POTENTIAL FOR ROBOTIZATION AND AUTOMATION IN THE GERMAN CIVIL ENGINEERING AND CONSTRUCTION INDUSTRY

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1. Introduction

As far as modern technology is concerned, the media and politicians in Germany are constantly reminding us that we're way behind in the race, with a big gap between us and the U.S. and Japan in particular. While this may be true, I have a feeling that this assessment relies to some degree on legend and rumor and that it certainly does not apply to every sector of industry. For instance, we recently visited a firm which builds machines for use in concrete construction. One thing that surprised us was that West German industry, in this case two firms, has a 95 per cent share of the world market for machines of this kind. Now, we go to great pains to collect material on the latest developments in robotics and automation elsewhere and have a growing collection of slides depicting these. We show these to frighten the rather backward and unimaginative German managers out of their complacency. Pride of our collection are several line drawings from Japanese-language journals. At the end of our talk, a colleague of mine, eager to impress our partner from the firm, pulled out a slide of an amazing Japanese robot designed to remove rubble from tunnels under construction, saying, "What about this? Wouldn't you be glad if you were able to sell something as advanced as this?"

Our partner gave the drawing a cursory glance and replied, "Oh, we already build those. In fact the Japanese are using them to build the Tokio subway."

Technological gap or none, one outcome of the concern about being left behind has been the setting up of our project. Since this is still at an early stage, I cannot reveal too much about it. One fairly novel feature is that it involves an interdisciplinary team of engineers from various fields as well as social scientists. You'll be able to judge for yourself on the wisdom of this composition if you care to keep track of the project. One outcome I can confidently promise is that we will have a reasonably accurate impression of the state of the art as far as automation and robotics throughout German industry are concerned.

My colleague from our partner organization IPA, Martin Wanner, is presenting a paper on the actual method of the project and reviewing selected technological trends in the construction industry /1/. I shall try to give you a flavor of the economic situation and social background in the industry, at the same time trying to demonstrate what kind of benefit the participation of social scientists in a technological project may bring.

Thus, in the first section of my presentation I shall be dealing with the current situation of the West German construction industry.

The second section will be a brief review of the history and current diffusion of automation and advanced technology in the German construction and civil engineering industry.

In the third and final section, I will be discussing rationalization strategies in relation to the kinds of tasks the firms wish to rationalize and examining the prospects for rationalization and robotization in the industry.

2. The economic and social background

I remember a very amusing talk Gene Woolsey of the Colorado school of mines gave at an international conference in Amsterdam /2/. One message that came across was that it's no use giving analphabetics alpha-numeric computer output to work with. In a similar vein, engineers in the developing countries are working on what they call "appropriate technology" /3/ which is advanced technology adapted to suit skill structures in their particular countries.

I'm not suggesting that the construction industry is underdeveloped or populated by illiterates, but, to give an example, there have been very few sales of U.S. - developed CAD architecture packages to Germany, simply because the scene over there is so different. So it is also possible that a robot designed for use in the American construction industry may be useless in Germany (of course this applies equally the other way around) and there may be restraints on the adaptability of robots for use in other industries.

The first point is the size of firms. These belong both to the crafts and industry categories with only minimal differences in average size between the two. The firms are generally of small to medium size with really big firms of over 500 employees accounting for a mere 0.1 % of the total. However, 7 % of the people working in construction and civil engineering are employed by these large firms. As a result, we are dealing mainly with small firms operating in limited, local markets. Only a minority of usually larger firms operate nation-wide or at the international level.

At present, the number of firms and of people employed in the industry is decreasing rapidly due to an economic recession which has hit construction and civil engineering possibly more severely than other industries. Several reasons may be put forward to explain why this is so.

- Public spending has suffered severe cutbacks in an endeavor to decrease public debt. This sector formerly accounted for the greater part of industry's income.
- The demand for rented housing has reached a saturation point so that there are stocks of empty dwellings. Thus, public subsidization of new low-cost housing is being cut back.
- There has been a cutback in industrial contracts due to a reluctance on the part of industrial investors to spend money on buildings rather than equipment.

