Human-machine technologies for construction sites : proceedings preparatory meeting CIB Task Group 27, 3 and 4 April 1997

Proceedings preparatory CIB Task Group 27

Human-Machine Technologies for Construction Sites

Frans van Gassel - Ger Maas

CIB Report

ISBN 90-6814-077-9

Publication 214

CIB Publication 214

Proceedings preparatory meeting CIB Task Group 27 - 3 and 4 April 1997

Human-Machine Technologies for Construction Sites

International Council for Building Research Studies and Documentation

November 1997

Frans van Gassel - Ger Maas

COLOFHON

PUBLISHED BY:

UCB University Center for Production.

Technische Universiteit Eindhoven

Eindhoven University of Technology,
Faculty of Building and Architecture,
Postbus 513,
NL 5600 MB Eindhoven,
The Netherlands.

CIB Proceedings Publication 214.
Additional copies of the proceedings available from the publisher.

CIP GEGEVENS KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Gassel, Frans van

Proceedings preparatory meeting CIB Task Group 27:
Human-Machine Technologies for Construction Sites.
Frans van Gassel en Ger Maas.
Eindhoven: UCB, Universitair Centrum voor Bouwproductie,
Technische Universiteit Eindhoven.

ISBN 90-6814-077-9

Trefwoorden: bouwkunde: congresverslagen, bouwplaats, bouwmaterieel, mens-machinesystemen: congresverslagen

PREFACE

The CIB Programme Committee at its meeting in October 1996 decided to terminate some working commissions and to take new activities.
The Secretary General, Dr. Wim Bakens, has asked me to prepare a proposal for a new CIB activity focused on international exchange and collaboration in the area of Small Scale Automation on Construction Sites.

On April 3 and 4, 1997, the preparatory meeting is held in Eindhoven to start a new Task Group. These proceedings report the results of the meeting.

The CIB Programme Committee decided during its meeting on 5th May 1997 to establish this Task Group under number 27.

The goal of this new Task Group TG27 is to structure the discussions on the items that are dealing with advanced production on the construction site. It is planned to do this in strong co-operation with the industry (world wide) as we are used to do this in the University Center for Building Production (UCB) in Eindhoven on Dutch level.
Special the Human related questions, the Machine developments and the relation between them, are very interesting. The Human mind and the Machine power together can make the future of site work less dangerous and more attractive and deliver a better quality on the building projects.

Eindhoven, November 1997.
Ger Maas,
co-ordinator TG27.

This is one of the five new Task Groups set up at the last Programme Committee Meeting in South Africa in May 1997.

CIB Members have already been notified and invited to nominate representatives.

Introducing the Coordinator

Leading TG27 is Ger Maas. He is Professor of construction engineering and management at the Eindhoven University of Technology in The Netherlands.

Also he is a Member of the Board of several Dutch research institutes (including the SBR Stichting Bouwresearch and the Dutch School for Advanced Studies in Building). Prior to taking up his academic position he was head of the research and development department at the construction company Strukton Groep N.V. His projects include the 1985 renewal of the Concertgebouw, Amsterdam and the 1988 Rail Road Tunnel under Schiphol Airport. Currently Prof. Maas is an advisor for construction for several companies. His publications include Production in building (1991), Designing the construction process (1992), Influence of construction on building waste (1993) and Partnership: it works (1994). This latter publication explains the cooperation in research with the industry by founding the Institute UCB (University Centre for Building Production). It is a joint venture between Eindhoven University and the 12 largest construction companies for projects and knowledge transfer.

What is the Mission for TG27?

Professor Maas sees an important objective of this new Task Group as being to structure the discussions on the items that are dealing with automation, mechanisation and robotisation of site-activities. It is planned to execute this in strong cooperation with the industry (worldwide) as is done in the UCB Eindhoven (see above). Of especial interest is the balance between the Human related questions and the Machine-developments and their mutual relationship. The Human-mind and the Machine-power together can make the future of site work less dangerous and more attractive, and deliver enhanced quality of the building projects.

Contact Address

Professor Ger Maas
Professor of construction engineering and management
Eindhoven University of Technology / UCB (University Centre for Building Production)
P.O. Box 513, 5600 MB Eindhoven
Tel: +31.40.247 2373
Fax: +31.40.243 4248
E-mail: g.j.maas@bwk.tue.nl
TG27 site: http://www.tue.nl/tg

CONTENT

APPENDIX

1. PREPARATORY MEETING

1.1 TENTATIVE SCOPE

The area is Small Scale Automation (and Mechanisation) on Construction Sites. This means applications of worker/equipment technologies in relation with topics as work preparation, site layout, transportation, construction waste handling, logistics and measurement on the construction site. These technologies are for instance hand hold equipment, ergonomics, drives, manipulators, machine controls and remote controls. The activity areas of the Task Group will complement the activities of the IAARC/ISARC (see Appendix C).

1.2 TENTATIVE OBJECTIVES

The tasks of the group for the coming two years are:

1. To make a 'state-of-the-art' report on developments with the Task Group areas. This report will describe:
   - The different applied technologies per country or/and culture.
   - The institutes with their research programs which are involved in the area of the Task Group.
2. To make a prognostication of the developments in the future.
3. To draw up a plan for a new CIB Working Commission.

The program, consisting of the report, the prognostication and the plan, will be determined at a meeting in 1999.

1.3 PROGRAMME

The programme of the meeting was:
- Investigation topics of the scope.
- Discussion.
- Investigation study objects.
- Discussion.
- Planning.

1.4 PARTICIPANTS

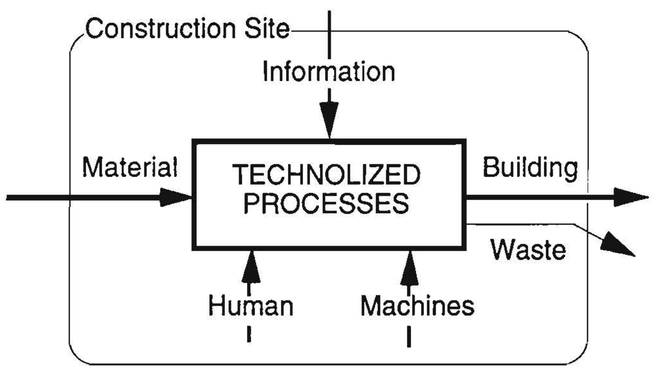
The following people participated the preparatory meeting:
Dr. Wim Bakens, CIB Secretary General
Denis Chamberlain, City University London
Ir Annelise de Jong, Delft University of Technology
Ir Frans van Gassel, Eindhoven University of Technology
Hannu Koski, MSc Tech, VTT Building Technology
Prof ir Ger Maas, Eindhoven University of Technology
Prof. Dr.-Ing R. Schach, Technische Universität Dresden
Dr. Robert D. Wing, Imperial College London
Dr ir Wim Schaefer, Eindhoven University of Technology

1.5 RESULTS

The investigation of the topics of the scope and study objects are listed in Appendix A. There are also made headings of it. See for this result Appendix B.
The result of the meeting is reported in table 1.

Table 1 Results preparatory meeting

CIB TG27 version 24 October 1997

Title	**Human-Machine Technologies for Construction Sites**
Coordinator	Prof ir Ger Maas Eindhoven University of Technology Faculty of Building and Architecture Department Construction Engineering and Management Netherlands
Secretary	Ir Frans van Gassel Eindhoven University of Technology Faculty of Building and Architecture Department Construction Engineering and Management Postbus 513 NL 5600 MB Eindhoven, Netherlands Telephone: +31 (0)40 247 40 77 Fax: +31 (0)40 243 42 48 E-mail: F.J.M.v.Gassel@bwk.tue.nl
Objectives & Scope	In the scope of this Task group the emphasis is on the application of technolised processes on construction sites and includes both the input factors: materials, humans, machines and information and the output factors: buildings and waste.  [Poortman, 1996] Within the indicated scope, the task group's objectives are to stimulate and facilitate international information exchange and collaboration between experts who are working in the area of industrial technologies for construction sites, the application of which is aimed at: - avoiding hazardous work, - improving the quality of work, - shortening production time, - improving productivity and/or - sparing the environment. TG27 strives for establishing an official relationship with IAARC.

Work Programme	The defined projects for the period 1997 - 1889 are: - Project 1 To make an International Status Report, which will include: i) the different applied technologies per country or culture and ii) the institutes with their research programmes in the respective area. Coordinators are: Prof. ir Ger Maas, ir Frans van Gassel, Eindhoven University of Technology, The Netherlands. - Project 2 To make an International Best Practice Report, with an analyses of how far Tool Handling Systems have been developed. Coordinator: Mr. Denis Chamberlain, City University, London UK. - Project 3 To do a Bench Marking Study on Technologies for Transportation of Construction Materials Coordinator: Mr. Robert Wing, Imperial College of Science, London, UK.
Meetings	After ISARC15 (30 March and 1 April 1998) in Munich. In this week also the BAUMA 98 is held.
Publications	Preparing Proceedings workshop april 1997 in Eindhoven Content: - structure and results workshop - work programme - related papers - members Task Group with their research institutes
Home Page	http://www.tue.nl/tg/
Relations	- W99 Safety and Health on Construction Sites - International Association for Automation and Robotics in Construction IAARC - International Symposium for Automation and Robotics ISARC - W24 Open Industrialization in Building - TG16 Best Practice for Sustainable Construction
Titled Members	Prof ir Ger Maas, coordinator, Eindhoven University of Technology, Netherlands Ir Frans van Gassel, chair, Eindhoven University of Technology, Netherlands
Members	Ir Annelise M. de Jong, Netherlands School for Advanced Studies in Construction, Netherlands Denis Chamberlain, City University, London, United Kingdom Hanu Koski, Msc Tech, VTT Building Technology, Tampere, Finland Univ - Prof Dr-Ing Rainer Schach, Technische Universität Dresden, Germany Dr Robert Wing, Imperial College of Science, London, United Kingdom Prof Dr-Ing/Univ Tokio Thomas Bock, Karlsruhe University, Germany Prof Dr-Ing. Wolfgang Poppy, Otto-von-Guricke-Universität, Magdeburg, Germany Univ-Prof Dr-Ing Manfred Helmus, Bergische Universität, Wuppertal, Germany Prof Dr.Gerhard Schmitt, ETH Zürich, Switzerland Prof Dr-Ing habil Günther Kunze, Technische Universität Dresden, Germany Joergen Nielsen, Danish Building Research Institute, Denmark Dr Ronnie Navon, Technion, Israel Carl Haas, PE, PhD, University of Texas at Austin, United States of America Ir Ronald Krom, TNO Bouw, Delft, Netherlands Ir F.J.M. Scheublin, HBG, Netherlands Dr A.D.F. Price, Loughborough University, United Kingdom Prof Dr B. Norton, University of Ulster at Jordanstown, Northern Ireland Mr L. Mao, Architecture & Building Research Institute, Taipei, China Mr J.R. Crawford, CSIRO, Highett, Australia Dr Y. Rosenfeld, Israel Institute of Technologie, Israel A. Stevens, BRE - Building Research Establishment Ltd, Garston, United Kingdom
CIB PC Liaison	Ir J.J. de Bruijn, SBR - Foundation for Building Research, The Netherlands
External Liaison CIB with IAARC	Mr. Hanno Koski, Msc Tech, VTT, Finland

2. HOME PAGE TG27

Internet adress: http://www.tue.nl/tg

TG27

Human-Machine Technologies for Construction Sites

- Objectives + Scope
- Workprogramme + meetings
- Coordination and secretary
- Mailing List.
- Links to other sites
- (September 24, 1997)

I am interested in the activities of this taskgroup, please enlist me as a prospective member

Last modified at Sep 24 14:25:45 1997

Comments about these web-pages may be send to Frans van Gassel: f.j.m.v.gassel@bwk.tue.nl
These pages are designed by Robert F. Lamping

3. RESEARCH PROGRAMMES MEMBERS

3.1 PAPERS

The following programmes are enclosed in this proceedings.

- Construction Robotics and Automation - A review of UK research.
  Robert D. Wing, Imperial College of Science, London, United Kingdom.

- Activities and projects of the department for automation in construction at University of Karlsruhe.
  Thomas Bock, Prof. Dr.-Ing./Univ. Tokyo.

- Construction Robotics Unit (CRU).
  D.A. Chamberlain, City University, London, United Kingdom.

- Information Technische Universität Dresden.
  Institut für Baubetriebswesen,
  Univ.-Prof. Dr.-Ing. Rainer Schach.

- Programme design of the Eindhoven University of Technology,
  Department of Construction Engineering and Management,
  Prof. ir. G.J. Maas.

Construction Robotics and Automation - A review of UK research.

Robert D Wing, March 1997

Research and development activities in the United Kingdom are mainly grouped around two funding opportunities, these being support from the UK government, and support from the European Union (EU). Thus it is important to examine both the European and the U.K. settings and their interactions.

1. Construction - a review of European R & D activities.

Ranging from major civil engineering projects to domestic refurbishment, construction constitutes the largest manufacturing industry sector in the EU, being responsible for 10 - 12% of GDP, or 25% of all of all manufacturing.

Europe has few major construction companies; those with a turnover exceeding 1 billion ECU number about 45, and the largest have less than 5% of their national construction market. Relative to major US or Japanese companies, many of which operate in Europe, these are small operators. In fact, most of the 2.7 million enterprises in Europe are very small; 97% employ less than 20 staff, and 93% less than 10. This, together with low spending on R&D, accounts for some lack of progress in operational concepts, processes, technologies (including automation and robotics), and the use of IT.

Another distinctive factor in Europe is the low replacement rate for buildings (2%), resulting in a substantial refurbishment market, and a curious juxtaposition of the evolution of new construction methods against the continued requirement for traditional techniques. Nevertheless technological changes are now making a significant impact on the industry, the arrival of automation being most visible in the software area.

It is important to recognise the specific priorities that the European Union is giving to research activities in the construction sector in its funded R&D programmes. The characteristics of the European construction industry affect its innovative capacity.

In particular:

leading construction companies are committed to technological development, but this is mostly carried out in institutions where the focus is more on standardisation and testing than innovation.

1 there are enormous regional variations in construction techniques across Europe due to materials availability, climate, etc., which tend to impede technology transfer and adoption of best practices.
2 mobility of construction workers is limited within Europe, due to local ties, hence there is poor continuity of the work-force. This is especially serious as the range of individual skills required of workers is very high and warrants substantial training.
3 the market tends to be led by the suppliers rather than the users (or purchasers), thus priorities in market demands are not fully exploited.

The European Commission=s response attempts to strike a balance between the demands to increase competitiveness (cost reductions, performance improvements, and better satisfaction of customers= needs) and wider issues, including care for the environment, and improvement of quality of life for society in general. A major part of the environmental thrust is focussed on energy consumption of buildings; for building owners, energy costs represent only a small part of financing and running costs and it is difficult for them to justify investing in energy-efficient features.

