Automation Systems in Housing Construction

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Automation in Germany

To compare the status of automation in housing construction in Japan with the situation in Germany and to derive further findings for possible development in automation, the Federal Ministry for Regional Planning, Construction and Town Planning have commissioned a survey within the scope of a research project[1].

The focus of the current development covers primarily all fields of mechanical engineering and process engineering, e.g. manufacturing building materials, concrete products and prefabricated concrete products, brickwork machines and brickwork robots, controlling and monitoring mobile construction machines, as well as tunnel and microtunnel construction.

Automation and robotics have long found their way into the building industry in actual fact due to a variety of elements which can only be automatically manufactured and without which nowadays construction would not exist at all.
Building materials, construction boards, construction parts, installations, windows, fittings etc. would always have remained high-priced luxury articles, if it had not been possible to manufacture them in fully automated processes.

Automation in Japan

Since the 80s this procedure has led to the fact that the prefabricated house in comparison with the past enjoys a far better image than conventionally constructed buildings.
The annually recurring international symposiums on automation and robotics in the building sector underline the fact that considerable efforts have been undertaken world-wide in Japan and in the USA to utilise automation in all fields of the building sector.
In Japan automation and robotics have been operated consistently for many years on a widespread basis in cooperation with building enterprises, manufacturers, research institutes and national authorities.

In Japan robots of the third and fourth generation have also been presented. As argumentation for these activities the same conventional reasons are stated world-wide, e.g. lack of qualified workers, facilitation in working, quality enhancement, labour protection, environmental protection and productivity improvements.
A highly important reason for the Japanese enterprises is, however, the enhanced image in the building branch, which as low-tech industry enjoys hardly any prestige.
The developments of the last ten to fifteen years show that the Japanese building industry has achieved remarkable success with this strategy.
Impressive examples are 20 partly automatic superstructure systems with which the key building companies Obayashi, Shimizu, Taisei and Takenaka have been constructing buildings in Japan since 1992.

Lack of skilled workers is a coercive reason for forcing such measures which exists in no other industrial state other than Japan where restrictive immigration regulations largely prevent the employment of guest workers.
The reason why the Japanese have not yet offensively offered their construction robots on the world's major building markets is no proof for their assumed unsuitability. The fully automatic superstructure systems cannot be dismissed with the statement that their economic application presumes serial production either.
The automation of building processes has been the object of research and development by key Japanese building corporations since the end of the seventies. Japan started off with the development of individual robots and remote controlled manipulators for certain processes at the building site. These include robots for concreting, concrete treatment, applying fire protection measures to steel constructions, handling and positioning large-scale parts and facade robots for applying plaster and paint.

Development in Germany

The majority of German building machine manufacturers and construction companies accompany these activities with an only moderate degree of interest.
As this is a part of the future building industry which is highly research- and development-intensive, there is the danger that this market with its long-term and probably existential technical and economic possibility will probably to a major extent be lost to foreign competitors without any resistance.

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As a result of the violent technical development in the electronic age more and more focus is being devoted to the need to redefine the opinions regarding the building standards.

The increasing discrepancy between the performance of tools, machines and robots and small tools in general creates an increasingly unstable situation between the craft trade and industrial branches. This development is now intensified by the increasing application of low wages and the pending EU extension to the east, as a result of which it will become more and more difficult to survive in view of European competition. Due to subcontracting low wage workers companies are heading for the innovation and qualification trap. Instead of new technologies being developped and construction workers being further trained and educated they subcontract to low cost / low wage companies.
When examining the construction methods applied in Germany, the building methods and building systems used in concrete construction, brickwork construction, wood construction and in steel construction were investigated.

Situation in concrete construction
A high degree of automation has been prevailing for several years in stationary systems to mix building materials (concrete and tar) and in serial production of standardised concrete products. The automated pre-fabrication of large-scale pre-fabricated reinforced concrete parts has experienced a fluctuating development. After a gradual increase of the automation degree to the early seventies the beginning recession forced several pre-fabrication plants with higher degree of automation to discontinue manufacturing their products.
A new development surge has been under way for some years which in individual cases has already led to Computer-Aided Manufacturing (CAM) and in some approaches to Computer-Integrated Manufacturing (CIM) of pre-fabricated concrete parts for ceilings, walls and roofs.
In the industry for pre-assembled units the term „Construction System" is frequently viewed as a competitive instrument. Every manufacturer states that he has his own special systems to grant the contractor maximum advantages. This is often misleading and leads to reservations among planners who are not familiar with the construction of pre-fabricated parts. The reality is, however, different: On the market there is a large number of systems for more or less complete solutions; these systems, however, almost all belong to a limited number of pre-fabricated systems with a more or less identical basis. In addition, these systems are as a rule limited to the carcass and the preliminary electrical installation. That means that the production systems are able to manufacture raw construction parts with the exactness of millimetres which are combined on conventional building sites with traditional building systems. Construction systems with a high, trans-trade pre-fabrication degree are generally non-customary.

