Automation and Robotics in Construction X
G.H. Watson, R.L. Tucker and J.K. Walters (Editors)

Functional Profile of a Wall Assembly Robot System and Different Solution Approaches

Thomas Bock[a], Friedrich Gebhart[a] and Werner Steck[b]

[a]Division for Automation in Construction, Institute for Mechanical Engineering in Construction Management, University of Karlsruhe (TH), P.O. Box 6980, 7500 Karlsruhe, Germany

[b]Institute for Machine Tools and Production Science, University of Karlsruhe (TH), P.O. Box 6980, 7500 Karlsruhe, Germany

Abstract

The presented robotic system is based on the idea of Computer Integrated Construction (CIC). This means the integration of all trades and processes from architectural planning to execution of construction work. It contains computer aided design and computer aided generation of robot programs, custom made prefabrication of small building components including logistics planning and roboterized wall assembly on the site. Within the framework of the presented project a handling system adapted to the construction-site environment is to be developed and realized. It enables with an autonomous vehicle and suitable grippers and sensors flexible masonry assembly and improves working conditions and safety on the construction-site. Parallel to the machine development, the information integration as well as the planning of the required logistics and construction-site organization is to be studied, developed and implemented.

1. INTRODUCTION

The structural problems of the construction industry can be solved long-term only through flexible automation of construction to releave the people on the construction site from the high physical demands and to increase the productivity of the building industry.

As a test case of a technology carrier for the building construction industry the processes of masonry work was chosen because of the clear definable and separatable sub-tasks and the demand and willingness of this industry to introduce advanced technologies to explore possible solutions for specific problems:

First there is the necessity to increase the production due to a strong demand in housing particular in Germany caused by the structural change from an emigrant country to an immigrant country.

A first approach to solve the problem was to enlarge the size of the blocks. However, this caused the second problem, which was adressed through mechanization: too heavy weights for manual processing necessitated the use of mechanical lifting aids, a pre-step towards robot-automation.

The third problem is the customization of each building. In combination with small assembly units like blocks a flexible automation of the assembly process seems possible to meet the individual demands.

The whole project is embedded into an European research program with a strong industrial participation and a continous feed back of potential end-users to enable fast and goal oriented R&D work.

2. MASONRY APPLICATION ANALYSIS

2.1 Decision Process

In a first step, the decision process should be illustrated, which occures, when a potential customer wants to build a house (see fig. 1).

Through the demanded flexibility with regard to the building materials resulting from the position of our potential user at the lower end of the decision process, first an analysis of the most frequently used building materials was carried out (see fig. 2).

Based on the results, the system should handle at least sub-groups of building systems of each of the four big material groups. In each of the groups are at least some systems existing, which meet the below mentioned requirements for a simplified automated assembly.

