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A Proposed Language, Syntax and Structure for Communication Between the Robotics and Construction Communities

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Abstract

Robotics and construction have at least one common characteristic, both are manifestly fragmented and subject to high levels of specialisation. As such, the sources of information and knowledge necessary to bridge the interface between the two communities is difficult to identify, and effecting comprehension of their technologies and cultures is problematic.

This paper outlines a collaborative project which seeks to develop a new common language, syntax and structure to enable effective communication between the two communities.

1. INTRODUCTION

The project aims to develop a synthesis between the technologies of advanced robotics, which essentially reside in the information and communications technology communities, and construction technologies, which reside in the building and civil engineering communities. At present the two communities are unable to satisfactorily effect the degree of communication and feedback which is a prerequisite of progress, and partly explains the present limited diffusion of robotics technology into construction. Once fully developed, the new common language can be exploited to evaluate the application of robotics to those basic work tasks which constitute the heart of the construction process, and to identify the changes required in the methods and procedures of construction in order to facilitate the development and extension of the robotisation of construction.

2. THE EPISTEMOLOGICAL BASIS OF THE PROJECT

The Neo-Shumpeterian theoretical concept of technological paradigms and trajectories has been taken as the general research model. Dosi et. al. (1988), propose that technologies develop along relatively ordered paths shaped by the technical properties, the problem-solving heuristics and the cumulative expertise embodied in **technological paradigms**. Each technological 'paradigm' entails a definition of the relevant problems that must be addressed, the user-demand requirements to be fulfilled, a pattern of inquiry, the material technology to be used, and the types of artifacts to be developed and improved.

The path enclosed by the upper and lower bounds of this range of user-demand characteristics is termed a **technological corridor**, within which technologies evolve (see Figure 1). Thus Freeman et al (1988) maintains that the socio-institutional framework "*... always influences and may sometimes facilitate and sometimes retard processes of technical and structural change, coordination and dynamic adjustment*". A **technological trajectory** (eg. Nelson and Winter 1977 and Dosi 1982) is then the activity of technological progress along the economic and technological trade-offs defined by a paradigm.

Within such a framework, the resultant technological and technical changes are not discrete but are grouped into *Nelson and Winter's concept of "**technological regimes** which dominate engineering and management decisions for decades"*. Their analysis closely corresponds to the **techno-economic paradigm**, an idea first advanced by Carlota Perez (1983). Her concept is one of a 'meta-paradigm'- a dominant technological style whose 'common sense' and rules of thumb affect the whole economy.

It is only when productivity along the old technological trajectories shows persistent limits to growth and future profits are seriously threatened, that the high risks and costs of adopting new technologies appear as clearly justified (see Figure 2).

3. THE CONTEMPORARY TECHNO-ECONOMIC PARADIGM

The contemporary techno-economic paradigm, which Freeman (1989) has defined as "*... predominantly based upon cheap inputs of information derived from advances in micro-electronics and telecommunication technology*", is already having a significant inpact on the rate and direction of technical change in many sectors of the economy. It is clear that the future direction of technical change within each sector, will be not only be influenced by their indigenous technological trajectories, but also by the characteristics of semi-conductor technology (Pavitt, 1966).

In construction its influence is already reflected in aspects of design and production - most notably in computer-aided design, knowledge-based design, communications, scheduling and financial control (see Figure 3). Programmable automation and robotics is the only area of this rapidly developing technology which has not significantly penetrated the industry. Many reasons for this have been postulated which mainly relate to the present technical limitations of robot control and performance, the culture and structure of the construction industry, the complex nature of its site-based tasks and the present lack of communication with the robotics community.

Robotic devices are in the earliest stages of development. Like all new inventions, their costs are high and their performance modest, especially in unstructured domains where the interpretation of the environment still poses major problems in terms of both obtaining and analysing sensor input (Davies 1991).

