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# 1

# Trends in Robotics and Automation in Construction

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## 1. Introduction

Until very recently, the construction industry was one of the most unfamiliar R&D fields for the robotics and automation community, despite the fact that this industry is one of the oldest and represents the largest economic sectors. The construction industry's contribution to the GDP in industrialized countries is about 7-10%. In the US this contribution rises to 12% and in the EU there are about 2.7 M enterprises (most of them Small and Medium Enterprises) involved in the business. This figure is comparable to that of the manufacturing industry. However, the investment in R&D is the double in the case of manufacturing.

The technological level of the construction industry during the old ages was very high for their historical period. The old civilizations have built very long lasting structures like pyramids, acropolis, aqueducts, cathedrals, etc. They used innovative processes and elements for their contemporary normal building procedures. Nevertheless, some of nowadays construction processes have changed little. For example, the building erection process has changed very little over the past eight hundred years. The old ages pulleys are substituted by cranes. These are more sophisticated than centuries ago, but they work with the same principles: manual control, human operator visual feedback, big positioning error, etc. The only elements that have change are: electrical or diesel actuators replaced the human force and steel structures replaced the wooden elements. These two advances allowed increasing the elevation speed, the payload and reachability, but the construction philosophy itself has changed little.

In recent years, the construction industry has become one of the most important research areas in the field of service robotics. The main difficulty of Robotics and Automation in Construction (RAC) is related to the nature of the work environment, which is highly unstructured in general. Working in this environment involves handling heavy objects, elements made with big tolerances, low level of standardization, medium level of industrialization and pre-fabrication, in addition to the intervention of numerous non-coordinated actors (architects, builders, suppliers, etc.). Therefore, a big effort needs to be made to increase the level of automation of this important sector and to coordinate more the involved processes in order to improve its productivity.

During the 90s the R&D activities in the field of RAC were lead by Japanese companies and universities, and were focused on the development of new robotic systems (most of them teleoperated) and in the automation of existing machinery. This era of the RAC research is

called *hard robotics* (Balaguer, 2003). These robots tried to automate several construction processes in the house building and the civil construction. These robots were for interior building finishing, brick layer masonry, modular industrialized building's construction, road paver's sensor-based guidance, excavator's control, infrastructure inspection, tunnel and bridge construction among others. The "bubble economy" crisis en Japan among other factors such as the unsatisfied over-expectation of the RAC strongly reduced investment in research activities during the last few years. Only few construction robots had succeeded to make their way to the market. Nevertheless, the situation is changing now and new RAC research trends have been launched. The actual R&D activities are centring more in the *software and IT technologies*. This is not limited to software only but also include hardware, but not in the machinery sense. It includes on-site sensory data acquisition and processing, human operator's field safety and security, chip-based process control and monitoring, automated inventory and shop keeping among many others.

The rest of this chapter presents a comparison between the construction and the car manufacturing industry and discuss some of the issues that limit more technological advances and higher levels of automation in the construction sector. The following sections are dedicated to present and discuss some examples of the state of the art in robotics and automations technologies in construction. The following section discusses some aspects that affect higher implementation of robotics and automation in construction, and the last section presents the conclusions.

## 3. Comparison between the construction and the automobile industries

As mentioned briefly in the previous sections, the construction industry has already seen the introduction of automated and semi automated means in the production of construction elements. The transition from totally manual process to nowadays semi-automated system permits to increase the productivity. Nevertheless, the advance in construction industry is not comparable to advances in other industries such as manufacturing and especially in the sectors of automobile, electronics, train, aircraft, etc. The car prices, the number of different models and variations, and the concept of mass production make the automobile industry much close to construction than the others.

One of the key factors of any industry's success evaluation is its productivity. Fig. 1 shows the comparison of the construction and automobile industries in the EU. This figure clearly demonstrates that the automobile industry productivity has increased several times more than that of the construction during the last decade. The main reason in this high productivity is the modern manufacturing concept: Computer Integrated Manufacturing (CIM). This concept was developed during the last two decades and has changed not only the manufacturing process itself but the concept of the product (Rembold et al., 1993), (Rehg, 1994). The CIM systems permit to balance the flexibility in the product with the manufacturing productivity. This relationship is one of the key factors of the success of the automobile industry.

While the house-building construction industry continue to be very close to craft work, constructing mostly singular buildings, the automobile industry continuously seek to reduce the cost of product development. This permits also to reduce the cost of the final product. The so called platform concept of the actual automobile industry is one of the newest advances of the CIM system. It is based on the use of a number of elements in various models. The same platform design, engine, electronics, etc. are used not only in different

models of cars of the same company but also in the cars of other companies. This concept reduces a vehicle cost and makes the automobile companies more competitive.
The high level of integration in all the production stages permits to start from the design process taking in mind the manufacturing and market aspects. The platform concept and integration lead to the high level of robotization and automation in automobile industry. In some of the EU plants the level of automation (the number of non-manually made operations respect to the total number of operations) is more than 60%. Mass production brings down the cost not only of the end product (in this case, the cars) but also the cost of manufacturing equipment (robots, machine tools, etc.). This is why during the last decade industrial robot prices in the EU have decreased and their number has increased (Fig. 2).