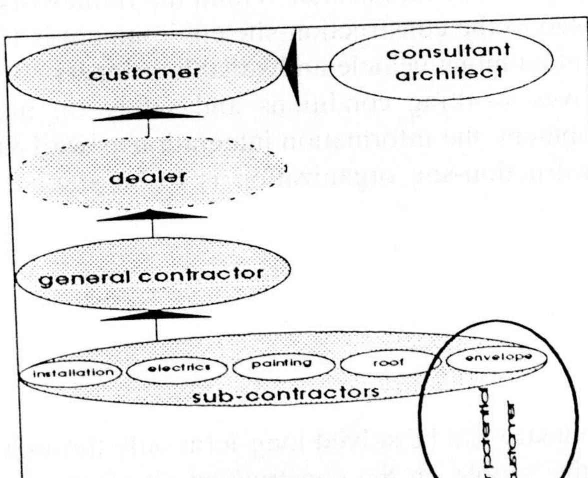

Fig 1: decision chain to build a house

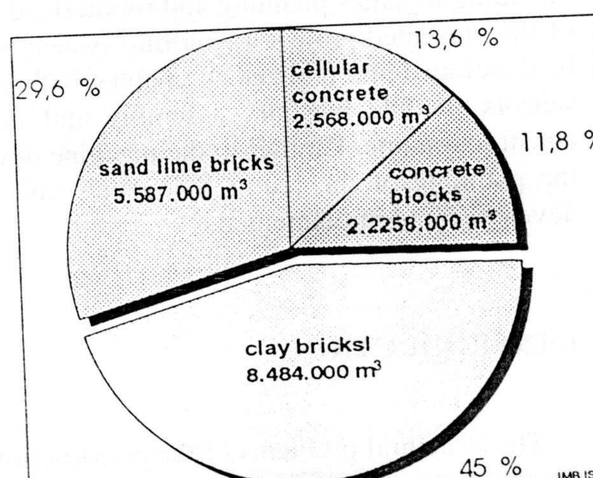

Fig 2: market shares of different building materials in Germany

2.2 Working Process

The second step was the analysis of the working process to integrate an automated tool in a complex environment with different simultanous activities on the construction site. In close cooperation with participating construction companies, the analysis was carried out.

It turned out, that different sub-tasks should still carried out manually, particulary the preparation of the construction site and the preparation of the respective walls to be built with an automated masonry assembly system. This includes the set-up of a first levelling layer to compensate the inaccuracies of the concrete floor and the cleaning of the floor and removing of obstacle to enable an easier movement of the mobile robot.

A second part of work, which should be carried out manually are after-works like closing of joints with mortar or the assembly of bigger concrete parts like large lintels.

The third activity, to be carried out manually in a first step, are the construction site logistics to provide the blocks for the robot. The use of the hereby necessary crane should be simultanously minimized according to the construction companies.

To have as less as possible lost time for the automated assembly, the approach is a segment oriented cycle process with parallel and synchronized manual and automated working parts for each wall segment.

3. FUNCTIONAL PROFILE OF A MASONRY ROBOTIC SYSTEM

3.1 Operational Task of the Robot System

The goal is the automated erection of vertical walls with the required openings for doors and windows. The material to build the vertical walls are bricks made of different raw materials (see fig. 2) and in different sizes.

As a restriction in the first approach only walls and openings are regarded, which are describable as three-dimensional volumes with rectangular, trapeze or triangle surfaces. No round walls or openings in any dimension are regarded. The walls may meet each other at any given angle and any kind of gable should be able to be erected.

An additional restriction for a first approach is the demand of gripping the blocks only from above. Therefore the last layer underneath a ceiling cannot be assembled. But according to building companies, this is not a significant restriction for the benefit of the system, because most of the walls are erected before concreting the next floor. In addition, this implies that the blocks are being delivered vertivally put on pallets, which actually happens in most of the cases.

The goal of the automated masonry process is first to grip the block directly from one of the pallets, which are attached to the system to calibrate them, then to make a quality control, to apply the thin bed mortar to the underside of the block, to move the block to the wall and finally to assemble the block on the wall with a final accuracy of 2 mm in each horizontal direction.

3.2 Boundary Conditions on the Construction Site

A robot, operating at a construction site is naturally exposed to all weather conditions. The operating requirements take this into account. These conditions are very diifferent to the conditions in a factory building:

- Operating temperature: -5°C to 60°C
- Storing temperature: -20°C to 60°C
- Protection class: IP 65 or better
- Employment in the vicinity of the construction area: wind, rain, dust, dirt

In addition, the operation at a construction site requires a mobile system, which is able to move on the concrete surface of a floor. The minimum requirement is the moveability on a surface with following features:

- Exactness of surface: ± 3 cm height difference refering to the length of support (≈ 3 m)
- Shoulders and steps: up to a height of 3 cm
- Floor loading capacity: 0,5 kg/cm² (with loads, that have their points of application in 2 m intervals, one can assume 16 m² as the carrying surface)

The maximum weight of the robot, therefore, is essentially limited by the loading capacity of the crane. The following weight is possible without any difficulties using a normal building site crane:

- Maximum crane payload: 2000 kg

The next limitation is caused by the necessity of transporting the robot system on a conventional truck. The size limits are:

- length: 3 m
- width: 2 m
- height: 2 m

The current security regulations for construction site equipment have to be considered. For the use of automatic systems at construction sites, however, there aren´t any clear rules or instructions yet. Therefore, the requirements, along with the development, have to be discussed with the responsible administrations.

