CONSTRUCTION AUTOMATION & ROBOTICS IN EUROPE - *STATE OF THE ART 1998*

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Abstract:

Changes in construction processes are opening the way for automation and robotics. Also, research in this sector is now seeing a more structured approach through the efforts of European Union central funding bodies and those in individual countries.

The diversity of applications and many specific issues such as navigation, vision, etc. make the integration of research programmes very difficult, but significant progress has been made, and a selection of notable developments across the EU are presented here.

1. The Construction sector in the European Union

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 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 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 particular factor in Europe is the low replacement rate for buildings (2%), resulting in a substantial refurbishment market, and a 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.

2. Opportunities for Automation and Robotics in Construction.

Many opportunities for the development of advanced industrial automation and robotic devices have been lost to powerful competition from Japan and the United States, coupled with a downturn in European economies at the time when serious development was being initiated. Whilst it is too late to enter the field of conventional industrial robots, now a mature technology, opportunities remain for specialised devices in several areas where economic or safety considerations restrict the use of conventional solutions using human operatives; these areas mainly include Offshore and Nuclear engineering, Space exploration and Construction.

Of these four areas, the offshore industry is currently the biggest user of robotics, but surprisingly, most of the devices in use are unsophisticated. Manipulators used on ROVs are normally of the master/slave type and rarely incorporate autocontrol or active feedback. The ROV and manipulator are run as separate devices, not as a system. This is not promising news for advocates of construction robotics, who have been waiting for spin-off from the offshore and space sectors to launch the technology in their sector.

The impetus to development of this technology is now likely to come from influence of clients. Large clients tend to operate with their own approved contractors, and there is a growing trend for company partnerships (consortia) to be formed to undertake major European construction projects; this can be seen as a very positive enabler for the development of specialised automation. In business terms, the consortia concept opens up the rather closed European market, a typical example being the COMET Design and Construct consortium (which includes Bachy (UK), Tarmac (UK), NCC (SW), SAE (F), Ilbau (A), and Astaldi (I)), sharing their resources and the risks in the construction of the Copenhagen Metro. Such partnering arrangements, once established, tend to hold together for further projects, and should provide security for the development of new tools and methods. The research thrust achieved by the major Japanese companies in this field was the result of their working in consortia for the pre-competitive research.

Opportunities will arise where the means for reduced cost, better quality, and improved Health & Safety will stimulate interest in the development of automation. Safety has not yet proved to be an effective driver for development, despite EC Directive 92/57/EEC and follow up legislation in member states (Construction Design and Management regulations), as the industry tends to adopt alternative solutions for dangerous operations wherever possible. However, longer term requirements and specific legislation such as the Manual Handling Regulations will eventually push automation developments.

Similarly the various initiatives now under way for improvements in the construction process will function as a driver: adoption of Best Practice, the quest for improved quality, for improved life cycle performance, and for defect reductions. These are likely to provide opportunities for serious automation development in the following areas:

- High quality housing production and assembly
- Building façade maintenance
- Highway surface inspection and repair
- Access devices for inspection and repair of high buildings
- Application of protective coatings to structures
- Remote machine operation, especially for demolition and earth moving
- Materials on-site handling and delivery systems

3. Construction - European R & D activities.

Research and development activities in the European Union (EU) are mainly grouped around two funding opportunities, support from the governments of individual member nations, and central funding from the EU.

The European Union has specific priorities for its funded R&D programmes, and it is relevant to examine those applicable to the construction sector. There is recognition that the special 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.

- 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.

- Mobility of construction workers is limited within Europe, due to local ties; hence there is poor continuity of the work force. This is serious as the range of individual skills required of construction workers is very large and demands substantial training.

- 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 clients' needs	Concurrent engineering, project management, and logistics.
Care of the environment	Improvement of transport, distribution and communications infrastructures, and of whole systems, including energy efficiency, exterior and interior environments, indoor air quality, 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. This is consistent with the general EU funding concept for pre-competitive research based on consortia across several member states.

4. European Union R&D programmes - selected projects in Construction

The example projects introduced in this section have been chosen to illustrate how many of the research requirements of the construction sector are finding opportunities in EU R&D programmes. To avoid repetition, the examples chosen have not been extensively reported at ISARC; they cover the field of automation in its broadest sense - communications, soft automation, as well as automation/robotics hardware.

4.1 ACTS (*Esprit* funded)

The ACTS Programme (Advanced Communications Technologies and Services) supports precompetitive research trials in the field of telecommunications. Specifically in the area of trans-European telecommunications networks, the following priorities for investment stimulation are identified:

- establishment of high-speed communications networks
- consolidation of integrated services digital networks (ISDN) across Europe
- consolidation of systems for electronic access to information
- development of European electronic mail services
- implementation of interactive video services
- stimulation of teleworking, and telematics links between administrations
- development of teletraining services
- development of telemedicine services and networks.