As well as the uncertainties and growing realism with respect to the form and future technical performance of robots, there are also uncertainties regarding the diffusion of robotics into particular domains. Whittaker (1985) argues that the different rates of diffusion among domains "*... relate more to industry motivations and economic vitality than to implementation hurdles and intellectual robotic issues*". It is also significant that although robotic devices have been applied in the manufacturing sector for more than a decade, their diffusion still fails to conform to a unique technological trajectory

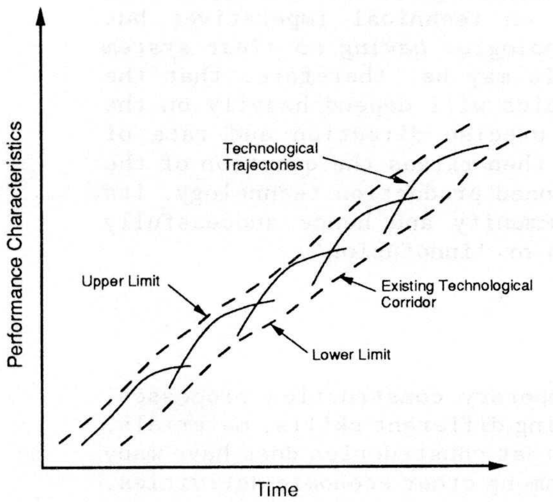

Figure 1. The Evolution of a Technological Paradigm

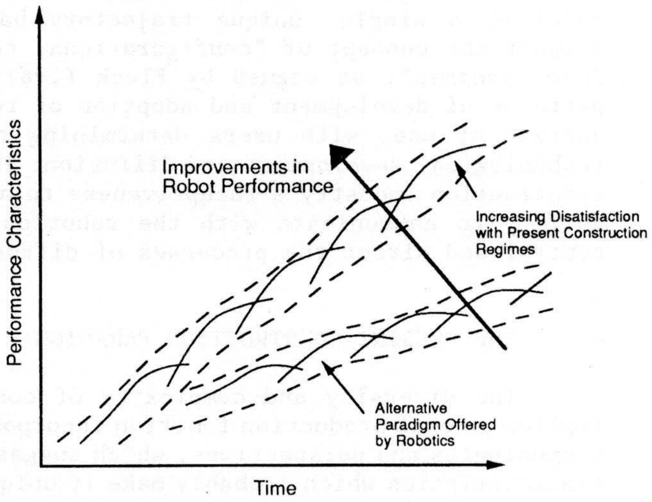

Figure 2. The Evolution of Competing Technological Paradigms

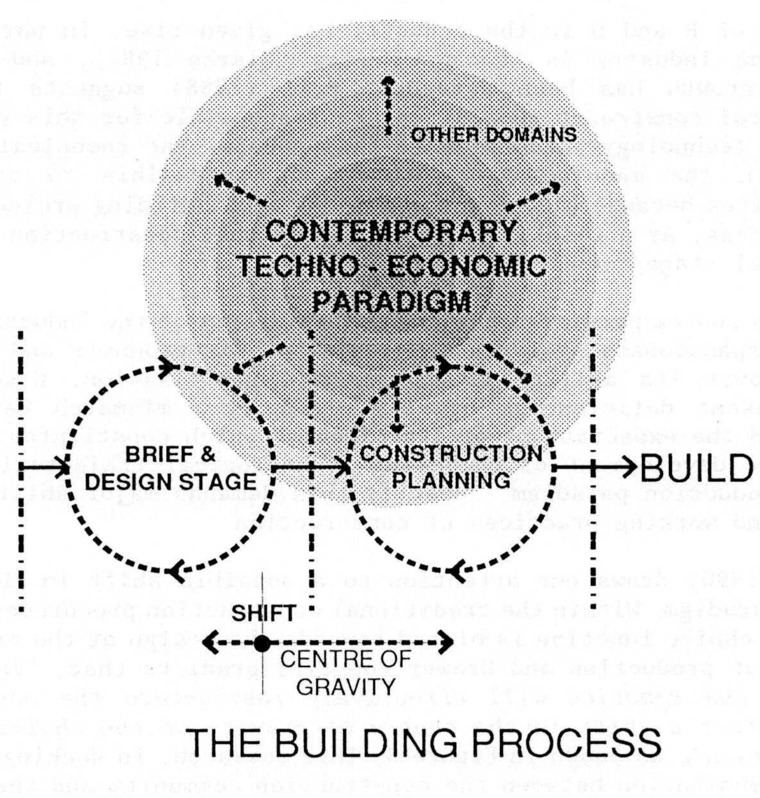

Figure 3. Diffusion of the Contemporary Techno - Economic Paradigm into the Building Process, and the Resulting Shifts in the Centre of Gravity of the Construction Process