3.3 Useable Block Types

With the intended robotic system, one should be able to use block types, which are normally used today for the above mentioned reasons of flexibility. On the other hand, it is important for an automatic system to have minimum tolerances of each assembly part.

According to different building material suppliers, they guarantee a sufficient parallelism of the horizontal brick surfaces. Particularly the sand-lime brick and cellular concrete block industries have an acceptable accuracy due to the material and production process. In the clay brick and concrete block industries only few suppliers have already installed post-processing equipment, which gives the blocks the necessary accuracy. But another problem occures now, due to the post-processing, a high percentage of blocks has small breaks or quarry faces. Therefore in the first approach, one should use sand-lime bricks or cellular concrete blocks for automated masonry.

This accuracy enables the use of thin bed mortar for joining the bricks. The advantage is an easier application of mortar on the bricks and different ways to level out the assembled bricks (see fig. 3). Additionally, thin bed mortar has better heat and noise insulation features than normal mortar.

In order to work with thin bed mortar, the inaccuracies of the floor have first to be levelled out by a first layer. This layer may consist of normal mortar and eventually the first layer of bricks. It is important to have an accurate first layer: The tilting of 1° leads to a deviation of 6 cm in 3,5 m height, if the blocks were assembled without correction. Therefore the first layer should be accurate to ±0,15° to have a maximum deviation of 1 cm in 3,5 m height.

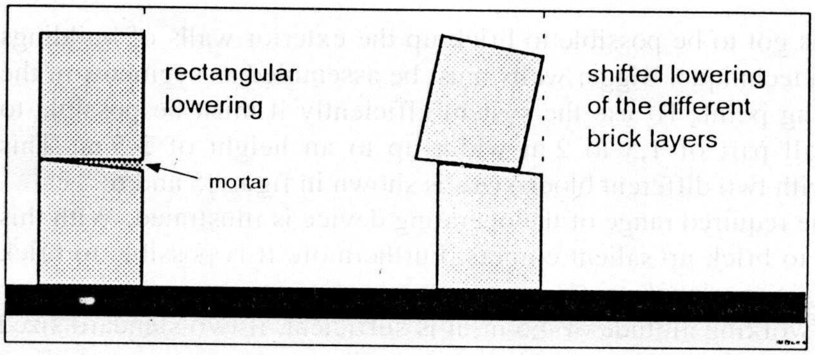

Fig 3: two ways of vertical levelling

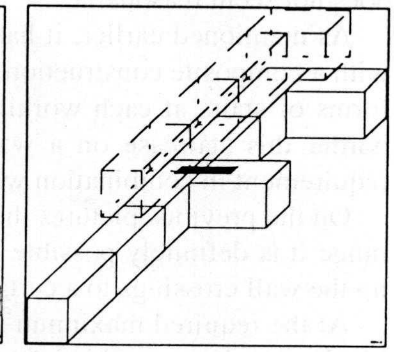

Fig 4: butt joint technique and composite construction

Due to the different requirements to put the first layer (absolute measurement and accuracy, working with normal mortar) in contrary to the further masonry process, this research section does not intend to develop the necessary equipment, which would be significantly different.

With all block types, there are fundamentally different wall thicknesses and other fitting lengths and heights. It can be assumed, that 30% of the blocks are to be regarded as non-standard blocks. The concept is based on a maximum block size of 100 x 50 x 36,5 cm and a minimum block size of 12,5 x 12,5 x 12,5 cm.

As the second important parameter, the weight of the blocks should be regarded: Normally used blocks for manual masonry have a maximum weight of 30 kg, blocks to be masoned with mechanical aids have a maximum weight of up to 300 kg.

As a first approach, we used a two step development: first a high speed and wider working space for the normal blocks and second a reduced speed and/or working space for the heavy elements.

3.4 Wall Connections

With wall connections, one generally distinguishes the butt-joint technique and a composite construction (see fig. 4).

The regulations and traditions in the masonry work state that it must be possible to connect two rectangular walls with a composite construction. To build a T-connection of two walls, it is possible to juse the butt-joint technique, which is easier to handle and has advantages in noise and heat insulation against a T-composite construction.

