CHANCES, OBSTACLES AND A POSSIBLE TREND OF AUTOMATION IN CONSTRUCTION FROM THE POINT OF VIEW OF THE GERMAN CONSTRUCTION INDUSTRY

Prof. Dr.-Ing. Klaus Feldmann,
Dipl.-Ing. Markus Koch

Institute for Manufacturing Automation and Production Systems
University of Erlangen-Nuremberg
Egerlandstr. 7 – 9, 91058 Erlangen, Germany
E-Mail: koch@faps.uni-erlangen.de

Abstract: In this article the results of an opinion poll analysing the basic attitude of the German building industry towards automation in construction are presented. Based on general fields of applications for automatic control engineering in building industry, chances and obstacles are pointed out and a possible trend of future building automation is investigated. It was from special interest, which potentials can be used with respect to automation and rationalisation of the building industry and which obstacles are opposed to an intensified application of these technologies. Finally, the possibilities and obstacles of automation are described by the example of assembling of suspended ceilings. Different solutions to automate this process are evaluated regarding their building site fitness.

Keywords: trend of automation in construction, chances of automation in construction, obstacles of automation in construction, assembly of suspended ceilings

1 INTRODUCTION

The German construction industry is confronted with a long running structural crisis. Inevitable substantial organisational or technical problems for the enterprises are affiliated with this crisis, leading to noticeable degeneration in quality. These problems can be met by an adapted automation, which will determine the future performance and competitive capacity of this important industry. This development will lead to a qualitative improvement of the working results apart from the substantial reduction of the costs. Therefore automation technology could become the key technology of the new century in the building industry.

From the point of view of the building industry however, there is still a large vagueness how an automation of the building processes can be featured and which effects on the individual enterprises this could have. The removal of these vagueness can help to secure the strategic adjustment and positioning of the enterprises for the coming challenges of the construction industry and to enable the early development of new products.

The results of an opinion poll executed by the institute for manufacturing automation and production systems presented in this paper supply a contribution to answer these questions. Therefore, first the current economical background of the German building industry is described. Subsequently, possible fields of building automation are explained and compared in their degrees of automation. To it closes on the discussion of the results of the opinion poll regarding the chances and obstacles of automation in the building industry. Afterwards, a picture of the future building site is sketched on the basis of the results of the opinion poll. The obtained results are verified exemplary by automation solutions for the assembly of suspended ceilings with different degrees of automation. They will be evaluated regarding their building site fitness.

2 ECONOMICAL BACKGROUND OF CONSTRUCTION IN GERMANY

The German building industry represents with approx. 1.2 millions employed persons and a proportion of approx. 12 % at the gross national product one of the largest sectors of the economy in Germany. Up-to-date the building industry in Germany (predominantly however in West Germany) is before a moderate economic boom, which will be absorbed however by the substantial decreases in the most important building sections of East Germany. With the progressive opening of boundaries and markets, particularly with the European economic and monetary union, the protective cover, sheltering the building sector up to now, became lately more and more porous. Due to this increasing transparency of the market the competition pressure rises on the markets for building work and supplies, building materials and construction machines. The reduction of the state investments leads in the building sector to a high-grade failure of an important demand for building work. This situation is reflected in figure 1 again, the low level stagnating economic data is shown clearly according to a collection of the ZDB.

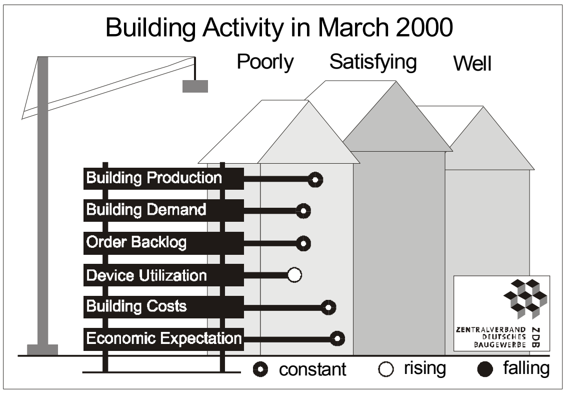

Figure 1. Economical Background of the German Building Industry [1]

Under the European-wide intensified competition pressure for building works and supplies the aspects of cost got still a higher weight for all demanders. Higher requirements are made to the quality of the execution of construction work. Many enterprises of the traditionally medium-size and craftsmanship related construction industry already gave up their dominating self understanding as supply trades and turned to a market orientation with active marketing policy. Thus many prefabricated building unit manufacturers occur no longer only than suppliers for the building industry, but offer the completion of a basement or whole housing units as a service from planning to execution.