The following themes summarise the European Union=s R&D activities which respond to the issues above:

Reduced costs	Costs reduction across the whole building life cycle, including planning, design, construction, maintenance, and maintainability.
Improved performance	Performance improvement of new and existing structures through better materials, fire and earthquake resistance, evaluation tools, use of I.T.
Satisfying customer needs	Concurrent engineering, project management, and logistics.
Care of the environment	Improvement of transport, distribution and communications infrastructures. Whole system improvements, including energy efficiency, exterior and interior environments, indoor air quality, reduced pollution and waste.
Quality of life	Restoration and conservation of European cultural heritage, effects of mass tourism, inner-city problems.

Future directions for European Union funded research recognise that although parts of the industry are highly innovative, and innovative research is going on, the fragmented structure and conservative nature of the industry means that a strong effort is required, particularly in the areas of technology transfer and adoption of best practices.

An initiative is under way to establish a Construction Task Force (funded by the European Union) under the name 'City of the Future'. The focus will be on urban issues, particularly on energy and environmental aspects of construction, transport, and telecommunications. At the time of writing this is moving forward, but representatives of the initiative are seeking to broaden its remit beyond energy related issues, to include construction processes, materials, and sustainability.

2 Construction Automation R & D activities in the U.K.

This decade's major industrial recession has had a particularly heavy impact on the construction sector, and has brought about a structured approach to research and development aimed at bringing the industry into line with other engineering sectors, and setting targets for cost reductions.

Important milestones have been the report by Sir Michael Latham, *Constructing the Team*, a new government funding scheme, *Construction as a Manufacturing Process*, and the setting up of a research centre concerned with information technology issues, *Construct IT*. These reports and programs indicate current research priorities in the U.K. and are summarised below:

The Latham Report

This far-sighted 1994 report is best known for its declaration that a *productivity target of 30%* real cost reduction in the industry by the year 2000 should be launched.

The report also calls for adoption of *best practice*, and the government is seen to have a lead r^le to play in achieving this.

Principles are called for upon which *modern contracts* can be based - a complete family of interlocking documents is required.
Quality must form a visible part of the criteria for evaluation of tenders, and quality registers of approved firms should be maintained.

Partnering arrangements, and *Codes of practice* for clients, and for the selection of subcontractors etc. are also called for.

The Latham report was effective in sparking off a number of initiatives to translate its recommendations into tangible actions designed to break the mould of an industry that was desperately clinging to the ways of old.

A direct result of the Latham recommendations is the *Innovative Manufacturing Initiative* launched by the Engineering and Physical Sciences Research Council (EPSRC), a major government funding body for industry and universities. The construction sector is targeted by the AConstruction as a Manufacturing Process@ programme, which operates within a business process framework to take account of the need to address business operations as well as the application of new technology. The programme has identified four leading research themes:

Identifying client needs for the future. Development of solutions to better understand client needs, to improve their satisfaction.

Integration of the project process, including re-engineering of the construction process, supply chain management, use of advanced information technology to enhance integration, co-ordination of activities within the process, time compression, and development of design support tools to facilitate integration.

Enhancing value through improved quality and productivity. Development of knowledge, techniques and best practice for improving the process of construction.

Creating a culture for improvement. Understanding and promoting a culture which encourages innovation, team-working, learning and commitment to shared goals for the whole construction process.

Notable in the context of this review is the emphasis on soft issues.

Construct I.T.

The U.K. government's Department of the Environment (DoE) has set up the Construction Sponsorship Directorate which aims to act as an interface and to develop a partnership with the construction industry to improve its competitiveness.A key enabler of this strategy is the formation of AConstruct I.T.@, a Centre of Excellence based administratively at the University of Salford. The Centre is an industry-led network of construction industry companies, universities, research institutes, institutions, and trade associations; its purpose is to co-ordinate their work in construction I.T. research and development.

The Centre has been appointed to implement the DoE=s strategy for I.T. in the construction industry, which has three main elements:

establishment of construction project databases within an integrated communication framework.

establishment of an integrated, industry-wide, on-line information facility that can be accessed by all sectors of the industry.

immediate use of I.T. to improve specific elements of the construction process itself.

Current achievements of the Centre include :

(i) establishment of a database of ongoing research projects on the World Wide Web (WWW), which can be searched and updated by any organisation wishing to make its research known to members of the Centre. (http://www.salford.ac.uk/docs/depts/survey/centex/homepage.html)

(ii) publication of a series of Benchmarking Best Practice Reports on various aspects of the construction process. By addressing each of the underlying issues in such an awareness generating exercise, these reports can be used as a vehicle for stimulating technology transfer. This is achieved through a shared experience of best practice in both the construction industry and other industry sectors with which construction might be compared.

B.A.A.R.C. and I.A.A.R.C.

I.A.A.R.C., the International Association for Automation and Robotics in Construction, is well known to researchers in this field. The organisation publishes regular newsletters, and organises an annual international conference, the I.S.A.R.C. (International Symposium on Automation and Robotics in Construction). The secretariat for I.A.A.R.C. is at the Building Research Establishment (BRE) in the U.K.

B.A.A.R.C., the British Association for Automation & Robotics in Construction was established in 1991 to provide a forum for researchers in the U.K., and is linked to the international body, I.A.A.R.C.. B.A.A.R.C. seeks through its membership to:

Promote UK research and development into the practical, cost effective use of automation and robotics in construction.

Encourage and advise the UK government, the EU and industry on the funding of R & D into automation and robotics for construction.

Provide a UK interface to the international association IAARC, and to other organisations, institutions, and the EU.

Provide a publication resource through Elsevier's 'Automation in Construction' journal. Members receive this publication; it is also the vehicle for members' own publications.

BAARC is undergoing reorganisation to become an Internet Club. Details on the home page: http://forth.cv.ic.ac.uk/baarc.html

3 Examples of UK R & D projects in Construction Automation and Robotics

The projects introduced in this section are a selection chosen by the author, and may not give a balanced representation of the construction automation research scene in the United Kingdom. They cover the whole field of automation in its broadest sense - communications, soft automation, and automation/robotics hardware.

BICC - ACTS Projects for the Construction Sector

The EU is giving an , 8M boost to the development of communications and IT for the construction sector, and the UK communications group BICC (which includes a major construction company, Balfour Beatty) is leading two projects in this area (CICC and RESOLV), and is a major partner in a third (MICC).

The construction sector has begun to change from being a follower to a leader in Communications and IT and is now viewed as a major new market for these technologies. This is primarily due to the current advances in mobile and video communications and in 3D modelling which are highly relevant to the industry.

The new projects follow up the successful RACE 2 **BRICC project (BRoadband Integrated Communications for Construction)** which ended in 1995; they are funded under the EU's new ACTS programme. (Advanced Communications Technologies and Services). BRICC helped to introduce the construction industry to the potential of new communications services and the new projects will further advance the use of multimedia communications and on-line access to project data.

MICC, Mobile Integrated Communications for Construction is the largest project, and is led by the major French contractor, Bouygues. Bouygues has recently gained approval for Bouygues Telecoms, the second telecommunications operator in France with a cellular network to the DECT standard. Balfour Beatty is the only UK participant in MICC. They will be assembling a prototype "Communications Container" that will be the first item to arrive at a construction site and the last to leave. The container will provide a complete range of mobile communications services for all site staff, including cellular telephones, walkie talkies, mobile computing and mobile video.
[MICC Partners: Bouygues, BICC/Balfour Beatty, Dragados, ETDE VDI, Hochtief, Hochtief Software , Institut Cerda, Fraunhofer Institut , Universitat Politencia de Catalunya, VTT Technical Research Centre.]

RESOLV, (REconstruction using Scanned Laser and Video), will develop a mobile robot known as the EST, Environmental Sensor for Telepresence, that will undertake a 3D survey of a building, including capturing the appearance of the visible surfaces. This information can be used to construct VR models for the visualisation of refurbishment and maintenance projects and for displaying 3D interiors on the World-Wide Web.
The RESOLV model can also be used to provide a 3D user interface for Facilities Management. This will speed up learning the layout of the building and enable new and temporary staff to make faster, more informed and better decisions, particularly in times of crisis.
[Resolv Partners: BICC/Balfour Beatty, INESC , IST , JRC , Leeds University , Robosoft.]

CICC (Collaborative Integrated Communications for Construction) is very much an integrating project, showing how technologies such as 3D CAD, mobile communications and reconstruction technologies together with video from the site can provide every member of the team with on-line access to project activities and information.
All three projects will implement trials, a number of which will be undertaken within the UK. [CICC Partners: BICC/Balfour Beatty, Bechtel, Bovis, Brunel University , BT , ECRC , Europroject SA, Institut Cerda, Ove Arup, Telefonica.]

Five Dimensional Project Modelling (Taylor Woodrow Management Ltd.)

This advanced object modelling system is an in-house development of Taylor Woodrow, and is representative of current advances in unifying the multiplicity of software packages used in construction projects from design through to cost management. A key element to this software is the capability of building time and cost attributes onto the model, effectively as fourth and fifth dimensions.

The underlying modeller is by Reflex Systems, and uses object-oriented code C++. The system combines design and engineering analyses, 2D drafting and 3D modelling into one totally integrated software package. Results from specialised analytical software can be imported directly into the model, and as pure object oriented principles are used, any additional data can be attached to the model elements. The model can also export data through direct links to existing programmes for project management.

Powerful tools for the production of photo-realistic images and interactive walk-throughs are included, and for construction planning, it is possible to assign dates to each of the model elements and run a construction sequence from start to finish, complete with time and cost information.

Clearly, integrated software of this nature allows interaction between all parties involved in the construction process, helping to achieve goals of cost, time and quality predictability and zero defects. Further benefits include: design optimisation for >volumetric build=; use of the model for hazard studies for compliance with safety regulations; assessment of access and tolerances; scheduling of materials using >just-in-time= principles; and use of the model for training of the workforce.

The system has been used on a number of high profile projects, including refurbishment of the Royal Albert Hall, development schemes at several UK airports, and feasibility studies for London Underground.

Teleoperated wall-climbing robot - Robug III
(University of Portsmouth Robotics Group / EU Teleman Programme)

The construction industry has identified wall-climbing robots as a priority, especially for inspection/refurbishment operations, but has been unable to fund development of these.

However, as robots developed for nuclear inspection have proved their potential, interest from other industries has followed, and the powerful machines resulting from the EU Teleman programme have obvious applications in the construction sector.

The latest in a series of wall-climbing machines from Portsmouth University is the compact and powerful >Robug III=, a large mobile lightweight carbon fibre vehicle having eight tri-linked legs, each containing four joints, and a central low-slung body, the conception being based on aspects taken from the spider and crab families.

Each articulated leg has an hybrid mechanical/vacuum gripper for wall climbing. The vacuum feet are fitted with flexible seals which can deal with irregular surfaces, and the latest design is able to hold a weight of 100kg. A redundant joint is included on each limb for climbing and crossing various surfaces and at the same time keeping the robot body close to the ground.

Currently the device is able to walk and grip on vertical surfaces in a semi-autonomous manner. Research continues on this project, aiming at improvement of the walking speed, and realisation of its full design potential, being the ability to:

drag loads of 100 kg horizontally while walking with a 25 kg payload.
4 drag loads of 100 kg vertically while climbing with a 25 kg payload.
5 perform floor-to-wall and wall-to-roof transfers, and
6 clamber over obstacles.

The CIMsteel project. (EU - EUREKA programme)

CIMsteel is a major EU project concerned with Computer Integrated Manufacture of Constructional Steelwork; it involves more than 70 organisations in nine European countries. The project seeks to improve the competitiveness of the industry in world markets, to produce improved and economic steelwork structures, to improve design, manufacture and construction times, and to unlock the potential for growth in the steel work market.

The industry consists of many small and medium-sized companies, which could benefit from transformation into a state-of-the-art integrated manufacturing industry, capable of competing with alternative construction materials and with overseas competition.

Improved computer integrated manufacturing will streamline the flow and improve the quality of information during the life cycle of a structural steelwork project. Project partners are developing advanced product model and information exchange standards, integrated design procedures, design aids, and compliant software. >Best Practice Guidelines= are being prepared to optimise designs for manufacture, automation, and construction, with particular reference to best practice in other industries.

One of many projects associated with CIMsteel is ASurebuild@, a panel house frame system that uses cold-rolled steel framing. The U.K. has not used steel housing systems to the same extent as most other countries, and two commercial systems, Surebuild and Gypframe, are developing this technology and its market. Surebuild is produced by British Steel Framing, a subsidiary of British Steel, and Gypframe from British Gypsum Ltd is a housing application to complement their widely applied Metframe range of steel superstructures for commercial buildings. Such systems are particularly well aligned to the concept of construction as a manufacturing process; they rely on accurate factory manufacture of all components to achieve the benefits of speed of erection, predictable high quality, and near-zero defects.

The kit-of-parts approach lends itself to a high level of factory automation; current production processes utilise direct links between the CAD design system input and the automated rolling and punching lines. There is enormous potential for developing the capabilities of such systems, both in terms of their dimensional limits (currently at three storeys), and especially in the development of automation for the components delivery and site assembly processes.

City University refurbishment projects (City University - University of London)

The Construction Robotics Unit at City University is currently engaged on robotics projects for the building inspection and repair sector. Repair work has particular characteristics which are generally distinct from new-build, including hazards to health and life, prolonged task repetition, and poor working conditions. Man-machine systems, rather than autonomous robot solutions, are seen as the way forward to improve this situation, and to enhance quality and productivity. The research concentrates on patch-repair strategies for steel surfaces and for reinforced concrete.

Steel Structure Restoration
Steel bridges, land based storage tanks, and refinery storage represent an enormous maintenance responsibility, as structural failure can produce a major catastrophe. Steel coating restoration has, until recently, involved complete removal and replacement of coatings. Patch repair strategies offer substantial savings, however, and there is much interest in paints requiring minimum surface preparation, i.e. surface tolerant high-build epoxy paints. Such techniques offer a chance for automated application, but first require innovations in automated NDT methods for assessment of the condition of the steel and its coating, and automated solutions for the safe and effective delivery of the coating restoration on these structures.

Reinforced Concrete Restoration
Similarly to the above work, the decay problem in reinforced concrete buildings and other structures requires innovative robotic solutions to both the NDT and repair delivery systems. Over the past decade, much effort has been put into solutions to wall climbing; the practical results have, however, mostly fall short of the practical needs of the construction industry. Research at City University is concentrating on (I) remote NDT methods for concrete condition assessment, (ii)closed loop control of the hydro-erosion method for concrete preparation, and (iii) automatic placement methods in patch repair, based on the use of suspended access equipment.