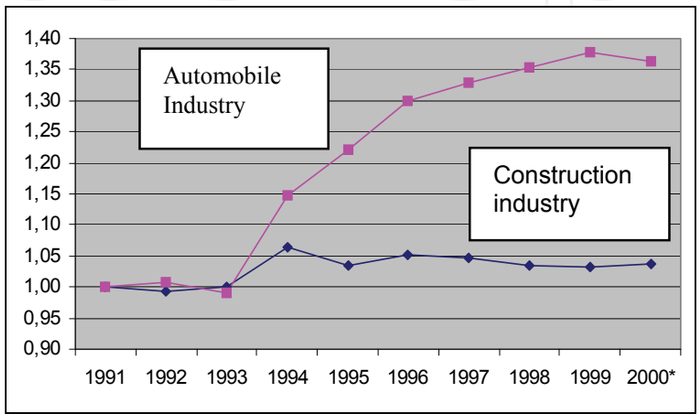



Fig. 1. Productivity of the construction and automobile industries in EU (sources: Euroconstruct, Eurostat, ACEA)

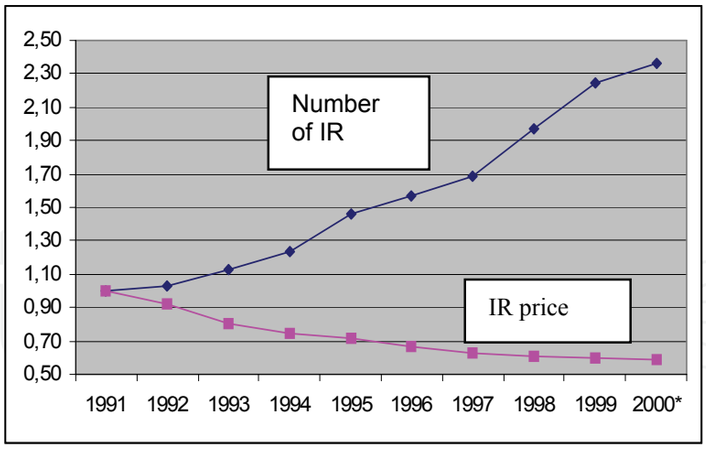



Fig. 2. Number of industrial robots (IR) in EU and its price in US$ (source: IFR)

Robotics in manufacturing industry is an evolution while the robotics in construction industry is the not yet finished revolution. While the number of industrial robots is counted in hundreds of thousands the number of robots in the construction industry is counted in hundreds only. Important efforts have been made to adapt the CIM concept to the construction industry created the Computer Integrated Construction (CIC) (Miyatake & Kangari, 1993) (Balaguer et al. 2002). Unfortunately, this effort has better results only in the

IT related stages of the construction process (planning, suppliers' relationship, etc.) but not as good results in the production stages (pre-fabrication technology, building erection, masonry, on-site automation, etc.). Despite the recent development in RAC, the gap between the technological levels of both industries is still very high

The CIM concept permits to reduce not only the cost of manufacturing but also changes the corporate culture (Kangarii, 1996). It is easier to introduce the new technologies in automobile industry than in the construction. In general, the construction industry continues to be very conservative. In many cases when the new automatic products are not complementary to the old ones, they are hardly implemented and their use is kept to minimum. Moreover, if these products introduce inconveniences to the whole construction cycle, they are openly refused. To the contrary, in the manufacturing industry the people and the environment respond very positively to technological innovation. Researchers and end users speak the same "language" and share the same objective, which allows introducing these new technologies very quickly.

According to ACEA, in 1999 the EU automobile industry investments in R&D were over 5% of the turnover while the construction industry investments in house-building technology were less than 3% (Euroconstruct, 1998). In the construction industry the big companies tend to limit their capacity to invest in "tomorrow's construction robots" from which return on investment is uncertain and too far in the future. This is also the case of the big construction machines companies, which tend to invest more in civil engineering equipments than in development of equipments dedicated for house-building.

## 2. State of the art in construction robotics

The main research activities of the RAC in the past decade were divided accordingly to applications into two large groups: civil infrastructure and house building. Typical civil infrastructure robot applications are the automation of road, tunnel and bridge construction, earthwork, etc. In the group of house construction, main applications include building skeleton erection and assembly, concrete compaction, interior finishing, etc. Classification according to applications is consistent with other possible classifications, which divide RAC R&D activities according to the development of new equipment and processes or the adaptation of existing machinery to transform them into robotic system.

In this section several examples of *robotics systems* are presented. In the group of civil infrastructure the examples are road pavers' sensor-based guidance, earthmoving control and infrastructure inspection. In the group of housing the examples are interior building finishing, brick layer masonry, column welding, modular industrialized building's construction.

### 2.1 Civil infrastructures

In the field of road construction, several projects had been developed over the last decade. They were mainly focused in the development of the new generation of semi-autonomous road pavers and asphalt compactors. The EU projects CIRC (Peyret et al., 2003) and latter OSYRIS (www.osyris.org) had as the main objectives, based in the GPS and laser data, the semi-autonomous guidance of the machines and the quality control of pavers and roller processes by controlling the speed, temperature, layer thickness, travelled distance, etc. (Fig. 3). The coordination of several machines in order to improve productivity is also the objective of the project.



Fig. 3. OSYRIS project sensor-based compactor

In the field of earthwork the research is centred in the introduction of new control techniques to existing machinery like excavators, bulldozers, draglines, etc. One of the major exponents of this research area is the control by CSIRO of the 100-m tall walking crane used in surface coal mining (Corke et al., 2006). The swing cycle of the dragline accounts for about 80 percent of time taken. The automatic swing cycle improves the efficiency of the machine, taking in mind that the bucket which weighs around 40 tonnes when empty and up to 120 tonnes when full, acts as a large pendulum and requires operator skill to control well (Fig. 4). The torque-force control during the excavation is also improving the productivity of the processes. The University of Sydney project (Ha et al., 2000) developed an automated excavator that accounts for interaction forces in analysing the required bucket motion therefore seems promising. As the bucket comes in contact with its environment, the contact force must be regulated such that it remains within a specific range by using specific control strategy (Fig. 5).