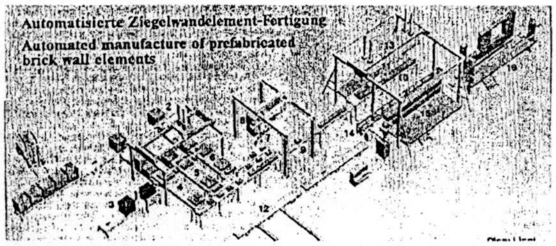
Development in concrete construction
The further developments from the generally offered raw construction product to the finished wall or ceiling/roof product pave the way to diverse possibilities with the product and product technology to manufacture pre-fabricated construction parts at low prices according to individual requirements for the housing construction industry.
For example, portal robots as they are already used as formwork robots could be further developed and transformed into installation robots for electrical cabling operations. In connection with that aspect the surfaces and assembly engineering should also be further developped. Finished roughcast and insulated wall surfaces could be manufactured in partially automated processes with systems already available on the market. With the increasing production depth, e.g. by installing windows, blinds, cabling etc. the added valuation at the production plant is enhanced. Suitable transport and assembly systems which supply and assemble just in time with optimised logistics are required for such products.

Situation in brickwork construction
Brickwork construction as production technology is based on a long tradition in the German construction industry and is still of exceptional economic significance. At the beginning of the 90s 23.16 million m^3 of artificial wall modules with a value of about 2.23 billion DM were manufactured per year in Germany. The share of brickwork in the whole turnover achieved by the building trade was 7 percent, in relation to overground workings even 10 percent. The percentage of brickwork construction in the housing buildings was about 90 percent, in non-housing buildings about 52 percent.
German brickwork construction is characterised by the high percentage of private builders and an extreme orientation to the craft trade. Machines and auxiliary devices are applied at a larger extent on widespread level, and hardly contribute to increasing productivity, but relieve the worker of physical load. Pre-fabricated brickwork elements are often not applied on smaller construction sites due to lacking crane capacity.

Development in brickwork construction
Brickwork construction in Germany reflects two development trends:
Brickwork without dislocating aids will no longer be acceptable in the near future and therefore reduced to exceptions in modernisation, renovation or reconstruction. The monolithic production of brickwork at the construction site with increasingly large-format bricks and further developed dislocating aids or robots will therefore be a continuing development.

On the other hand the pre-fabricated brickwork elements will gain increasing significance, as they represent the economic solution due to the improved working conditions and independence of weather conditions and because they are the more economic solution for many construction companies due to more reliable calculations. For stationary production of pre-fabricated brickwork parts various machines are known.

With stationary brickwork machines drastically raised production capacities can be achieved. Moreover, they lead to considerable relief in labour and manpower savings.



The deliberations to manufacture pre-fabricated brickwork elements have taken a whole series of ideas in the mechanical-technical development into account so that individually planned brickwork elements can now be manufactured in a wide variety of production plants with semi-automatic production systems or fully automatic brickwork robots under industrial conditions.

The high capital involvement is one difficulty which production outlets of brickwork elements have to face in view of economic fluctuations and which is caused by establishing the expensive production systems.

There is also a certain dependency on the supplied exactness of contractor products which have to observe certain tolerances not only in a geometric, but also in a physical respect to meet the exactness in robot dislocating.

An additional difficulty is the necessary standardisation of software and hardware used by the architects, engineers, building material manufacturers and constructing companies involved in the building process. Prerequisite for automated construction technologies is in other words the exact definition of all software and hardware standards as well as the respective interfaces.

Data processing systems in the construction business

Despite some efforts (for example STEP 2 DBS) which have been undertaken to date, no standardised product data model exists in compliance with the regulations stipulated in ISO 10303.

The DXF format by Autodesk which is principally only able to transfer geometries is widespread, as far as the exchange of CAD data is concerned.

