A Mobile Robot System for Assembly Operations at Interior Finishing

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Abstract

This paper presents the fundamental concepts for automation of assembly processes at interior finishing. First the technological and organizational workflows and influence parameters of typical process chains at interior finishing are analysed. Then, potentials of rationalization utilizing hybrid configurations of automation systems are derived. Taking into consideration the fundamental requirements and specific assembly influences, an innovative solution is proposed based on a flexible transport unit and assembly units for various tasks. Exemplarily, an alternative assembly strategy for the fixing of anchor bolts at assembly of suspended ceilings is detailed. In addition, the solution is analysed for its practical qualification with a prototypical implementation. Fundamental restraints for an efficient approach of rationalization in building industry are also located in the technical and human environment of the process. Therefore, requirements for automation-suitable building sites are outlined as well as the essential changes in qualification and motivation of the employees.

1. Introduction

The German construction industry is confronted with a continuous structural crisis. Inevitably substantial organizational or technical problems for the enterprises are connected with it, which lead to noticeable degeneration in quality. Thus the construction firms are increasingly forced to use unskilled workers due to the high proportion of manual activities, the rising lack of skilled workers as well as the intensified price fight. These structural problems can be met by an adapted automation, which will determine the future performance and competitive ability of this important industry. Apart from the substantial reduction of the costs this development will lead to a qualitative improvement of the working results. For the building workers it is connected with a noticeable humanization of the workstations and enrichment of work contents by new technologies. Thereby a rising attractiveness of the construction work can be achieved long-term.

2. Exemplary analysis of an assembly process of the interior finishing work

In order to receive the requirements for automation solutions, a careful analysis of the process chains occurring with the interior finishing work is necessary. In addition to that the surrounding field on the building sites must be determined and documented accurately. Among them are the documentation of the building structures, the climatic conditions, prevailing logistics, the safety regulations, etc.

Exemplarily the fixing of anchor bolts at assembly of suspended ceilings is to be examined.

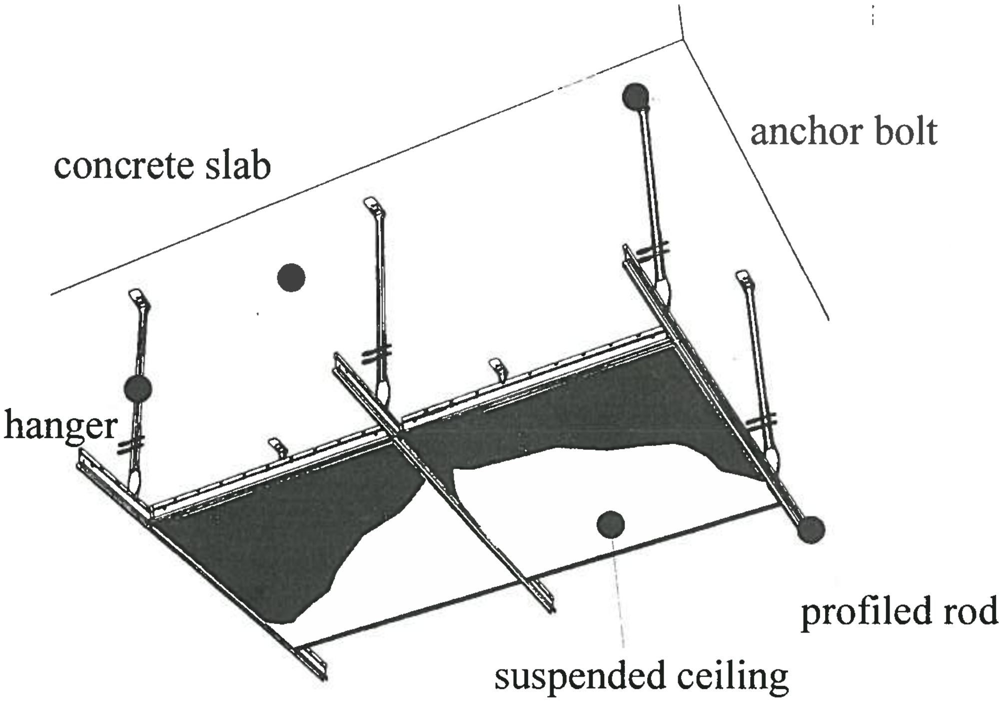

Figure 1: Fixing of suspended ceilings with anchor bolts

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. Thus the ceilings are often aligned for example at facade components.