Fig. 4. CSIRO's dragline project




Fig. 5. the Automated excavator of the University of Sidney

The periodic inspection and maintenance of the civil infrastructures was another important research activity. The inspection of building skeletons, complex roofs, off-shore platforms, bridges, etc. represents an extensive and valuable field of work. It is estimated that in the EU there are over 42.000 steel bridges with a replacement cost of 350 M€. The ROMA family climbing robots (Balaguer et al., 2000) able to travel in a complex 3D environment carry out several inspection sensors (laser telemeters, colour cameras) in order to transmit the field data to the "ground" system (Fig. 6). The key issue of these robots is the grasping method (grippers, electromagnets, suction cups, etc.).

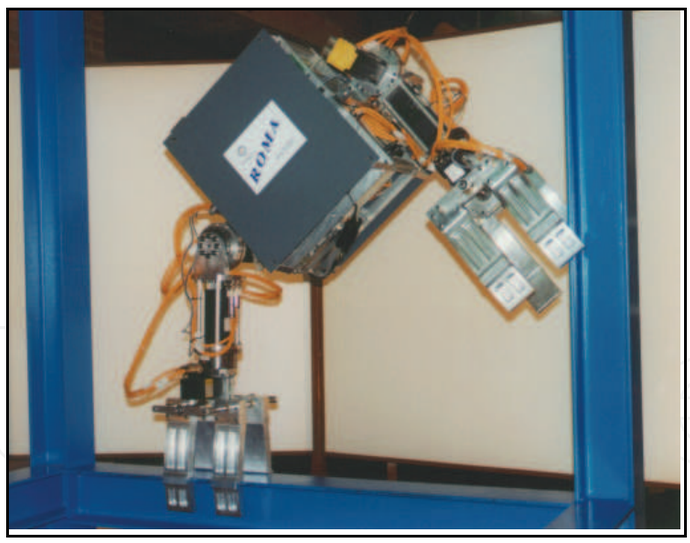



Fig. 6. ROMA climbing inspection robot

### 2.2 House building

Interior-finishing operations in the building are very time consuming and requires high degree of accuracy. There are several mobile manipulators able to perform variety of operations like extend, compact and control the thickness of the floor concrete, painting and steel column fire protection spraying, assembly of interior walls and ceilings, etc. Most of these robots are teloperated and perform only simple operations. The most representatives'

robots of this type are Japanese ones. Three examples are presented: the "Mighty Hand" robot from Kajima (www.kajima.co.jp), which lifts heavy elements in construction as concrete walls, etc. (Fig. 7), and the SurfRobo from Takenaka (www.takenaka.co.jp), which automatically compact the concrete floor by using two sets of rotary floats (Fig. 8). The right hand side of the figure shows Kajima´s concrete floor surface finishing robots. These robots are already used in several building construction sites where they succeeded in releasing workers from thousands of operations (Hasegawa, 2006).



Fig. 7. Kajima's interior wall assembly robot

The last decade has witnessed the development of several robots for automatic assembly of buildings. An effort had been done in the brick laying masonry and the development of robotic prefabrication of façade and wall ellements. The EU project ROCCO developed a large-range (10 m reach) and high payload (up to 500 kg) hydraulic 6 DOF robot for brick assembly (Gambao et al., 1997). The robot is equipped with auto-tracking laser telemeter in the tip in order to perform prices (up to 5 cm) brick assembly. In this way the control system avoid important arm flexion. The robot performs the assembly sequence obtained by the planning software and needs an initialization process in order to know the bricks pallet position (Fig. 9).

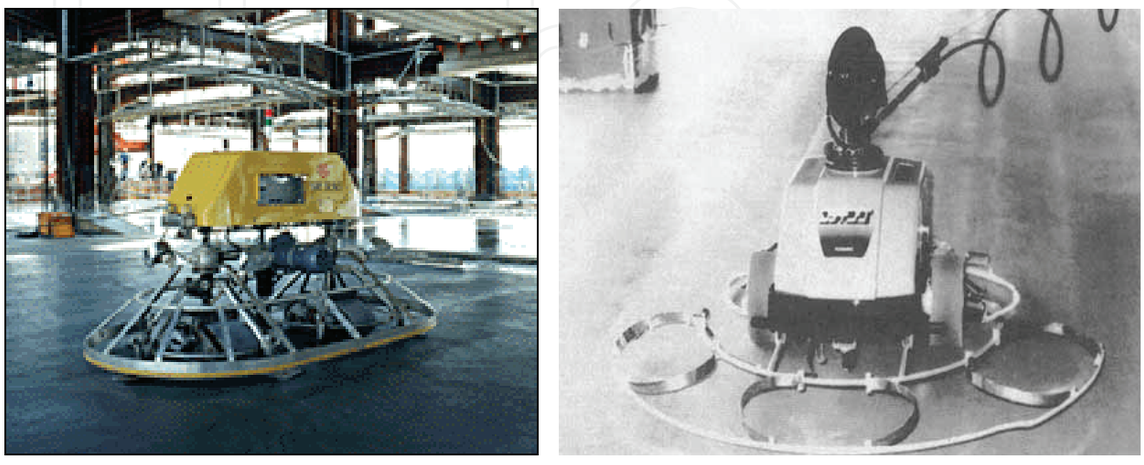


Fig. 8. Takenaka's concrete compactor robot and Kajima´s concrete finishing robot



Fig. 9. ROCCO project brick assembly robot

During the last few years a tendency to develop wearable robots for different applications immerged. First this type of robot were thought of from a military point of view, and that is to provide soldiers with powered exoskeletons to allow them handle heavy loads and resist longer periods without being exhausted. The main limitation of these robots is their power supply, but in the construction site this should not be a serious problem, since the robot can be iambically connected to a power source while being wearied by an operator. A wearable/exoskeletons robot is able to endow the operator with more strength beyond his natural limits and allow him/her to handle heavy objects during their construction activities such as carpentry or fitting ceiling boards as they require large muscular power. The prototype developed in (Naito et al., 2007) is an example of such application (fig. 10).