- Tax-relief schemes to encourage investment in real estate are coming to a close with uncertainty on equivalent replacements.
- Established firms are faced with competition in the shape of illicit work, which according to one estimate, accounts for up to 70,000 houses per year /4/. This means that industry is losing up to 300,000 jobs. That this should be so is variously blamed on the high wage level and on the taxation system.

There are suggestions that the industry is in fact at a turning point, mainly because the post-war boom is now over. This applies both to public amenities and infrastructure and to housing of which there was a severe shortage, particularly in urban areas of widespread wartime destruction. As a generalization, this may be true, but there are exceptions:

- In areas of high unemployment, there are stocks of empty housing - probably not as large as some claim - with the consequence of stagnating or declining rents. However, in urban areas with high employment levels and a high living standard like Munich, demand and rents are high.
- The structure of demand has changed significantly since the immediate post-war period. This applies both to the standard of luxury and to the living space per inhabitant. In addition, young people tend to leave home earlier.

About 40 % of the occupants own the dwelling they live in. Thus, the structure of ownership is markedly different compared with say Great Britain. As a result, there is much less buying and selling of accomodation and ownership tends to limit mobility. Since house ownership is regarded as an investment, demand is for very durable dwellings designed to last for hundreds of years. This is reflected, if we look at the type of construction used in buildings licensed during 1982.

TYPE OF BUILDING	TYPE OF CONSTRUCTION									
	SKELETON CONSTRUCTION					MASSIVE CONSTRUCTION				
	TOTAL	OF WHICH				TOTAL	OF WHICH			
		STEEL	STEEL-RE-INFORCED CONCRETE	TIMBER	MISC.		STEEL-RE-INFORCED CONCRETE	RED BRICK	OTHER BRICK	MISC.
RESIDENTIAL	9.7	— 0.8 —		8.2	0.7	90.3	3.9	43.3	42.2	0.9
NON-RESIDENTIAL	30.9	10.7	10.3	8.3	1.6	69.1	10.2	27.1	29.1	2.7

(in per cent)

TABLE 1: Buildings licensed in 1982 by type of use and type of construction, Source: Statistisches Bundesamt.

Residential buildings accounted for about 2/3 of the value of these contracts and non-residential buildings for 1/3. Less than 1 in 12 of the residential buildings were pre-fabricated but almost 1/3 of the non-residential buildings.

I don't have equivalent figures for the U.S., but I suspect that there is greater demand for less durable buildings and that more buildings are pre-fabricated.

Although prices are comparatively high, the industry claims it is making little or no profit. This is due partly to the keen competition: tenders for contracts are kept as low as possible, sometimes under actual costs with an eye to follow-up contracts. It is also difficult to conduct an accurate calculation, since each contract differs. This applies both to the environment and climatic features in addition to the design. There is a tradition for very individual design upheld by architects of whom there are large numbers, which means that there is also very keen competition in the area of architectural design.

In all, it seems very likely that the industry is going to shrink from its present size which was, after all, largely determined by excessive demand in the post-war reconstruction period. At present, it is very difficult to forecast the pattern of future demand as there is controversy on which path to take.

- There is discussion on whether the subsidization of owner-occupied dwellings or of subsidized rented dwellings will be of greater benefit to the industry and help save more jobs.
- The housing-stock built very rapidly as an emergency measure to combat shortage after the war is no longer up to modern standards and requires renewal or replacement.
- There is an increasing awareness of environmental problems which will almost certainly have effect on construction and civil engineering. The kind of measure and amount to be spent are the subject of political controversy.
- It seems highly likely that the Federal government will initiate a program for urban renewal to "revitalise towns and cities ecologically".
- The Federal government also expects the increase in public spending to have the effect of reducing illicit work, simply because no public contracts are awarded to illicit workers.