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 trailers can be from 0.2 m to 1.2 m long.

The process chain (Fig. 2) for fixing anchor bolts can be structured as follows:

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. Such deviations can result for example from the fact that the front farmer did not operate in an accurate raster. Then the building worker can mark the elevation on the soil.

The elevation is now perpendicularly projected from the soil to the cover with the help of a construction laser and marked there. In order to execute the work on the cover, the building worker has to prepare a ladder scaffolding. From this point on, there are often two building workers simultaneously at work.

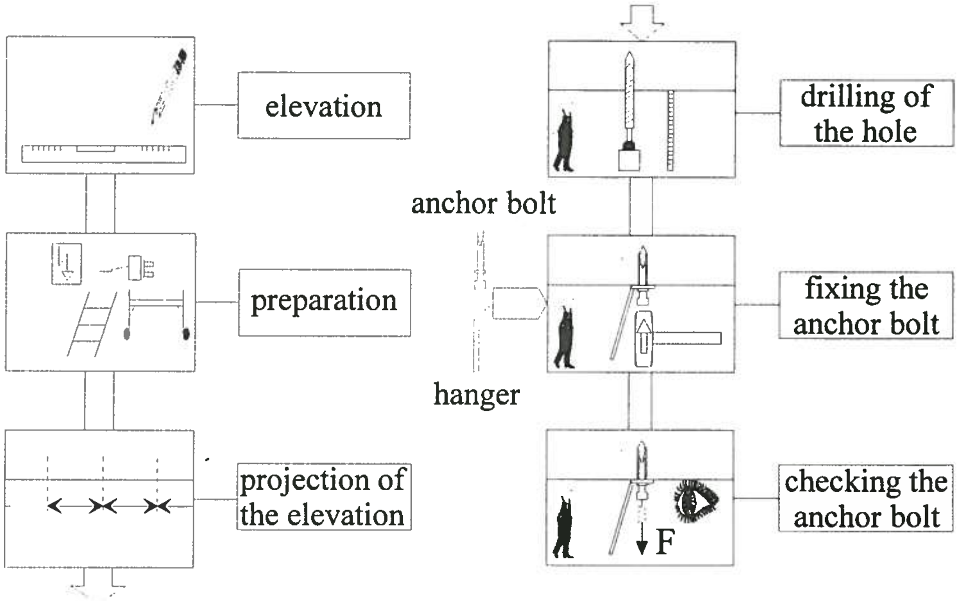

Figure 2: Process chain for the fixing of anchor bolts at assembly of suspended ceilings

Subsequently, the worker drills the hole for the anchor bolt with a hammer drill. The weight of the hammer drill is approx. 2 to 4 kg. The service life of the drill is approximately 200 drillings. The drilling position may deviate in raster direction by ±5 cm and perpendicularly to the raster by ±1 cm. It can be necessary to reduce these tolerances depending upon the type of hanger and its height.

After drilling the hole the anchor bolt is connected with the upper section of the hanger and hit with a hammer into the hole. Finally the anchor bolts are checked and an inspection report is written.

3. Requirements for an automated solution

When drilling and hitting the anchor bolts the unfavorable over heading work is remarkable. 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.

Therefore, an automation solution should find the correct drilling position independently, drill the hole and hit the anchor bolt into it.

Thus, the robot needs a suitable positioning system, which enables it to determine its position in the work space with the necessary accuracy.

In order to transport the device within the building site, it may lower than 2.1 m (door height) and smaller than 0.89 m (door width) in the transport position. Therefore, the assembly tool has to have a suitable vertical adjustment. Thus it is at the same time possible to pass under possibly occurring obstacles at the cover (e. g. pipes already installed). Additionally sensor technology must be available for detecting obstacles in the work space.

Possible steel girders running in the cover are representing a problem. These must be detected, since they influence the service life of the drills quite crucially. This can take place for example by a measurement of the force way process during the drilling. Additionally the drill wear can be determined and the user be informed, when the drill must be changed.