Lancaster University Computerised Intelligent Excavator (LUCIE)
(University of Lancaster / EPSRC)

LUCIE is a modified JCB801 mini excavator. The original hydraulic equipment has been replaced by Danfoss electro hydraulic proportional valves, and the operator replaced by three compact PC104 computer systems. Navigation is achieved using a satellite global positioning system (GPS) allowing a positional accuracy to within 25mm, and a new scanning laser is used to detect collisions.

System Architecture: Control of the excavator relies on three PC104 computers, each computer being responsible for a separate task: Low Level Control; Activities Management; and Safety Management. Communication between the computers is provided by CAN-Bus (Controller Area Network) a robust communications protocol developed within the automotive industry.
The Low Level Controller is responsible for driving the valves and tracks by commands either issued by the joysticks or other processors. It also accepts inputs from the various potentiometers giving positional feedback.

The Activities Manager is responsible for planning of activities and navigation. It is connected to the GPS navigation system, and compass.

The Safety Manager ensures that the machine remains in a safe stable condition; it is connected to a laser scanning sensor for detection of obstacles.

Future developments of LUCIE will include:

Extension of CAN-Bus to incorporate all sensors.
Development of linking task planning to CAD drawings.
Research into underground obstruction sensors.
Further development of safety systems.

Automatic Positioning System (APS) for Piling Rigs

(University of Lancaster / Stent Foundations Ltd / EPSRC)

Both bored and driven large-diameter piled foundations are now commonly constructed using fully hydraulic piling rigs, as opposed to the more traditional crane-mounted technology. Fully hydraulic rigs provide an opportunity for the addition of enhanced automatic control.

In 1994 Stent Foundations Limited launched their SAPPAR system, which utilises a GPS receiver with antenna mounted at the top of the rig mast (the extra height gives optimum receiver performance even when working in relatively congested urban sites), a two-axis verticality sensor, a flux-gate compass for rig orientation, and a PC computer in the cab.

The system software guides the driver of the rig towards the designated pile with a bulls-eye type target. Once within 500mm using the vehicle tracks, the driver carries out final positioning using hydraulic actuators to control the mast, resulting in positioning to within 25mm. The system has been proved effective under site conditions and current research aims to further develop the system by automating the final mast positioning, i.e. to set the mast vertically and within the required positional tolerance.

Twin PC104 processors separate the positioning and the rig control tasks, and a 1/5th scale model of the rig was constructed in the laboratory for testing purposes. The model uses a pseudo-GPS system which simulates GPS data reception indoors.

Automatic control presents many safety issues, hence rather than relying on software, the interface card between the PC104 stacks and electro hydraulic driver cards has several hard wired safety features built in:

* Fail-safe if power is lost (valves returned to neutral positions)
* Return to manual control if the joysticks are touched.
* Timeout feature in case software crashes or communications lock up.
* External tilt sensor to return rig to manual control if tilt limit is reached.

A full-size working prototype is currently being tested using the same control principles developed on the model. Future work will include automation of the piling process itself, and using the computer in the cab for logging site data, and for linking directly into CAD.

Thomas Bock
Professor für Automatisierung im Baubetrieb an der Universität Karlsruhe

Activities and projects of the department for automation in construction at the university of Karlruhe.

1989 (Construction Automation Div. is being founded):

Development of a gantry robot for the assembly of customary form stones.

Development of a modular robot control system.

Foundation of the Steinbeis Transferzentrum *"Robotics and Automation in Construction"* with support of the ministry of trade and commerce.

1990:

Development of a control system for an AGV.
Integration in the CAD/CAM-Program of Baden-Württemberg.
Project: CAD/CAM applications in construction.

1991:

Study for a Japanese firm producing building machinery: potential for automation of construction in Western Europe.
Further development of the gantry robot system for prefabrication.

1992:

CAD/CAM project for prefabrication
Aquisation and beginning of the European research project ROCCO: development of a semi-autonomous mobile building assembly robot.

1993:

ROCCO - Robot Assembly System for Computer Integrated Construction
CAD/CAM
Research assignment from the Allgemeine Industrieforschung AIF: Development of a building construction system for the automatic assembly of stones without binder.

1994:

ROCCO - Robot Assembly System for Computer Integrated Construction
CAD/CAFM for automated maintenance of exterior walls.
Tower Crane automation project

1995:

Software Laboratory: Virtual building site project

CAD/CAFM, ROCCO

1996:

Teleoperation of 3 robots via satelite from Karlsruhe to Tokio

ROCCO, CAD/CAFM

1997:

Final presentation of ESPRIT III „ROCCO“ (Robotic Assembly System for Computer Integrated Construction) project

Rationalization of conventional masonry systems and Automation for low cost housing study

CONSTRUCTION ROBOTICS UNIT (CRU)

http://www.city.ac.uk/~sc366/
D.A.Chamberlain@city.ac.uk
0171.477.8144 (Lab)
0370.500.431 (Mobile)

CITY UNIVERSITY, LONDON EC1V OHB

CRU MISSION

The application of automation and robotics to construction processes for the improvement of productivity, quality, health and safety, environmental protection and the social profile.

PERSONNEL

- ***Denis Chamberlain*** (Civ. Eng), Senior Lecturer & Head of Unit: Mechanisation of Construction Industry Processes (Inspection, NDT, Maintenance and Repair).
- ***Robert Edney*** (Mech Eng.), Lecturer: Control Theory and Design of Mechatronic Systems.
- ***Alastair Paterson*** (Elect Eng), Post Doctorate Researcher: Electronics Engineering and Image Processing.
- ***Graham Bleakley*** (Mech. Eng.), Research Assistant: Mechatronic System Design and Development
- ***Shereen Akrawi*** (Comp. Sc), Post Graduate Researcher: IT and Robot Programming
- ***Caterina Alves*** (Civ. Eng), Post Graduate Researcher: Finite Element Modelling and NDT
- ***Andrew Bates*** (Civ. Eng.), Research Assistant: IT, Internet and Multi-Media Development

ACTIVITY & SERVICES

The CRU is a research provider. It is part of the Structures Research Center, which is based in the Department of Civil Engineering, City University. In the most recent national Research Selectivity Exercise, the Department was rated as 5, the highest possible score.

The Unit operates on a multi-disciplinary basis and is thus able to provide services in a number of fields. Its outputs include prototype mechatronic hardware, engineering software, computer models and simulation, finite element analysis, reports and externally published papers. Apart from its own capability, it has close links with research groups working in complementary fields. These offer additional expertise in areas such as photogrammetry and laser measurement systems.

The Unit has recent and current projects with DOE, HSE and DTI. In Europe, the Unit is a full partner in both a Brite EuRam project and a CRAFT project. Other partners are industrial organisations based in the UK, Germany, Sweden, Greece, France, Spain and Portugal. The CRU is currently involved in a proposed Euro-Japan study on advance building technology (IMS).

The research currently addresses the following application areas:

- Remote inspection of tall RC buildings (CURIO Robot)
- Remote control of defective concrete removal by hydro-erosion (CURER Robot).

- Design methodology for safety critical mechatronic systems
- Remote inspection and coating removal for steel bridges
- Human-Machine Interface (HMI) design
- Modelling and neural network interpretation of Impact Echo systems
- Location of a building inspection robot by image processing
- A masonry tasking robot cell

We anticipated that the unit will increase its activity in the areas of (i) mechanisation of inspection and maintenance of building and structures, (ii) software tools supporting reliability and safety in mechatronic system design (microprocessor based electrical-mechanical equipment), (iii) mechanisation of structural concrete patch repair and (iv) Internet and Multi-Media services and systems for the construction industry.

A list of recent reports and publications produced by the CRU is attached.

RECENT REPORTS AND PUBLICATIONS

1. D.A.Chamberlain, G.A.West and P.R.S.Speare, 'A masonry tasking robot', Journal of Mechatronics Systems Engineering, Kluwer Pub., The Netherlands, December, 1990

2. D.A.Chamberlain, 'Developments in construction robotics', Symposium on Construction Automation, Reading University, March 1991

3. D.A.Chamberlain, 'Two advisory expert systems for structural engineering', 1st Symp. on Expert Systems In Struct. Eng., I Struct.E.,1991

4. D.A.Chamberlain and S.Blake, 'An advisory expert system for trenching works', Proc. 3rd. East Asia-Pacific Conf. on Structural Engineering, Shanghai, June 1991

5. D.A.Chamberlain and P.R.S.Speare, 'Progress in a masonry tasking robot', Proc. 8th International Symposium on Automation and Robotics in Construction, Stuttgart, Germany, July 1991.

6. Ellis, R Hung and D.A.Chamberlain, 'A colour vision facility', Proc. 3rd. International Conf. on Systems Engineering, Coventry, August 1991, TA7/1

7. D.A.Chamberlain, An advisory expert system for structural applications, 1st Seminar on Practical Design Applications of Expert Systems', The Institution of Structural Engineers, London, June 1991.

8. S.R.Ala and D.A.Chamberlain, 'An efficient boundary data structure for integrated CAD-CAM', Robotic and Factories of the Future, Elsevier, August 1991.

9. S.R.Ala, D.A.Chamberlain and T.Ellis, 'Real-time inspection of masonry units', Proc. of 4th Conf. on Image Processing and its applications, Belgium, April 1992.

10. D.A.Chamberlain, 'A remotely operated building inspection cell', International Journal of Automation in Construction, Elsevier, May 1992.

11. D.A.Chamberlain, 'A rebar detection robot', Proc. of 9th. International Symp. on Automation and Robotics in Construction, Tokyo 1992.

12. D.A.Chamberlain et al, 'Masonry construction by an experimental robot', Proc. 9th International Symp. on Automation and Robotics in Construction, Tokyo 1992

13. T.C.K.Wong and D.A.Chamberlain, 'Essential factors in the automation of building inspection', Proc. 9th. International Symp. on Automation and Robotics in Construction, Tokyo 1992.

14. A.McCrea and D.A.Chamberlain, 'Towards the development of a bridge inspecting automated device, Proc. 10th. International Symp. on Automation and Robotics in Construction, Texas, Pub. Elsevier Netherlands May 1993.

15. D.A.Chamberlain, S Akrawi & J Watson, 'Path Planning and sensing for an experimental masonry building robot, Proc. 10th. International Symp. on Automation and Robotics in Construction, Texas, Pub. Elsevier Netherlands May 1993.

16. G.J.Bleakley and D.A.Chamberlain,'NDT tasking robot for concrete and steel structures', Mechatronics and Machine Vision in Practice, Pub IEEE Computer Society, CA USA. Sept. 1994.

17. A.M.Paterson, G.R.Dowling and D.A.Chamberlain, ' Identifying key features in a building using a single uncalibrated camera', Proc. 11th. International Symp. on Automation and Robotics in Construction, Pub. Elsevier, Netherlands, May 1994, pp657-663

18. A.M.Paterson, G.R.Dowling and D.A.Chamberlain, Locating a building inspection robot on a tower block using visual methods', Proc. 3rd. International Conference on Automation, Robotics and Computer Vision. IES, Singapore, November 1994

19. D.A.Chamberlain and G.J.Bleakley, 'CURIO NDT robot for the construction industry', Industrial Robot, Vol. 21, No.4., Pub. MCB University Press, 1994

20. D.A.Chamberlain, 'Enabling technology for a masonry tasking robot', Industrial Robot, Vol. 21, No. 4., Pub. MCB University Press, 1994

21. D.A.Chamberlain, 'A remotely operated building inspection cell', Advanced Robotics, The International Journal of the Robotics Society of Japan, Vol.6. No.5, Utrecht, The Netherlands, 1994

22. D.A.Chamberlain, Chapter 43: A robot for masonry construction, Building the Future, Edit F.Garas. Pub E & FN Spoon, 1994, pp 439-449

23. A.M.McCrea and D.A.Chamberlain, Worker Safety and Environmental Protection in Automated Steel Bridge Restoration, Automation & Robotics in Construction XII, Edit. E.Budny, A.McCrea & K. Szymanski, Pub. IMBiGS, Warsaw, Poland, June 1995, pp27-38

24. A.M.Paterson, G.R.Dowling and D.A.Chamberlain,'The science and engineering of robot location', 5th International Congress on Image Processing, IEE, IPA, Edinburgh, July 1995 pp 692-696

25. R.Begum and D.A.Chamberlain Integrity testing of concrete structures using Neural Networks, Int. Symp. on Non-Destructive Testing in Civil Engineering (NDT-CE), BAM, Berlin, September 1995, pp1339 1347

26. J.C.Alldred, J.Chua and D.A.Chamberlain, Non-destructive testing in civil engineering, Int. Symp. on Non-Destructive Testing in Civil Engineering (NDT-CE), BAM, Berlin, September 1995, pp721-729

27. D.A.Chamberlain and A.N.White, 'Improving the bridge restoration process through automation', Proc. International Conf. on Bridges into the 21st Century, HKCEC HK, Hong Kong Institution of Engineers, October 1995.

28. D.A.Chamberlain, Construction robotics at City University: Prospects for inspection & repair, Waseda Construction Robot Research International Workshop, Pub. Waseda University, Tokyo, June 1996, pp 61-68

29. D.A.Chamberlain, R.Edney & G.Bleakley, Robotic handling of Gamma sources in site radiography of steel storage tanks, the 13th ISARC, Proc. Int. Sym. on Automation & Robotics in Construction, Pub. Japan Robot Association, Tokyo, Japan, June 1996, pp213-222.

30. D.A.Chamberlain, Robotics and automation in building maintenance and repair, Chapter 4, Working at Height, The Institution of Civil Engineers, Edit M James, Pub. Thomas Telford. UK., 1997 (to be published)

TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Bauingenieurwesen

Institut BBW

Institut für Baubetriebswesen

Univ.-Prof. Dr.-Ing. Rainer Schach

Ausgabe April 1997

Besucheradresse: (ab Mai 1997)	Nürnberger Str. 31a 01187 Dresden
Postanschrift:	Mommsenstr. 13 01062 Dresden
Telefon: Telefax:	0351/463-4242 0351/463-4680
E-mail:	schach@rcs.urz.tu-dresden.de
Internet:	http://www.tu-dresden.de/biw/bbw

Das **Institut für Baubetriebswesen** (Institut BBW) wurde 1954 gegründet und ist damit eines der ältesten im deutschsprachigen Raum. Die Schule des Baubetriebswesens am Institut BBW war und ist geprägt durch eine komplexe Betrachtungsweise Bauwerk - Bauverfahren - Bauorganisation/Baumanagement und Baubetriebswirtschaft.

Die **Lehraufgaben** im Grundfachstudium (4.-6. Semester) beinhalten die Grundausbildung „Baubetriebswesen" und „Bauverfahrenstechnik" für alle Studenten des Bauingenieurwesens.
In einer eigenständigen Studienrichtung „Baubetriebswesen" werden am Institut BBW pro Studienjahrgang ca. 30 Studenten im Vertiefungsstudium (7.-9. Semester) ausgebildet. Das Lehrprogramm dafür ist auf der Folgeseite ersichtlich. Wesentliche Ausbildungsbestandteile sind das Projektsemester (Okt.-Dez. im 9. Semester) sowie die Diplomarbeit, wobei eine eine enge Kooperation mit der Praxis angestrebt wird.