For an automated system, possibly a different device than the wall clamps for the butt joint technique has to be developed to ease the automated assembly process.

3.5 Working Space

Two aspects need to be taken into account: first, a required maximum assembly range and second a required minimum gripping range.

According to an examination of building sites, with a maximum assembly altitude of 4,5 m, 86% of all floors can be assembled completly. Therefore, a higher working height does not seem reasonable.

As mentioned earlier, it has got to be possible to brick up the exterior walls of buildings with a composite construction technique. Biggèr walls must be assembled as segments in the forms of stairs at each working point. To uše the system efficiently it must be possible to border this staircase on a wall part of 1,5 to 2 m width up to an height of 3,5 m. This requirement in combination with two different block sizes is shown in figure 5 and 6.

On the previous pictures the required range of the operating device is illustrated. With this range it is definitely possible to brick up salient corners. Furthermore it is possible to brick up the wall crossings to a certain overlap degree.

At the required maximum working altitude of 4,5 m, it is sufficient, if two standard sized blocks can be assembled from one working position due to the rare occurence of these heights.

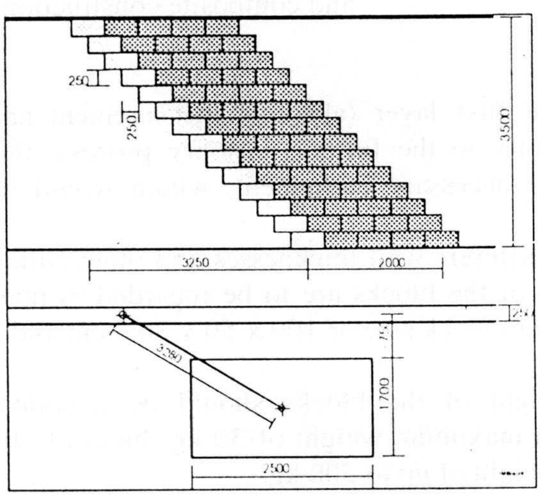

Fig. 5: wall segment with standard sized blocks (50 x 25 x 25 cm)

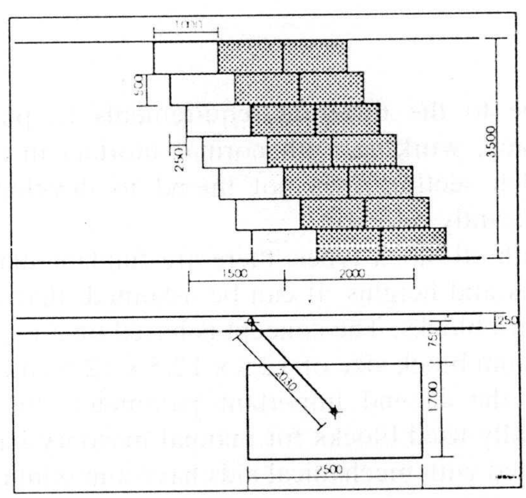

Fig. 6: wall segment with bigger blocks (100 x 50 x 25 cm)

4. CONCEPT FOR THE MASONRY ROBOT

4.1. Operation Sequence

The total operation can be devided into different tasks carried out by the components of the system:

1. Calibration of the absolute measurement system.
2. Calibration of the robot system on the respective working points.

3. Movement from one working point to the next one.
4. Support of the robot system with the outriggers.
5. Docking and calibration of the block pallets.
6. Gripping of the next block.
7. Application of mortar and quality control.
8. Collision free movement of the block from the pallet to the wall.
9. Assembly of the block with the desired accuracy.

The task no. 1 must be carried out one time after each movement of the absolute measurement system. The tasks no. 2 to no. 5 have to be done one time for each working point. The tasks no. 6 to no. 9 are the actual assembly procedure of each block.

4.2. Different solution approaches

To perform the tasks mentioned above we developed both a set of individual components to carry out particular tasks and a set of different approaches to attack specific types of problems.

The first task can be carried out by the absolute measurement system itself by measuring fixed points on the floor surface.

The second task is very similar to the first one with a replacement of the fixed floor points by fixed points on the robot system. For a first approach, a manual tachymeter system is chosen for the absolute measurement. It is possible to upgrade it step by step to an auto-tracking system based on the first test results. The measurement procedure is carried out after the support of the robot system.