Although the ACTS programme covers all industry sectors, the above list covers many of the construction industry's I.T. needs both for improving the process and for providing the infrastructure within which automation and robotics can be used, and three linked projects are currently being funded in this area:

4.1.1 ACTS: CICC, MICC, and RESOLV

Under this programme, the EU is giving a boost to the development of communications and IT for the construction industry, as Communications and IT in this sector is 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.

Of the three projects, **MICC**, Mobile Integrated Communications for Construction is the largest, and is led by the French contractor, Bouygues. 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 video.

The **RESOLV** project, (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.

CICC (Collaborative Integrated Communications for Construction), is an integrating project, showing how technologies such as 3D CAD, Telepresence, WWW, 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.
The primary objective is to show how intuitive and three dimensional user interfaces to new information and communications services can enable dispersed and temporary teams to work together as effectively as established co-located groups.

Major efficiency improvements are anticipated from two factors:

- Improving understanding by presenting the right information in the right format to the right person at the right time.
- Improving collaboration by using visualisation techniques to help participants see project issues from a common point of view.

Information will be presented in a visualisation that is analogous to the mental model built up by a project manager. By making the model accessible to all relevant staff it becomes possible to assign responsibility to the person most competent to tackle each task. The project model will also be used to support an intuitive data navigation method that closely resembles searching for information on the construction site.

The technical approach is to develop and integrate the following components:

- A People and Information Finder, PIF, which presents relevant people and documents in a browsable spatial WWW/VRML landscape. The objective of the PIF is to convey the implied relationships and intuitive communications channels that make team working in a shared office so effective.
- A three dimensional project model that reinforces client, project team and end user understanding of the characteristics of a particular project.
- "Augmented Reality", integrated video and virtual reality, that assists in 3D visualisation of the construction project and integrates the real site with object oriented data drawn from the project model and the information mesh.
- Multimedia Communications across a variety of hardware platforms including workstations, PCs and mobile body-worn workstations.

Website: http://138.248.65.193/resolv/model/

4.2 IMS - Intelligent Manufacturing Systems (joint *Brite-Euram / Esprit*)

IMS is an initiative of the the world's leading industrial nations to prepare for the next generation of manufacturing technologies and systems through cooperative research and development, by encouraging research projects into all aspects of manufacturing.

In the example IMS project below, the partnership extends across 4 continents, and includes some 52 organisations.

4.2.1 IMS: GLOBEMAN '21 Enterprise Integration for Global Manufacture for the 21st Century

Globeman 21 is an industrial project aimed at creating the new processes and technologies for managing and operating global manufacturing businesses in the dynamic market environment of the twenty first century, with networked enterprises and the continuing information technology revolution. The Globeman 21 consortium will build the business practices and the management techniques using simulation systems and modelling tools based on the information infrastructure for integrating the elements of an enterprise across geographic, cultural and time barriers.

Although the project is concerned with manufacturing industry in general, its objectives are also of crucial importance to construction process development, including:

- Creation of the business processes; the methods, models and technologies, for the emerging global manufacturing environment. Global life-cycle management and enterprise integration will be included as key elements.
- Improve the quality and professionalism of manufacturing.
- New management tools to operate in a world of global virtual enterprises.
- New technologies and new applications in fields such as: modelling, simulation, control, artificial intelligence, team leadership and human organisation issues.
- Architecture for more efficient, high quality, production in all domains of manufacture.

4.3 ToCEE (*Esprit* funded)

The goal of ToCEE is the development of systems of information exchange in support of a concurrent engineering environment. The construction industry differs from other engineering sectors in that the players - the designers, engineers, suppliers, manufacturers and builders - only form as a team for one project with new problems of co-ordination on each occasion. Because S.M.E.s dominate the construction industry, the virtual enterprise structure consists of many units that are widely located, with different organisational structures and computer systems.

That members of each new enterprise should have compatible management and Computer Aided Engineering/Computer Integrated Manufacturing (CAE/CIM) is not practical, given such a fragmented industry. For Concurrent Engineering innovative techniques to co-ordinate and manage information, resources and documents need to be developed to integrate successfully and reduce lead times, increase quality and keep within budget constraints.

ToCEE seeks to develop an overall framework for a concurrent engineering environment, along with the initial development of supporting and enabling tools, compatible with existing software already marketed by members of the consortium. Emphasis is placed on the application of Artificial Intelligence (AI), such as decision support, knowledge based and machine learning methods and multi agent and distributed database systems.

4.4 SCENIC (*Esprit* funded)

SCENIC is developing a European Best Practice Network for IT (Information Technology) dissemination and Technology Transfer in the Construction Industry.