or distinct regime (Tidd 1991). These findings challenge the Neo-Schumpeterian model of a single, unique trajectory based on technical imperatives but support the concept of *"configurational technologies having no clear system level dynamic"*, as argued by Fleck (1987). It may be, therefore, that the patterns of development and adoption of robotics will depend heavily on the context of use, with users determining the precise direction and rate of technological development and diffusion. This then raises the question of the construction industry's receptiveness to advanced production technology, its ability to communicate with the robotics community and hence successfully control and direct the processes of diffusion or 'innofusion'.

4. THE PRESENT CONSTRUCTION PARADIGM

The diversity and complexity of contemporary construction processes, implies a total production function incorporating different skills, materials, technologies and perspectives, which suggests that construction does have many characteristics which probably make it unique among other economic activities. It has been suggested, that it is this perceived uniqueness of the construction industry that contributes to its present deficiencies. A number of researchers have identified its shortcomings. For example, *"technologically stagnant"* (Business Roundtable 1982), *"fragmented"* (Barrie and Poulson, 1978), and *"negligible R and D"* (National Economic Development Office, 1985). It is perceived by its customers as being *"slow"* and *"costly"* (NEDO, 1985 and Financial Times, 7 January 1981) and delivering poor quality.

The lack of R and D in the industry has given rise, in part, to the charge that the industry is *"backward"* (eg. Clarke 1985), and that its technological growth has been retarded. Ball (1988) suggests that *"the absolute physical constraint thesis"* may be responsible for this reluctance to embrace new technology. According to this thesis, the technical advances associated with the manufacturing sector are impossible to achieve on construction sites because of the uniqueness of each building project and the production process. As a result, it is concluded that construction is doomed to technological stagnation.

This deep rooted pessimism regarding the ability of the industry to make a fresh and dispassionate analysis and review of its products and practices casts doubts over its ability to accommodate robotisation. However, the industry's present deficiencies have resulted in a mismatch between its performance and the expectations of its clients, which constitutes a growing impetus for the development of competing technological trajectories and an alternative production paradigm - even if this demands major shifts in both the products and working practices of construction.

Drewer (1990) draws our attention to a possible shift in the present construction paradigm. Within the traditional construction procurement process the technology choice function is biased towards the design of the product and not the means of production and Drewer (op cit) predicts that, *"innovations in automation and robotics will effectively restructure the construction process and effect a shift in the centre of gravity of the choice function towards production"*, as shown in Figure 3. This research, in seeking to create a means of communication between the construction community and the robotics community, aims to determine the extent of that shift, the nature of the emerging production paradigm and hence the implications for the ultimate performance of the built environment, its procurement processes and the wider community.

5. THE PROPOSED COMMUNICATION SYSTEM

Any proposed methodology for the analysis of construction operations from the perspective of automation and robotics must encompass the nature of construction work-tasks and robot attributes and performance. Definitions of construction need to be structured to accurately represent the contemporary construction industry and yet mesh with existing classical (Kuan et al, 1988), and emerging robot architectures "... *which typically amalgamates sensing and acting at low levels in the system and combines them synergistically*", (Malcolm 1989).

The first stage in the development of the proposed communication system was to undertake a fundamental review of the basis of language, an identification and evaluation of the communication and classification systems currently employed by the construction industry, and the contemporary knowledge representation languages employed in computing and artificial intelligence (Reichgelt 1991).

