OPEN ISSUES AND FUTURE POSSIBILITIES IN THE EU CONSTRUCTION AUTOMATION

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Abstract: The open issues and the main barriers to introducing automation in the construction industry are analyzed. Future possibilities of massive introduction of automation are also analyzed. These analysis are focusing in the house-building construction in the European Union (EU). The level of advances and comparative study with others industrial sectors show that more effort are needed. In this way two examples are presented: bricklayer robots and modules assembly robots, focusing in the main barriers for its massive introducing.

Keywords: Construction automation, robots, bricklayer, assembly, comparative study.

1. INTRODUCTION

The construction is one of the oldest industries. The majority of the old civilizations, like Egyptian, Aztecs, Greg, Chinese, Roman, etc., paid special attention to their buildings and civil infrastructures. They had a very high technological level for their historical period. Singular and very long lasting structures were erected: pyramids, acropolis, aqueducts, cathedrals, etc. During the last centuries, and especially during the present one, the construction technology made important advances. New skyscrapers, bridges, tunnels, and highways were constructed all over the world. Nevertheless, it will be interesting to check the comparative level of the innovation in construction industry, and especially in house-building construction. For this purpose two main question have been made:

1) How much the house-building construction industry has advanced through the years?
2) How do the house-building construction industry advances compare with other industries?

The detailed analysis of this two question will permit to identify important aspects of construction industry technology from the automation point of view: a) the open issues of automation in construction industry, b) the barriers for massive introduction of robotic systems, c) the main driving forces, d) the future possibilities, etc. The numerous excellent studies of these aspects were developed during the last two years in Japan, EU and USA [1], [2], [3], [4]. However, it is evident that nowadays level of automation in construction is very low in comparison with the exiting technological advances.

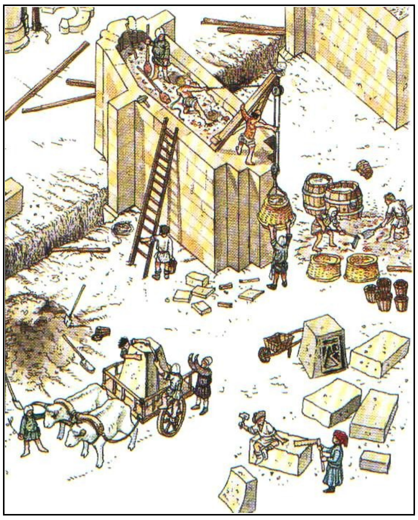
2. HOW MUCH CONSTRUCTION INDUSTRY HAS ADVANCED?

The construction of the middle age cathedrals in Europe where made with simple construction technology (Fig. 1-a). The bricks and columns elaboration were performed manually and on-site. Their elevation were also performed manually using simple mechanisms, like pulleys and similar [5]. The material supply, the transportation, the assembly technology and other many aspect were very important. All of them made that the construction period was very long (even centuries).

During the present century the house-building construction process has changed. But how much? In reality, the procedure for erecting building structure has changed very little over the past eighty years [6]. The middle ages pulleys are substituted by cranes (Fig. 1-b). They are more sophisticated than centuries ago, but work with the same philosophy: manual control, human operator visual feedback, big positioning error, etc. The only elements that have change are: the actuators (electrical motors instead of human force) and materials (metal based instead of wood). These two advances permit to increase the elevation speed, payload and reachability. In general, the house-building construction machinery philosophy is not changed a great deal.

Another important aspect is the prefabrication technology. During the construction of middle age cathedrals the majority of elements were produced on-site. Various small factories were created around the site. The transportability of the non elaborated products (trunks, stones, etc.) was a serious disadvantage. Today, this aspect has changed considerably, but serious limitations still exist: small maximum dimensions for truck transportation, high price for long distance transportation, etc. In comparison with the past, nowadays prefabrication has a high productivity [7], but at the same time it has a very low flexibility. This means that the prefabricated parts are highly project dependent [8]. The actual buildings continue to be mainly singular structures. This leads to a very low level of standardization and to increase the gap in comparison with the mass production techniques.

a) Middle age cathedral construction



b) Nowadays residential house construction

Figure 1. a) Past and b) present of construction technology

The architect-constructor coordination is another important aspect. The old constructor was commonly at the same time the designer (architect), the manager, the supplier, etc., i.e. they were the real integrators. While the existing construction technology are going in a different direction. The coordination of design and construction stages are usually very small [9]. The architect makes his/her designs without taking in mind the on-site construction processes and vice-versa, the constructors, on the other hand, inform the architects about the changes only superficially. New IT technologies will play an important role in avoiding this divorce in the future [10].