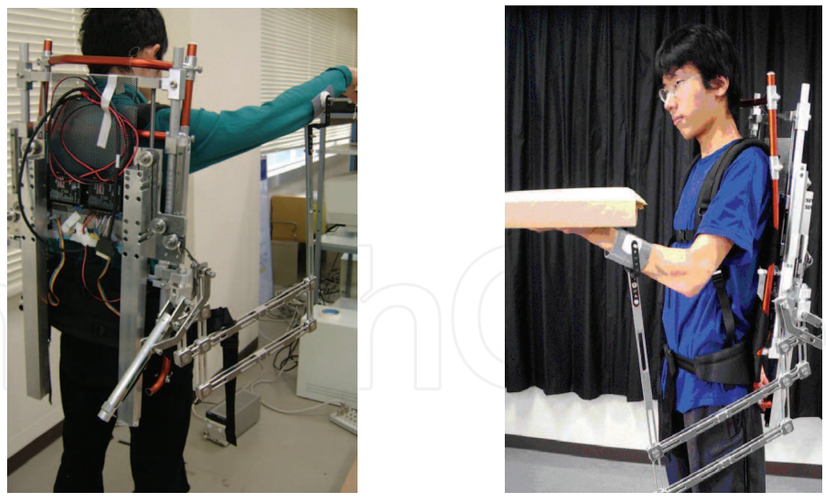


Fig. 10. An example of a carpentry aid wearable robot under development

The assembly of steel-based buildings is performing by welding, such as column-to-column and column-to-beam joints. The Japanese WR mobile robot performs a variety of column-to-column welding (Fig. 11). The steel columns of up to 100 mm thickness can be round-, square-, or H-shaped, as well as box-sectional members. For column-to-beam welding, there is a combination of welder/transport type which can run on decks and a type which can weld lower flanges from below.



Fig. 11. WR mobile robot for column welding

Automation and robotization of the complete building erection is the most exciting experience. Applying to the high-rise building there were several Japanese projects. The most significant is the SMAT system developed by Shimizu (Miyatake, 1993). It was used for construction of more than 30 stories office building. It consists of all-wheatear, full-robotic factory on the top of the building. The lift-up mechanism automatically raises the construction plant and at the same time raises the on-site factory, called *field factory* (Fig. 12). More recently the Dutch companies develop the new whole building erection technology but in opposite way of the previous system. The building is totally constructed in like factory environment and then transported to the final location. The 10 floor building called Bolder was transported by water in a three day operation (Fig. 13).



Fig. 12. SMART factory in the top of the building



Fig. 13. Bolder building transportation by water

## 3. Software and IT technology in RAC

As discussed in earlier sections, software and IT technologies (also called soft robotics in earlier publications by the authors) is not only limited to software itself but also includes other related technology as sensory data acquisition and processing, human operator's field safety and security, chip-based process control, etc. This section describes the main applications and some examples of the actual software and IT trends in the automation of the construction industry.

### 3.1 Software integration

Software integration in the field of RAC is crucial for implementing the concept of the Computer Integrated Construction (CIC). The idea is to integrate in a common exchange format all the stages of the construction, i.e. from architect's desk and planning tools to site robots. The EU FutureHome projects develop the AUTOMOD3 system (Fig. 14) that integrates in a common CAD environment several tools like design, planning and automatic robot and machine programming (Balaguer et al., 2002). Due the high level of conservatism of building designers, the main idea is to use the common 2D architectural design (drawings) and automatically transform it into 3D drawings. In this way it is possible to perform also automatically the modularization of the traditionally designed buildings. This process permits to industrialize the house-building by modular pre-fabricated construction.

Schedule management software packages are used more and more in construction. Nevertheless, its dynamic integration whit all the actors participate in the construction is not yet done. In a construction project, although the completion day is clearly decided, construction schedule is often changed by the weather or the actual progress situation of the project. When a difference arise between present state and the master schedule, it is necessary to adjust the construction schedule and to execute it immediately. The communication with part's produced factory, transport agents, stores and other suppliers is performing in real-time and in automatic way (Lipman & Reed, 2000).

