The Current Status and Key Issues in the Future on Automation and Robotics in Construction in Germany

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Abstract

This article describes the state of art, relating to automized processes, in different fields of the German construction industry. First the German demands for future construction efforts are shown and the specialities of the German construction sites are presented. Then the actual state of the art of different automized construction systems used in Germany is presented. Compared to a country like Japan, in Germany the efforts to automize construction processes are just in the beginning. Therefore the most popular prototypes of automated construction machinery are presented and intended developments until the year 2010 are shown.

1 Introduction

The use of robots and manipulators for the construction of buildings, at the one hand on construction sites or on the other hand in plants for prefabrication, and the existence of fully automated building systems in Japan has recently led to discussions in Germany. The capability of the German building and construction industry to create innovative construction systems as well as robots was questioned. The main change in the German construction industry during the past fifty years was the transition from the expenses for man power to the intensifying of the use of construction machinery[1]. This transition mainly took place in the field of below-grade engineering, where the costs for machinery are 80% of the whole expenses for construction. In the field of building construction the belonging rate is between four and eight percent; the costs for wages make 40 - 60%. Rationalisation steps are especially required in those fields of construction work with the highest future demand. Figure 1 shows, that in Germany the share of building construction of the total construction yield is 90%. Therefore the main efforts in the past and future were and will be made in this sector of construction machinery. The aim of this presentation is to describe mostly the development of the German building construction technology in the last years and the plans for the future.
The emphasis of the examination is laid on technological trends of the construction industry, mechatronical robotics and automated building systems in the field of building construction. It

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is described, which possibilities regarding to automation exist or can be developed in construction procedures used in the German construction industry.
The formation of article is partitioned into the different construction styles, which occur in the German construction industry. Figure 1 shows the future demand of construction work in the future. The house building industry makes half of it and German houses are mainly constructed with bricks. With a mechanisation rate of about eight percent only, the rationalisation potential in this field is the biggest. Therefore developments mainly took place in the brickwork industry and the formwork and concrete sector.

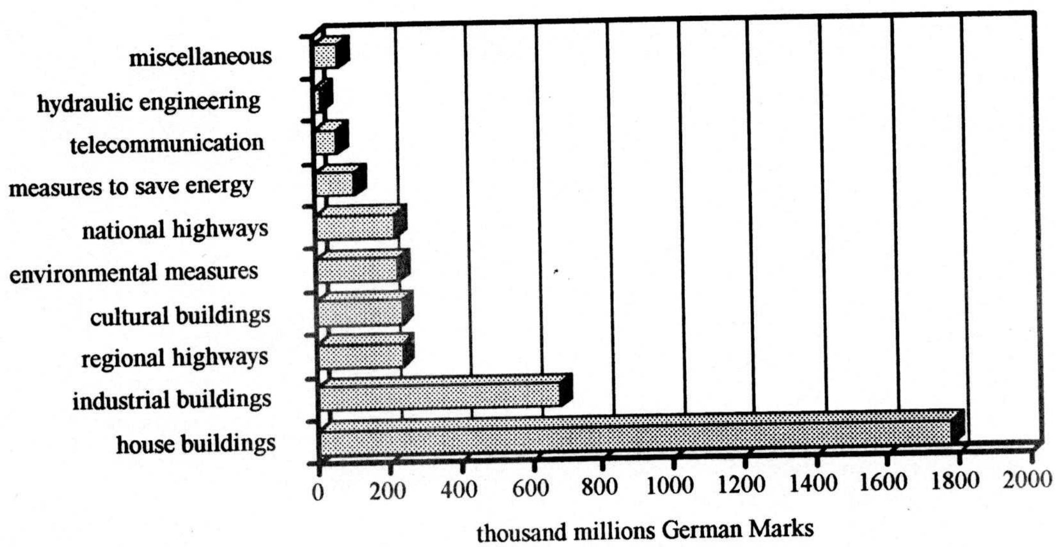


Fig. 1: Prognosticated demand of construction work up to the year 2000

2 Actual stage of construction automation in Germany

As mentioned before, compared to the Japanese way of innovations in the construction sector during the last twenty years, German above ground constructors have been keeping up most of their traditional work. Since the end of the eighties, due to the lack of apprentices in construction jobs and to an increasing discussion about the high costs of buildings, rationalisation developments were started. They mainly took place in the masonry and formwork sector and in the field of precast concrete, where no ready solutions from other countries were available.