DXF files are used for example to program brickwork machines. The geometry of the wall to be brickworked is exported from the architect's CAD system in DXF format.

These data are used to element the wall according to which the brickwork machines are monitored. It is necessary to process the data. Data processing is also essential, if more complicated multiply curved forms are to be transferred to ensure that they can be displayed at all. In general a consistent three-dimensional product data model is lacking.

Development targets

A largely automated production would be necessary to achieve rationalisation effects similar to those which can be expected in vehicle construction, as individual production is traditionally applied to a large extent. Whereas in automobile construction series of several hundred thousand are nothing exceptional, in the building sector unit numbers around one are the rule with the exception of some few cases.

It would therefore be possible to efficiently use flexible production systems to produce single parts in largely automated production with a suitable interpretation of the production task in the construction sector. One prerequisite herefor would be to develop a consistent three-dimensional product data model analog to the procedure applied in vehicle construction for the building sector. This model should be designed in a three-dimensional form for tasks in the field of visualisation, construction and production monitoring, construction engineering as well as facility management, even if the majority of layout and detail drawings produced by the architect are two-dimensional.

At present it is often easier to have three or more separate data models for the geometry of the building. Architect, visualisation office, technical engineers and facility management use their respective own software solutions which are at most able to replace the basic geometries error-free, meaning that a data conversion would be more complicated than a completely new input of the building data. It is easy to understand that such a large number of different models will multiply the expenses incurred in modifying the plans.

The aim to be achieved therefore has to be to achieve an internal computer representation of the building system which can be used from the first draft to recycling the building materials and which is available to the same extent to all parties involved in the construction job.

Situation in wood construction

The market share of wood construction in Germany is relatively low. It is at 14% (1997) in the sector of detached houses. The prefabricated housing industry which produces a large quantity of houses in wood construction covers a percentage of 8% in the old federal lands and of even 25% of the new buildings in

the detached and semi-detached housing sector in the new federal lands.
The prefabrication degree in wood construction can be characterised as favourable according to the current state-of-the-art prevailing in technology in Germany in comparison with other European countries. All conventional wood construction systems are applied. In the recent past focus has particularly been on the „novel block construction" system (glued laminated wood, bulk wood and log wood construction). Perhaps also because this - in the form of massive constructions normally made of bonded two-dimensional wood - associates wood construction more intensively with massive construction („knock test", wood/massive compound constructions).
The processing technology in wood construction is developping continuously from manual processing with small machines to full-scope processing on CNC machines.

The requirements with regard to flexibility in processing are noticeably rising.
The division between raw construction and interior design no longer exists. Wood constructions are transformed into pieces of furniture. The standards required with regard to precision in production exceed the general level of a carpenter by far.
In production there is an enormous difference whether raw wood constructions, construction parts for prefabricated houses, staircases or winter gardens or even all together have to be processed on one machine. In serial production the aim is to manufacture the largest possible quantity of identical or similar parts within the shortest possible space of time. For the wood construction worker the most important aspect is traditionally bonding construction wood. For these operations optimally functioning and reliable bonding systems have been on the market for many years. They are characterised by high performance and relatively low programming requirements.
The processing liberty is nevertheless limited: Only construction wood for roof construction, layers of beams or timber framework can be processed. Additional manual processing is in many cases essential; the dimension and form of the parts to be manufactured is also restricted to straight timbers in the majority of cases.

Development in wood construction

The technical evolution in the production sector indicates a development which will make the application of CNC systems with up to five axes the state-of-the-art in technology in a few years. Above all in the sector of CAD/CAM solutions there still seems to be a great deal of concealed development potential. In the field of prefabricated house manufacturing almost fully automatic plants in production belts are available in individual cases which leave only very few supplementary operations and finishing the surfaces to be performed by hand.
The intensified use of machines with several degrees of freedom has paved the way to new fields of operation for the wood processing companies, also beyond the construction wood sector, whereby new sales options and a higher diversity for the customer can also arise.
The further development of the software required will be a key field of tasks to exhaust the capacity of the machines and the diversity of the product. Direct machine monitoring on the basis of architecture plans without converting efforts by an additional engineer will be a cost factor of rising significance in the future. The advantage in comparison with competitors in this sector may result from the fact that due to the almost complete automation it is possible to manufacture in line with specific customer requirements and individual needs. In particular in the sector of prefabricated wooden house construction the aim of mass individualisation now seems to have come within reach.

