

Presentation of EUREKA/GEO Project :

A Façade Working Robot

Bertrand TONDU and Gilles CLEMENT

Comissariat à l'Energie Atomique, CEN FAR, IPSN/DPT/UGRA

B.P n°6 - 92265 FONTENAY-aux-ROSES Cédex, FRANCE

Claude ROUVEAU and René COLAS

Campenon Bernard Construction, 29-31 rue de l'Abreuvoir

B.P n°12 - 92101 BOULOGNE, FRANCE

Denis AHSWORTH

Simon Engineering Dudley LTD.

DUDLEY - West Midlands DY1 2HA, ENGLAND

Abstract :

The purpose of this paper is to present the EUREKA/GEO project : a robot for finishing work on façades. This project joins presently three partners : the french building construction CBC company (Campenon Bernard Construction), coordinator of the project, the british Simon Engineering company, world leader in auto-elevators, and the french CEA (Comissariat à l'Energie Atomique), responsible for attached robotics research and control system development. The considered field of applications of the GEO robot concerns mainly spraying applications like cleaning, painting, sandblasting and others. Its structure is composed of a large size robotized carrier which supports a terminal robot handling the tools. Its working procedure is based on an off-site programming phasis thanks to a CAD model of the façade and a task level programming language, then an on-site execution phasis supervised by an operator which can intervene by using an on-board hand controller for teleoperating the robot.

1. Introduction

The goal of the EUREKA/GEO project is the realization of a robot for finishing work on façades. The considered field of applications concerns presently a large number of spraying applications in Construction, easily robotizable, like painting, coating of concrete or plastics, cleaning, sandblasting and others. Similar applications could be also found in the future in naval or in oil industry like cleaning or shotblasting.

Such a project is in accordance with the actual effort of transposing the industrial Robotics techniques into the field of Construction Robotics. However, it is well known that such a transfer is not easy, especially because of the unstructured and changing environment of a construction site, in contrast with the closed environment of the factory floor. In this context, the robotization of finishing work on façades, though submitted to certain unexpected events, is however more easily predictable than the global environment of a construction site. Moreover the selected applications in the frame of the GEO project resemble some painting applications of industrial robots. Lastly, first economical simulations /1/ let think that surface finishing work robotization offers considerable economical potential.

This paper succesively presents the general organization of the project, the viewed structure of the GEO robot and the way in which it will be programmed.

2. General Presentation of the Project

2.1. The Partners

The GEO robot project was accepted in 1986 by the EUREKA committee. It presently joins three main partners :

- the french building construction CBC Company (Camponon Bernard Construction), coordinator of the project,
- the british Simon Engineering company, world leader in auto-elevators,

-the french public organism CEA (Comissariat à l'Energie Atomique), responsible for attached Robotics research and for control systems development.

2.2. The Project

The project must lead in five years to the realization of a robot prototype which can act on a large range of urban façades. The main problems raised by this project are the following ones :

- the GEO robot will work in an open environment, though limited to a façade. Consequently, the development of appropriate sensors will be necessary to insure safe working of the robot,

- the GEO robot will be a large size robot, in order to cover the totality of a medium size façade of about 20 by 30 meters. The mechanical definition of large size robots and of their control systems are new problems in Robotics,

- the GEO robot will work in various weather conditions, and effects of bad weather and wind must be taken into account in the mechanical definition of the robot as well as in the controls (compensation).

Facing these problems, present research axes are following :

A. Use of a CAD model :

The use of a graphical model of the façade and of their surroundings will allow a simplified and interactive programming of the different sub-tasks on the façade. This use of CAD models appears to be especially promising since CAD in Construction becomes widespread, and more and more constructions are built from CAD models.

B. Use of a hybrid robot working mode: an autonomous mode and a teleoperation mode :

Presently it is hard to imagine a robot working in urban environments in a completely autonomous mode. The least unexpected event can have unpredictable consequences for the achievement of the task and the security of the persons. For this reason, the presence of an operator on site who supervises the task

execution appears to be essential. This leads to consider a hybrid working mode for the robot :

- a robot mode, similar to the autonomous working mode of programmed industrial robots,
- a teleoperation mode, which is activated when the automatic execution of the task is interrupted because of an incident, detected by the operator or by the sensors, or when the task is not entirely programmable.