The project aims at fostering the use of advanced IT in the daily practice of the Construction Industry and especially among the large number of SMEs of the sector. It includes benchmarking studies to establish best practice and comparisons between companies from the different EU countries, technological surveys, and on-going research. (http://scenic.fagg.uni-lj.si/about.htm)

The UK partner in this network is **Construct I.T.,** a Department of the Environment (DoE) 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 IT research and development.

The Centre has been appointed to implement the DoE's strategy for IT in the construction industry (Construct I.T., 1995), 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. These include:

(i) establishment of a searchable database of ongoing research projects on the World Wide Web (WWW).

(ii) publication 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. (http://www.construct-it.salford.ac.uk/)

4.5 Brite-Euram Industrial and Materials Technologies programme

The environment, employment and means of transport are the three topics which form the focus of this programme. The overall objective is to help work towards sustainable development, one of the major challenges of this century The intention is to prepare for the factory of the future, making the best possible use of new technologies, (especially clean technologies), and providing a congenial working environment, to stimulate product innovation and hence employment, and to reduce the pollution caused by transport.

4.5.1 CONCUR (*Brite-Euram* funded)

CONCUR follows the recently completed ATLAS project (which aimed to enhance the effectiveness of the building and process plant sectors by improving the flow and the accuracy of information exchange and sharing through software tool integration).

The goals for CONCUR are to:

- integrate design, engineering and construction support software applications used by the industrial partners in construction management projects - both those which are currently used but also new, innovative commercial applications.
- improve internal and external integration of industrial partners,
- implement and demonstrate concurrent design and engineering in distributed, multi-partner projects, and
- deploy electronic information exchange and sharing. As examples, the progressive re-evaluation of project costs stage to stage and the upstream availability of alternative technical solutions in the inception stage.

The project partners intend the project to improve their business processes significantly, thereby making them more competitive on the international market. Systems will be deployed in live construction projects and be based on formal neutral data models (relevant to other management, design, sub-contractor and supply organisations) of the project information shared and exchanged by software applications in the Building and Civil Engineering industry. (http://www.vtt.fi/cic/projects/concur/index.html)

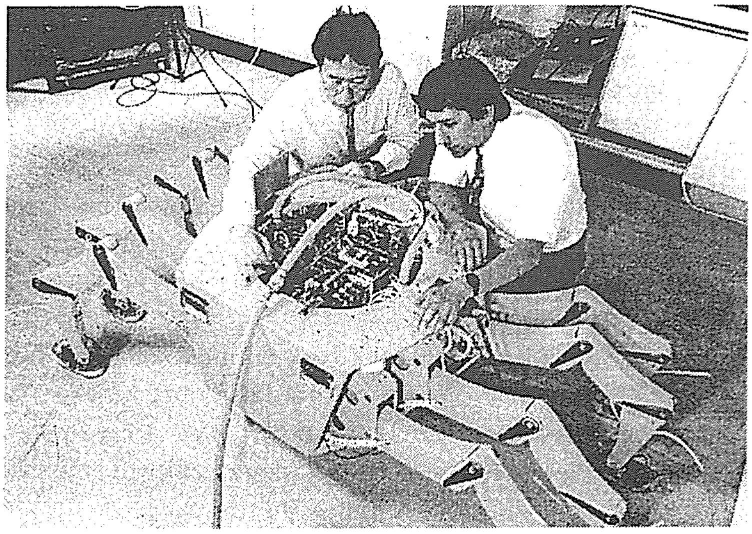
4.6 **ROBUG III Teleoperated wall-climbing robot** (TELEMAN programme).

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 (Figure 1).

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, 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, to:

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



(http://www.ee.port.ac.uk/~robotics-www)

Fig. 1 ROBUG III

4.7 **EUREKA**: A Europe-wide Network for Industrial R&D

The EUREKA programme aims to strengthen European competitiveness by promoting 'market-driven' collaborative RTD using advanced technologies, resulting in cost-effective products, processes and services. It is a framework through which industry and research institutes can develop and exploit the technologies crucial to global competitiveness and a better quality of life. EUREKA research projects run under different rules to other EU funded programmes:

Conventional EU funded projects	*EUREKA projects*
Precompetitive R&D	Development of marketable products and services
Top down Programme generation by the EC	Bottom up project generation by partners
EC supervision	Business agreements between partners
Large central funding source	Decentralised funding source – the EUREKA label improves chances of national funding support
Research results are property of both EC and partners	Research results are property of partners

EUREKA supports several automation and robotics projects, those in the construction area include machines for cleaning, tunnelling, and bricklaying. The example below is aimed at promoting the use of constructional steel.

4.7.1 **EUREKA: The CIMsteel project.** (project 130)

CIMsteel is a major EU project, now entering its second phase, 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.