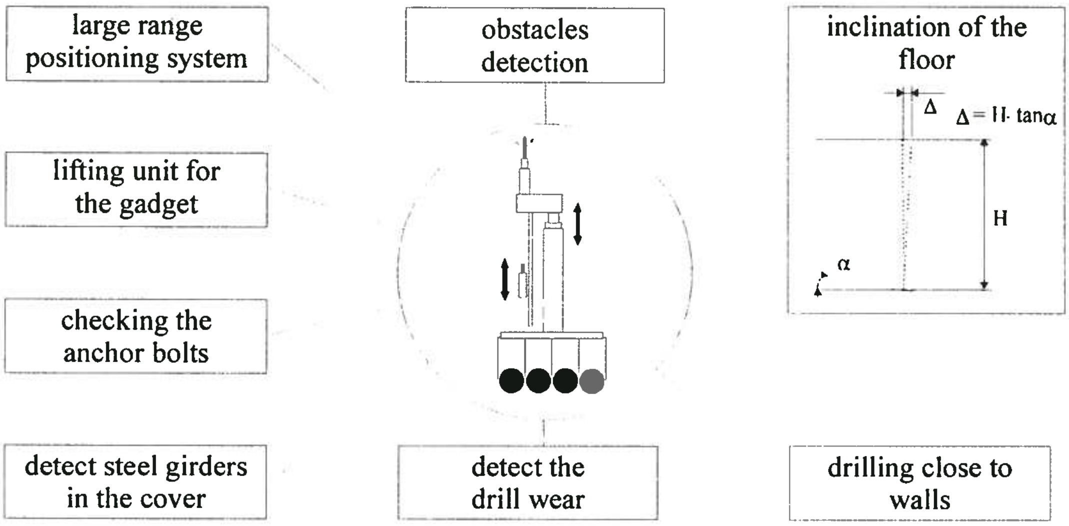

Figure 3: Requirements for the fixing of anchor bolts

All the tolerances with the inclination of the soil, which ensure an exact positioning of the robot at the soil, but influence the axle of the assembly tool are problematic for the setting process. So already an inclination of the soil of 0.6 degrees, with a ceiling height of 3.6 meters causes a deviation of the setting tool of 3.7 cm. The exact position of the anchor bolt may deviate however in raster direction by ±5 cm and perpendicularly to the raster only by ±1 cm depending upon the type of the used suspended ceiling. Inclinations of the soil affect the positioning tolerances, especially perpendicularly to the raster. Since inclinations of the soil occur due to manufacturing inaccuracies, a balance mechanism has to be designed. The robot measures the inclination of the soil by inclination sensors and the result is used to correct the positioning of the tool axle. Then the axle would meet still diagonally the cover, but the deviation would be however avoided.

For a decrease of the necessary positioning accuracy of the transportation module a horizontal axle or even a cross table can be integrated into the technology module. The transportation module needs to reach the desired working position only in a relatively rough area. Then the fine positioning is done by the technology module. Thus the ranking expenditure can be substantially reduced.

4. Planned total concept

From the results of the process analysis a specification for the desired automation process can be set up. It contains both the processes and the type and condition of the occurring building materials which can be automated. According with that a profitability analysis runs in order to be able to measure the market potential of the automation components.

It can basically be stated that all different operational sequences can be essentially structured in process specific technologies (e. g. setting of anchor bolts) and transport or positioning flows. Therefore a modular total concept is pursued, which uses as basic module a flexibly applicable transportation module. This can be extended over standardized interfaces with process specific technology modules.

Autonomous guided vehicles (AGV) are suitable for the function of a transportation module, however new ways regarding navigation and progressive movement ability have to be found. The factory AGV is mostly led by means of guidelines or by firmly measured reference labels. Both possibilities cannot be used for a building site, since they would require too much installation expenditure. The AGV moves on small rubber wheels and is suitable only for smooth hall floors. A building robot has to deal with dirty and very rough concrete soils and needs special ranking possibilities, in order to achieve its goals as rapidly as possible. A further problem are installations, e. g. heater pipes, which already are on the floor.