Situation in steel construction

In Germany building with steel with a share of one percent in comparison with Japan with 20% or the USA with 5% can be referred to as hardly existing. The development of steel construction in Japan began in the 50s and has developed since then at an almost consistent pace.
The reasons for the fact that steel has never been able to gain ground in the housing sector are on the one hand due to the lacking acceptance of this material by housing construction clients and on the other hand due to the steel industry focusing on other fields, for example, after World War II when the backlog demand in plant construction gave steel such intensive impulses that the housing industry was fully supported by the traditional construction industry.
From a technical point of view, in any case, it is hardly possible to explain the weak development. The current situation in steel construction and assembly can be characterised as follows: The building market mainly demands solutions from the steel construction companies which fulfil the clients' individual needs and therefore only conditionally allow rational standardisation with regard to production and assembly. This applies to all fields of steel construction, e.g. bridge construction, multi-storey building and hall construction, container construction, compound construction and steel machine and plant construction. As the percentage of steel in the housing sector is low, the steel frames applied in prefabrication for room cells are to a large extent welded or screwed manually.

If we wonder as to how the acceptance of steel in the housing industry can be enhanced in Germany, then Japan could be given as a good example. We see a possibility to learn from the experience made by Japan in the way the building material steel has been supported consistently and with perseverance by direct marketing with united forces.

Developments in the steel sector

Today the material steel offers a variety of new possibilities in comparison with the first steel enterprises. Material and production technology have gone through enormous developments, whereby technological developments were in the majority of cases initiated by other branches (automobile industry). It can, however, be imagined that as a result of a new intensified use of steel in the housing industry innovation potential for the material will arise. By research, experiments and applications, steel can be improved in its capacities and characteristics so that any possible objections raised against steel in the housing sector will lose their validity.

CAD/CAM solutions are the state-of-the-art in steel construction companies to ensure the flexibility required from projecting via CNC production to delivery (logistics) to the construction site and, if applicable, to assembly organisation.

The aim is to produce constructions tuned to manufacturing and assembly requirements to a large extent without reworking at the construction site (e.g. adapting resp. cutting operations) enabling short assembly or construction operations. The construction parts are cut by laser, gas burner cutting, sawing, drilling, before undergoing straightening including metallic cleaning, interim and end coating and complete corrosive protection which are normally processes applied in pre-fabrication. These operations are performed with consistent high quality.

Findings from Japanese developments

To date over 400 different prototypes of robotic solutions have been developped in the construction industry and tested on building sites. One common factor is that they have all been determined for specifically defined tasks under construction site conditions and moreover designed to prevent the building site workers' activities from being disturbed. Experience has shown that under these premises only a few robots can be applied economically. The restrictions for workers, the necessary safety regulations paired with the unforeseeable and unplanned influences at the building site impose restrictions on the application of individual robots in parallel to normal construction site operation. Only a few are currently in economic operation or are offered on the market for sale. These comprise, for example, the concrete smoothing robots manufactured by Kajima or Shimizu.

The outcome of this development is the finding that it is not possible to transfer production situations similar to those prevailing in the production hall to the construction site either without having to face difficulties or economic drawbacks. This may seem to be a trivial and foreseeable result, but it is necessary to realise that these developments were seen at the beginning of work only as a way into the automation of construction processes and that their economic use was not the foremost goal to be achieved. Two other results which play a key role in the future of Japan's building industry were moreover decisive. On the one hand these were the findings and capacities acquired in the field of automation and robotics resp. sensitisation of the employees for innovation in the building sector. On the other hand, preparation of the actual goal, this being the fully automatic production of a terrain on the building site under application of the regularities known from serial production.

Guidelines for robot development on the construction site

Focus in robot development in Germany is to be mainly determined from the viewpoint of the workers. It is necessary to inquire in which sectors high or unacceptable burdens are registered and it is exactly there that analyses should take place to find out which technical aids are required. An analysis of requirements based on the types of load is therefore urgently necessary.

Robots are primarily developed for the sectors in which poor labour conditions prevail and in which a reduction of the load is possible. The comparatively high frequency of accidents as well as the high statistics of labour-related sickness and premature retirement in the building industry are an indication for the special requirements. Robot systems should take over the task of handling heavy loads, of performing dirty or dangerous work or of working at hardly accessible locations and in unfavourable physical positions.