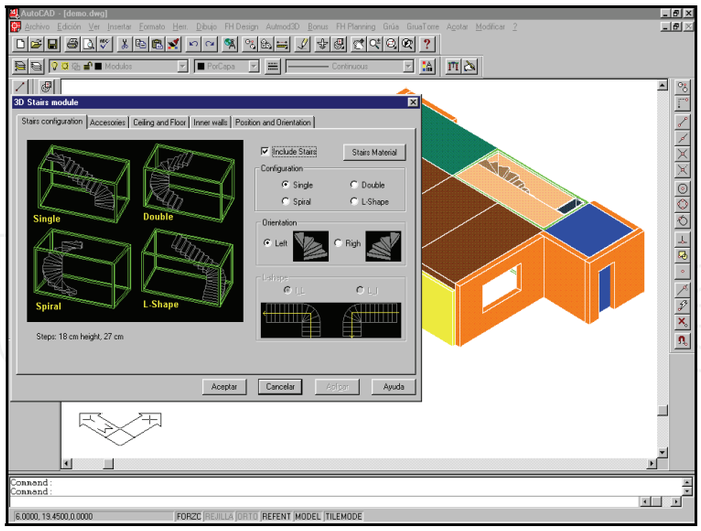



Fig. 14. FutureHome integrated design and planning tools

Mobile computing systems for data transfer between constructor managers and different web-sites have been implementing. The progress monitoring wireless mobile system permits to check the progress of the work. At the same time field note system is used to note unacceptable parts of works (Fig. 15). Inspection system is also used for inspect the result of construction. The document management system not only can communicate with the designers DBs in order to download the CAD drawings, but also permits the on-site modifications of these drawings. This soft technology is very useful and has a low cost which make it candidate for massive introduction in the site environment. The day when construction managers and operators carry only some paper drawings will be finished soon.

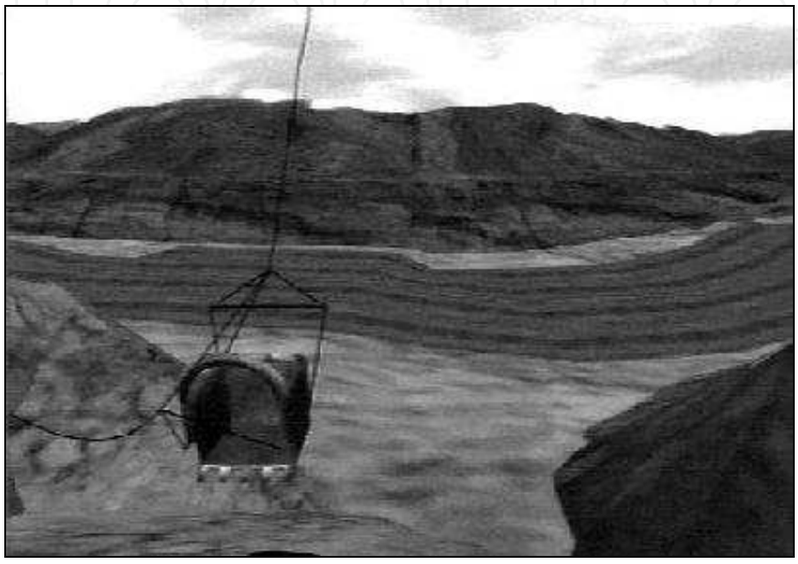


Fig. 15. PDA-based document management system in the site environment

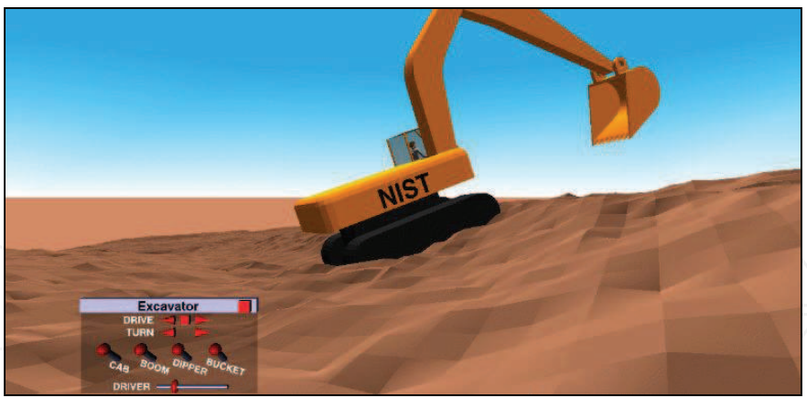
### 3.2 Virtual Reality systems

The Virtual Reality (VR) software together with an immersive projection display (IPD) allows construction managers to enter and interact with the contents of a full-scale building,

before start of the construction or during the execution of the project. The virtual mock-up offers first person presence, or the feeling that you're actually in the room when you're just standing in a space bounded by five large screens that surround you with a projected image. The virtual mock-up experience is real enough to enable welders, for example, to crawl under virtual structures and hit their heads on virtual pipes to determine if there's enough room to work. Several immersive VR systems were developed during the last years, like at the Penn State University (http://www.arl.psu.edu), at the NIST (http://cic.nist.gov/vrml/equip.html), etc.



a)




b)

Fig. 16. VR environment for excavators training system: a) from inside the cabin, and b) outside the cabin

In the world of construction operations analysis, the ability to see a 3D dynamic animation of an operation that has been simulated allows the experts, field personnel, and decision makers can discover differences between the way they understand the operation and the way the model developer understands it. The dynamic VR is more close to animation than geometrical visualization. The actual research is focusing on designing automated, discrete-

event process simulation-driven methods to visualize construction operations and the resulting evolving products in dynamic, smooth, continuous, 3D virtual worlds. The discrete-event simulation systems, allows a computer to create a world that is accurate in time and space; and which shows people, machines, and materials interacting as they build constructed facilities.