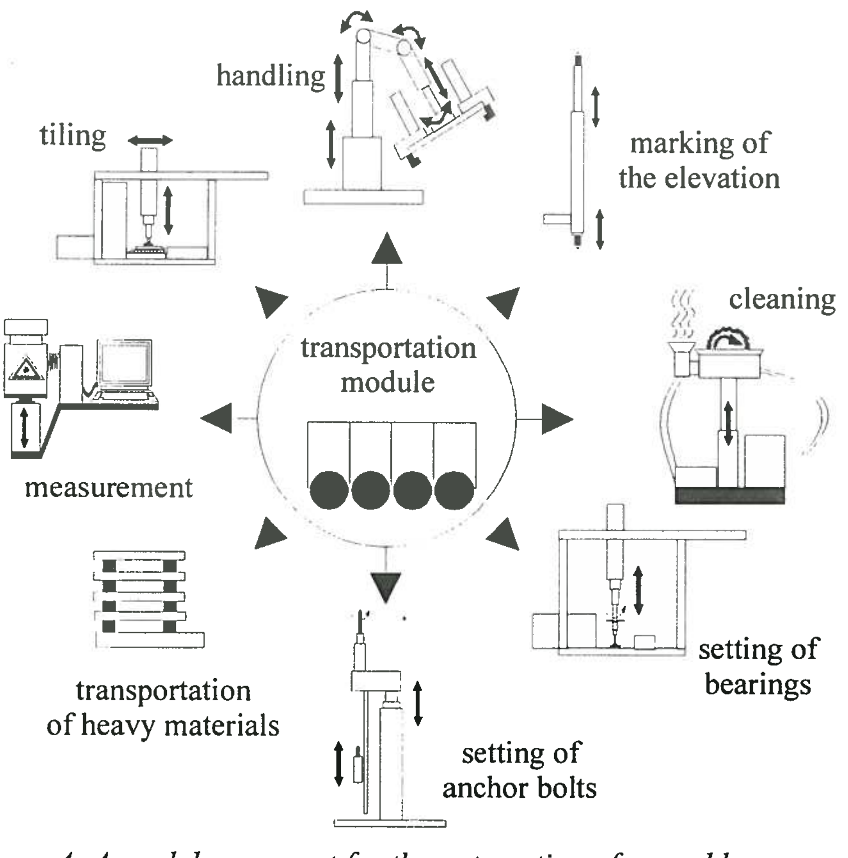

Figure 4: A modular concept for the automation of assembly processes at interior finishing

An important point is the adherence of suitable dimensions and weights for the building site, i.e. the entire robot has to fit still by elevator or building doors. The admissible weight is limited on the one hand by the demand after transportability and on the other hand by the admissible maximum loads of the concrete floor or already installed raised floors.

The technology modules are particularly laid out in each case for a certain application and can be put on the transportation module. Cases of application are for example measuring the spaces, tiling, setting anchor bolts cleaning soils, ceilings or the supply with heavy materials for the workers.

5. Implementation of an automation solution

In the following a prototypical construction, which was already implemented, is to be presented.

The prototype consists of a chain-driven transportation module and a working module fastened on it. By the chain drive the vehicle can easily overcome smaller obstacles or drive on dirty soils. The technology module possesses a lifting unit, in order to bring the gadget' to the ceiling height. Thus a height during the transportation of nearly 2 m and a work height of approx. 3.6 m can be achieved. Additionally the micro-adjustment of the drilling depth or the loading of the setting device is realised with this lifting unit.

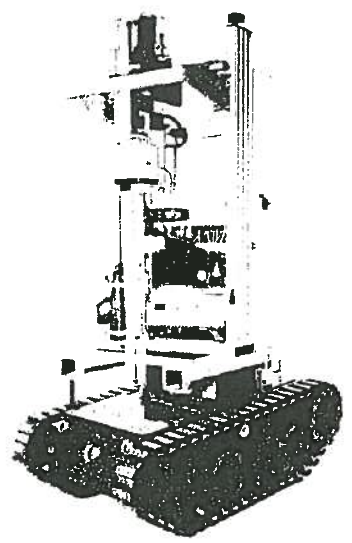

Figure 5: Prototypical implementation for the automated fixing of anchor bolts

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. Then the vehicle is positioned by the worker at the beginning of a line. The vehicle can follow these lines with the help of the camera and detect the operating points. As soon as a operating point arrives in the field of vision of the camera, 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. These two deviations are added and transferred to the control system of the technology module. By NC-axles in x and y direction these deviations can become corrected. Thus the ranking expenditure for the transportation module can be minimized. 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 pre-drilled hole. Afterwards the robot moves to the next operation point. Drillings close to walls in a distance from 10 cm can be set by special constructional measures as well.