3. <u>The diffusion of edp and automation in the industry</u>

As is to be expected considering the dire state of the industry and the small average size of the firms, the application of edp and automation is at a less advanced stage than in other industries, particularly those with a large share of exports. In fact most firms were just introducing, or considering the introduction of, electronic data processing. CAD/CAM was generally a thing of the future. A similar situation prevailed as far as equipment was concerned: while there is certainly a great deal of pressure to rationalize, very little had been achieved in the way of automation or robotization. The firms cannot determine their own production program but rather have a certain production capacity which is offered for contract work. Thus civil engineering and construction firms are forced to react to rapidly changing markets and to adapt their capacity to demand.

The firms are in danger of purchasing too much equipment for their contract capacity. Thus one recommendation for rationalization is to concentrate purchases on multi-purpose machines which are interchangeable and may be combined into systems with other equipment and which have only minor costs for transport and assembly /5/. Specialized equipment or equipment required only sporadically for individual jobs can then be hired or leased. At present, there is comparatively little of this done and then mainly of trucks and other vehicles. However, there is a certain amount of division of labor between firms. To give you a flavor of developments in the equipment sector, I'll quote some results from an analysis of the statistics conducted by the Federal Office of Statistics /6/.

The method employed was to analyse statistics on building equipment from 1950 to 1981. One most interesting observation was that the list of categories changed significantly during this period: In 1950 the list included 17 different types of machine, in 1981 there were 33. Of the original 17, 9 have survived while the other 8 have been dropped due to lack of significance and some types of machine added after 1950 have also since been dropped. 14 types of machine included in the 1981 list are newcomers (Fig. 1).

The number of <u>cement mixers</u> per employee in the industry has tripled in the period, although their importance is decreasing since the introduction of transported concrete.

<u>Swivelling turret cranes</u> are the piece of equipment to have gained most in importance during the period. This is partly due to their use in rationalization strategies and partly due to their use in place of elevators.

<u>Mobile cranes</u> also gained in importance, one reason for this being the advent of pre-fabrication in civil engineering and construction.

The number of <u>trucks</u> increased eight-fold during the thirty year period. Although trucks in themselves may seem unsensational, their increased use is due to the development of types for use in previously inaccessible terrain, thus increasing the flexibility of construction

Items included during the entire period 1950-1981	Items dropped from statistics during the period (included from ... to ...)	Items added to the list with year of first inclusion
cement mixers	construction elevators(1950-1973)	transport mixers (1968)
swivelling turret cranes	locomotives (1950 -1957)	mobile and mounted cranes (1964)
conveyor belts	rail material (1950-1953)	concrete pumps (1978)
trucks	rail-bound tip-up trucks (1950 - 1957)	equipment to convey and apply mortar (1964)
multi-purpose excavators	tractors (1950-1973, included with trucks after 1974)	dumpers, tip-up trucks (1964)
rammers	prospecting vehicles (1954-1973)	loaders (1957)
rollers	pumps (1950-1956)	caterpillar graders (1964)
compressors	motorized spraying machines for tarmac coatings (1958-1967)	planes for roads (1974)
tubular and profile steel scaffolding	gantry mixers for concrete roads (1958-1963)	stampers and vibrators (1974)
	soil stabilizers (1962-1973)	mixing equipment and processing machines, cookers for bitumen, tar and liquid asphalt for road surfaces (1958)
	steel shells for casting concrete (1950-1956)	processing and distributing equipment for concrete roads (1958)

FIGURE 1: TYPES OF EQUIPMENT INCLUDED IN OFFICIAL STATISTICS ON THE CONSTRUCTION INDUSTRY 1950 - 1981, Source; Statistisches Bundesamt

companies. The advances in truck technology led to rail transportation being edged out of civil engineering and construction to a large extent.

Multi-purpose excavators are typical of machines being used for rationalization in underground construction engineering and road construction. They have gained importance, partly due to the use of hydraulics in place of cables for their construction. Whereas the older type of cable excavator was restricted almost entirely to use for leverage, the modern hydraulic excavator has interchangeable tool-heads making it useful for a variety of purposes.

Bulldozers and graders gained importance from the early 1950s to the point where they were standard equipment for underground workings. Their significance is now declining due to their being replaced by hydraulic excavators and various types of loader.