Above all robots should function as tools of the human being. They are to be developped as intelligent tools and must not force the human being to the limits of working activities. It must be possible to integrate the robot systems into labour procedures. These must not disturb the existing communications structures and cooperation, for example, within the scope of a gang. Robot development should therefore be implemented together with those persons who will operate these systems at the building site at a later point of time. Changes in the labour environment and labour organisation by the application of robot systems must be primarily oriented to the working people in the first step and then in the second to technology.

One important aspect is high system flexibility to adapt the robots to the prevailing structures. Fully automatic systems are therefore only suitable in exceptional cases, for examples in areas with high safety risk. Semi-automated machines, in contrast, can be flexibly monitored and applied. The focus of development must therefore lie on semi-automated systems. Other industrial sectors have in the mean time also withdrawn from the aim to achieve inappropriate full automation. Semi-automated systems are by far cheaper and more flexible than fully automatic systems. They can be applied by smaller-sized and medium-sized building companies to improve their competitiveness.

Development of automated building processes

The building processes and systems to be automated and furnished with robotic controls have to be redeveloped. The existing management methods require revising before qualifying the staff involved according to the application of new technologies. A successful implementation of robot technology is enabled with a robot-oriented construction industry which reflects certain characteristic features: flexible industrial pre-fabrication, flexible production of different building parts on the site and project management enabling the application of construction robots.

Automated building comprises industrial and flexible prefabrication of complicated standardised building parts and their automatic construction and maintenance using construction robots. Automated building production enterprises are able to achieve a high level of variations with a wide range of construction parts. With the help of freely programmable robots a flexible production of a wide variety of building parts is enabled and administered using the suitable software. The industry manufacturing prefabricated parts should benefit in particular from the advantage that it is possible to flexibly manufacture with a large degree of automation by aligning production technology in order to meet the requirements of mass individualisation in the housing construction sector.

As far as automation of the construction company is concerned, the development of an integrated system to plan and produce buildings should be envisaged. This system can be used not only in drafting buildings, but in operational planning for robots and in logistics for building sites.

Due to the high wage costs in executing construction work the largest rationalisation effects are achieved by an intensified rationalisation of the construction work with the help of automation components. On-site construction work has to be aligned to subsequent robot operation in the planning and construction phases. That means that all construction planning phases have to be integrated into the computer systems before being processed. The conventional building processes have to be tuned to automation requirements. These new building processes will differ fundamentally from the known building processes. The normal sequential procedures of building production will also be replaced by parallel procedures. Partial systems from prefabrication will also be integrated into building operation and will therefore drastically reduce the construction period.

By contracting a project for an automated building construction, the whole activity has to be furnished with robotic controls, planning, construction and manufacturing of construction parts. These parts will have been largely prepared and completed so that after signing the contract the construction project only represents a geometric configuration problem, timely organisation problem and a physical implementation problem.

The corporate structure is transformed from the current assembly company to a future service company.

Contemporary buildings consist in comparison with pre-industrial buildings of many partial systems. Planning, production and the product are increasingly mechanised and will be additionally mechatronised. This fundamental development in the building sector requires an integrated and interdisciplinary problem-solving approach. In implementing building management this means the specification of conditions for operating robots on the site with a geometric, physical and timely definition of the elements for every constructional subsystem.

That requires an interlinking of the data and information flow from the draft to design, manufacture, assembly and facility management. The interlinking in the prefabrication of partial systems and their integration into the building processes plays a decisive role hereby.

Summary

The short- and long-term development of automation will take place step-by-step and will be oriented to the respective application and requirements. In the initial phase existing building machines will be automated step-by-step. In the medium term a mixed concept consisting on the one hand of manual operation with programmable partial processes and on the other hand of automatic operation with manual monitoring options including all controlling concepts lying in between will gain ground.

In the end phase the CIB concept (Computer Integrated Building) will be implemented. The use of robots will be more effective, the more appropriately it is integrated into a CIB production chain.

Not only in stationary industry, but also on-site the computer-supported building production of the future could be monitored by the human being in a control room, whereby a qualified building worker can simultaneously control several building machines. All that is needed is an effective communications system between the control officer and autonomous building machines. Application planning and monitoring will be automatically controlled, whereby every individual building machine will constantly communicate with the central control room. In the event of irregularities which are not stated in the program, automatic operation can be manually monitored by the control officer.

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