Die **Forschung** des Instituts BBW ist anwendungsorientiert ausgerichtet und offen für alle Lehrgebiete des Baubetriebswesens (siehe Lehrprogramm). Derzeit erkennbare Schwerpunkte in diesen Fachgebieten liegen

- im Management von Baustellen und Unternehmen einschließlich durchgängiger EDV - Anwendung,
- im Facility Management von baulichen Objekten,
- in der Optimierung von Bauverfahren unter Einbeziehung intelligenter Bautechnik,
- in einem Projekt zur Multimedia -Anwendung im Bauwesen.

Professuren des Instituts BBW:

Professur für Baubetriebswesen

Univ.-Prof. Dr.-Ing. Rainer Schach

Univ.-Prof. Dr.-Ing. Rainer Schach nahm am 01.10.1996 den Ruf an die TU Dresden an und ist seit 01.01.1997 als Direktor des Instituts BBW tätig. Er studierte an der Universität Stuttgart Bauingenieurwesen. Berufstätigkeit in Südafrika und Kanada, wiss. Mitarbeiter bei Prof. Drees in Stuttgart. Tätigkeit im internationalen Kraftwerksbau. Zuletzt 12 Jahre bei der mittelständischen Bauunternehmung G.Dreßler & Sohn, anfangs verantwortlich für Organisation und EDV, danach 6 Jahre Leiter der Niederlassung Rastatt.

Professur für Baumechanisierung und Bauverfahrenstechnik

Univ.-Prof. Dr.-Ing.habil. Johannes Schindler

Univ.-Prof. Dr.-Ing.habil. Johannes Schindler studierte an der damaligen TH in Dresden, er ist ein Schüler von Prof. Lewicki, dem Begründer des Instituts BBW. Berufstätigkeit im Kraftwerks- und Industriebau der Lausitz und im Raum Dresden; wiss. Mitarbeiter bei Prof. Ludwig in Dresden, tätig als Oberassistent und Dozent in mehreren wissenschaftlichen Gremien; 1991-1996 Leiter des Instituts BBW, seit Juni 1992 berufener Hochschullehrer.

Professur für Bauvorbereitung und Baubetriebswirtschaft

N.N.

Lehrprogramm:

Studiengang Bauingenieurwesen	Lehrkraft
• **Grundfachstudium**	
Baubetrieb 1 / 2 / 3 — Einführung in die Bauwirtschaft und in das private Baurecht, Grundlagen des Rechnungswesens und der Kalkulation, Arbeitsvorbereitung, Einführung in das Controlling und das Qualitätsmanagement	Prof. Schach
Bauverfahrenstechnik 1 / 2 — Grundbegriffe einschließlich Baumechanisierung, Einsatz von Hebemaschinen; Grundlagen der Verfahrenstechnik im Erdbau, Betonbau, Montagebau, bei Abbruch und Recycling	Prof. Schindler
• **Vertiefungsstudium Studienrichtung Baubetriebswesen *)**	
Pflichtfächer	
Bauverfahrenstechnik	
– Erdbau	Dr. Kämpfe
– Betonbau	Dr. Dobbelmann
– Versorgungsprozesse	Dr. Überla
Bauautomatisierung	Prof. Bulgakow, Dipl.-Ing. Kanelberg
Baumanagement	Prof. Schach, Dr. Kämpfe
Bauvorbereitung und -organisation	
– Arbeitsvorbereitung	Prof. Schach
– Rechtsfragen des Baubetriebs	RAin Jagenburg
– Bauvertragsabwicklung	RAin Jagenburg
Baubetriebswirtschaft	Prof. Schach
Baubetriebsrechnung	Prof. Kloß
Wahlfächer (Auszug)	
Rechnungswesen im Planungsbüro	Prof. Jäger
Spezialmontagen	Prof. Schindler
Finanzwesen im Bauunternehmen	Prof. Kloß
Vorfertigungstechnologie	Dr. Dobbelmann

Lehrveranstaltungen außerhalb der Fakultät Bauingenieurwesen zu Grundlagen des Baubetriebswesens werden in folgenden Studienrichtungen angeboten

Architektur
Landschaftsarchitektur
Wasserwirtschaft
Wirtschaftsingenieurwesen

*) Der Entwurf eines strukturell und inhaltlich geänderten Lehrangebotes wurde an der Fakultät Bauingenieurwesen eingereicht.

Forschungsschwerpunkte:

Am Institut BBW werden zur Zeit folgende Forschungsthemen bearbeitet:

(1) **Modellierung und Simulation von Bauprozessen auf der Basis stochastischer Petri-Netze**
Projektleiter und
Bearbeiter: Dipl.-Ing. Kantelberg
Laufzeit: 1992 - 1997
Beschreibung komplexer Bauvorgänge und deren Modellierung mit stochastischen Petri-Netzen, Erweiterung eines Petri-Netz-Simulationssystems zur rechnergestützten Modellierung und Simulation

(2) **Adaptive Greifer- und Hubgeräte für Baumontagearbeiten**
Projektleiter: Prof. Schindler
Bearbeiter: Dipl.-Ing. Bulgakowa
Laufzeit: 1994 - 1997
Methodologien und Bauprinzipien für die Entwicklung adaptiver Greifer und Erarbeitung von Anwendungsempfehlungen

(3) **Rechnergestützte Baustelleneinrichtung**
Projektleiter: Prof. Schindler
Bearbeiter: Dipl.-Ing. Töpfer
Laufzeit: 1995 - 1997
Rechnergestützte Kostenoptimierung der Baustelleneinrichtung unter Berücksichtigung der verfügbaren Bauzeit bei Einhaltung bestimmter Randbedingungen (gültige Vorschriften u.a.)

(4) **Benchmarking im Facility Management**
Projektleiter: Prof. Schach
Bearbeiter: Dipl.-Ing. Flemming
Laufzeit: 1996 - 1999
Analyse von Möglichkeiten zur Kostensenkung in der Phase der Gebäudebewirtschaftung im Rahmen einer lebenszyklusorientierten Sichtweise, Anwendung von Benchmarking-Methoden im Bereich Gebäudemanagement

(5) **Kostenentwicklung im Wohnungsbau**
Projektleiter und
Bearbeiter: Dr. Sperling
Laufzeit: 1995 - 1998
Ausgeführte Projekte des Hochbaus und der Sanierung werden nach Kostenursachen und Kostenstrukturen untersucht, um Anwendungsempfehlungen und Prognosen ableiten zu können

Als Gemeischaftsprojekt mit der BTU Cottbus (Univ.-Prof. Dr.-Ing. Petzschmann) und der Universität Dortmund (Univ.-Prof. Dr.-Ing. Blecken) wird zur Zeit die Thematik **Multimedia im Baubetriebswesen** bearbeitet.

Die 1996 am Institut BBW bearbeiteten Themen der Diplomarbeiten sind im Internet unter *http://www.tu-dresden.de/biw/bbw* zu finden.

Mitarbeiterinnen und Mitarbeiter des Instituts BBW:

Neben den Professoren sind am Institut tätig:

Hochschullehrer

Dozent Dr.rer.oec.habil. Wolfgang Sperling diplomierte 1967 an der TU Dresden als Dipl.-Ing.oec. für Bauwesen, danach Assistent, 1970 Promotion und 1975 Habilitation zur Kostenentwicklung im Wohnungsbau, 1969-74 Tätigkeit in der Baupraxis, u.a. als Projektleiter und Kaufm. Direktor. Ab 1974 wieder an der TU Dresden, Leiter des Bautechnischen Konstruktionsbüros, seit 1979 Hochschuldozent für Planungsgrundlagen, Bau- und Planungsökonomie.

Wissenschaftliche Mitarbeiterinnen und Mitarbeiter

Dr.-Ing. Hansgünther Dobbelmann diplomierte 1962 als Bauingenieur an der TU Dresden, danach 14 Jahre tätig im Kraftwerks- und Industriebau in der Bauausführung, Bauvorbereitung und Forschung, speziell im Betonbau; 1979 Promotion an der TU Dresden, seither Lehr- und Forschungstätigkeit mit Praxisbezug auf dem Gebiet der Schalungs-, Bewehrungs- und Betonarbeiten.

Dipl.-Ing. Ingo Flemming hat an der TU Dresden studiert, anschließend Trainee-Programm in den Bereichen Arbeitsvorbereitung, Kalkulation und Bauleitung, seit 1996 wieder am Institut mit dem Forschungsschwerpunkt Facility Management.

Dr.-Ing. Klaus Kämpfe ist Absolvent der Hochschule für Verkehrsbau (HfV) Dresden, nach der Tätigkeit als Bauleiter wiss. Mitarbeiter (Forschung Eisenbahnbau) und Oberassistent an der HfV, seit Oktober 1992 wiss. Mitarbeiter in der Funktion des geschäftsführenden Oberassistenten am Institut BBW, seine Fachgebiete sind der Erdbau und das Baumanagement.

Dipl.-Ing. Antje Kantelberg studierte in Leipzig, ihre Forschungsschwerpunkte liegen im Bereich der Automatisierung und angewandten Informationsverarbeitung im Bauwesen sowie in der Modellierung und Simulation von Bauprozessen.

Dipl.-Ing. Regina Töpfer studierte Bauingenieurwesen an der Uni Stuttgart, danach in der Arbeitsvorbereitung und Bauleitung, anschließend als wiss. Assistentin an der Uni Stuttgart und der TU Dresden tätig, jetzt Forschungsschwerpunkt Baustelleneinrichtung.

Sonstige Mitarbeiterinnen und Mitarbeiter

Herr Helmut Böhme - Ingenieur für Forschung und Lehre

Frau Helga Nitsche - Technische Zeichnerin

Frau Elke Zirnstein - Institutssekretärin

Dipl.-Ing. Irina Bulgakowa - Aspirantin aus Rußland

Gast- und Honorarlehrkräfte im Studienjahr 1996/97:

	Lehrfach
Professor Dr.sc.techn. Alexej Bulgakow Universität Nowotscherkask, Rußland	Bauautomatisierung
Professor Dr.-Ing. Wolfram Jäger Planungs- und Ingenieurbüro Jäger Radebeul	Rechnungswesen im Planungsbüro
Rechtsanwältin Inge Jagenburg Rechtsanwaltskanzlei Jagenburg, Sieber, Mantscheff Dresden / Köln	Rechtsfragen des Baubetriebes Bauvertragsabwicklung
Professor Dr.rer.oec.habil. Siegmar Kloß Dresden	Baubetriebsrechnung
Dipl.-Ing. Gerhard Lomb Bauberufsgenossenschaft Bayern / Sachsen	Grundlehrgang Sicherheitstechnik
Dr.-Ing. Frank Schellhorn Ingenieurbüro Schmid Dresden	Bauleitung des Planungsbüros
Dr.-Ing. Alfred Überla Dresden	Technologie der Versorgungsprozesse

Gastvorträge von Vertretern verschiedener Planungsbüros und Bauunternehmen werden den Studenten als Ergänzung oder im Rahmen von planmäßigen Lehrveranstaltungen angeboten.

Das Institut BBW (bzw. Mitarbeiter) sind in folgeneden **Fachgremien** vertreten:

- Deutscher Betonverein
- Forschungsvereinigung Bau- und Baustoffmaschinen im VDMA
- Deutsche Gesellschaft für Projektmanagement (GPM)
- VDI
- Verband Deutscher Betoningenieure - VDB

Hinweis: Das Institutsfaltblatt gibt den aktuellen Stand per April 1997 wieder. Aktualisierte und teilweise detailliertere Angaben können den Homepages im Internet unter *http://www.tu-dresden.de/biw/bbw* entnommen werden.

PROGRAMME DESIGN EINDHOVEN UNIVERSITY OF TECHNOLOGY DEPARTMENT OF CONSTRUCTION ENGINEERING AND MANAGEMENT

Prof. ir G.J. Maas.

The programme is concerned with Construction Engineering and Management and Building Techniques. The objective of Construction Engineering and Management research is to improve the quality of the construction process.

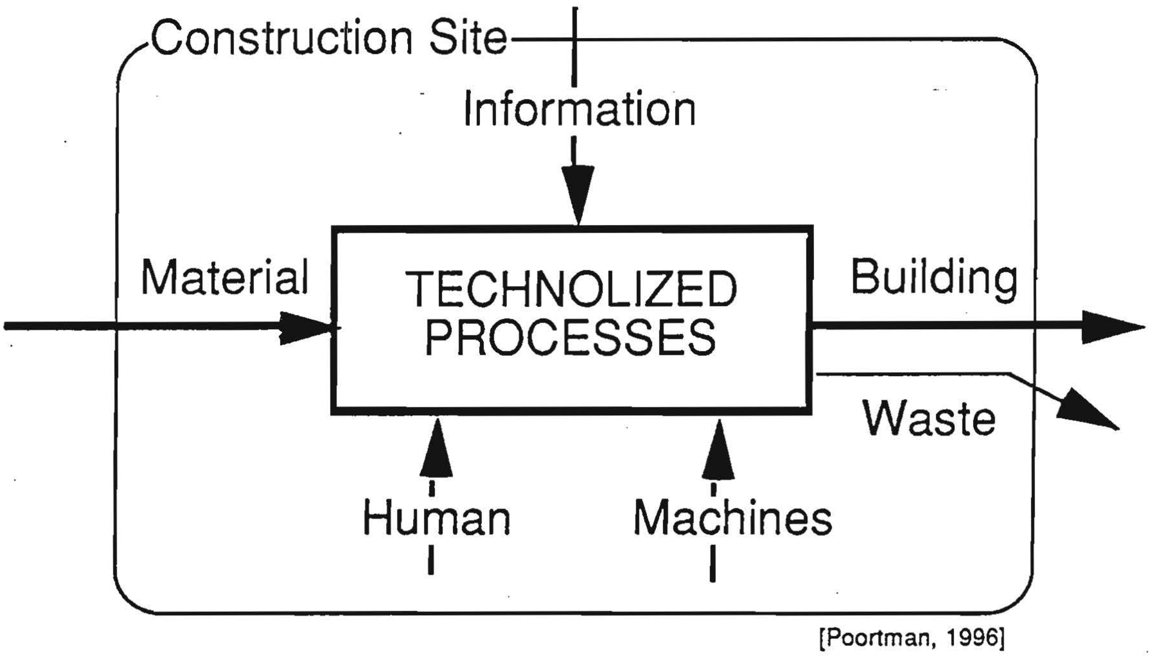


Figure 1 Basic scheme of the Construction Process with its main elements.