3. CONSTRUCTION INDUSTRY VS AUTOMOBILE INDUSTRY

In the previous section it presents how the nowadays house-building construction industry technology advance. The transition from totally manual process to semi-automated nowadays system permits to increase its 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 each industry sector is its productivity. Fig. 2 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 key point in this high productivity is the modern manufacturing concept: Computer Integrated Manufacturing (CIM). This concept was strongly developed during the last two decades and changed not only the manufacturing process itself but the concept of the product [11], [12]. 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 try 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. The same platform design, engine, electronics, etc. is used not only in different models of cars of the same company but also in the cars of other companies. This concept reduces a car cost and makes more competitive the automobile companies.

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 strongly has increased (Fig. 3).

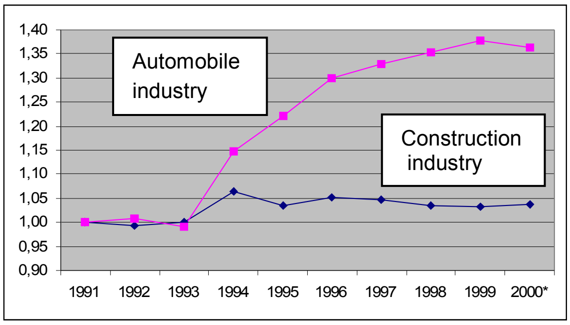


Figure 2. Productivity of the construction and automobile industries in EU (sources: Euroconstruct, Eurostat, ACEA)

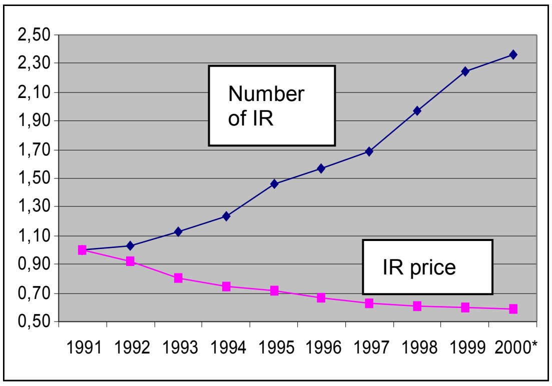
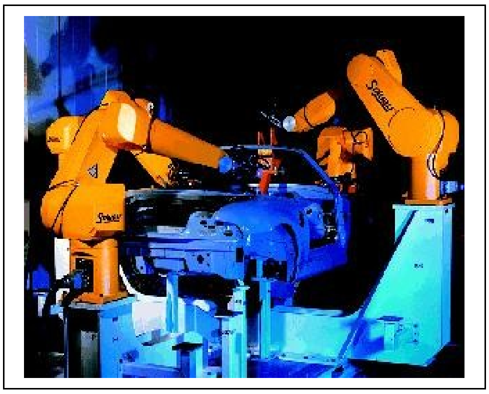


Figure 3. Number of industrial robots (IR) in EU and its price in US$ (source: IFR)

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 [13]. The important efforts during the last decade to adapt the CIM concept to the construction industry created the Computer Integrated Construction (CIC) [14]. Unfortunately, this effort has its success only in the IT related stages of the construction process (planning, suppliers relationship, etc.) but not in the production stages (pre-fabrication technology, building erection, masonry, on-site automation, etc.). The gap between the technological level of both industries is still very high (Fig. 4).

The CIM concept permits to reduce not only the cost of manufacturing but also changes the corporate culture [15]. It is more 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, their use is limited. Moreover, if these products introduce inconveniences to the whole construction cycle, they are openly refused. In the contrary, in the manufacturing industry the people and the environment respond very friendly to technological innovation. Researchers and end users speak the same “language” which permits to introduce these new technologies very quickly.

The EU automobile industry investments in R&D are over 5% of the turnover (ACEA, 1999) while the construction industry investments in house-building technology is less than 3% (Euroconstruct, 1998). In the construction industry the big companies end up limiting 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 machinery companies, which invest more in civil engineering equipment than in house-building one.



a) Automobile industry technology

b) Construction industry technology

Figure 4 a) Automobile and b) construction nowadays technologies

4. BARRIERS FOR INNOVATION: TWO EXAMPLES

Most of the barriers for introducing robots in house-building construction industry are mentioned in the previous section. Nevertheless, for more detailed analysis of these barriers, two important examples are examined: a) bricklaying robots applications, and b) modular houses assembly robot.

4.1 Bricklaying robots

In the field of masonry several projects of specific bricklaying robot were developed during the last years in the EU. Examples of these are: [16], [17], [18] (Fig.5), [19]. All of these robots had successful technical results: acceptable working cycle, good precision requirements, high payload, etc. However, only one of them was commercialized (by the German company LISSMAC). They sold only a small number of units and mainly not for the masonry applications but for palletizing applications. Where are the barriers for its commercial expansion? The three main barriers are easily summarized as follows:

Figure 5. The ROCCO-2 bricklaying robot in construction site.