Additionally synergetic effects can be used by project-related, firmspreading co-operation. Further productivity and efficiency can be increased by more prefabrication, by an increase of the degree of automation, by improved planning and organisation as well as by specialisation on special products.

3 FIELDS OF APPLICATIONS OF AUTOMATION IN CONSTRUCTION

A further aspect within the discussion of the topic “building automation” is the knowledge, which fields of application can be opened up for it and which degree of automation is reached in this areas so far. Figure 2 clarifies four areas for automation in construction, i.e. production of building materials, the prefabrication, the processes at the building site as well as the supply processes of the building.

The automation of process cycles in the building material industry has always been a classical area of application for automatic control engineering. The degree of automation is comparable to modern industrial plants [2]. Optimisations of the individual production processes are to be expected first of all in this area.

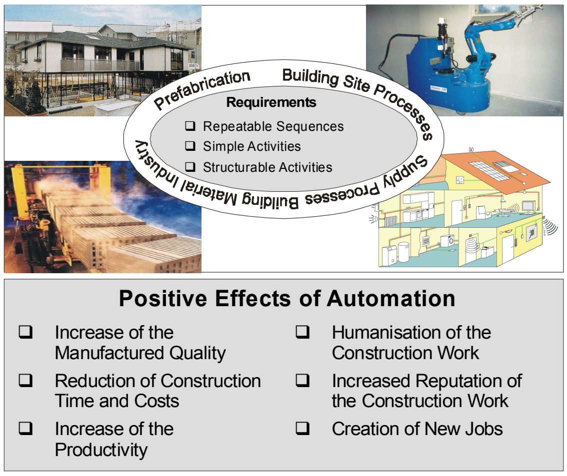

Figure 2. Fields of Applications of Automation in Construction

Production processes of elements and components running under stationary conditions are always well suitable for an automation due to their similarity for manufacturing processes in mechanical engineering. There are differences such as the small number of items of the elements which can be manufactured per time unit, the insufficient monitoring or controlling by process measuring technique as well as the qualification of the workers [2]. The opinion analysis presented in the following verifies that the use of prefabricated components and in the same time an increase of the device complexity is to be expected.

The automation of building site processes represents, due to the unstructured building site environment, the probably most fastidious area. But there are also already automation solutions for this topics. It is common to all of these prototypes that they were developed in each case for only a certain building site process and that they were not allowed to impair substantially the activity of the building workers. It was shown that under these premises just a few machines are economically applicable. The restrictions for the workers, the necessary safety regulations and the non-predictable influences on the building site limit rigidly the application of individual robots parallel to normal building execution.

The automation of the necessary supply processes in buildings (heaters -, ventilation and sanitary engineering) belongs for a long time to the preferential areas of application of the automatic control engineering. Matured solutions, like for example the European installation bus EIB, are available. Innovations are particularly expected by direct coaction of new principles of thermal insulation and energy production (e.g. solar technique) in connection with a favourable design of the building [2].

4 CHANCES AND OBSTACLES OF AUTOMATION IN CONSTRUCTION

There are so far uncertainties about the chances and obstacles of the increase of productivity by automation described above. In the context of a study of the Institute for Manufacturing Automation and Production Systems these problems and their effects were examined. Altogether 5300 executives of German building contractors and German universities within the area of construction were asked for that purpose. Over 500 persons answered the questionnaires. The subjective opinion about this topic of the building contractors and researchers from the building area as well as possible reasons and starting points for an automation in construction, which resulted from the inquiries, are pointed out in the following sections.

As expected, all asked ones of the study regard it as very important to produce in the required quality and to keep the agreed dates and costs. The creation of good working conditions for the building workers and the implementation of a detailed production planning are likewise regarded as relatively important, but compared with the first two points they are of subordinated importance.

According to the entrepreneurs, there are chances to organise construction more efficient. Special efforts within the area of an optimised preliminary planning in combination with an improved co-ordination of all participants at the building are regarded as the optimal way to increase the efficiency of the building construction. Large rationalisation potential is granted to the prefabrication, in contrast the automation of construction activities is regarded as fewer promising.

The most important reasons against an intensified automation at the building are seen generally in its individuality and the rough environment conditions. The common opinion that construction has, due to the individuality of the building, almost no similarity with the classical mass production, represents a further obstacle. This means that automation devices or robots operate most rationally, if they can execute cyclically again and again the same job, as for example in the automotive manufacturing the spot welding, and if they have to be adapted to as few changed site conditions as possible.