The mission in the research of Construction Engineering and Management is to obtain quality improvement of the construction process by focusing on two elements of the basic scheme of figure 1:

1) the human-machine technology

This aspect concerns the responsible use of production labour, equipment and materials. The studies on labour and mechanisation aim to develop instruments, techniques and methods to contribute to sustainable production systems. Sustainable production systems are closely related to working conditions (the quality of labour). The essence of a sustainable production system is the way in which personnel can work safely and without adverse effects on health, i.e. sustainably. The gradually rising age of the working population also necessitates the further development of the current production systems.

2) the information and communication technology

As cooperation in this industry is largely based on projects, it is necessary to develop models for management methods and communication structures which are independent of projects, based on the cultural aspects of cooperation and the risks of these projects to participants. Incomplete information, the lack of accepted definitions and agreements and undefined information management are problems impeding the greater use and development of information and communication technology. In complex projects, it is essential that the participants cooperate through electronic networks in which all use the compatible databases. It is important that not just the management of the database is arranged, but also who is responsible for each aspect of developing the plans for the construction project.

Topics in human-machine technology

Labour

The objective of this theme is to develop working methods and means of production that result in safe and healthy labour systems for production on site. Social and technical factors such as legislation, public sector insurance against illness and disability, training, experience, supply and demand, working conditions, collective labour agreements. conflicts and increasing automation and mechanisation lead to complex interactions. Current and future designers of the building process need to understand these interactions. Within the viewpoint of this objective, the essence of a sustainable production system is the way in which personnel can work safely and without adverse effects on health. Based on the developments for "methods" and "means", the aspect plan "Labour", as one of the parts for the generic Construction Plan, is provided. In relation to social and technical actualities three subjects for this research theme are addressed: production systems according to flexible labour systems, methods for establish a required safety culture and methods for participative ergonomic developments of innovations.

Building methods

In relation to labour and mechanisation and to the use of materials in building, the choice of the proper building method for a certain situation is based on a mixture of variables. This research aims to identify these variables and understand their relationships.

Mechanisation

The research concerns the optimisation of tools, the use of drives and guides, control equipment, remote control and simple computer applications.

Topics in information and communication technology

The design and management of the construction process

The preparation of the construction process is a design assignment in which product data are transformed into process data (Construction Plan). The Construction Plan comprises aspects plans and scenarios to manage the construction process. This research focuses on the development of tools and structures to support the analysis, draft definition and development of the design assignment. The results of the research will be included in a work planning manual. This will focus on selecting the most appropriate construction method and the coordination and consolidation of information. The research on management structures in the construction industry covers responsibilities, developments, and the management of electronic databases in which all those involved in the construction process share a common building project database.

Logistics

The construction of a building is accompanied by many movements of the means of production, labour, equipment and materials. To use labour and equipment effectively and efficiently on site, the right materials, of the appropriate quality and in the required quantity, have to be in the right location at the right time. The logistics research covers the control of the flow of material to ensure that the operatives always have the materials they require. Again, information and the distribution of information are core issues. This research aims to improve the control over the flow of building materials, i.e. to improve the planning and management.

Dimensional control

The research in dimensional control is focused on the control of tolerances in building, which exist during the building process or are caused by deflextions of building parts during use of the building. The negative consequences of tolerances are minimized. The dimensional control in the construction industry study will focus on the streamlining of the information in CAD drawings, from the architect to the total station. The objective is to come to effective agreements on dimensional information on working drawings and the management of this information.

The objective of the Building Techniques aspect of the research programme is to apply this general framework to building techniques. Through analysis of historical techniques, new options are generated and assessed. In addition, new building products are developed. This knowledge and expertise is applied to problems of renovation and sustainable building.

Future of topics in human-machine technology

General

The Board of the Faculty has decided in March 1997 to split the Department in two: Building Technology and Construction, Engineering and Management. Moreover, Prof. Henket and Prof. Westra will move to the Department of Architecture. As a result, the research activities will also be repositioned.

Labour

Three threads in the programme of this topic refer to improving health issues in the construction industry. Two of these threads focus on developing construction production systems. The emphasis will mainly be on the physical workload. The third thread is focused on chemical exposure. The research and research projects which follow these threads were defined as follows:

1 production systems and the climatic conditions in the Netherlands
2 building production systems and the physical capacity of site personnel
3 the chemical composition of materials used on site and the health of site personnel

Two research threads were defined in relation to safety:

4 research on the safety culture in building companies
5 research on risk management in building companies

Mechanisation

The future research in this field in focused on the use of the equipment and labour in a desired proportion by the (re-)design of the production processes on the construction site. Specific topics are the use of labour friendly equipment, equipment for sustainable construction, the development of interactive computer simulation programs to optimise the choice of equipment, and the development of equipment and building products.

Building methods

A structured approach should be followed when determining the most suitable building method to ensure that all relevant arguments are considered. The research on building methods aims to provide a widely accessible documentation system on Construction Methods, containing the tools needed to determine the best possible options. The model-based approach to the storage and processing of the large volumes of data, be it technical, financial or managerial, is most important during both the work planning and the construction period. Information (i.e., expertise) and the flow of information will have to be studied in greater detail to facilitate further automation. Futere activities involve the documentation of construction methods to provide the tools to arrive at the best possible choices, in both qualitative and quantitative terms. An important aspect will be the development of standardised connection details of construction elements and preferred detail, to facilitate construction.

Future of information and communication technology

Design and management of the construction process

The main elements of the future manual for the design of construction plans will be the plan and the information management tools. The doctoral research on the use of systems in the design of construction processes aims to develop the requı management tools. The elements of the construction plan will provide the basis for links between the information in the various component plans. The contents of construction concepts and the plans used on site can then be linked next. The develc

steps in the design of construction plans will be attuned to the required information structure.

The comparison of problems relating to interstate work in Europe and the USA is carried out in cooperation with Harvard Graduate School of Design (Boston, Massachusetts). A proposal has also been drafted for a dissertation study in the SOBU framework in cooperation with the Management and Strategy section of the Business Management Faculty of KUB. The objective of this study is to increase the understanding of the potential risks in envisaged building projects and to assesses these on the basis of the quality structure of the actors to be involved in the construction process.

Dimensional control

In 1996, a doctoral research project was started on the transfer of digital information from CAD drawings to electronic measuring instruments on site. The location and dimensions of building elements are increasingly determined on site using electronic instruments such as 'total stations'. In theory, the digital information used for setting out and positioning could be derived by electronic means from the CAD drawing which are now made for almost all construction projects of any significance. However, there are no agreements and systems to automatically include the data required for efficient and forward looking dimensioning in CAD files. This research may lead to both a system for the most effective use of sophisticated measuring instruments on site and extensions to CAD systems which automatically provide the required information on the basis of agreements or an expert system.

Logistics

In the engineering industry, distribution centres are currently used to handle supply and storage issues. Distribution centres provide the interface between the supply and delivery of materials. By providing such an interface, control of the flow of materials is facilitated. Distribution centres may be managed by manufacturers or trading companies. Additionally, specialised physical distribution companies, sometimes referred to as Public Warehouses, are being set up. This refers to the contracting out of all aspects of physical distribution, including stores management, stock management, transport, etc. Concepts and models to guide these processes will be developed.

Future of building techniques

As part of a separate programme, one of the first activities will be to search for a new chair. Of course, the specific background of the chair will have a major impact on the research direction. It is to be expected, however, that renovation, sustainable building, building production technology and building product development will remain the areas of research.

Societal/technological relevance

The construction process is affected by changes in society. There are significant developments in information and computer technology which demand that the expertise and information in the field is clearly structured and managed. The positions of and cooperation between the actors in the construction process are changing and, on the site, working conditions ('quality of labour') are becoming more important in our society. The number of building materials and products and the functionality of computers and CAD programmes continue to increase. This is one of the reasons for the increasingly varied geometry of building projects. These changes also lead to a shift in the tasks and responsibilities in the construction process and affect construction engineering, the deployment of new means of production and the application of new methods. More and more information and expertise has to be exchanged between the participants. Therefore, valid structures for communication are required.

The status quo of safety and health on the construction site is rather low in comparison to other branches of industry. Studies for the European Framework Directive indicated that many accidents on the sites were due to the design of the construction process. The stress on the operatives on the building site is high. Also, the average age of the operatives is rising and they increasingly want greater flexibility in setting out their worklives. Society is less and less prepared to accept that productivity and a high level prosperity are founded on illness and accidents due to poor working conditions. Profound analysis of human machine systems on construction sites must provide new technology and working methods.

3.2 HOME PAGES RESEARCH INSTITUTES OF TG MEMBERS

Institutes of TG members	Home page
City University, London, United Kingdom.	http://www.city.ac.uk/~sc366
VTT, Building Technology, Finland.	http://www.vtt.fi./rte/cmp/index.html
Technische Universität Dresden, Germany.	http://www.tu-dresden.de
Imperial College of Science, London, United Kingdom.	http://www.ic.ac.uk
Universität Karlsruhe, Germany.	http://www.-imb.bau-verm.uni-karlsruhe.de/index.html
Otto-von-Guerick-University, Magdeburg, Germany.	http://www.uni~magdeburg.de/~ifsl.ifsl.html
University of Wuppertal, Germany.	http://www.uni-wuppertal.de/fb11
ETH Zurich, Switzerland.	http://www.ibb.baum.ethz.ch http://www.arch.ethz.ch
SBI, Danish Building Research Institute, Denmark.	http://www.sbi.dk
Technion, Israel Institute of Technology, Israel.	http://www.technion.acil/~civil/
The University of Texas at Austin, USA.	http://civil.ce.utexas.edu
TNO Bouw, The Netherlands.	http://www.tno.nl/instt/bouw/home.html
Eindhoven University of Technology, The Netherlands.	http://www.tue.nl/
Hollandsche Beton Groep.	http://www.hbg.nl
Loughborough University, United Kingdom.	http://www.lboro.ac.uk/departmets/cv
University of Ulster at Jordanstown, Northern Ireland	http://www.ulst.ac.uk/faculty/eng
Architecture & Building Research Institute, Tapei, China.	http://www.
CSRO, Highett, Australia.	http://www.dbce.csro.au
Building Research Establishment, BRE, Garston, Watford, United Kingdom.	http://www.bre.co.uk/bre

4. PAPERS

The following papers are enclosed in this proceedings:

- Connection Systems for Robotic Construction,
  Robert D. Wing, Imperial College of Science, London, United Kingdom.

- Automation and Robotics (AR) in Inspection and Repair,
  Denis Chamberlain, City University, London, United Kingdom.

- The development of human-machine systems for the construction process.
  Annelise de Jong, Onderzoekschool Bouw, Delft and Frans van Gassel, Eindhoven University of Technology, The Netherlands.

- Laying the foundations for better brickwork
  TNO Bouw, Delft, Netherlands.

CONNECTION SYSTEMS FOR ROBOTIC CONSTRUCTION

Research at the Department of Civil Engineering,
Imperial College of Science, Technology and Medicine,
South Kensington, London SW7 2BU, United Kingdom.

Robert D. Wing, March 1997

INTRODUCTION

This project represents an attempt to provide the construction industry with designs for fixing systems which can be easily handled by robotic devices.

Common and uncommon fixing methods have been studied in a survey covering all areas of engineering industry. Some of the methods are currently in use in factory automation systems; however, for use with robotic and automation equipment on construction sites a more detailed and innovative approach to assessing the suitability of connectors is required.

A mechanism modelling software package integrated into a visualisation system has been developed to provide a realistic simulation of the engineering performance of the connectors. The software permits application of quantified forces and restraints to the mechanical model, and thus allows primitive simulation of field conditions.

This technique has been used as a preliminary stage in the design and assessment of connectors for robotic assembly, and has thereby avoided the necessity of prototype testing numerous different design possibilities.

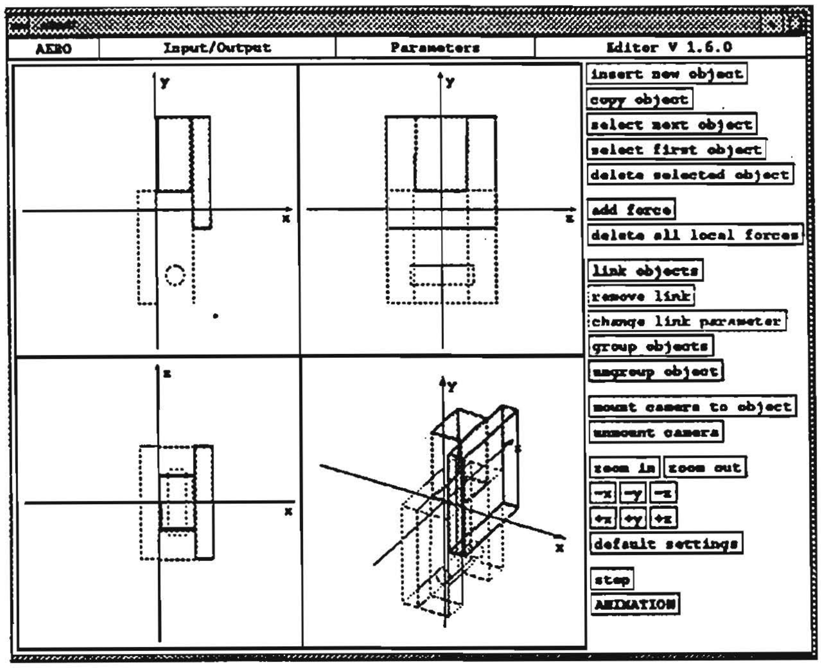
A demonstration of the method, with examples of various feasible connector types for the fixing exterior wall cladding with robotic assembly tools was given at the 1996 ISARC conference [1].

The project continues to look at further forms of >intelligent connectors which could find application in the prefabrication industry. These connectors will be designed to generally improve the safety of assembly, assurance of attachment, and provide labour and financial savings to the prefabrication industry.

THE PRESENT SITUATION

The assembly and fixing of prefabricated panels is generally labour intensive and involves potentially dangerous tasks. Heavy panels are manhandled into position using a combination of cranes, scaffolds and ladders, and the nature of current fixing systems requires operatives to assemble brackets and bolts in awkward positions [2]. The process lends itself to automation, but requires substantial investment in purpose-built manipulators and innovative fixing systems. Operators would benefit from removal of much of the physical effort required and safer conditions; constructors would see an improvement in reliability and quality of the product.

At the start of this project a general survey of fixings allowed us to identify and group the methods into classes of usage by different sectors of the engineering industry [2,3]. The associated fixing processes were identified and classified into a standard sequence, which was found to be present in one form or another for every fixing type:



Preparation of components;
- Assembly of components;
- Mating of assembly to fixing device;
- Initiation of fixing process;
- Withdrawal of the machine when fixing is complete;
- Post-fixing inspection, finishing and adjustment.