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. In the future sensors will do it automatically.

Beside a careful and durable construction of the mechanical components one has to pay attention to an error-tolerant and user-friendly control system. With the implementation of the control concept not the development of new characteristics is the centre of attention rather the adaptation and fusion of existing procedures under the criterion of the application on a building site. With the development of the control concept it was made certain that the system is expandable and configurable. The expandability was achieved by the allocation of each control problem into individual software modules, which can communicate and exchange data over a common memory. Additionally a system attendant can take over the configuration of all important parameters of the individual modules by a special menu option.

Especially in the construction industry it must be assumed that the workers are not familiar with operating a computer. Therefore the user-interface has to be structured as simply as possible. Therefore the operation of the robot by the worker takes place with the help of a touch screen on which the statements or error messages are displayed in an understandable form.

Fig. 6 shows the control panel of the robot. The picture provided of the camera is displayed on the right side, in order to bring the vehicle on the line and monitor the driving process. On the left side there are different control buttons, in order to make inputs subjected to the current state of the vehicle. For each internal message the worker has only two or three options to choose from (e. g. "step back", "aborting", "manual driving"). These are displayed with an additional explaining text.

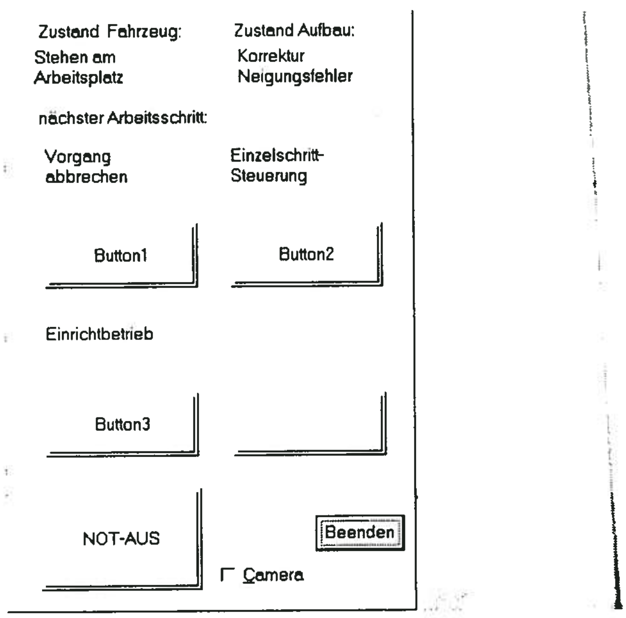

Figure 6: User-Interface of the robot control system

The fundamental layout is preserved during all statuses, which can obtained by the vehicle and the technology module. Only the text within the frameworks changes, which are titled with "current status of the vehicle", "current status of the technology module" and "select next step". Status and error messages appear in plain text and a guidance for error correction is given to the user on demand. The user influences the further actions by pressing one of the buttons, which are called Button 1 to Button 4 and emergency stop.

In the example the robot stands at a bias point and the technology module corrects the position error as well as the inclination error of the device with its axles. The user can abort this process or switch into a single step mode, in order to learn how the device operates. The fourth operating button can not be chosen, because there are only three options selectable in this example. A large emergency stop button is responsible for the interruption of the current activity while unexpected events appear.

If necessary the man-machine interface can be transferred into other languages or be supported of meaningful graphic symbols without large expenditure.

The actual control system was implemented on a DOS computer, using the real time system RTKernel. Thereby the individual modules were configured in each case as a task.