2.1 Brickwork

In Germany and also in most parts of Europe an often used building material is stone. Most of the building projects are constructed with this material.
Due to rationalisation efforts brick dimensions were increased resulting in additional weight, which required mechanical assistance for asssembly. Main efforts were made in this field.

In the last time activities to develop machines that support the laying of bricks and even a fully automated robot are increasing in Germany. These activities are a result of the gloomy outlook that sooner or later hardly anyone will build in bricks, because hardly anyone will still be able to do so. Brickwork is a very heavy work, which can lead to severe illnesses and early retirement. Consequently a very small number of skilled workers is available nowadays. This in turn is reflected in ultimately high prices and wages, which will make brick building in some time prohibitively expensive. Therefore it should just be a question of time before only houses are put on the market that have not been erected on site by a team of bricklayers, but by a robot in the production shop. This chapter presents some developed devices for brickwork and gives information about the proceedings in an automated plant for brick units. Solutions to simplify the bricklayers work or to substitute their hard physical labour jobs by devices and robots, that need skilled operators instead of workers, can be divided into three different groups, depending on their grade of automation and their area of usage.

1. Brickwork manipulators: they are mechanical aids for the bricklayers work.
2. Machinery for erecting walls in plants; automised prefabrication of wall elements.
3. Robots for assembly on the construction site.

Examples of 2. and 3. are shown in the following:

2.1.1 Automatic masonry machines for prefabrication of walls

Automatic machines for prefabricating walls have a capacity of 3,5 m² to 40 m² per man and hour. Compared to the construction on site, they guarantee continous and humane working independent of the weather, an optimised quality, an increase of the procductivity and a mechanised dimensional control. Actually there are two automatic machineries for prefabrication of walls working in Germany: A CAD/CAM productionline of the German firm SÜBA and the "Multistone" of the Anliker GmbH.
The CAD/CAM productionline of the SÜBA allows the use of the CAD-input of the Architect's Office. This is the most important aspect of the rationalisation effect, because on the average 200 data instructions have to be passed to the automatic machine. The walls are buildt up to 90% of whole brick units. Special sized stones are provided by using the automated sawing machine that belongs to that production line. The whole wall system bases on a grid system of 125 mm. For buffering reasons a magazine of stone pallets is provided. The bricks are picked up, row by row, and allocated to individual brick buffers. Special stones are seized from these buffers and feeded to the sawing machine. The stones are set depending on the assembly datas of the program to the assembly conveyor. This assembly conveyor transports the rows of bricks in the correct order to the automatic setting machine. The automatic gripper of the setting machine then individually transfers the masonry units to their described position in the processing stand. After the completion of one row, mortar is applied to the top with automatic mortar nozzles. After lowering the masonry panel by the height of one row of units plus the mortar joint, the next row is set by the automatic setting machine. In addition to this, the automatic setting machine allows to set reinforcing steel bars and longitudinally laid tension bars for safe transport. Without heating the wall panels need 36 hours for drying before they can be transported to the store or the construction site.

2.1.2 Masonry robots for construction on site

Two robots for erecting walls on the construction site have been developed in Germany during the past years. The mobile bricklaying robot that is developed at the University of Stuttgart and the Rocco robot which is developed under participation of the authors. Both of them are still at the stage of prototypes.
The basic ideas both systems have in common are:

- Mobility of the robot system that enables the robot to move autonomous on the construction site.
- Sensor system for determination of the robots positions and its environment.
- Off-line generation of the robots motions.
- Automatic grappling of the stones from the pallets.
- Automatic application of mortar.
- Automatic positioning of the bricks.