The third task of moving from one working point to the next one will be carried out by a 4-wheel steered vehicle. In the first approach, it is intended to move only with the help of relative sensors like encoders. The vehicle will be able to move in each direction without the necessity of shunting due to the choosen kinematic. The positioning errors detected by the absolute measurement system, are not compensated by the vehicle but by the robot kinematic. Therefore it is necessary to keep the positioning errors as small as possible, because they are influencing directly the working space of the robot system.

The fourth task of supporting the robot system will be carried out by 4 outriggers. It is planned to measure the tilting errors but not to compensate them with the outriggers.

The construction site logistics as the fifth task are done manually with the help of the crane and a small manual fork lift. It is necessary to provide docking points at the vehicle to bring the pallets into a defined position relative to the robot system.

There are several restrictions to grip the blocks from the pallets as the sixth task. First one has to compensate the positioning errors of the blocks on the pallet due to pre-production and transportation influences. Second only two of the 6 surfaces of the block are reachable simultanously and in every case. Therefore passive complient elements are necessary for the first restriction. For the second one a new gripping concept has to be developed with extensive building material analysis and tests.

With the intended use of thin bed mortar, it is possible to realize the first part of task seven by immersing the block into the mortar during the movement from the pallet to the wall. The second part of the task, the quality control, is more difficult to perform. In the first approach, mechanical sensors integrated in the gripper shall recognize material damages.

The collision free motion (task no. 8) from the pallet through the mortar to the wall including the gripping and assembly process will be guaranteed by a computer integration concept that covers the information flow from the architectural plan, to the working sequence planning, to the palletising planning, to the automated robot program generation (for the vehicle and the robot) and highly sophisticated simulation and on-line control interface. The necessary computing power is provided by the separate control components off-line station, on-line coordinator, robot control and vehicle control.

Mechanically, it is intended to employ a 4-DOF kinematic with rotatory joints and hydraulic drives due to the heavy load and large workspace. After an analysis of different kinematic approaches, it turned out, that four degrees of freedom are enough for the intended tasks. The blocks are vertically stacked on the pallet and have to be vertically assembled on the wall. Therefore, only the three main axis and one orientation axis are necessary to reach each point in the working space and to assemble wall corners with different orientations. To keep the blocks vertical, a parallelogram design of the kinematic is sufficient. The only errors, which the kinematic is not able to compensate, are the rotational components of the vehicle´s tilting errors. A vehicle tilting of 1° causes a tilting of the block of 1°. It is intended to compensate these errors with the passive complient systems mentioned above.

To assemble the blocks with a stated accuracy of 1 mm as the last and most important task, a two step concept will be realized in this approach. First by moving the robot kinematic to a position near the end position of the block with an intended accuracy of 5 cm. This way, the inaccuracies are always in one direction. Secondly by performing the fine positioning with active compensation elements integrated in the gripper. In first tests a concept without additional sensors will be developed, were in further steps according to the results necessary sensors can be integrated step by step.

5. CONCLUSION

The current state of the research shows the whole amount and spectrum of difficulties, occuring while trying to automate as simple tasks as putting a block onto another. Yet different solutions approaches for the different sub-tasks are presented, which encourage us to go the chosen way further. In addition the parallel carried out economic calculations and market analysis are positive enough to let us hope for a competive system in the future, which helps us to humanize and automate hard and dangerous construction working tasks.

6. REFERENCES

1. Bock, T., Blaser C., Gebhart, F.: *Automatisierungsgerechtes Planen und Konstruieren für computerintegriertes Bauen.* in: Bautechnik 69 (1992), No. 3, Ernst & Sohn Berlin.
2. Bock, T., Gebhart, F., Steck, W.: *Automatisierung von Hochbauprozessen.* in: Baumaschinen- technik, April 1992 ff., Bauverlag Wiesbaden.
3. Laukemper J.: *Automation im Mauerwerksbau: Voraussetzungen, Verfahren, Wirtschaftlichkeit.* 1992 Expert Verlag, Ehningen b. Böblingen.