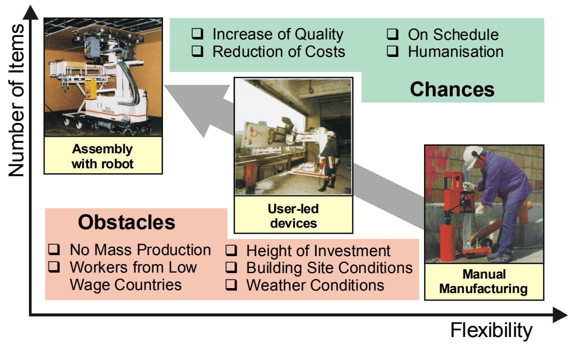

Figure 3. Increase of Productivity with Automation?

Unfavourable building site conditions are the third cause of impediment. The building site represents a dynamic environment, which changes constantly and which is additionally under strongly varying climatic conditions. Automation solutions, which are equipped with sensitive sensors could thereby easily be damaged. In this connection also fears are expressed that the partially very expensive automation devices could be stolen or damaged deliberately.

The possible height of the investment for automation devices is a further argument against an increasing automation at the building. Particularly, if workers from low wage countries can be still employed. A further obstacle is the necessary higher planning expenditure. The system security and the small possibilities of modification on the building site are regarded less critical. Also the parallel trades do not play a too large role according to the opinions of the asked ones.

5 TREND OF AUTOMATION IN CONSTRUCTION

Altogether two substantial statements can be derived for the future development of the building industry from this public opinion poll. On the one hand the necessity for an increase of the planning expenditure before the execution of construction and on the other hand an increase of the proportion of prefabrication.

Since this work can be executed in a well defined factory environment, the rise of the prefabrication degree will cause an increase of the production quality and a noticeable speed increase for the execution of construction. Further an increase of the device complexity of the prefabricated units can be foreseen. It is to be expected that many of the installations, like electrical- water or heater installations, are already brought into the elements in the factory and have only to be interconnected on the building site. The problems of the connection technique for these components, which must be partially under pressure or absolutely tight, are not yet solved and require intensive research and development. The high prefabrication proportion means an increase of the dry construction method on the building site. Thus, assembly activities will outweigh on the building site of the future.

An increase of the prefabrication presupposes increased planning expenditures, in order to avoid an expensive production of low-quality goods. Additionally the opinion is held that the planning during the construction should be replaced by a final detailing before beginning the execution of construction. In addition efficient planning tools must be developed, to achieve a very exact conception of the future building (for example with a visualisation of the future building in 3D and virtual reality) for the owners. Thus later suggestions for improvement can be reduced. The opinion is very often held, that more standardised components should be used than so far. On the other hand standardisation is often equated with uniformity and rejected therefore.

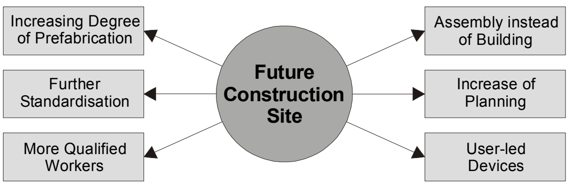

Figure 4. Substantial Statements about the Trend of Automation in Construction

There is a large majority approving the fact that smart user-led machines represent an effective tool to increase the productivity at the building.

However an economic application of such devices presupposes automation-fair materials and a planning co-ordinated with the requirements of the devices. The complexity of the machines requires qualified users and trained service staff. With the use of smart machines on the building site also the necessary data processing becomes more and more complex.

6 AUTOMATION OF AN ASSEMBLY PROCESS AT THE INTERIOR FINISHING

In a development project of the institute FAPS these theoretical results should be verified by the building of prototypeful automation solutions. Intentions of this project were the rationalisation and humanisation of assembly works in the interior finishing as well as the investigation, how modern automation solutions for the construction industry must be arranged, in order to allow integration in the current building site structure or which changes are necessary to enable the implementation of automatic control engineering at the building industry.

6.1 Description of the Selected Assembly Process

The dry interior finishing represents an area of the building industry, in which so far almost no automation solutions were presented. However it consists of many assembly processes, which are quite suitable for automation. After a detailed analysis of the different alternatives the setting of hangers at assembling of suspended ceilings was selected. This process can be divided very well into sequential work procedures, indicates a large humanisation potential due to the high proportion of over heading work and holds large rationalisation potentials because of the complex measurement work for the accurate positioning of the anchor bolts.