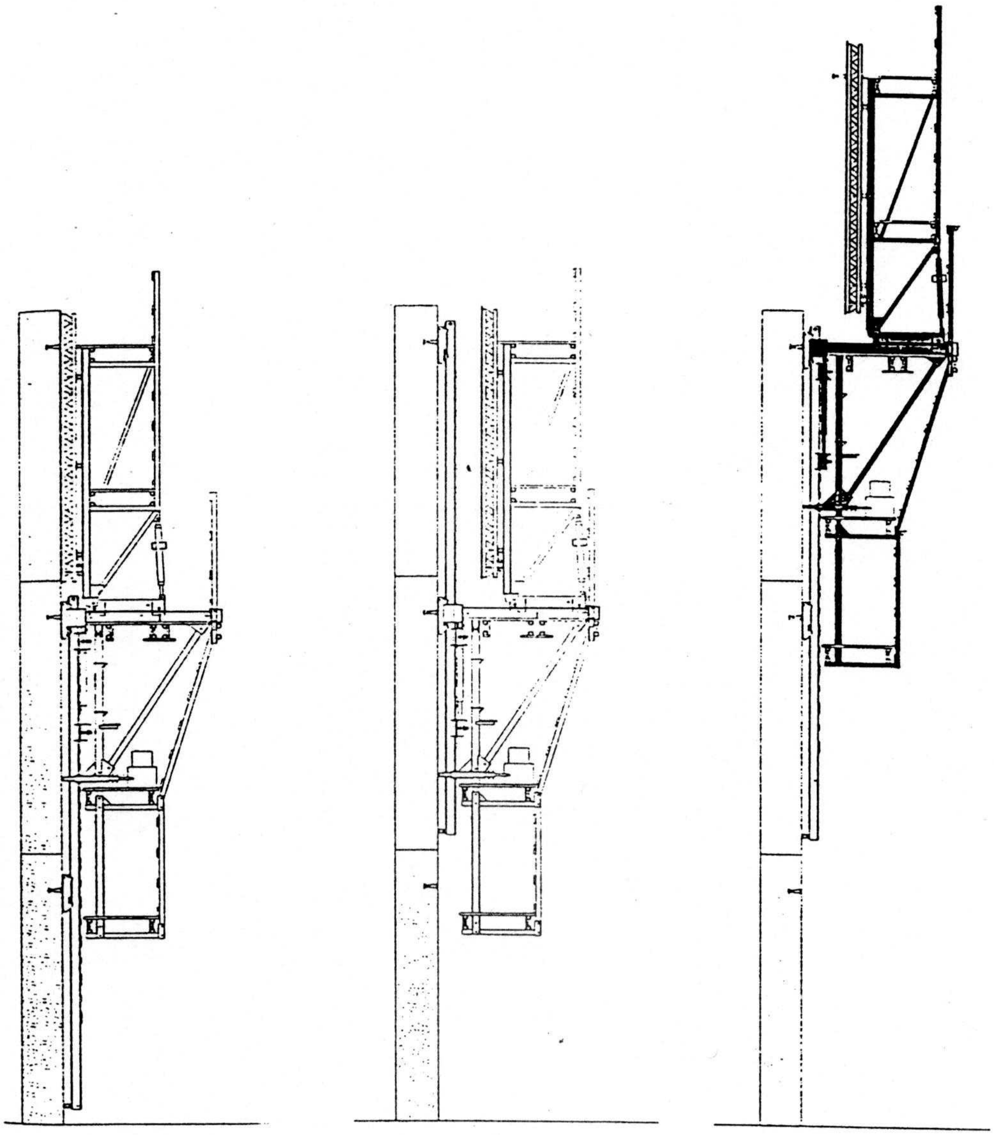
The Rocco robot allows a throughout automation of the masonry building process. Using the architects CAD-plans of the building the wall is partitioned into different segments. Those segments mainly have the size of standard stones. Special sized stones are sawed in prefabrication and placed on determined positions on pallets. With the data of the wall partitioning and the construction site layout the assembly sequences of the different walls are planned. With the input data about the location of stones on the pallets, the pallets position on the construction site and the assembly position in the wall, an off-line program generates the robots motions. On the construction site the robot moves autonomously between different working positions. The automatic assembly sequence of a stone starts with the grappling of one or two stones from the pallets. These wall units are put on an automatic mortar application machinery with at least two working places. afterwards the bricks are placed on the actual wall unit.

2.2 Formwork

2.2.1 The automatic climbing system (ACS) for formwork on site

The production of formwork is always a large-scale work. Today in most of the cases pre-fabricated pieces of form are used. The shuttering and the removal from stripping afterwards take a lot of time. Especially when manufacturing individual formwork for the structural component each piece has to be adjusted to the building unit. In the sixties for example the average time for shuttering was 1,0 h/m^2.
The development in this construction field has increased a lot for some time now. It leads from the described wooden formworks to climbing formworks. For all kind of different building structures suitable shutterings exist. Nowadays the index for the producing time of shuttering has increased to a value of 0,23 h/m^2. The latest innovation on the market is an "Automatic Climbing System" (ACS).
The climbing process takes place with an electronic controlled hydraulic cylinder. This lifting plant pushes the climbing unit without intermediate anchor to the following section to concrete. This feature leads to a constant and gentle climbing procedure. The arrangement of the climbing console is variable and can be adjusted to the local circumstances. A carrying out of the climbing is possible in all weather conditions. Even in heights greater than 100 meters

the operation of climbing can take place during maximally wind loads, because the unit will be connected with the building [4].