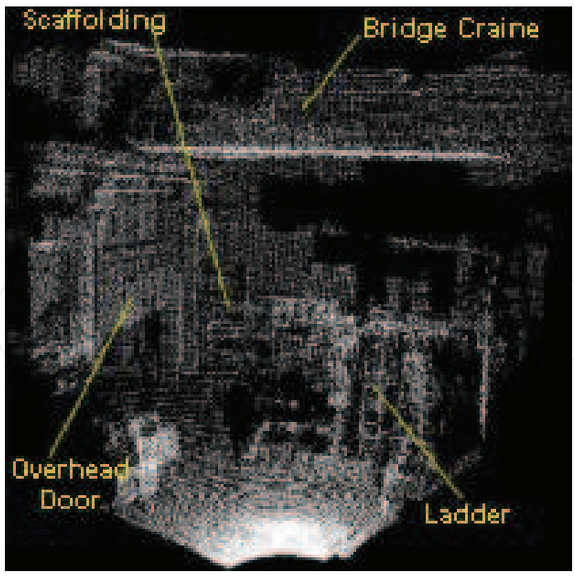
Using VR system for simulation and training is another software and IT technology (also designated soft robotics by some authors) area. For complex machines like excavators, the VR system needs not only to simulate the geometry and kinematics of the machine but also the terrain and the interaction between the machine and terrain (Lipman & Reed, 2000). The simulation of digging and driving over the terrain is the crucial test. The terrain model is generated with an elevation grid technique which specifies a height field over a uniform grid. If the size of an individual grid in the simulation is smaller than the footprint of the excavator the system will work correctly and the operator's sensation will be good. The system permits the simulation of the view from inside or outside the excavator cabin. To visually represent the digging process, the location of the bucket relative to the terrain and relative to the excavator needs to be known. A complete Caterpillar 3D backhoe simulator, can be consulted at the site page http://www.howstuffworks.com/backhoe-loader.htm.

### 3.3 Sensory data acquisition and processing

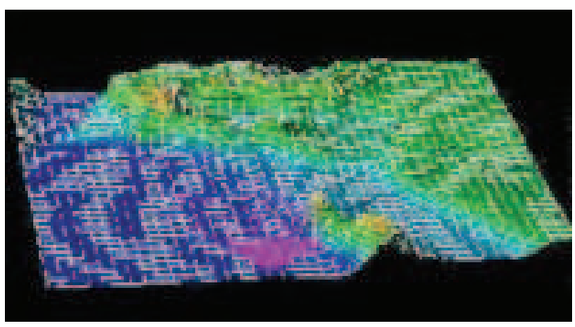
One of the most promising areas of research and development in software and IT in RAC is the sensory data acquisition and processing. The use of sensors for modelling the environment and then use this data for processing is much valuable for the control of automatic construction machinery or robots. The LADAR (Laser Radar) on-site data acquisition was one of traditional research area at NIST (Cheok at al., 2000). Nevertheless, only recently this technology has produced important applications in the automatic excavation, truck guidance, topography and inspection. LADAR technology is based on the high precision pan-and-tilt mounted laser rangefinder with the frame rate at least 10 Hz (commonly 25 Hz). The range of the laser scanner is up to 150 m for objects with reflection coefficient grater than 80% and 50 m for objects with reflection coefficient grater than 10%. Once the data are registered, they are used to generate 3D models or surfaces (Fig. 17).

Evaluation of surface generation algorithms involves a three parts process. In the first part, the characteristics (accuracy, noise, and related uncertainties) of the sensor would be determined. This set up or calibration would be performed in an indoor facility, which allows for a controlled environment. In the second part, mathematical procedures are used to determine the statistical uncertainties of particular calculations (e.g., volume) based on the results of the instrument calibration. In the third part, the characteristics of the algorithms used to generate the 3-D model would be determined. These characteristics determine how well the algorithms handle missing points, outliers, discontinuities, vertical surfaces, etc.

The using of GPS for data collection has become very common. Some applications are very well known such as automatic truck guidance, topography, etc. But nowadays low-cost facilities of using PDA-based GPS and web data transmission and collection make new applications possible. One of these applications is the GPS-aided earthquake monitoring. The data is collected via a GPS station with a circular antenna firmly fixed in a 4.5 tonne slab of 300 million year old sandstone from Yorkshire, which is in turn embedded almost three metres into the earth. This natural landmark is monitored every 15 second via web.




a)



b)

Fig. 17. NIST's LADAR data: a) environment map, and b) 3D reconstruction

### 3.4 Safety of operators and machines

Thousands of construction workers are injured or killed in construction accidents each year. Researches and development efforts have been made in the last few years to look into new ways of improving the security and developing methods and reliable systems to detect possible failures and to avoid any harm to the workers, machines and installations. Studies showed that the main risk sources in on-site environment are collision with the machine transporting heavy and big objects, fallings, machine running over, and therefore these have to be taken into consideration when designing preventive security systems (Abderrahim et al., 2003)

In this research and development effort based on *IT and mechatronics systems*, the compulsory safety helmet required for all workers in the site can be used as the base to hold miniature positioning and communication instruments (Fig. 18) (Abderrahim at al., 2003). In the work described by the authors, bidirectional voice channel, portable GPS and micro-camera with video link have been integrated in the security the helmet. The position and ID of each worker is communicated periodically via radio link to a monitoring station. This information is compared with a dynamics Data Base containing the tasks and processes to

be perform in the site. If a given worker is at what the system considers a hazard source it acts according to the nature of source.

There are two basic security levels: machine and human ones. Machine level refers to the failures in the machinery, possible erroneous operation, bad condition of the components, etc. As far as the human level is concerned, the objective is to prevent the operatives from suffering the accidents. The strategy to adopt consist in the definition of different safe and prohibited zones around the workers and the sources of danger, so that in the moment in which these areas comes into contact a danger situation is triggered and warning is generated. There are several actions to be done in this situation such as advising the worker thought the voice instructions, halting a machine movement via central computer among others. The proposed prototype systems records all the detected risk situations for later examination and is able to be used for monitoring of some activities of the site as it records the position of workers and automated machines continuously.