Most common fixing methods can be automated to a high degree in a factory setting, and well-established *Design for Assembly* principles are used to redesign components and fixings to ensure that the automated process is reliable, efficient, and cost-effective.

The research at Imperial College is investigating the potential of various novel forms of jointing for new fixing systems; these include high-performance adhesives, robotic riveting, and component interlock techniques as used in the electrical industry. The aim of the work is to obtain a rationalised set of fixing systems that will satisfy a wide range of building elements and material types, will adapt to the increasing use of on-site automation and off-site prefabrication, will generally improve the safety of this aspect of building construction, and provide real savings to the industry.

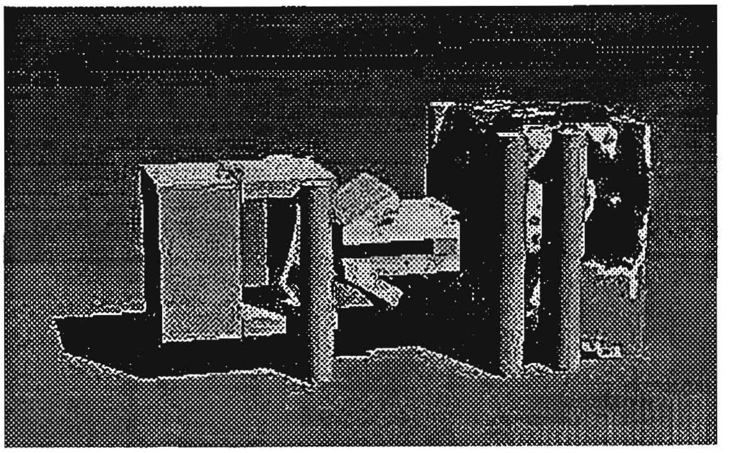
VISUALISATION AS A DESIGN TOOL

Visualisation is now finding serious application in many branches of engineering, notably in the aircraft and automobile sectors, where the building of real prototypes can now be minimised. The technique can be applied to a process such as prefabricated panel assembly at two levels:
(i) the macro level, where the complete building model is visualised together with the assembly of the panel components and visualisations of the site equipment to be used, and (ii) the micro level, where the detail of processes such as (in this case) the connectors and their assembly can be modelled and studied.

The usefulness of such visualisations extends beyond the design process; it facilitates explanation of the processes to be used to contractors and technicians involved in the actual work, and presents a model for use as a working standard.

MECHANICAL MODELLING

Modelling of the *geometry* of processes such as connector assembly at micro level can be easily achieved using one of the excellent object modelling software packages available today. This approach is too limited for effective mechanism design, and a package that allows true modelling of mechanisms including *applied forces* was sought. A virtual mechanical/realistic object simulation package created by the University of Stuttgart for general mechanism design work (X-Aero - Animation Editor for Realistic Object Motion) proved effective for our purposes, and was adopted as the underlying modeller for this study.



It should be made clear that the object of this work was to develop the *tools* for designing component assembly systems rather than the detailed design of the systems themselves.

Mechanical simulation models to demonstrate the techniques as applied to various designs of fixings have been developed. The package allows the creation of virtual environments from scenes created from simple 3-dimensional geometrical objects (sphere, cylinder, box, point and plane). Objects can be linked to each other by a variety of methods (rod, spring, damper, and joint).

Realistic object movements are achieved by a simulation procedure, where forces are applied to the objects in addition to gravity, friction and air resistance. Collisions between objects are simulated using either the Penalty method or the Analytical method [4].

CREATION OF VIRTUAL CONNECTORS

The scene editor is used to create the model; it allows the user to enter solid (3-D) objects, forces, reactions, and connections, using four views to display the model. By selecting different materials, the user can influence physical properties such as density or coefficient of friction and elasticity. The user can accelerate or induce rotation of bodies in a defined direction using forces.

After creating the virtual image with all the necessary forces and connections between members in place, the data are then saved in a file. On compiling this file a sequence file is generated which contains parameters for step-by-step synchronisation points (*sync points*) in the animation. Since any number of sync points can be declared, the sequence can be divided up into steps as small as required. The playback of these sequences using the animation feature provided with XAERO allows the generation of new output files for every image frame which can then be used for ray tracing. This process is carried out using another software package, POV (persistence of vision), to create output files compatible with the MPEG movie encoding and decoding standard.

Several models connectors have been developed using the AERO package described above. The output of the modelling process is normally presented in the form of an MPEG video, but for the presentation of this work on the printed page, wire and photo realistic frame sequence animation figures are used; clearly, the force and gravity attributes are not visible in the processed video stills.

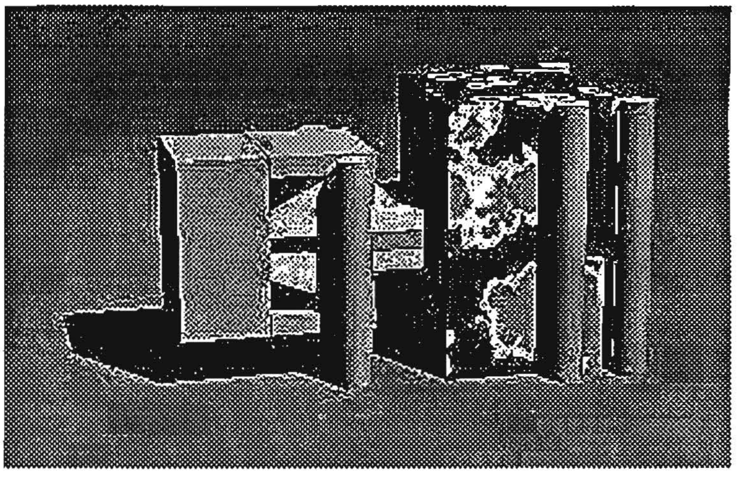
As an example of the models created, the screen shots below show a snapfit connector type; it uses a spring mechanism which displaces the fixing into its locked position. The fixings are attached to the back of the cladding panel, and the spring mechanisms lock into pre-drilled holes in the structure as shown.

FURTHER DEVELOPMENTS

Further enhancements to the demonstration models are currently underway using *ProEngineer* and *Iris Performer* software to model the location, positioning and installation of typical cladding panels on frame structures. This stage forms part of the macro modelling process explained above, and includes the model of an adapted telescopic boom mobile crane. The macro models are being linked into a virtual reality image simulation, and will eventually incorporate the micro modelling of the connector details.

Development of connectors as complete systems is also in progress. For robotic use, connectors will ideally form part of systems which not only guide the connector during assembly, but on completion will provide a certain indication of security of fixing.

Our rational approach to jointing is to develop and use connectors which are less labour intensive, of higher quality, are matched to the precision of the construction equipment, and which will provide other relative benefits such as improved safety on site, and indication of locking.



REFERENCES

1. Atkin B.L., Popo-Ola S.O., Wing R.D., Visualisation Technique for Robotic Component Connection Systems, *Proc. 13th Int. Symp on Autmn and Rob in Constr*, (ISARC), Tokyo, Japan, 1996, pp.691-698.

2. Atkin B., Atkinson P., Bridgewater C., Davies B., Wing R., Assembly Techniques For Large Construction Components, *Proc. 11th Int. Symp on Autmn and Rob in Constr*, (ISARC), Brighton, UK, 1994, pp 473-480.

3. Atkin B., Atkinson P., Bridgewater C., Davies B., Wing R., Construction Cladding Joining Methods: A Guide to Design for Automation Assembly,: *Proc. 10th Int. Symp on Autmn and Rob in Constr*, (ISARC), Construction Industry Institute, Houston, Texas, USA, 1993, pp 157-164

4. Keller H., Stolz H., Ziegler A., Braunl T., Simulation and Animation of Rigid Body Systems, University of Stuttgart, IPVR, Computer Vision Group. 1993.

The development of human-machine systems for the construction process

A.M. de Jong[1] and F.J.M. van Gassel[2].

[1]Delft University of Technology, Department of Civil Engineering, Section Building Technology, Stevinweg 1, 2628 CN Delft, The Netherlands, e-mail: a.m.dejong@bouw.tudelft.nl, facsimile +31 15 2784333
[2]Eindhoven University of Technology, Faculty of Architecture, Building and Planning, Department of Construction Management and Engineering, P.O. Box 513, 5600 MB Eindhoven, The Netherlands, e-mail: f.j.m.v.gassel@bwk.tue.nl

1 Human-machine systems

1.1 Introduction

Work in the construction industry may in many situations still be characterized by the three D's; Dirty, Difficult and Dangerous. Compared to other industries, the construction industry makes little progress in mechanisation and robotisation. However, mechanisation and robotisation can eliminate many activities which are either dirty, difficult or dangerous.

Fortunately, nowadays more attention is paid to these activities in the construction industry, partly due to more strict regulations concerning the consequences of occupational safety and health. This paper deals with human-machine systems which reduce the physical strain (Difficult) by (partly) taking over the workers' job. These systems vary from for example a simple hand-drill to complex computer-driven positioning tools.

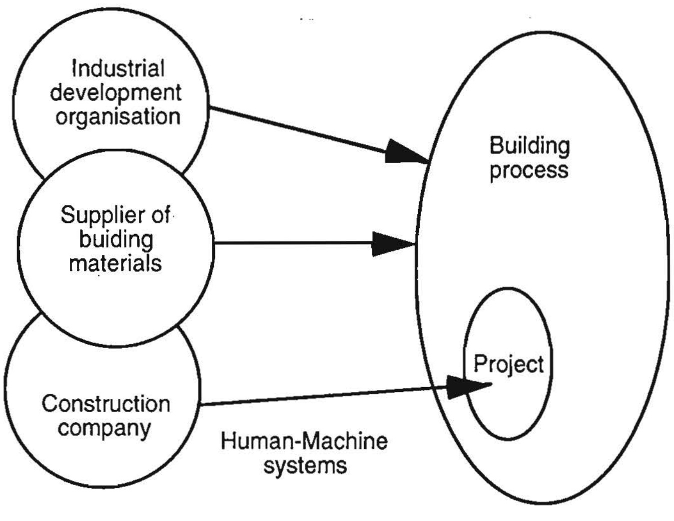


Figure 1 *Developing organisations.*

Figure 1 gives an overview of three types of developing organisations; an industrial development organisation, a supplier of building materials and the construction company. They all supply the building process with human-machine systems. The development process of a system is the way in which the system has been developed.

The systems may be developed by three different organisations. The results of the development processes of these three organisations show important differences, which will be discussed in this paper.

1.2 The construction process

The construction process is the transformation of building materials to a building by humans and machinery. This transformation is based on specifications of the building, technical drawings, normalisation etc. (see figure 2). The construction process must also be designed before actual production starts, in order to determine the production methods. The design consists of many parts which each focus on a specific aspect of the construction process, such as transport and methods of assembling [Leijten, 1996] [Vastert, 1994].

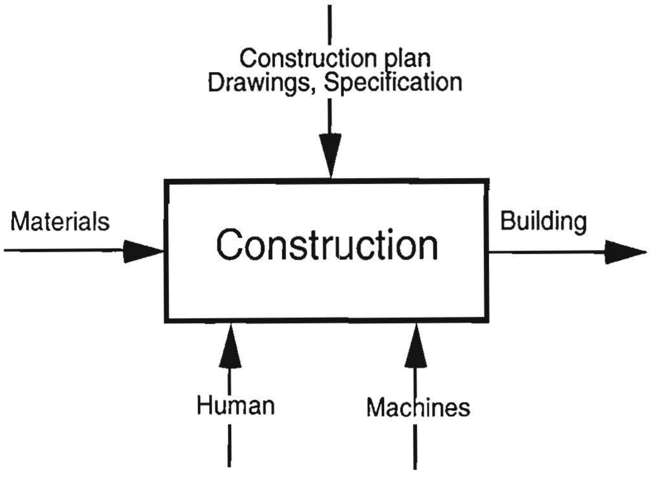


Figure 2 *Production model.*
The design of the construction process also provides information on the tasks of humans and machines. Therefore, the designer has to look for situations in which tasks are well allocated to humans and machines. These situations are determined by the following goals:
- avoid hazardous work
- improve quality
- shorten production time
- improve the productivity and
- spare the environment

Mechanising the production process is the process of allocating tasks from humans to machines. Robotisation on the other hand means full allocation of tasks from humans to machines (Figure 3) [Van Gassel, 1995].
This allocation must be well chosen to achieve the above mentioned goals. Optimal situations can be achieved by using human-machine systems on construction sites.

1.3 A human-machine system

A human-machine system consists of two parts, which can both be interpreted as a 'black box' in which processes happen. In figure 4, based on Eekels and Poelman [1995], these two black boxes are displayed. The product can only be used if the processes that take place at the product side are adapted to the human side and if the environment is taken into consideration.

Humans have receptors which pick up signals and pass them through to the brain. The brain is a complex processor which translates these signals to actions carried out by several effectors, such as limbs, voice and face muscles. These actions can have both a physical as an informational outcome, to give instructions to the machine part. The machine part has sensors to notice incoming signals, a processor for translation and actuators to carry out the mechanical action and/or give information to the human part.