Typical of many projects associated with CIMsteel is Surebuild, a panel house frame system that uses cold-rolled steel framing produced by British Steel Framing, a subsidiary of British Steel. 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, and current production processes utilise direct links between the CAD design system input and automated rolling and punching lines. There is potential for developing the capabilities of these systems, both in terms of their dimensional limits (currently at three storeys), and in creating automation for the component delivery and site assembly processes.

(http://www.leeds.ac.uk/civil/research/cae/cimsteel/cimsteel.htm)

5. Construction R & D activities in EU member countries.

Projects funded by industry and by member governments are numerous, and the author can reasonably only give information on his local situation. Similar approaches are, of course, to be found in most of the EU member states.

This decade's major industrial recession has had a particularly heavy impact on the UK 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, which indicate current research priorities in the UK are:

- the report by Sir Michael Latham, *Constructing the Team*, best known for its target of 30% productivity improvement by the end of the century,
- the government funding scheme, *Construction as a Manufacturing Process*, which follows up many of the issues raised in the Latham report. The programme, which has an emphasis on soft issues, has four leading research themes:

- Identifying client needs for the future. Developments 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.
  http://www.epsrc.ac.uk/progs/area/imi/imi-cont.htm

Two projects are described below to give a glimpse of current UK progress in this field.

5.1 Automatic Positioning System (APS) for Piling Rigs (*EPSRC* funded)

Both bored and driven large-diameter piled foundations are now commonly constructed using fully hydraulic piling rigs, providing an opportunity for the addition of enhanced automatic control.

The research seeks to enhance the SAPPAR system (Stent Foundations Ltd), which utilises a GPS receiver with antenna mounted at the top of the rig mast, a two-axis verticality sensor, a flux-gate compass for rig orientation, and a PC computer in the cab.

Future work will include automation of the piling process itself, address the many safety issues which automatic control presents, use the computer in the cab for data logging, and for linking directly into CAD. See ISARC reference below.

(http://www.comp.lancs.ac.uk/engineering/research/mechatronics/constrobotics/main.htm)

5 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.

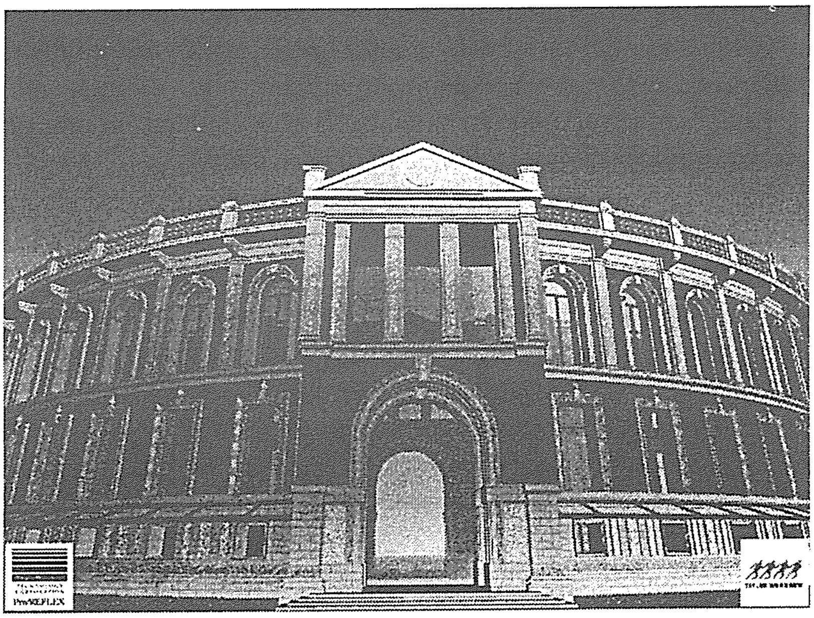


Fig.2 Royal Albert Hall model for refurbishment planning

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..

Taylor Woodrow: http://www.taywood.co.uk

Reflex Systems: http://www.ptc.com/reflex/

6. Conclusions

Automation and Robotics research for the construction industry is beginning to find a structured approach through the efforts of European and regional funding bodies. The diversity the robotics field, however, implies the necessity for a much wider integrated programme. The research projects summarised above indicate some of the work specifically aimed at the construction sector, but this sample does little justice to the efforts of bodies such as the Universities of Oxford and Edinburgh, the Fraunhofer Institute, and many other European research centres where specific issues such as robot vision and navigation are being addressed.

No longer are there any serious weaknesses in any of the required technologies, and a development thrust into areas where robotics technologies could clearly assist existing processes (*e.g.* waste management, housing systems, and façade maintenance), would enable the remaining challenge, that of integration into the construction process, to be addressed, demonstrated, and experienced.

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