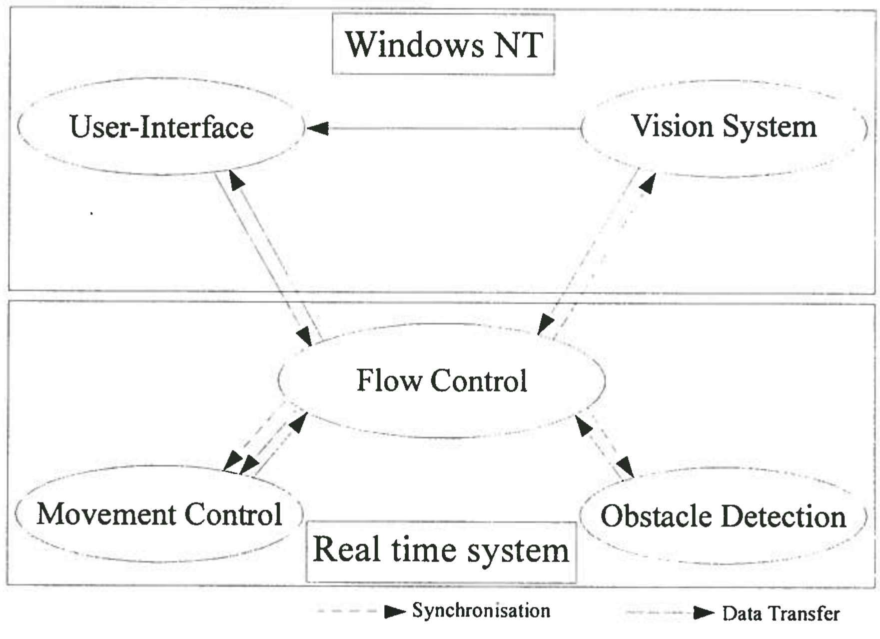

Figure 7: Functions of the control system

The flow control does the coordination of the execution of the flow diagram in accordance with the current state of the hole system. This includes the call of the control procedures according to the individual plan steps, the monitoring of their correct execution by comparison of the planned with the actual status as well as the reaction to error conditions [2].

The movement control transfers the internal movement messages for the vehicle platform (e. g. travelling straight ahead or driving along curves), given by the process planning, into a temporal operational sequence of set-point commands for the driving motors. The generation of the course can take place either on fixed, mathematically given trajectories or based on a real time analysis from sensor signals. The actual values are obtained thereby exclusively through couple-navigation. This is sufficient despite the available wheel slip, since the accurate positioning takes place via an overlaid position regulation [3].

The environment recognition serves predominantly to detect static and dynamic obstacles and to initiate appropriate evasive actions of the vehicle. So far ultrasonic sensors are used, however the module is expandable also on other sensor types.

A fewer automated prototype was tested on a large-scale building site and well accepted by the workers, since the immediate visible facilitation of their work let overcome the fear by the new technology rapidly. In addition to the subjective impressions of the workers the times and the costs of the automated assembly were compared with the manual one. This monetary evaluation furnished a saving of 25 % per set anchor bolt.

6. Effects of automation on the working sphere

However, an over-all concept may not only remain limited to the hardware components of the future robot. The integration of the robot into a suitable infrastructure as it has been done during the introduction of the robots in the industry has also to be considered. This means that not only suitable control concepts have to be developed, but also subjects like logistics and stock management have to be taken into account. Robot-fair materials and site conditions have to be created similar to those in the manufacturing technology. This ranges from the building design and the timing of the individual assembly steps up to the modification of existing activities. Additionally suitable design features for the later application of service robots can already be provided during the planning and the erection of the building. For example, a guideline assistance for autonomous robots can be created through suitably structured floors.

Another question of importance is, which effects on the working sphere such an automation concept will have.

- An increase of the manufactured quality is achieved by a selective automation. The fatiguing and therefore error-prone work will be shifted from the mechanics to the machine. The manufactured quality will be monitored and documented by the available sensor technology of the machines.
- The construction period and the construction costs are both reduced by automation.
- Automation means a noticeable humanisation of the activities for the workers. So a reduction of the rate of sick persons can be achieved in this industry.
- Higher qualification of the workers will be necessary, since the complex and technically demanding machines require qualified users and trained service staff. This will help the building workers to an increased reputation.

Even the German Builders' Union IG-Bau-Steine-Erden longs for the introduction of the robots: In a position paper from November 1995 the trade unionists hope that the activities, which are executed by subcontractors from cheap wage countries up to now, can be taken over by robots. Then, the remaining work will be done by high-qualified workers. Additionally, new jobs in the robot industry come into existence [5].

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