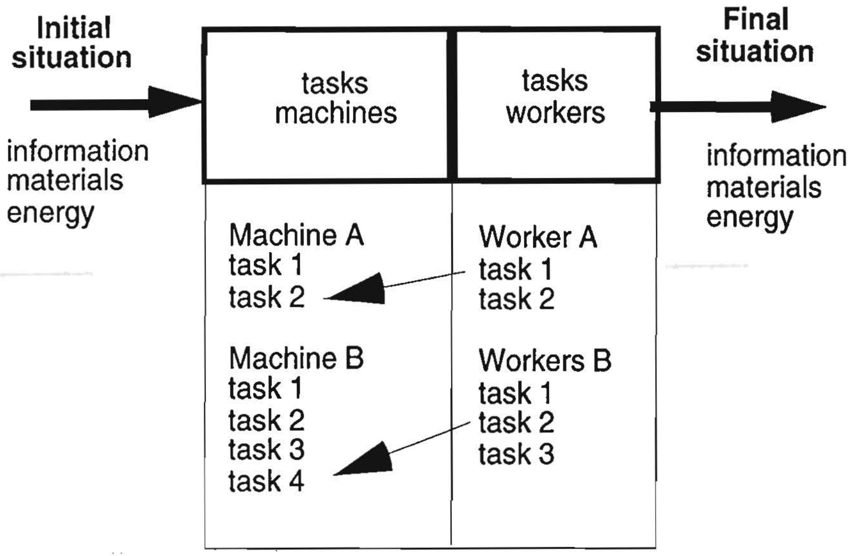


Figure 3 *Allocation of tasks.*

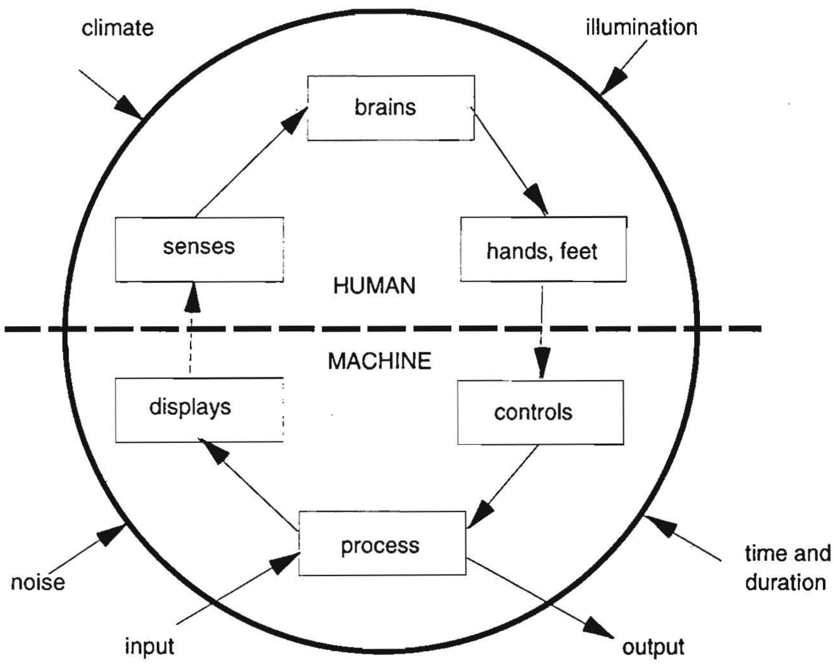


Figure 4 *Man-machine model.*

These interactions must be made clear during the process of analysis to develop a well functioning system. On the contrary, if the human-machine interaction is overlooked, the chances on a product that is accepted are small. The interaction can only be defined by involving the target group, i.e. workers who shall be using the system. Other participating parties are also interesting for the developer, since they all have a say in the benefits of a system.

2 Development processes

2.1 The development process of the construction industry

The development process is in the construction industry initiated by a practical problem and therefore has the nature of a problem solving process. Apparently, the construction process has a job for which no existing method or machine is available, which means that either the job has to be eliminated in some way or a method has to be developed to carry out the activity.

In the latter case, the situation is translated in goals and demands which have to be achieved in order to solve the problem. These goals and demands are set in the context of an actual situation; the environment of the construction site, the physical strain of the workers and the available time and budget. Therefore, existing technologies are combined in the problem solving process to resume the construction process as quick and cheap as possible.

After using the system in the specific situation, the benefits for use in other situations is hard to find. It will then be thrown away or forgotten, except in the rare case that a similar situation occurs and the development can be used again. The emphasis of the construction company is put on the construction process and the specific situation that has to be dealt with, but not on the system or the development process.

2.2 The development process of the supplying industry

The supplying industry supplies building materials to the construction company. The problem that initiates the development process in this industry is more general in terms of more productive or job efficient work. The goals of the supplying industry are essentially different from the construction company; a maximum share of sales of the building material. Therefore, the supplying industry must offer a total solution for specific situations. By offering this solution the supplying industry provides in addition production methods to process the supplied materials.

The supplying industry must convince the construction company to accept and use their developed systems. This can only be done by getting used to the production methods of the target group with the specifications of the system in view. The emphasis of the supplying industry is both on the construction process and the market on which the system is to be used, but the main drive is the promotion of sales of their materials. This implies that the aim is not to improve working conditions in general but to improve processing the materials of the supplying industry, which leaves us with a gap of optimizing working situations.

2.3 The development process of the industrial organisation

The industrial organisation has two general goals in mind when starting the process. First, the physical strain of workers must be measured and evaluated to determine the activities which must be reduced or eliminated. By measuring the frequency and duration of each activity carried out by workers, a detailed overview of jobs can be determined. The outcome of the measurements can then be compared with norms to determine the difficult jobs. Secondly, a technically and economically sound product to perform certain specified jobs has to be designed, developed and produced. A specified list of product demands can be set up based on the outcome of the first phase. Meanwhile, the interaction between human and machine can be designed (see paragraph 1.3).

The first goal puts the emphasis on working conditions by analysing the activities in the construction process. This implies a continuous contact with the target group to determine their needs with regard to the system and the changes in the construction process. The second process is even more complicated because of the many interest of involved parties [De Jong, 1997]. Not only are many parties involved at the production (supplier building materials, construction company, branch organisation) but at the purchase another three groups can be defined.

The purchase of a product (implementation) is decided by those responsible for (1) paying, (2) deciding and (3) using. The next chapter will focus on the differences as described above by modelling the descripted processes.

3 Differences between industries

3.1 Comparison of industries

Table 1 shows the differences in starting points of the three types of organisations. These differences give us an idea of the causes of the varieties in the outcome of the development processes.

Table 1 Differences in starting points of the organisations.

STARTING POINTS	CONSTRUCTION COMPANY	SUPPLYING INDUSTRY	INDUSTRIAL ORGANISATION
problem initiation	by project	by market	by market
goals	control time and costs	improve sales of supplies	reduction physical strain of worker
expectation of result	solving problem of project execution	as strategy plan of company	as strategy plan of company
selecting solution	by project manager or site manager	by construction company	by construction company
accepting solution	ordered by project manager	convincing management of construction company	providing well-performing solutions for all employees of construction company
further development	construction company/ machine production company	machine production company (i.e. industrial organisation)	industrial organisation

The starting points of the supplying industry and the industrial organisation agree for a large part, but the construction company shows large differences. In the next paragraph we will give an explanation for these differences by modelling the development processes of the three organisations.

3.2 Development model

To shed some light on the nature of development processes we propose to use a model of the integrated product development by Andreasen and Hein [1987] in figure 5. This model separates three main development flows namely market, product and production visualized by the three horizontal arrows. Though the figure implicates a linear process, it is in fact highly iterative and cyclic which is emphasized by the authors. The development starts with the recognition of a need by the construction company or the workers, which is the basis for the measurement of the physical strain. The three development flows have five similar phases, namely (1) investigation of need, (2) product principle, (3) product design, (4) product preparation and finally (5) the execution. The phases are depicted as the columns in the figure.

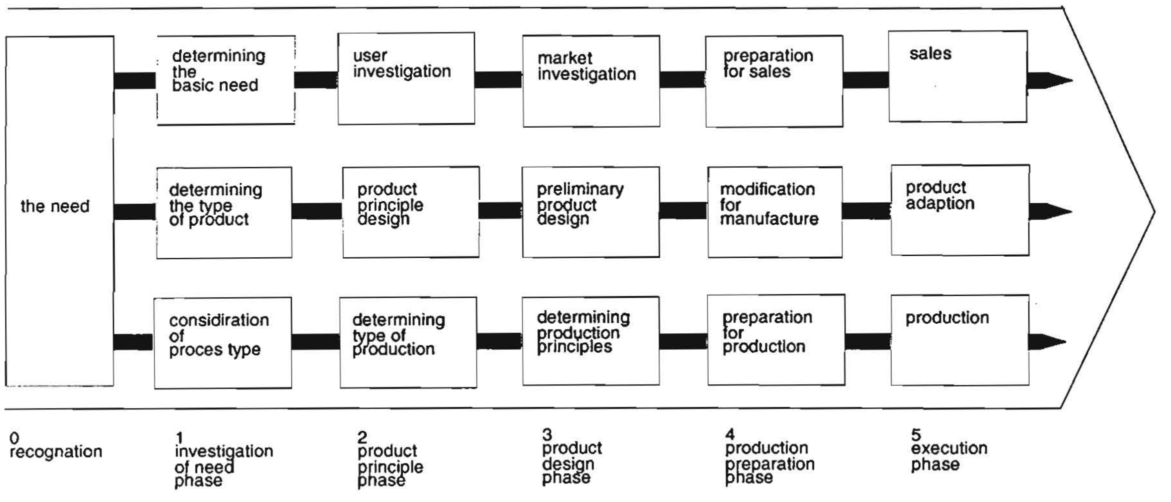


Figure 5 *Model of the integrated product development.*

If we translate this model to the situation where human-machine systems on construction sites are developed, we can determine the outcome of each phase.

1.

The first phase contains the measurements and evaluation of the physical strain of the worker. With the product specifications a scheme of a human-machine technology can be made. The outcome of this phase is the determination of a basic need of the target group, combined with the knowledge of possibilities to solve the need.

2.

The second phase has a problem-solving character and defines product principles of human-machine interaction and technical construction. This gives an idea of the production process of the product and the competition possibilities with other similar products.

3.

The third phase concludes a market-research with results of areas and their size. The detailed product design gives information of its technical and economical functioning.

4 and 5.

The fourth phase is preparation of sales and production, followed by the fifth phase as an evaluation of the theories of the fourth phase. These last two phases are strictly not product development but are an integrated part of the development process.

The model of the integrated product development gives a theoretical background of the process of development and can be used to explain the differences between development processes of industrial development organisations and those of the supplying industry and construction companies.

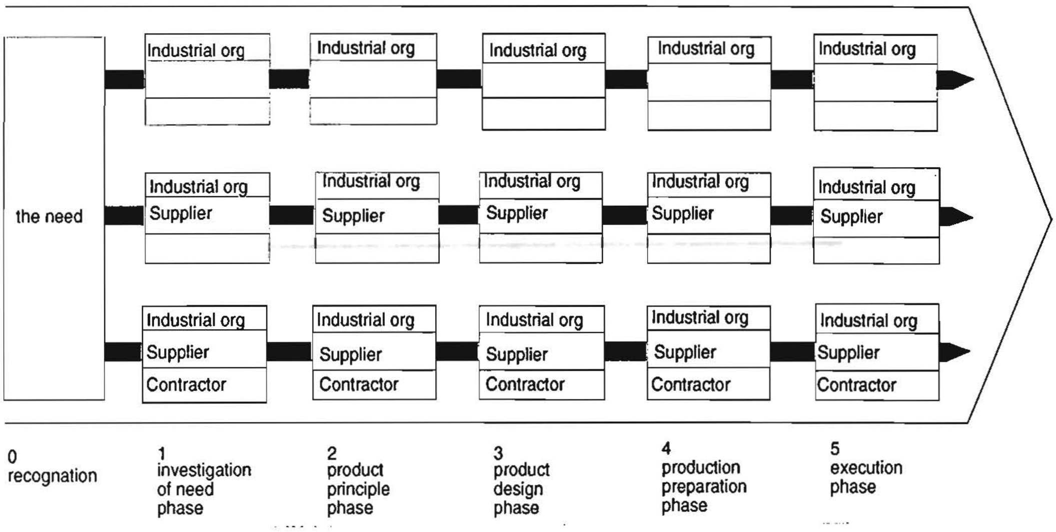


Figure 6 Developments processes of the three types of organisations.

3.3 Conclusion

The types of the development processes of the three organisations differ. Figure 6 shows the development processes of the three types of organisations discussed in this paper. We have strongly generalized the situations since it is not possible to show detailed information of such a large group of organisations. Therefore, the figure should be seen as a caricature which emphasizes extreme characteristic features and has no specialized function.
The construction company only carries out part of the process which explains the reduced impact of the result of the process. The supplying industry and industrial development organisation have more general goals in mind and intend to develop human-machine systems that serve a larger market and therefore have more opportunities to be used in many different situations. The supplying industry though, has a more narrow focus than the industrial developer, since it focuses on processing specific materials. The industrial organisation aims to improve working conditions and to reduce physical strain. Therefore, it has to focus on the needs of the entire market from the start of the development process.

Accordingly, if the all phases of the model are passed through by all industries, the results of the development processes have more in common. On the other hand, the goal of the construction company might be to develop a solution for a single situation. The consequences of choosing specific starting points have to be made clear at the beginning of the process, to avoid disappointing results of the development process.

References

M.M. Andreasen and Hein, L., 1987. Integrated product development. IFS, Bedford.
J. Eekels and W.A. Poelman, 1995. Industriële productontwikkeling; deel 2 Methodologie. Uitgeverij Lemma, Utrecht, (NL).
F.J.M. van Gassel, 1995. Mechanisatie op de bouwplaats. Collegediktaat Eindhoven University of Technology, (NL).
A.M. de Jong, 1997. The process of implementing ergonomic innovations at building sites. In: Proceedings of the 13th Triennial Congress of the Int. Ergonomics Association, June 29-July 4, Tampere, Finland, Vol. 6, pp. 84-87.
E. Leijten, 1996. Plaatsbepaling, verslag van de eerste fase van het onderzoek: "Bewaken van samenhang tussen aspecten van het bouwkundig uitvoeringsplan". Internal report, Eindhoven University of Technology (NL)
E. Vastert, 1994. Uitvoeringstechniek 2; Ontwerpen van de uitvoering. Collegediktaat, Eindhoven University of Technology (NL)

Automation and Robotics (AR) in Inspection and Repair

By Denis Chamberlain+

CIB Meeting 3rd-4th April

+Senior Lecturer & Head of the Construction Robotics Unit, City University, Northampton Square, London. EC1V OHB. *E-Mail: D.A.Chamberlain@city.ac.uk*

1. Introduction

Repair work has some characteristics that are distinct from those of new-build. Those that particularly affect the workers include hazards to life health, prolonged repetition and poor working conditions. Man-machine systems, rather than autonomous robot solutions, are seen as a progressive way forward in improving this situation and enhancing productivity and quality. Inspection and preparation of steel structures in protective coating work and inspection, preparation and repair of reinforced concrete structures are the adopted application targets for this approach. In both cases there is great need to improve on current practices.

2. Characteristics of repair tasks

PRINCIPAL PARTY	CHARACTERISTIC
Client	• Unpredictable Scope & Costs • Low Reliability & Longevity • Low Added Value • Loss of Facility Utilisation
Engineer	• Lack of Obvious Structure • Lack of Design Methodology • Reliance on NDT • Method & Material Technology Uncertainties • Containment Difficulties • Hazardous/Difficult Primary Access*
Worker	• Hazardous to Life Health* • Laborious & Repetitive • Poor Working Environment* • Poor Social Profile
Society	• Generation of Waste Products & Pollutants*

* *Health, Safety & Environmental Issues*

Table 1. Characteristics of Repair Work

Repair work tends to have distinctly different characteristics from new-build work. Table 1 gives these characteristics and attempts to associate them with the partner principally/directly affected. New-build projects can also have some of these characteristics.

Where projects are conducted under regulatory controls, however, the principal party picture is somewhat different from that indicated in table 1. With these, there is a tend towards joint consideration and shared responsibility for safety issues and environmental protection. Examples of these are CDM in the UK and instruments of OSHA and EPA in the USA.