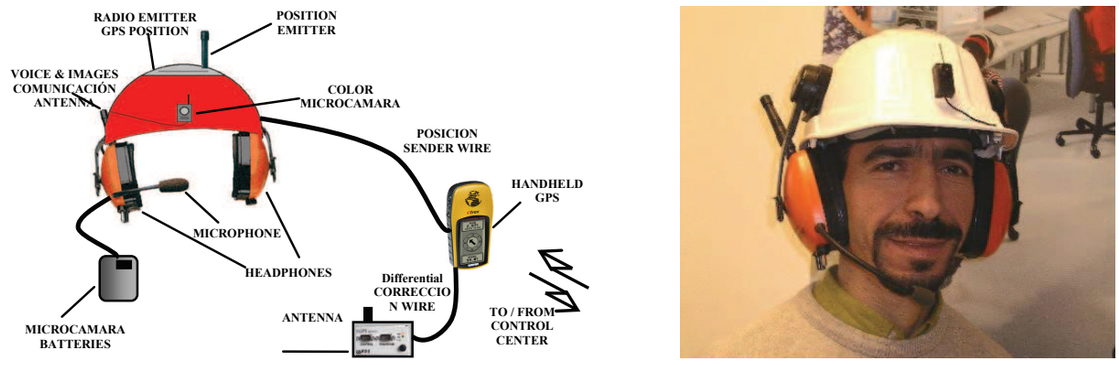



Fig. 18. UC3M's active security system's elements and a picture of the equipped helmet

### 3.5 Identification tags and part-oriented construction

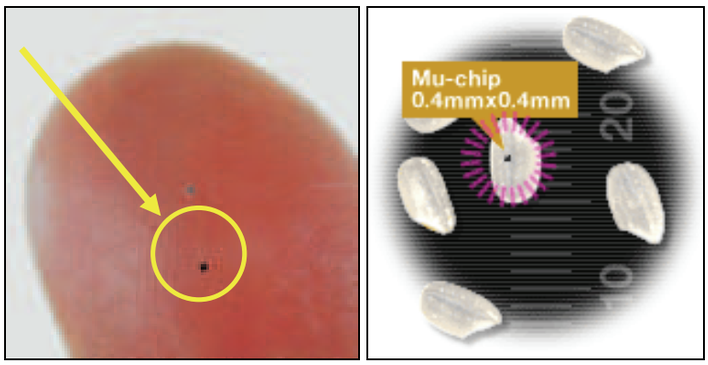
One of the most innovative *software and IT Technologies* applications in the construction industry is the so called *part-oriented construction* (Yagi, 2003). The idea is very compatible with the above mentioned security system, where The main idea is to link the fixed and temporary facilities of construction site (ground, cranes, field factories, etc.) with the parts-peoples dynamically changing world via information network. It means that the status, position and timing of parts and human operators in the site are known in every moment. Moreover, it is possible to dynamically plan, command, tracking and monitoring all the construction recourses.

To perform this monitoring each part, machine and operator has assigned an identification chip which wireless connects with external devices. This chip is a wireless semiconductor integrated circuit that stores an ID number in its memory (Radio Frequency Identification Device -RFID). The μ-chip developed by Hitachi is a micro-device with square of 0.4 mm that uses the frequency of 2.45GHz. It has a 128-bit ROM for storing unique ID (Fig. 19).

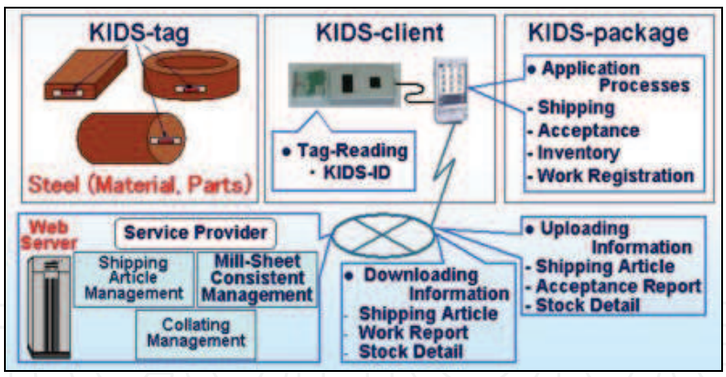
The system which controls whole the construction process is called *glue logic*. This system binds multiple application software modules, referred as "agents", developed and compiled separately, and coordinates those agents. As "glue logic" supports even notification and conditioning monitoring features based on active data scheme, users can easy build real-time event-driven application agents. The *glue logic* consists of two major parts:

communication subsystem exchanging data with concurrently running agents and the data management subsystem.