The use of loaders of various types for work in earth-moval and on the site has also increased. One example is the excavator-loader, a comparatively small multi-purpose machine which is being used increasingly by smaller firms without any distinct specialization and those specialized in building one-family housing. The popularity of the machine is due to the interchangeability of their toolheads for a variety of purposes such as loading, gripping, prospecting and grading.

The classic steam-roller has gradually been replaced by other types which no longer require as much weight due to the use of vibration.

The authors of the analysis identify 3 distinct phases of rationalization, also marked by specific manpower policies:

- Phase I which lasted throughout the 1950s. During this phase mechanical aids were used to "extend the arm" of auxiliary workers, for example winches, scrapers and cement mixers. This phase was marked by an increase in the average size of firms and by a shift from unskilled labor to skilled labor.
- Phase II was during the 1960s and is characterized by an increase in the importance of skilled labor for the operation of specialized machines. This was due to the development of specialized processes and

machines for earth and rock workings and for leverage, conveyance and transportation.

- Phase III which began in the 1970s and, in the opinion of the authors at the Federal Office of Statistics, is still continuing is characterized by the endeavor to develop methods for prefabrication and to economize on labor and materials. In addition, this phase is characterized by efforts to enable seasonally uninterrupted construction and to improve conditions of labor and training. In this phase, the proportion of white-collar workers increased since these are required to optimize procedures, develop new equipment and processes.

4. The outlook - prospects for robotization in the West German Construction and Civil Engineering Industry

You will, no doubt, have noticed that all this has very little to do with robots and will be expecting me to announce the emergence of a revolutionary breakthrough in the near future. On our travels, we saw no example of real robots or robot-like machines in use on building sites and only one example where the application of robots in pre-fabrication was being given serious consideration. (This example will be discussed briefly later on and Martin Wanner is telling you about other examples from the literature.)

A number of reasons can be put forward to explain this situation:

- The lack of suitable sensors and diagnostic programs: in construction, we are generally dealing with an environment which cannot be completely defined. Unexpected events such as freak weather almost inevitably take place, making human intervention necessary. Similarly, situations occur which require human diagnosis. There may be potential for the use of artificial intelligence in the shape of expert systems but the performance capability of artificial sensors lags so far behind that of the human being that their application is usually an emergency measure in dangerous situations. In particular, human capability for combined recognition and diagnosis looks unlikely to be rivalled by artificial intelligence for a long time.

- A second important argument against on-site use of robots is their present size and lack of mobility. Robots used to assemble pre-fabricated parts or windows would have to be small enough to fit through apertures for doors or windows. There is also the problem that several different gangs of laborers may be on the site simultaneously, meaning that even if a CAD/CAM link or something of that kind were used to control the robot, there would be unplotted obstaces lying around in its way. It is also very likely that there would be regulations, prohibiting simultaneous work by a robot and human labor so that any efficiency gain for one task would be lost by having to perform the tasks in sequence.
- There are also several problems of economics, one being the amount of money available for investment for reasons shown at the beginning of this talk. Another is that the numbers of large, expensive machines for special purposes might be too small to warrant investing a considerable sum for automatic control. It would also appear that existing technology is sufficiently advanced for everyday purposes as may be surmised from this quote from manufacturer's advertising:
"Our equipment does cost a higher price - but it is often the "money maker" of the whole fleet of pumps. They are the "contract winner" for the small and medium sized machines in your fleet; the key to gain admission to large-scale building sites and to sophisticated construction companies. Big masts are an important step on the way to leading the market, to facing the future and to accomplishing more per man. Even the M 43 is too small for many sites. So why should it be too big for your firm?" (Fig. 2)
- There are also several important psychological ostacles for robotics or even less sophisticated aids in construction. For instance, our partners in construction companies thought it would be unlikely that laborers would accept robots on the site. In a slightly different vein, we saw examples (not in construction, I may add) where laborers were not using aids to lift heavy loads, either because this ran counter to their idea of virility or because the aids were too complicated to operate, possibly taking longer for the same task than doing the job manually. Much the same applied to equipment provided with interchangeable toolheads: in one instance laborers were using - and had developed considerable dexterity in the use of - a tool not fully suited for a specific purpose, simply because it took too long to mount the head designed specifically for the purpose.