Stage 1:	Stage 2:	Stage 3:
- the pouring of concrete of - the wall is completed	- shuttering is driven back - climbing shoe is mounted - climbing rail drives up and secures itself automatically	- climbing unit moves without intermediate anchor to the following height - the shuttering is ready for duty for the next section of concrete

Fig. 2: The order of the ACS climbing process /4/

2.2.2 Presentation of a formwork robot for prefabrication

The functions of the formwork robot are the plotting of individual formwork geometries, oiling of specific formwork areas and computation of the positions for claps magnets on the formwork surface and their exact location and setting. Furthermore it has the task to slip over the U-shaped formwork profiles over the magnets in arrangement, which is calculated in each case to the optimum. Additionally it is possible to make the loading and off-loading of buffer stores for formwork profiles and magnets and administration of these stores.

The construction is made of a gantry type robot with four axes of movement and a grab head. The two horizontal axes, the vertical axis and the rotation axis are driven and positioned by means of highly dynamic alternating current servo-motors. The compact grab head is provided with either two or four grab units, one oil jet and a plotting jet. A multiplicity of sensors reports anomalies and the condition of the system to the controls. The formwork profiles are stacked up vertically over each other in a compartmentalised store set up within the working range. The fouled up formwork profiles are transported in whatever order through the automatic operating, oiling and cleaning plant by a continuous conveyor. The transportation unit terminates in the range of the formwork robot after a separating plant in an identification station. All different formwork types, lengths and their chamfer location are recognised and communicated to the controls by means of various sensors. Parallel to it a transportation unit is arranged, which conveys the magnets also through a cleaning and oiling plant and places them at the disposal of the robot on a buffer belt in two distinct separation stations.

The formwork robot system has a multiprocessor controls, which contains its own processor controlled axis module and a powerful process computer for each of the four movement axes. The visualisation of the process conditions is served by a colour monitor screen.

The formwork robot starts its working cycle by tracing out the formwork contours, which later must be completed manually, with its colouring jet. It also marks out the position of windows, walls and other built-in parts. All surfaces, which will be later on the underside of the formwork profiles, will be slightly oiled by the robot. This has the advantage that the run-out concrete underneath the formwork can be removed in an easy way later. One or two magnets respectively are simultaneously removed from the magnet buffer conveyor by a mono or tandem grab system and positioned on the formwork. With the tandem grab two magnets can be picked up together and deposit separated on the pallet. The advantage is the increase of the average formwork robot's speed in the transfer of the magnets. Thereby the rotation axis of the robot permits arbitrary angular positions of the magnets. Subsequently the robot slips over of the formwork profiles over the magnets. The profiles are received, thereby, from the store or if fitting from the identification belt.

Some activities can bring optimisations to the system. The robot can e.g., pick up in an operational stop any possible available formwork profile from the identification belt and convey them to storage in the buffer store. Furthermore the positioning of the formwork and of the magnets can proceed interlocked, in which case the controls take into account the mutual dependencies that are conditioned by the position of the individual elements.

The subsequent work cycle receives the geometry data of the elements, which are to be provided with formwork, from the central master computer of the production plant. The decision regarding the order in which the individual elements are shifted is taken over by the processor computer.

2.3 Automated operations and processes in the concrete sector on site

2.3.1 Computer-controlled distribution of concrete

The development of a computer-controlled concrete pump with AMC (Automatic-Mast-Control) was the first step to Computer Aided Concreting (CAC) on the construction sites in the future. The AMC results in an increasing of productivity when pouring the concrete. State of the art are truck-concrete pumps. The rough draft of a truck concrete pump comprises the pump unit of the concrete, which is integrated in a frame construction. Likewise this frame construction contains the integration of the concrete distribution-mast as well as the necessary construction elements for the supporting of the device. The complete arrangement unit is put on a standard truck chassis.