Every part has attached μ-chip (which includes antenna). When a chip-implanted part passes through the gate, the gate reads the product URL. It determines what it is, when and in what state it is. The corresponding data point in the *glue logic* is then altered, which generates an event and a chain of succeeding actions. For communicates with human operators some of them carry a wireless PDA which is capable to connected to the main web server where *glue logic* is running and, at the same time, is capable to read μ-chip attached to the part. Moreover, the system is applied to automated handling of devices, by communication with automatic cranes and *glue logic* DB. The correct assembly of parts is also be monitoring.




a)




b)

Fig. 19. Hitachi's RFID μ-chip a) in comparison with the human finger and rice grain, and b) their application for steel-based parts' tracking

## 4. The future of robotics and automation in construction

The automation in construction has moved through several historical periods, according the ISARC trends (Ueno, 1998): a) cradle (1984-85), b) growing (1986-89), and c) developing (1990-98). However, even at the time of preparing this document one can assert that the consolidated has not been achieved yet. This may happen in the near future, but it is difficult to imagine that the houses will be built in the future like today's cars. However, as

illustrated in the examples above the automation in construction is increasing and many of the developed prototypes will see their way to real application. Some factors are very important and will affect the way to real implementation in the near future. These factor are summarised as follow:

- Change of attitude in the construction companies, the machinery industry, the research centres and the government R&D officials, in order to develop new high tech commercial products and pass the phase of prototypes.
- Implementation of new IT and telecommunications technologies is already changing the work process in all the social segments, including the construction people. Today's form of work is unimaginable only a few years ago.
- Globalization of the market and consequently adaptation of the commercial structure in today's construction sector introduces a very high level of competitiveness, which urges companies to adopt more automated and efficient means.

To achieve the consolidation period in the construction automation big efforts need to be made in different fronts:

1. **Integration**. This is one of the key issues which are necessary to be consolidated during the next years, being the main lemma "from architect's desk to site robots". For this purpose three main actions should be taken:
   1.1 Feedback design of houses, taking into account the prefabrication, erection, assembly, transportation and other stages of the construction process.
   1.2 Diversity of the design using the highest number of the similar standard pre-fabricated elements (i.e. building different houses with the same parts).
   1.3 Software standardization which permit the easy and fast data exchange between architects, civil engineers, electrical engineers and computer science experts.
2. **Pre-fabrication**. Expand this technology to cover other materials other than the concrete (including composites), which shall immediately boost the productivity. Three main actions are:
   2.1 Mass production using pre-fabrication in order to select the parts from a catalogue. This means that CIM concept must be introduced, including JIT production.
   2.2 Standardization of the maximum number of parts through the use of grid dimensions, common joints, connections, etc.
   2.3 2.3. New materials for pre-fabricated parts which make them lighter, maintaining the same mechanical features.
3. **Robots and automated machines**. The robots and highly automated machines are the key issue. Using them ensures a high level of productivity. Some of the main actions are:
   3.1 "Easy" to use robots. Develop robust robots which are easy to control and program through friendly human machine interfaces.
   3.2 Cheap robots. Develop cheap robots which cover single type of application, being not general. This will permit to increase the sales of units.
   3.3 Increasing the level of automation of existing machinery. Modify the conventional construction machines (cranes, compactors, etc.) in order to convert them into robotic system.
4. **Investment in R&D**. More research and developed investment in RAC both in basic and applied research through national and international targeted programs, such as the EU research frameworks. One of the main objectives has to be targeted also at changing

the culture of the operators directly involved in the construction process, through education and training. Otherwise the operators would resist the introduction of innovation.

## 5. Conclusion

This chapter presented the summarised -state-of-the-art in the area of *robotics and automation in construction* focusing on the new robots development and machine automation. This area of robot development was very strong during 90s. However actual research and development in the RAC is more focused on new emerging technologies and mainly based on *software and IT technologies*. This is based on the software integration, simulation and Virtual Reality environments, sensor-based monitoring and tracking, part-oriented construction, etc. These examples are the most representatives but are not exclusive of others. It is important to mention that *software and It technologies* in RAC include other important applications such as artificial life modelling of the construction process, life cycle engineering, RFID chip-robot interaction, etc.

The research in RAC' focus on *software and IT technologies* does not mean that *construction robotics* development from the hardware point of view has seen a cessation, but their development is actually slow. Integration and coordination of both *hard* and *soft* areas is the objective of the long-term research in the field of RAC. It is important to note that this research focus strategically appeared in several national and regional research programs, like the EU 6th Frame Program and was also supported in the inter-regional global program IMS. In order to rapidly advance in RAC and reach the consolidation period the ideas discussed in the previous section need to be adopted and especially new national and international research programs have to be established.

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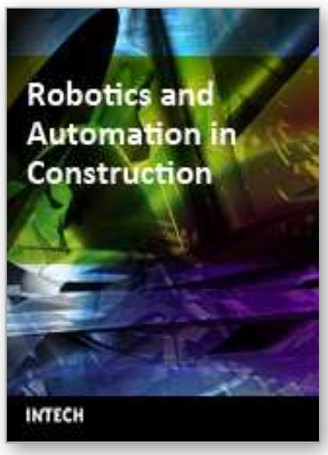
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**Robotics and Automation in Construction**

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This book addresses several issues related to the introduction of automaton and robotics in the construction industry in a collection of 23 chapters. The chapters are grouped in 3 main sections according to the theme or the type of technology they treat. Section I is dedicated to describe and analyse the main research challenges of Robotics and Automation in Construction (RAC). The second section consists of 12 chapters and is dedicated to the technologies and new developments employed to automate processes in the construction industry. Among these we have examples of ICT technologies used for purposes such as construction visualisation systems, added value management systems, construction materials and elements tracking using multiple IDs devices. This section also deals with Sensorial Systems and software used in the construction to improve the performances of machines such as cranes, and in improving Human-Machine Interfaces (MMI). Authors adopted Mixed and Augmented Reality in the MMI to ease the construction operations. Section III is dedicated to describe case studies of RAC and comprises 8 chapters. Among the eight chapters the section presents a robotic excavator and a semi-automated façade cleaning system. The section also presents work dedicated to enhancing the force of the workers in construction through the use of Robotic-powered exoskeletons and body joint-adapted assistive units, which allow the handling of greater loads.

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