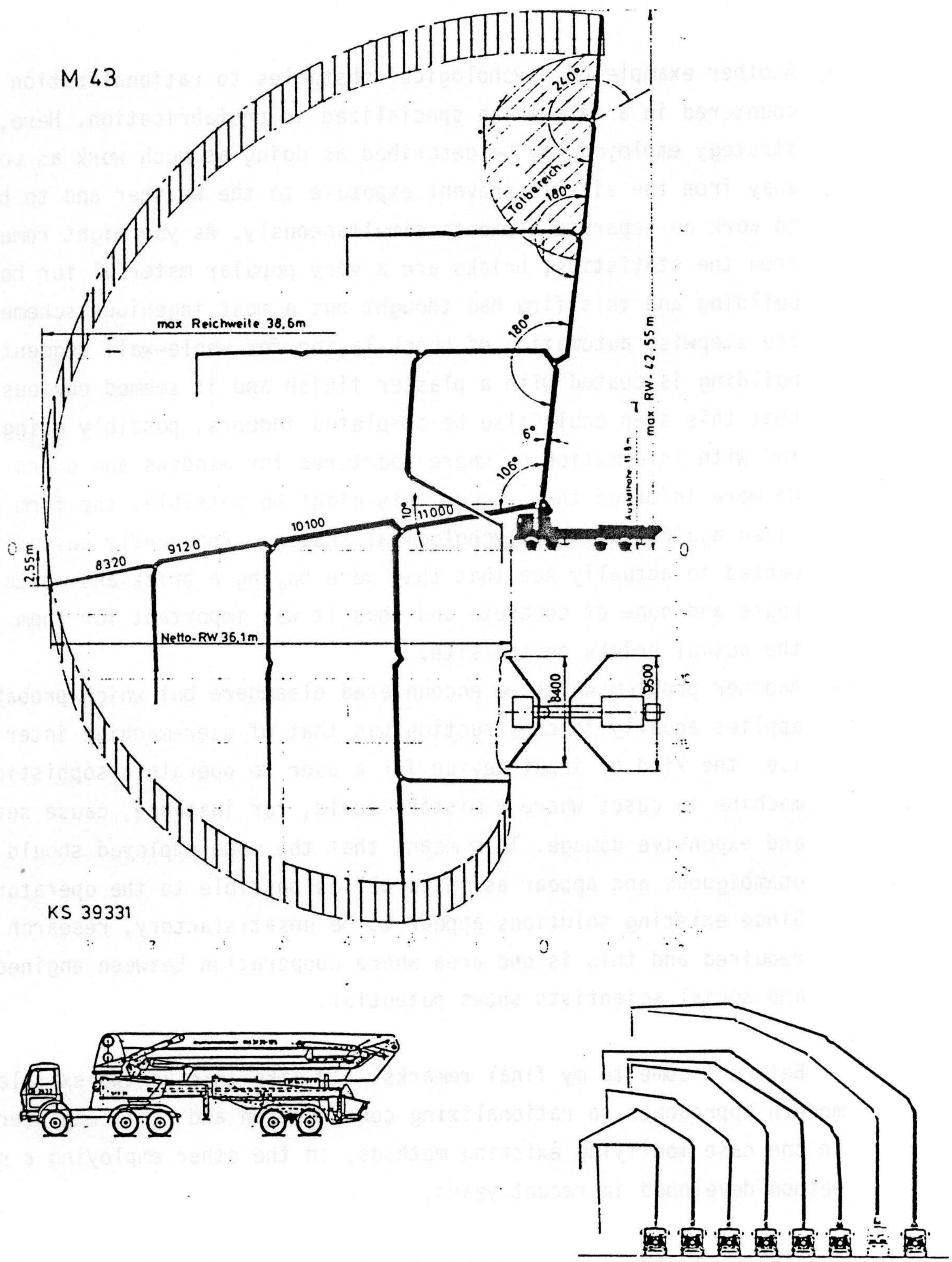

FIG. 2: LARGE CONCRETE APPLICATION AND DISTRIBUTION MAST

(Putzmeister)