3. Supporting human activity in repair

In considering the application of AR in the construction industry, it is important to consider the human value of the work. Considering table 1, this is particularly so with repair work. For researchers, the mere existence of a task should not be taken as sufficient grounds for altering or reducing the role of the human worker through AR. For the industry, short term profit gains should not be the dominate factor controlling their ongoing R&D strategy. Both parties need to take the broader and more long term view, that leads to justifiable and timely realisation of technology which reflects the need to safeguard the natural environment, protect the life health of the workers and develop decent employment activity whilst achieving the technical and commercial objectives.

At the CRU, the research is bias towards robot based, man-machine systems rather than autonomous robot solutions. Considering the lack of structure and unpredictability commonly found with repair work, the former is considered more realistic than the latter. With this outlook, the human worker remains the key element in the activity, deriving reach, power, precision, safety and health protection and a humane working environment from use of the man-machine system. At the same time, there is increased productivity through robotic handling of heavier and more powerful tools, continuous quality control through sensing and artificial intelligence and protection of the natural environment by local, closed loop containment and recycling of waste material.

4. Steel structure restoration

Considering the surface preparation methods currently employed in the steel structure restoration industries, these are small scale mechanical tooling, and large scale blasting with dry abrasives, ultra-high pressure water and slurry mediums. Whilst there are highly desirable alternatives, blast medium free and volatile medium methods are not used because of lack of suitable implementations, trials and performance data. There are also no photographic standards for them.

Manual handling of surface preparation tools represents a substantial hazard for workers in terms of repetitive strain, accidental injury and exposure to dust and noise. The allowable handling weight limits the tool size and power and thus productivity. For the same reason, with hand held blast tools, it is not possible to add local containment devices which protect the work place and natural environment as well as making possible closed loop recycling of blast media. A further problem is the lack of NDT techniques to support continuous quality control during the surface preparation process. As for existing condition survey, the quality of surface preparation is currently judged according to photographic standards. For each method of preparation, these relate the surface preparation to the existing condition. Use of these photographic standards is also unrealiable due to the effects of surface lighting and hue, and the varying skill of users.

Reseason for the lack of application of the alternative methods include unfamiliarity, uncertainty in the achievable quality and cleaning rate, uncertainty in the applicability of existing photographic standards, lack of know-how in large scale tool design and delivery methods, and lack of other data necessary for evaluation of the technical and economic performance. The established dry abrasive and slurry blasting methods produce large amount of dust and debris, which can contain lead and the carcinogen, zinc chromate. Protecting the natural environment by means of large scale containment, and disposing of the contaminated blast medium can be a large part of the project costs. Use of the alternative methods could ease this burden.

Remote delivery of the established commercial methods, with some measure of local containment, has so far only been achieved for continuous flat plated and low curvature surfaces. A method giving 100% local containment in the preparation of structural components and profiled and stiffened plate, such as found on bridges, has yet to be worked out. Furthermore, there are frequent cases of extreme and unacceptable noise levels with existing tools and methods, instances of 135dB being recorded.

5. Performance targets in steel structure restoration

The adopted targets for research and industrial development in steel coating restoration technology include the following:

- Near zero failure rate with patch repair and overcoating strategies through large scale use of quantifying NDT methods for existing condition of the coated steel.
- 100% increased reliability in the classification of surface preparation for coating renewal, by using a quantifying NDT method. This will result in improved life expectancy for coatings.
- 50% overall increase in surface cleaning rates through use of more powerful surface preparation tools than possible with manual handling. Tool rates should typically be increased from $10m^2/hr$ to $100m^2/hr$ with robotic handling systems.
- Substantial reductions in worker health risk and natural environment pollution risk through local collection and containment of debris in work on all type of members and surface shapes. Noise levels, currently experienced at about 135dB, should in no circumstances exceed a maximum of 80 dB.
- Considerably greater flexibility in the choice of surface preparation methods, through substantiated performance evaluation of alternatives. This recognises the existance of alternative surface preparation methods which are currently experimental or relatively untried.

For commercial exploitation, the NDT methods would need to be made robust for the harsh environment. Flexible tools and primary delivery systems are also needed with integrated waste handling systems.

6 Reinforced concrete restoration

The nature and extent of the decay problem in reinforced concrete buildings and other structures and an approach to robotic delivery of NDT has been previously reported. Over the last decade much R&D effort has been put into different solutions to the 'wall climbing problem', some of which are reported elsewhere. Unfortunately, in spite of this obvious AR application opportunity, the research community has, for the most part, only managed to produce prototype devices which fall short of the practical needs of the industry. The author suggests that this is due to the research not being focused and driven by realistic performance targets.

The areas currently being studied at the CRU are (i) remote NDT for concrete condition assessment, (ii) closed loop control of the hydro-erosion method for concrete preparation and (iii) automatic placement methods in patch repair. For each of these, performance targets have been set which represent considerable enhancements on what is currently achievable.

7. Performance targets in reinforced concrete structure restoration

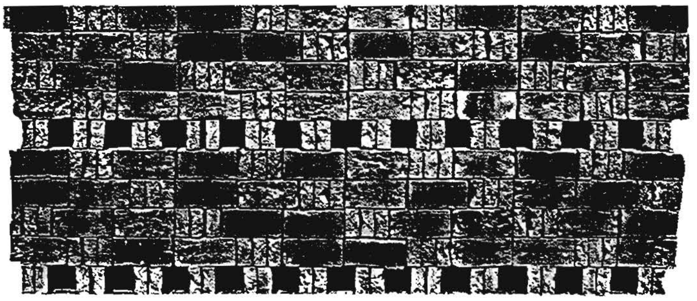
For the NDT part under (i) above, the performance targets adopted by the CRU include:

- The robot is to be design according to customer restraints and on a risk assessed basis to satisfy the EC Machinery Directive
- Risks to all parties are to be assessed and found acceptable in respect to the delivery, preparation, operation and termination of work with the robot.
- Including NDT tools, stabilisers and onboard power supplies, the robot shall not weigh more than 200kg.
- The robot should have a maximum tool travelling speed of 5m/min, 1m x 1m local surface working envelop and be capable of working on a vertical structure at any height.
- The robot should be capable of resolved motion at 200mm/sec velocity (max.) and 200mm/sec^2 (max.) acceleration for a tool load of 15 kg.
- A high level Man-Machine-Interface and an automatic location system shall be provided for remote control of the NDT tasks.
- The robot shall be capable of handling all commercially available, commonly employed NDT probes (tools).
- Production versions of the robot shall cost no more than £100,000 (1996), excluding NDT probes.

8 Conclusions

The research objectives and activity of the CRU have been presented, these concerning the repair of both steel and reinforced concrete structures. In considering repair work, it is suggested that its characteristics are quite distinct from new-build, particularly in respect to the human and environmental factors. AR is proposed as the way forward in improving this situation, as this gives the possibility for remote tool handling with waste management. In advancing the steel coating restoration application, new non-contacting NDT methods and alternative methods for preparing surfaces are essential for the AR solution. For realistic and useful outcomes with the innovation, it is suggested that verifiable performance targets are necessary. Aspects of performance targets have been stated for advancement of steel and concrete structure inspection and repair. These are essential drivers for useful outcomes in the research and development.

Laying the foundations for better brickwork



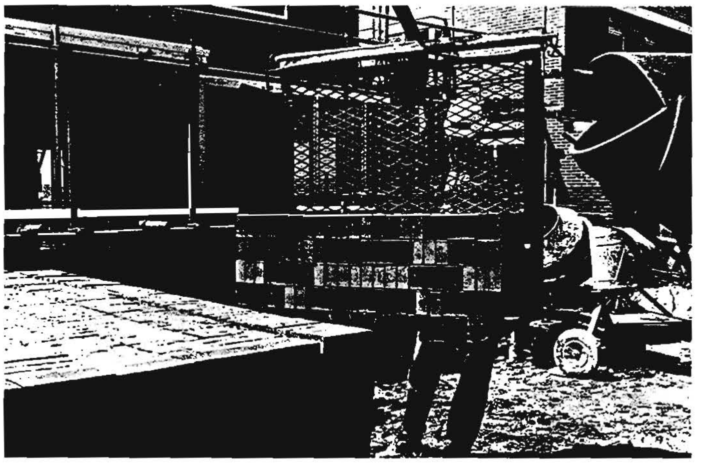
The noble art of bricklaying can be traced back to the fourth millennium B.C.. But just because the bricklayer's skills have evolved over six thousand years, does not mean to say that absolute perfection has been reached.

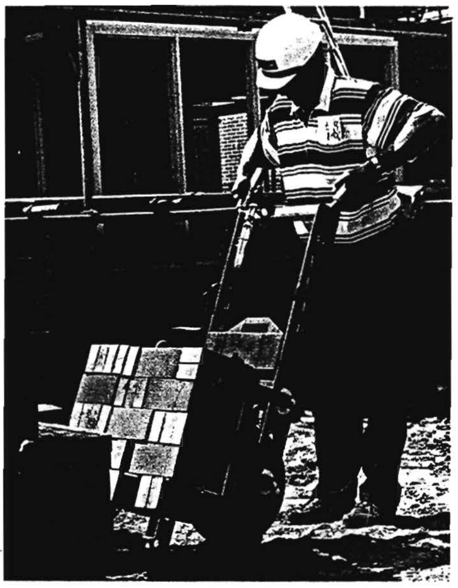
In fact, bricklaying is still a physically demanding job - as many in the industry can testify. Back problems are far too common among bricklayers and disability rates remain alarmingly high.

With this in mind, TNO Building and Construction Research and the TNO Institute of Preventive Health Care have made a systematic study of how the bricklayer's lot can best be improved. High on the list of priorities was the need to eliminate much of the heavy lifting and unnecessary bending that has long been associated with the work.

After careful thought and lengthy discussions with representatives of the construction industry, the TNO project team has come up with a number of surprisingly simple solutions. To start with, it has revolutionized the way bricks arrive at the building site. Gone are the pallets, plastic wraps and metal straps that used to be used for packing bricks. Instead, the project team has devised a clever way of stacking bricks that does away with the need for packaging materials (see top photograph). This means that, on arrival at the building site, individual stacks can either be hoisted directly to where the bricklayers are working or split down into smaller portions which are suitable for being moved on a trolley.

To facilitate the hoisting process, the TNO project team has developed a special six-pronged grab, which fits neatly underneath the stack (see photograph below). The team has also designed a two-wheeled trolley,





known as the *'opkar'*, for carrying up to 50 bricks at a time. The big advantage of the *'opkar'* is that bricklayers can use it to take the required number of bricks from the main stack, without having to lift them first. The *'opkar'* has also been designed so that the trolley's centre of gravity is just above the wheels, which makes it easier to push than conventional wheelbarrows.

Further improvements devised by the TNO project team include raised work tables and special scaffolding units. By ensuring that the bricks are always at the right height, these aids should help to eliminate much of the tiresome bending that bricklayers have long had to put up with.

But the story does not end here, as the TNO project team is now hard at work developing a mortar pumping unit to make life easier for bricklayer's assistants as well as special systems for transporting and handling window frames.

It is clear that with these and other developments in the pipeline, the TNO team is well on the way to laying the foundations for better brickwork. ■

APPENDIX

Appendix A

Topics

Ergonomic tools
Hand carts
Craftsman training
Transport people (high rise buildings)
Tools and safety
Equipment to extract dust
Site cleaning tools
Transportation equipment for waste
Returnable packages
Disassemble equipment
Site communication tools
Communication equipment for the worker
Penn computer
Communication system on site
Instruction equipment for the wordker
Remote crane control
Positioning tools (satelite)
Tele operated load handling
Advanced positioning equipment
Radio controlled machines
Distance control
Equipment for positioning building parts
Positioning devices
Make sure the place in 3D
Automatic maesurement to start work
Ergonomics
Weight of tools
Acceptance mechanization by workers
User interface
Light weight portable systems
Manipulator design
Improved dewsign tools fir intrinsically safe design of mechatronic systems
Performance crtiteria drivers
Human-Machine interfacing
Mobil factory
Towercrane visiualatation
Virtual reality
Design of metarials
Design for automation
New fixing system
Investment in tools
Cost labour/robot
Control on site right materials
Safety
Physical strain reduction
Towercranes
Man-Machine toolhandling
Gluing
Transportation in containers
Handling position devices
Clean building surface

In site transportation
Horizontal transport systems (guided vihicles)
Intelligent materials transport
Transportation equipment
Vertical transport systems
Automatid machine
Inspection tools climbing devices
Intelligent tools for for maintenace and renovation
Hand held maesurement equipment
Mortar pumping systems
Motorized trasport & hoist equipment
Hand held hold equipmet for special purpose
Special scaffolfding
Remote crane control
Positioning tools (satelite)
Tele operated load handling
Advanced positioning equipment
Radio controlled machines
Distance control
Equipment for positioning building parts
Very fast assembly techniques
Partition wall panel assembly equipment
Planning methods
Kit-of-parts construction tools
Intelligent connectors
Bad weather equipment
Workcells (temporaray factory for eg working and handling of wood)
Design for intelligent production on site
Intelligent structure
Design for acces &maintenance
Organization work process
Building design
Training labour
Education
Acceptance
Overcaome architects
Technology networking
Influence standards
Cross sector study
Research funding
Adoption of construction as targetedarea in EC funded research
Packages of materials
Fixing materials
Lifting devices
Man/Machine toolhandling systems
Transport small elements
Waste collection and handling
Transportation of windows

Appendix B

Headings

Applications
Networking
Multi sector approach
Regulations
Funding
Economics
Real Quality assurance
Desimination
Design building
Performance newq system
Jointing technology
Measurement system
Production assembly concepts
Equipment concept
Material transport
Communication
Control
Environmental issues
Human concepts

Appendix C

I.A.A.R.C. International Association for Automation and Robotics in Construction

Welcome to the IAARC Home Page

IAARC is an international automation and robotics community with specific concern for all fields of construction, operation and maintenance, including nuclear and offshore structures, road and transport systems and construction in space.

Membership is open to researchers, manufacturers and users.

The objectives of the Association are:

- To encourage, facilitate and promote the coordination of scientific and technical development
- To facilitate the collection, compilation, publication, exchange and dissemination of scientific and technical data and information.
- To encourage the execution of fundamental studies, to advance research, laboratory investigations and field tests and to accelerate the use of automation and robotics in construction.
- To assist with the application of automation and robotics in the construction industry

Benefits of membership are:

- To keep up to date in this rapidly changing technology.
- To influence the objectives and direction of IAARC and its annual conference (ISARC)
- To receive periodic newsletters and an annual membership directory
- Discounts for IAARC activities such as attendance at ISARC and subscription to Automation in Construction.

Various categories of membership are available. For membership details and an application form, please contact the Secretariat at the address below. Further material will be added to these pages at a later time

---

IAARC (Interim) Secretariat
Building Research Establishment
Garston, Watford WD2 7JR, UK

Telephone +44 (0)1923 66 42 44 --- Fax +44 (0)1923 66 46 90
e-mail treadawayk@bre.co.uk

Peter White 10/4/96