6. EXISTING METHODS OF KNOWLEDGE AND INFORMATION REPRESENTATION IN CONSTRUCTION

For many years the construction industry has endeavoured, largely unsuccessfully, to produce a classification, information and communication system that is appropriate for all its 'actors', sectors and professional organisations. The resulting systems have been structured to satisfy a number of functions, such as the production of project drawings and for work descriptions used in bills of quantities. In 1961 the Royal Institute of British Architects introduced the Swedish SfB system of classification, which is established internationally through the International Council for Building Research Studies and Documentation, as a common language for the UK construction industry. The CI/SfB Construction Indexing Manual, published in 1976, incorporates the UK version of the international SfB classification as it applies to project information. The Construction Industry's Research and Information Association's thesaurus, which was published in 1971, comprises both a preferred vocabulary and terminology, and the rules of language and classification which regulate the form, flow and storage of construction information. The Common Arrangement of Work Sections (CAWS), which was published by the Co-ordinating Committee for Project Information in 1987, includes about 300 work sections derived from a close observation of the current pattern of sub-contracting in the UK construction industry and which also reflects the large range of building materials, products and specialists which currently exist.

Haplin and Woodhead (1976), have identified five hierarchical levels of structure from "*Organisational*" through "*Project, Activity, Operation (and Process)*" to "*Work Task*". Everett (1990) suggests that, "*Any problem in construction requires examination of the industry at an appropriate level of detail*", and identifies nine levels of the construction industry, "... *each an order of magnitude more detailed than the previous level*".

A number of more recent studies have attempted to identify and classify construction work in relation to automation and robotics. For example, Everett's (op cit) "... *nine divisions of Industry*", Holtorf's (1987) "*physical susceptibility*", Tucker's (1988) "*automation potential*", Warszawski and Sangrey's (1985) ten "*basic activities*", Kangari and Halpin's (1989) "*robotics feasibility*" and (1990) "*implementation factors*", and Russell and Skibniewski's (1990) "*ergonomic analysis framework*".

Elements of most of these systems have been used in this study to develop specific word lists to describe the products of construction, the operations and work tasks associated with its processes and the rules of language and classification which are needed in order to structure the information and allow the flow of data between information stores.

7. THE METHODOLOGY FOR DEVELOPING THE COMMUNICATION SYSTEM

The postulation and development of new technological trajectories for construction robotics implies a diversity and complexity of skills, materials and perspectives, which present unique challenges in comparison with other areas of technological innovation and development. These skills and perspectives are to be found in the technologies of the construction industry and in the advanced scientific and technological sectors associated with the design and application of microchip technology. An essential requirement for progress is the development of a communication system capable of commanding universal acceptance across the wide range of disciplines involved.

There are a number of techniques available to enable groups of experts to communicate and to make decisions without a meeting of the participants being necessary (Stecher and Davis 1987). The approach being adopted is based on the Delphi Technique, which is illustrated in Figure 4. This is a systematic, iterative tool, which normally employs written questionnaires and cycles of feedback for developing consensus within groups.

Using a combination of existing published material, site observations, and structured interviews with a panel of experts representative of the construction community, the research team are collecting data on the products and processes of construction. The data is being structured to include contextual data on the Site and the Project, as well as detailed descriptions of Operations and Basic Work Tasks. A total of twenty-eight Basic Work Tasks have been derived which represent the current portfolio of construction technologies. These include Planning, Sorting, Identifying, Inspecting, Measuring, Grasping, Releasing, Transporting, Assembling, Positioning, Connecting, Attaching, Jointing, Casting, Finishing, Covering, and Excavating.

The Basic Work Tasks are being modelled using a variety of techniques that capture and depict the essence of construction work. 'Storyboards', video, text and photography, as well as computer simulations and animations are all being employed in the development of the models. Computer simulation has already proved its worth for both task definition and the evaluation of production systems in other domains (Pritsker and Sigal, 1983). Here, it is providing a pliable, abstract medium which allows a more symbolic representation of the real world to be constructed. In addition it has the flexibility for subsequent alteration and manipulation. Screen prints from the computer simulation depicting steel frame erection are given in Figure 5.

As well as being converted into visual images, the information is being arranged and 'translated' from the language of the construction community into the language of the communication system using its 'grammar', which in the context of this study includes the system of meanings or semantics, the rules of word formation or morphology, the rules of sentence formation, or syntax and the vocabulary of words, the dictionary or lexicon.