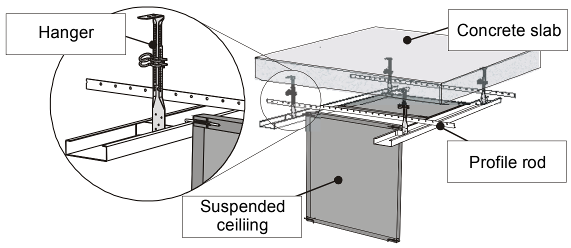

Figure 5. Assembly of Suspended Ceilings

With assembling of suspended ceilings hanger upper sections have to be fastened with anchor bolts in the concrete slab. After a previous vertical adjustment the lower parts of the hanger and the profiled rod, in which the floor ceilings are hung up, are attached to these. One has to pay attention to specific conditions, in order to ensure a perfect optics of the ceiling. Therefore, the anchor bolts have to be set with a tolerance of ±5 mm around their debit position. The basic requests for the fixing of anchor bolts are: A work height of 2,1 m up to 3,6 m or more is required, whereby the closest distance to the wall is 10 cm. The used hangers can be from 0,2 m to 1,2 m long. In order to transport the tools or devices within the building site, they must be lower than 2.1 m (door height) and smaller than 0.89 m (door width).

Up to now the assembling of suspended ceilings is executed completely manually, whereby normally only a hammer drill is used. First the building worker has to compare the planned placing of the anchor bolts with the real conditions on the building site, in order to determine possible deviations. Then the building worker can mark the elevation on the soil. The elevation is now perpendicularly projected from the soil to the ceiling with the help of a construction laser and marked there. But it is problematic that this job is executed often parallel with other trades of the interior finishing and so the access to the soil or to the ceiling is impeded with obstacles or already fixed installations (heater pipes, partitions...). Subsequently, the worker drills the hole for the anchor bolt with a hammer drill. After drilling the hole the anchor bolt is connected with the upper section of the hanger and hit with a hammer into the hole.

An analysis of this job supplies essentially two remarkable weak points, which can be improved with the help of the automatic control engineering:

On the one hand the marking of the working points is very time-consuming. Thus a procedure has to be developed, which enables an accurate positioning of the anchor bolts without drawing the elevation. But otherwise, this activity is very important for the quality of the ceiling mounting. In the case of deviations between the structural drawing and the real building site the know-how of the workers is often required. Therefore, a complete automation of this process does not appear meaningful. Rather a compromise must be achieved, for example by marking the reference lines only at the soil or even by drawing only each second marking axle.

On the other hand the unfavourable over heading work is noticeable when drilling the holes and hitting the anchor bolts. It is not only time-consuming, but the building worker carries out straining work attitudes over a long time. Additionally he has to shift the ladder scaffolding after a few holes, which results in an additional expenditure of time. It should be operated therefore from the soil, i.e. both boring and hitting the anchor bolts takes place from the soil using suitable aids.

6.2 Description of the Different Prototypes

The weak points of the manual execution described above can be eliminated with devices with differently high degrees of automation. In the following three solutions are described and discussed afterwards with their pro and cons.

A first proposal is a simple drilling rack with the structure shown in figure 6. An adjustable telescopic cylinder is fastened on a base plate with swivel rollers. At the upper end the hammer drill is attached, which can be pressed over a pedal against the cover. The device can be moved easily with the swivel rollers on the building site. Additionally the transportation into the building is unproblematic, since the device can be divided into smaller individual parts and assembled fast again. The anchor bolts are however still hit with the hammer. The positioning of the drilling rack has to be done manually by the worker. For that purpose the elevation has only be marked on the soil, the transfer to the ceiling takes place with a laser plumb bob which is attached under the drill.