- Another example of psychological obstacles to rationalization was encountered in a firm which specialized in prefabrication. Here, the strategy employed may be described as doing as much work as possible away from the site to prevent exposure to the weather and to be able to work on separate elements simultaneously. As you might remember from the statistics, bricks are a very popular material for house-building and this firm had thought out a most ingenious scheme for the stepwise automation of brick-laying for whole-wall segments. The building is coated with a plaster finish and it seemed obvious to us that this step could also be completed indoors, possibly using a robot fed with information on where apertures for windows and doors were. We were informed that though this might be possible, the firm had decided against it for psychological reasons. Apparently customers wanted to actually see that they were buying a brick-and-mortar built house and none of concrete and thus it was important for them to see the actual bricks on the site.
- Another problem which we encountered elsewhere but which probably applies equally to construction was that of user-machine interface, i.e. the kind of input device for a user to operate a sophisticated machine in cases where a mistake could, for instance, cause serious and expensive damage. This means that the mode employed should be unambiguous and appear as "natural" as possible to the operator. Since existing solutions appear to be unsatisfactory, research is required and this is one area where cooperation between engineers and social scientists shows potential.

Before I come to my final remarks, I'd like to give two examples of modern approaches to rationalizing construction and civil engineering, in one case modifying existing methods, in the other employing a novel method developed in recent years.

I have already made a couple of references to the first example of which I will show you a primitive sketch. (Fig. 3)

This represents an attempt to change the environment for a specific traditional task in addition to making the task easier for the laborer performing it. The materials the laborer needs for the task are all as-