When developed these models will be used in the first cycle of the Delphi process (see Figure 4), to demonstrate the nature of construction work to panels of experts representing the disciplines involved in the design,

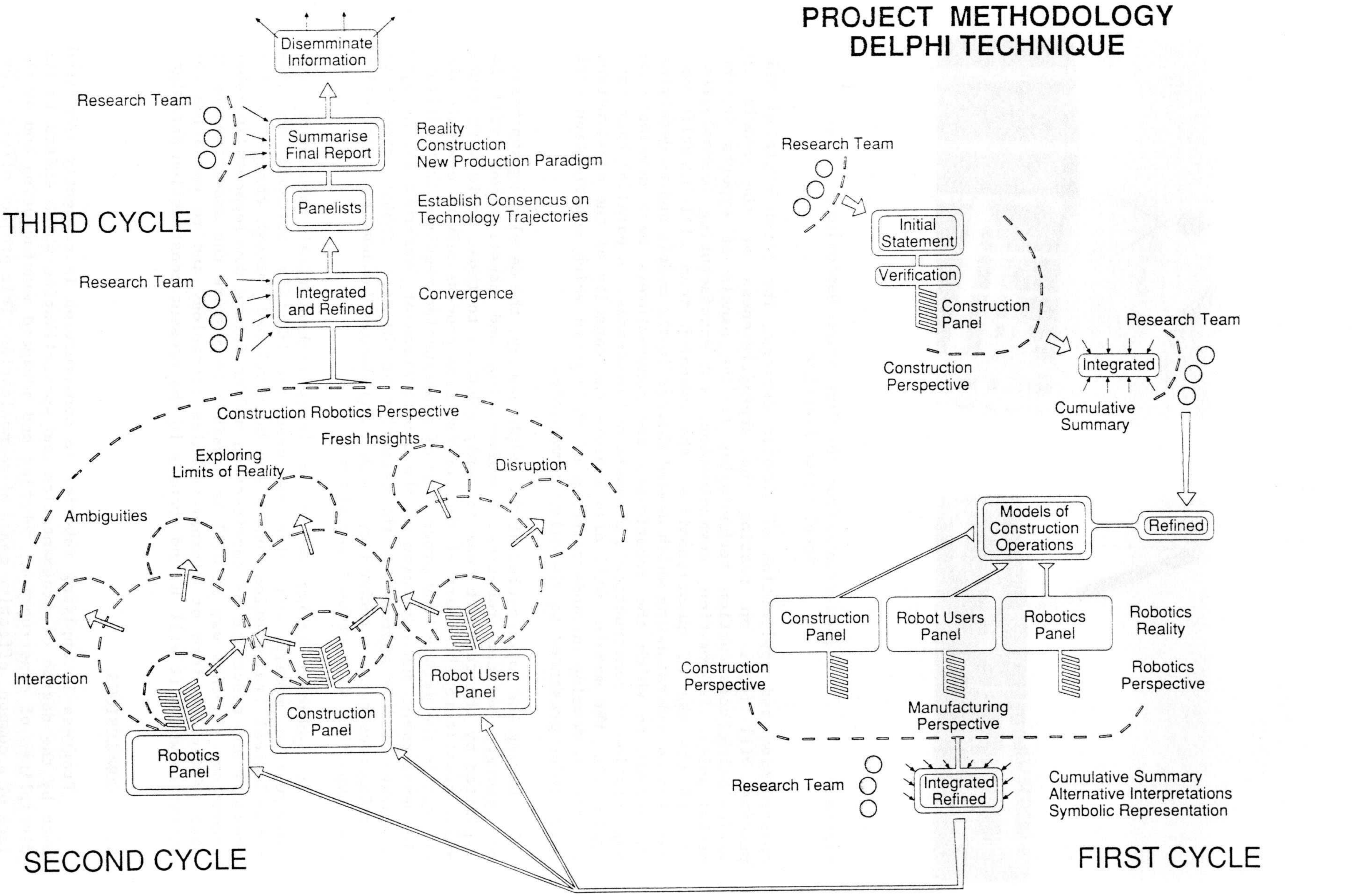
PROJECT METHODOLOGY
DELPHI TECHNIQUE
Disemminate Information
Research Team
Summarise Final Report
Reality
Construction
New Production Paradigm
Panelists
Establish Consencus on Technology Trajectories
THIRD CYCLE
Research Team
Integrated and Refined
Convergence
Construction Robotics Perspective
Fresh Insights
Exploring Limits of Reality
Disruption
Ambiguities
Interaction
Robotics Panel
Construction Panel
Robot Users Panel
SECOND CYCLE
Research Team
Initial Statement
Verification
Construction Panel
Construction Perspective
Research Team
Integrated
Cumulative Summary
Models of Construction Operations
Refined
Construction Panel
Robot Users Panel
Robotics Panel
Robotics Reality
Construction Perspective
Robotics Perspective
Manufacturing Perspective
Research Team
Integrated Refined
Cumulative Summary
Alternative Interpretations
Symbolic Representation
FIRST CYCLE