For the increase of the profitability, when using concrete pumps, a main demand consists of a maximum range of the concrete distribution-mast with exploitation of the maximum permissible total weight and of the respective axis loads of the mobile truck concrete pump. Based on different restriction on admissions for trucks in each country the ranges of truck concrete pumps vary from 24 meters up to approximately 60 meters.

The operator of such a concrete pump has the task to control the concrete pump and to position the concrete hose, where the concrete comes out, on the last jib of the multiple-distribution-mast. Because of the up to six degrees of freedom of the concrete distribution-mast, this is not an easy operation.

The technology in the sector of concrete pumps has increased constantly. Today especially high-rise conveying has become more and more important, as the building heights have increased, particularly in Asia and North America. Presently a pump achieved 532 meters and in long-distance conveying the best performance was measured with 1661 meters. Advantages which speak for the use of concrete pumps are the low unfolding and highly movable distributor booms for the usage in tunnels and indoors. Furthermore light and easy movable hoses and pipes make concrete pumping accessible in the most confined areas (see Fig. 4.5). Another advantage is the high mobility of the four and five arm folding booms, which provide unrestricted concreting, exclude dead areas and make the large boom pump a compact unit (see Fig. 4.5). The usage of these devices lead also to an improvement for the workers. The concreting gets easier and faster and with the installed safety devices, such as steering with remote control, the risk for the operator is decreasing.

The world's largest concrete pump is a five-boom pump with an output volume up to 200 m^3/h and an overall weight of 62 tons. As the four- and five-section pumps represent the most advanced present state of research, they are mentioned closer in the following.

2.3.1.1 Schwing - KVM 52, Truck-mounted concrete pump

This particular type of concrete pump with four booms provides high flexibility, also in cramped working surroundings as shown in Fig. 4.6 on the following page. The different folding variations of the boom allow the reaching of all kinds of positions.This concrete pump provides an overhead-roll-folding that leads to an optimum working range. It is even possible to work in areas above and below the vehicle. Such works could never be done manually in the same time and accuracy.

The end hose of the stationary boom has length of 3 m and a ranging height of 51,2 m. The swinging range amounts to 360°. The concrete pump's maximum output is 150 m^3/h and the maximum concrete pressure is 95 bar.

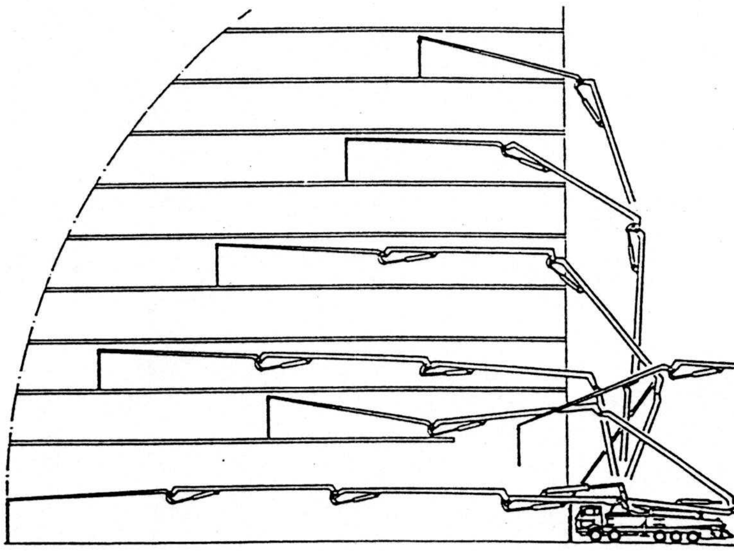


Fig. 3: Overhead-roll-folding [5]

2.3.1.2 Five-section concrete pump

The M 62 five-section concrete pump by Putzmeister is the largest concrete pump. With an output volume of 200 m^3/h it is suitable for highest demands.

Although it is large in its size, the unfolding height is very low (see Fig. 4.9). Additionally the outrigger system with telescope legs means that set up space is kept to a minimum. The chassis' short wheel base gives the unit high manoeuvrability in restricted areas. Also safety operations are provided in order to prevent a risk for the operators. All boom and outrigger movements are controlled by spring centred switches and valves that arrest and lock the boom in place when released. The concrete pump and the boom are stopped instantaneously when pushing the emergency stop button. The steering is made by a radio remote control. The infinitely-variable speed control allows the operator an easy operation and the concrete pump can also be infinitely controlled from zero to maximum. A reducing of fuel costs results from the option to start and stop the engine by remote control during breaks. This also makes the unit environmentally friendly.

