T. & Kaneko, Y., 1988, Coding System for ACT Advanced Building Information System. CIB W74 + W78 Seminar "Conceptual Modelling of Buildings". October 1988. Lund.