Figure 4

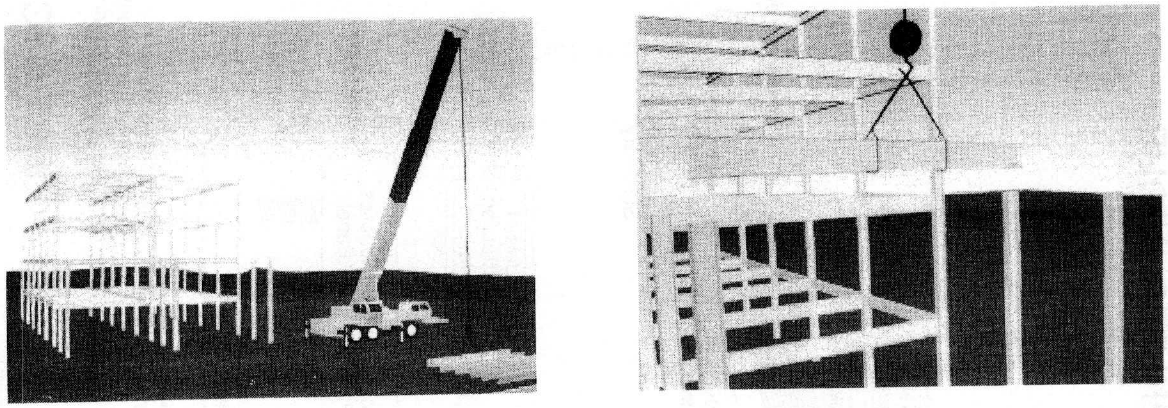

Figure 5 Screen Prints from the Simulation Depicting Steel Frame Erection

construction and application of robotic devices. The first cycle of the process will focus on testing the appropriateness of the models in articulating construction technologies to the panels of experts in the mechatronics, information, communication, and manufacturing technologies. Through the use of questionnaires, the research team will identify any barriers to understanding which demand changes in the models and to determine the extent to which the roboticists and manufacturers have developed an appreciation of construction's products and processes. A parallel exercise, again using the models, will also measure the capacity of the construction experts to develop an understanding of the way in which construction work needs to be presented to the other communities.

During the later cycles of the Delphi survey, the developing synthesis, or synergy, between robotics, manufacturing and construction, will be exploited by the research team to apply robotics to those basic work tasks which constitute the heart of the construction process and to evaluate the changes in the methods and procedures of construction required to facilitate the development and extension of the robotisation of construction. A major advantage of this approach is the retention of the more 'robust' aspects of existing construction technology, so that any changes demanded by robotisation are compatible with product performance.

If symbiosis cannot occur, or lacks technological robustness, the construction models can also be used to identify suitable enabling technological trajectories, which can be developed through changes in the products and processes of construction and/or future developments in robot technology. In this way it will be possible to measure the assertiveness of this particular form of microelectronics technology and to establish the extent to which it will demand changes in the present construction paradigm.

8. CONCLUSIONS

Progress in applying robotics to construction is currently inhibited both by the degree of fragmentation and specialisation which exists in the disciplines of construction, robotics and advanced manufacturing and by the lack of a common, effective means of communication. This project offers a new, rational and systematic method for establishing links between the construction community (and its technologies and practices), the robotics community (and its robotic devices) and the manufacturing community (and its experience of applying automation and robotics).

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