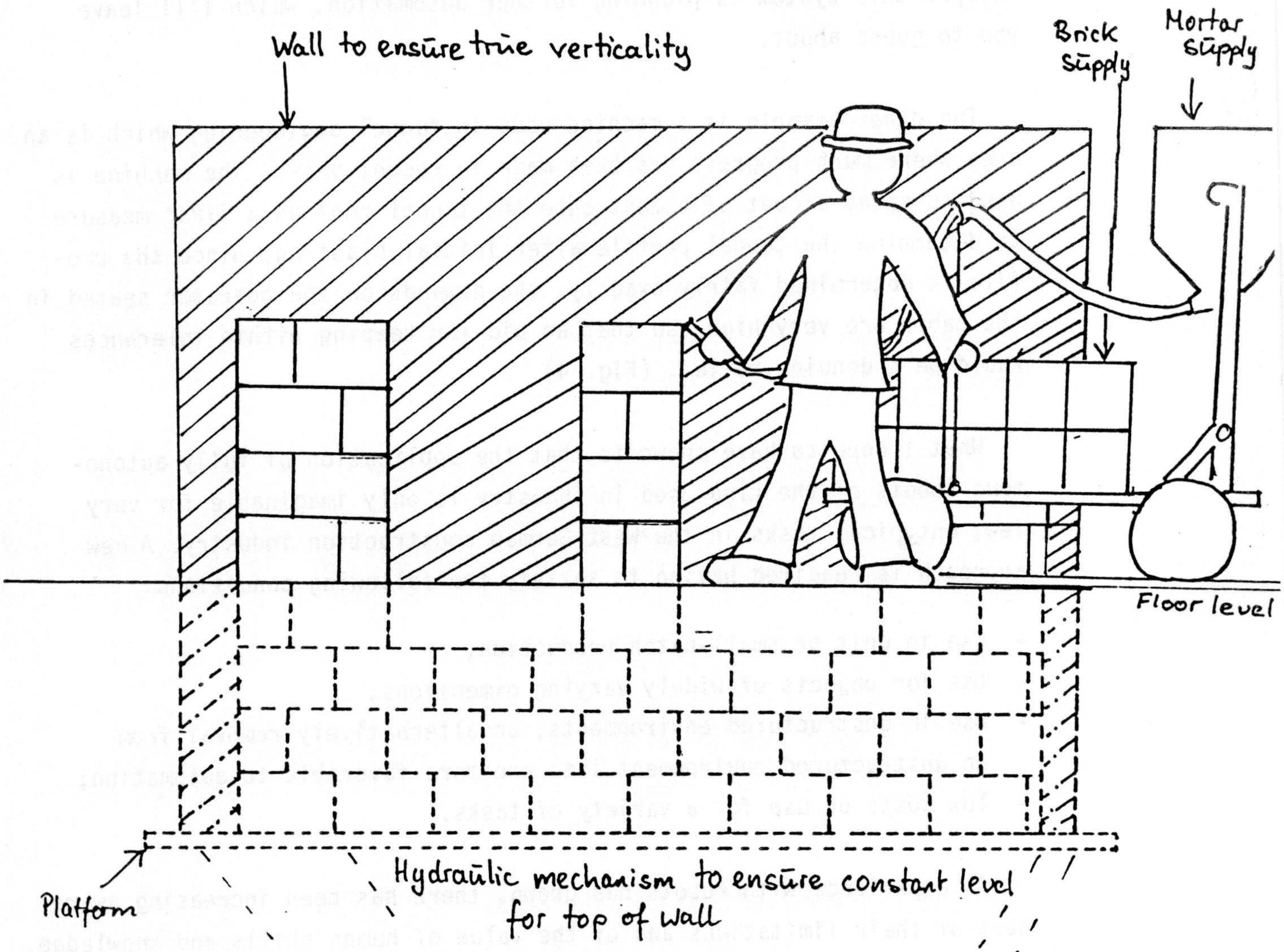

FIG. 3: SCHEME TO PRE-FABRICATE WHOLE BRICK-WALL SECTIONS
(Drawing by author from memory, SÜBA)

sembled on a mobile flat-car on rails, i.e. bricks, a supply of mortar, which is replenished from time to time and sprayed on by hose, and the tools he needs like hammers, trowels etc. The whole wall is built on a platform divided into two halves by a vertical wall which ensures the brick walls are constructed vertically. This platform is adjustable in height to enable the laborer to work at a convenient level causing as little strain as possible. Since brick-walls are prone to damage, a concrete beam is built in to enable transportation. The firm which developed this system is planning further automation, which I'll leave you to guess about.

The other example is a machine used in tunnel engineering which is an area where much progress has been made in recent years. The machine is used to spray a coat of cement onto the tunnel roof as a first measure to determine the tunnel profile after initial blasting. Since the profile is determined fairly exactly, the demands on the operator seated in the cabin are very high, so that an aid for keeping within tolerances would be a genuine relief. (Fig. 4)

What I hope to have shown is that the application of fully autonomous robots of the kind used in industry is only imaginable for very few, untypical tasks in the West German construction industry. A new approach is required having to satisfy the following conditions:

- Use in unit or small-batch production;
- Use for objects of widely varying dimensions;
- Use in unstructured environments, or alternatively removal from an unstructured environment into one more favorable to automation;
- low costs or use for a variety of tasks.

As experience with robots has grown, there has been increasing awareness of their limitations and of the value of human skills and knowledge. To give but one example, considerable knowledge on the properties of materials and skill is required to weld a stretch of 20 meters because the heat generated in the process deforms the material. It is conceivable that this problem could be solved at great expense and with a great deal of effort, but why bother? Humans are certainly better at performing certain tasks than computers or any other kind of machine, as