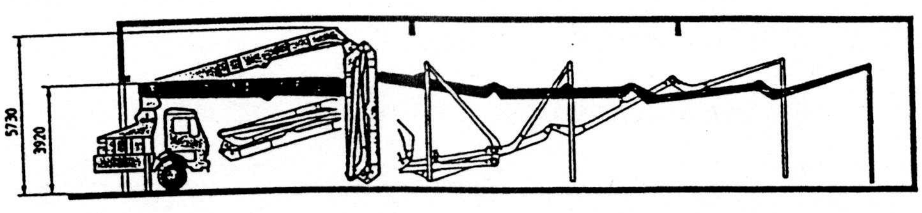


Fig. 4: Low unfolding height of a five-section concrete pump [6]

3 Developments beside the building construction sector

The main emphasis of this presentation is laid on developments in the building construction sector. Besides that, some picked out devices, that touch the construction sector as well, are shortly mentioned in this paragraph.

3.1 Manipulators for inspection and service tasks

The described Putzmeister concrete pump (2.3.1.2) is only one possible application of a development that was done by this company. Other robots with the same or similar kinematics are the development of the Skywash, a system for automised airplane washing or the Seawash for ship washing. Other possible areas of use are the inspecition and the washing of buildings. These robots include an to the common steering integrated vehicle with controlled outtriggers to guarantee the safe working when taking into consideration all forces and moments at the end of the manipulator, special sensors for rough environment etc.

3.2 Robots for inspection and restauraration of sewers

The restauration of sewers has become an increasing field of german constructors. Because of a lot of ailing sewers and environmental restrictions, investments of about 130 billion Deutsch Marks will be made within the next years. Depending on the grade of demolition the measures reach from robots for filling to the complete relining of the sewers. A special task is the reconnection of laterals in case of a complete relining. In 1995 a robot system was introduced, that reconnects the laterals with the main sewer by a new trenchless method. This newest technologie is described in [8].

3.3 Automation in the sector of road construction machinery

In the group of road construction machinery, the road pavers are characterised by the largest number of repetetive work functions with a high degree of complexity. Road pavers promise to increase the productivity of the whole road construction process when automized. Furthermore a constant quality of of the produced pavement will be provided when new technologies are coming into the paver machinery.

The latest development is a road robot, where full automation was achieved by grouping the working functions of the road paver into four principal modules. Those are the paving material logistics, the traction drives, the surface geometry and the screed. Those modular work functions are connected by a field bus system.

4 Expected developments in the next ten years

Table 2 shows a numerical overview about planned and developed automated systems of service robots in the construction sector depending on their area of use.

	Maintenance	Repair	Transport	Cleaning	Others	Total
Conceptual design	13	14	10	10	21	68
Prototypes	12	12	7	10	18	59
In production / use	5	6	5	2	11	29

Tab. 1: Service robots in development and use [7]

An investigation with the aim to define the demand of service robots in the future confirmed the high demand of automated systems for the construction sector. The following table describes a selection of those systems and their prognosticated year of introduction to the market. The selection was made depending on the estimated effectiveness for cost reduction and the potential to be sold.

Autonomous robot for transport/handling tasks in the internal extension of buildings	1998
Plastering robot	2000
Robot for screed work	2000
Robot on mobile platform for tile setting	2000
Facade maintenance and cleaning device	2000
Automatic sandblasting of steel constructions	2005
Flattening of concrete surfaces	2002
Manipulator for reinforcement	2005
Telemanipulated systems for wrecking of old buildings	2002
Formwork: Manipulators for setting and connecting	2005

Tab. 2: Selection of service systems that are expected to be developed in the future

5 Conclusion

During the past years some remarkle efforts for the automation in construction have taken place. Some of the presented systems are still at the stage of prototypes and the demand for other development and innovation is huge. The German technological gap, e.g. to a system like the T-UP of Taisei, where different automated systems led together to an integrated automised construction system is still high. The number of required automised systems highly exceeds the amount of systems in use or under development in Germany. The authors expect that with the just starting change in mind of constructors the next fifteen years surely will bring a big jump in the German construction sector.

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