- *High cost of the robotic system* which makes them non competitive with respect to the masonry workers salaries. The estimated price of the mentioned robots is 100-200 KEuros, while the average price of industrial robots is about 35-65 KEuros. This low cost of industrial robots permits to amortize the investment in automobile industry in the average of 18 months only, while this will be impossible in construction.
- *High sophistication of the robot* control system, and especially of the programming procedure [20], leads to its difficult introduction in the construction sector. The average level of masonry workers has a low level of education. More than 70% of workers in the bricklaying works do not have a medium education level [21].
- *Necessity of using special parts* (brick, blocks, etc.) with these robots. The parts must have special geometry (cavities, holes), high tolerances (about 1 mm), and special material (aerated concrete, send-lime, cellular concrete, etc.). In general, it is possible to say that these robots are not prepared to work with low cost standard parts. This leads to the use of sophisticated grippers and new mortar application methods.

4.2 Modular houses assembly robots

Several attempts of modular housing systems were developed in the EU during the last years [22], [23], [24]. These systems permit to erect the residential houses by assembly of 3D and 2D pre-fabricated modules. This technology reduces the assembly time and transportation costs. Nevertheless, the modules assembly procedure continue to use conventional cranes. This fact strongly limited the modular system advantages. This is why the modular house assembly robots are needed. Several robotd and automated cranes were developed in the EU for this purpose [25], [26], [27] (Fig. 6, courtesy FutureHome). However, serious barrier for its massive application still exist:

Figure 6. The FutureHome modular house assembly automation

- *Standardization of the modules connectors.* The connections between modules must be performed by means of connectors. But the standardization of connectors is not established. In this way, the use of modules produced by different manufacturers is difficult and seriously limits the introduction of module assembly robots.
- *Manufacturing tolerances of modules.* The manufactures have not guaranteed the modules geometrical and structural tolerances. This fact limited the use of precision robots for this purpose.
- *Modification of the cranes control.* The conventional cranes and robots must be modified in order to achieve good precision during the assembly. The friendly user interface is also not developed, making the use of this type of system very demanding.

5. FUTURE POSSIBILITIES

The automation in construction has moved through several historical periods, according the ISARC trends [28]: a) cradle (1984-85), b) growing

(1986-89), and c) developing (1990-98). However, the consolidated has not been achieved. Does this mean that this consolidation will happen in the near future? In my opinion, yes, it is. It is difficult to imagine that the houses shall be built in the future like today's cars, but in the near future the construction industry will be close to the automobile one. The crucial factors are:

- *Change of attitude* in the construction companies, the machinery industry, the research centers and the government R&D officials, in order to develop new high tech commercial (but not prototype) products.
- *New IT and telecommunications technologies* 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 of today's construction sector introduces a very high level of competitiveness.

To achieve the consolidation period in the construction automation big effort need to be done. In my opinion this effort will be focused in 4 main direction:

1. *Integration.* This is one of the key issue which is necessary to consolidate 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 in to 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 same 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.* Increasing this technology for not only the concrete but for other materials (including composites), the productivity will be immediately rise. Three main actions are*:*
   - 2.1. *Mass production pre-fabrication* in order to select the parts from a catalog. It 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. *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. Three main actions are:
   - 3.1. *"Easy" to use robots.* Develop robots which are easy to control and program through friendly graphical interface (GUI). The robustness is another key factor.
   - 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. *More investment.* Increasing the level of investment in robotization and automation of construction processes is the future key issue. This investment must be balanced between basic research and applied development.
   - 4.1. *Education*. Changing the culture of the operators directly involved in the construction process, through the specific type of education (like FSE and other EU courses). Otherwise the operators would resist the introduction of innovation.
   - 4.2. *R&D investment.* Creating specific R&D programs for construction automation, like the Targeted Research Action in Infrastructures: Industrial facilities, Construction and Civil infrastructures of the EU Fifth Framework Program (1998-2002) [29].

Using these ideas, it will be possible to radically change the construction process in the near future, in similar way to what happed in other industrial sectors. Probably, the today dreams will come true very shortly (Fig. 7, courtesy EU Haus AG, Germany).

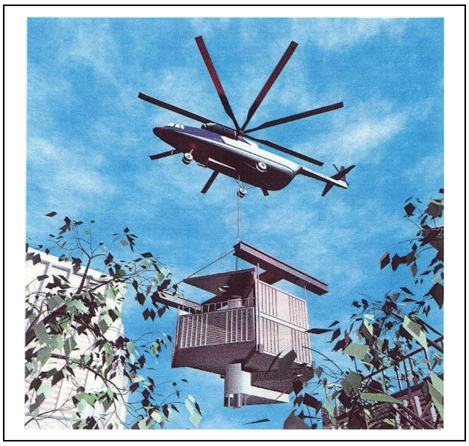


Figure 7. The future of construction technology

6. CONCLUSIONS

The critical analysis of today's level of construction automation (made in the first part of the papers) opens the way to the future possibilities in construction automation. The great expectation created in the past lead to the evident pessimism of some key actors: companies and researchers. This situation probably will change in some years, being the level of automation in construction industry in concordance with its contribution to GDP in the EU.

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