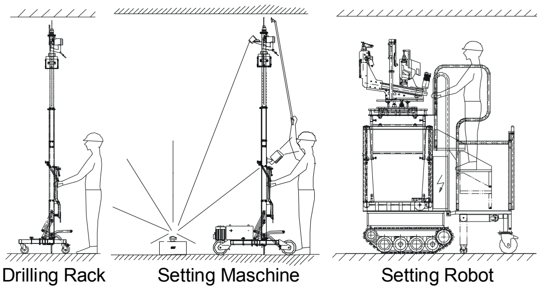

Figure 6. Assembly of Hangers by Devices with Different Degrees of Automation

A manually led setting machine is the second proposal. The basic structure is the same like the one of the drilling rack, functionality was however substantially extended. The complete manual marking of the working points is omitted, instead these are determined now by a combination of a laser range measurement and a laser guide beam. For that purpose, the distances of the anchor bolt series must be measured at two facing walls of a work space and marked at the soil. A building laser is then aligned in such a way that it creates with its laser beam a vertical connecting level between two opposite points. The setting machine is now placed into this guidance beam. It can detect with the help of a receipt mechanism whether a correction of the position to the left or to the right is necessary. Additionally the distance to one of the reference walls is measured and depending upon the desired distance of the anchor bolts within a series, a stop signal is shown on a display. The anchor bolt and the hanger can be put on the drill with a simple supply assistance and hit with the impact mechanism of the hammer drill into the predrilled hole.

A solution with a very high degree of automation is the setting robot. The prototype consists of a chain-driven transportation module and a working module fastened on it. The technology module possesses a lifting unit, in order to bring the gadget' to the ceiling height. Additionally the micro-adjustment of the drilling depth or the loading of the setting device is realised with this lifting unit.

At present, the guidance of the robot in the work space still takes place with an image processing system. The workers attach the elevation lines at the soil. The vehicle can follow these lines with the help of a camera. As soon as a operating point arrives in the camera's field of vision, the vehicle is slowing down and stops. Then the deviation into x and y direction is determined. Additionally the inclination of the vehicle is measured and the deviation of the tool axle due to it is calculated. By NC-axles in x and y direction these deviations are corrected. After that, the hole for the anchor bolt will be drilled. Then the anchor bolt setting device is brought into position under the hole and the anchor bolt will be shot into the predrilled hole. Afterwards the robot moves to the next operation point. If obstacles step into the course of the vehicle while driving, the vehicle stops and the user is requested to eliminate the obstacle or drive around it by manual control.

6.3 Evaluation of the Different Prototypes

All three systems were used on several test building sites, so that a founded comparison can be made among themselves and an evaluation regarding the building site fitness can be done. For that purpose, the three main criteria ergonomics, economy and building site fitness were refined and an evaluation pattern as in figure 7 was set up.

Criterion / Device	Drilling Rack	Setting Maschine	Setting Robot
Economy			
Height of investment	++	+	--
Cycle time	++	++	++
Preparation time	++	+	-
Building Site Fitness			
Transportability	++	++	-
Obstacle overcoming (ceiling and floor)	++	++	+
Accuracy	-	+	++
No impairment of the building flow	++	++	--
Ergonomics			
Easy positioning	-	+	++
Simple operation	++	++	-
Legend: ++ very well fulfilled	+ fulfilled	- partly not fulfilled	-- not fulfilled

Figure 7 Evaluation Pattern of the Different Prototypes

The evaluation shows clearly that on today's building sites a part-automatic device, which on the one hand relieves the user from monotonous activities but on the other hand integrates the worker into the work routine, is the best choice. Economy is guaranteed by noticeable savings due to the fast specification of the working points and the omission of the ladder or the scaffold. At the same time the device causes a relatively low total investment. Due to the unsatisfactory process planning obstacles must often be overcome or there are only limited work surfaces available. For these problems the partly automated device offers a very good solution by the simple and fast demountable structure. The operation is very simple and can take place after a short briefing by each mechanic.

In contrast to the drilling rack the moving to the working points is much simplified with the help of a display and relieves the mechanic additionally. Thus the accuracy of the anchor bolt placement is higher.

The setting robot in comparison is characterised by an almost complete discharge of the mechanic and the highest work accuracy, but there are certain disadvantages, that make its application particularly on today's building sites more difficult. Thus substantial difficulties may occur bringing the heavy device to its working area and the operating of the robot requires a high training expenditure. The robot causes very high investment costs and operates economically only if long distances without larger ranking expenditure can be processed, which presupposes the absence of any obstacles at the soil and the cover. However this can not be ensured without a substantially improved process planning.

Summarising, it can be noted that the obstacles specified in the opinion poll, but partially also the chances for automation solutions at the building, could be verified. For a successful further development of this area however the configuration of the devices is crucial, like the comparison between the three automation solutions clearly showed. Thus there are possibilities of rationalising the existing assembly processes by a careful combination of automatic control engineering and manual assembly.

Acknowledgments

Parts of this publication were acquired in the context of a project promoted by the Bavarian research donation.

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