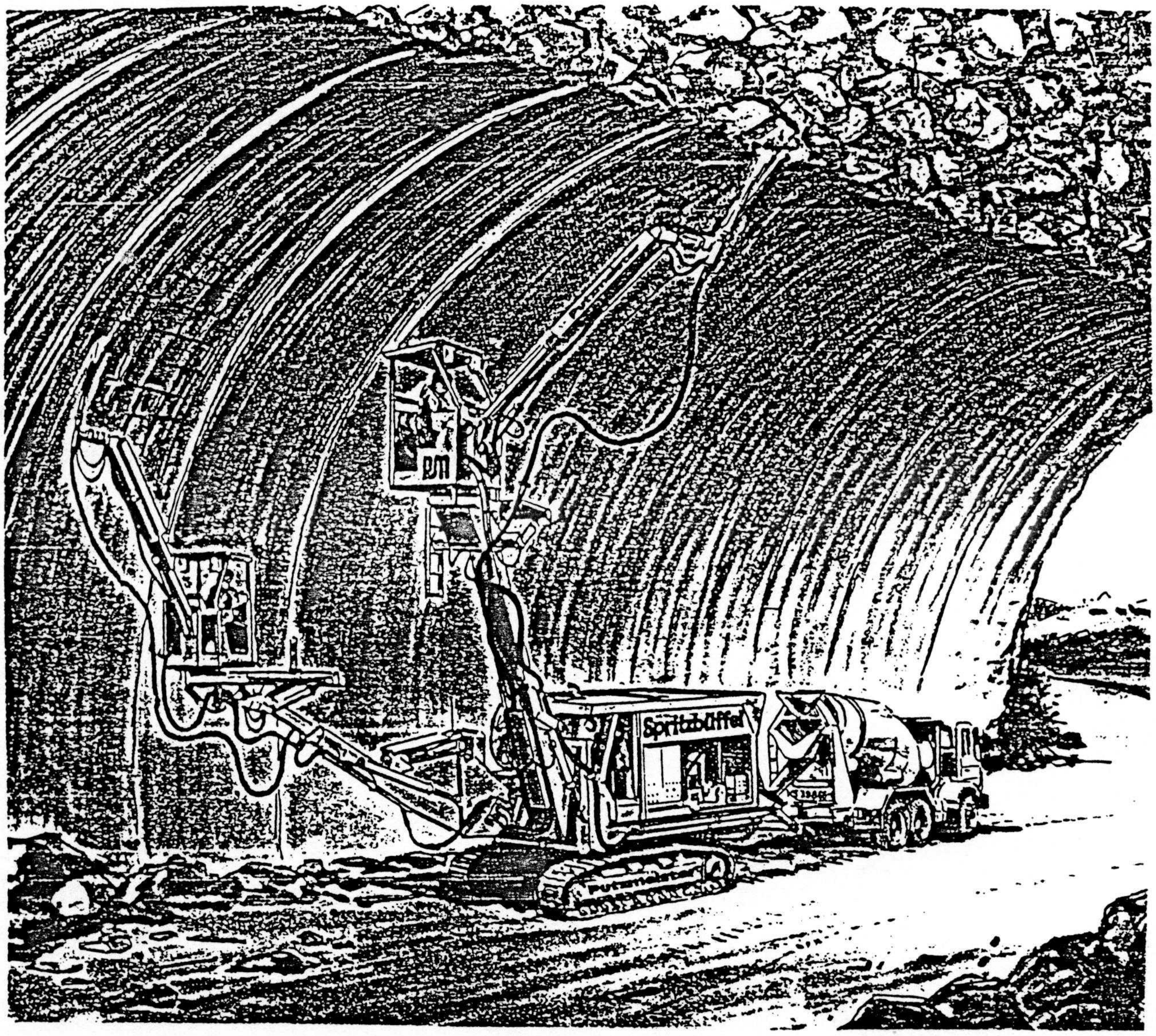

FIG. 4: "SPRITZBÜFFEL" - MACHINE USED TO COAT TUNNEL-PROFILES WITH CONCRETE (Putzmeister)

Mike Cooley, to give one example, has continually pointed out /7/. He has very clearly stated the case in favor of machines which incorporate and, where possible, enhance human skills, taking away only tedious repetitive tasks. So what is needed is a new kind of machine which can perform this kind of task, at the same time drawing on humans' capabilities and skills for tasks where these are necessary and can be performed better. Construction and civil engineering are areas where automation is still beginning, so why not take up the opportunity and show that automation can be used to remove tedium while preserving meaningful jobs?

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