The advantages of developing hybrid systems from teleoperated to autonomous robot modes has already been emphasized on as a future direction in Construction Robotics /2/.

3. General Structure of the GEO Robot

The general structure of the GEO robot is presented in Figure 1. This structure is composed of the following sub-assemblies :

- a vehicle which transports the robot and which is equipped with an on-board control station,
- a robotized carrier derived from the architecture of an existing auto-elevator from SIMON (Super Snorkel SS600). Figure 2 presents an example of utilisation of this machine,
- a terminal robot supported by the carrier platform. The field of action of this robot is comparable to the field of action of a industrial painting robot. It handles the tools and operates on the façade after being placed by the carrier in front of a working zone,
- a set of sensors essential for obstacles detection, atmospheric conditions determination, task quality determination and human presence detection,
- a control system which is composed on the one hand with the carrier and the terminal robot controllers, and on the other hand with the on-board host computer which supports the task execution program.

4. Programmation of the GEO robot

Working procedure of the GEO robot is envisaged in two steps :

- In the first step off-line programming is realized on an off-site computer thanks to a CAD model of the façade and a task level programming language,
- The second step is on-site execution supervised by a non-specialist operator which can eventually intervene by using a hand-controller for teleoperating the carrier or the terminal manipulator.

4.1. Off-site Programming

The task description is based on a task level programming language. This language is linked to the CAD data base to allow a direct programming of each sub-task by showing the concerned element of the façade and selecting the desired process. Trajectories methods are associated to each process and eventually take into account the geometrical characteristics of the façade elements. Each created sub-task leads to a tool-trajectory visualized on the screen. When the complete task description is performed, a set of simulations using a CAD model of the GEO robot will allow to check the feasibility of each sub-task, and eventually to reprogram it.

During this task description, the programmer has the possibility to define computer assistances which, if the task is interrupted, will help the operator to handle the hand-controller for pursuing the task in teleoperation mode. Such assistances can be, for example, to keep a constant orientation of the tool on the surface that has to be "manually" finished or perfected. This idea is based on the concept of "Computer Aided Teleoperation" /3/,/4/,/5/. It leads to consider in the programming of the task the possibility of associating to each automatic sub-task an assistance procedure. This process is illustrated on Figure 3.

4.2. On-site Execution

The task execution program is transmitted to the on-board computer of the control station. The on-site operator will follow the indications given by the program to run the task and to supervise its execution.

After the necessary calibration of the real façade on the CAD model, the task execution is set. Each sub-task is supervised thanks to the computer messages and thanks to the cameras and the process sensors. The operator can intervene to adjust a parameter for improving the task quality without interrupting it, or when the program calls a rerun or a pursuit of the task in teleoperation, or when an unscheduled event happens. In this last case, the operator has the possibility to continue the sub-task in teleoperation or to reprogram it.

The sequence of phases for the processing of a façade is summarized on Figure 4.

5. Conclusion

The EUREKA/GEO Project will result in a robot of large use for finishing work on façades. We have presented in this paper the outlines of the project by showing the important place of CAD and the interest for programming of the robot to consider a hybrid working mode, combining robot modes and teleoperation modes. Present work is concentrating on the complete finalization of the project, to initiate the developments phasis next year.

References

- /1/ M. Skibniewski, P. Derrington, C. Hendrickson
"Cost and Design Impact of robotic Construction Finishing Work", CAD and Robotics in architecture and Construction, HERMES, Paris, 1986, pp. 496-517
- /2/ W. L. Whittaker
"Construction Robotics : A Perspective", CAD and Robotics in Architecture and Construction, HERMES, Paris, 1986, pp. 413-422
- /3/ B. Espiau
"The Advanced Teleoperation Project", RoManSy 86, Cracow, Poland, 1986, pp. 3-11
- /4/ P. Gravez, B. Lepers, R. Fournier, G. Andre
"Control and Supervision in Computer Aided Teleoperation", RoManSy 86, Cracow, Poland, 1986, pp. 12-21
- /5/ G. Andre, A. Fournier
"The Generalized Information Feedback Concept in computer Aided Teleoperation", RoManSy 86, Cracow, Poland, 1986, pp. 22-32

- ① Vehicle
- ② Command station
- ③ Crane carrier
- ④ Operational robot
- ⑤ Sensors
- ⑥ Command control
- ⑦ Tool

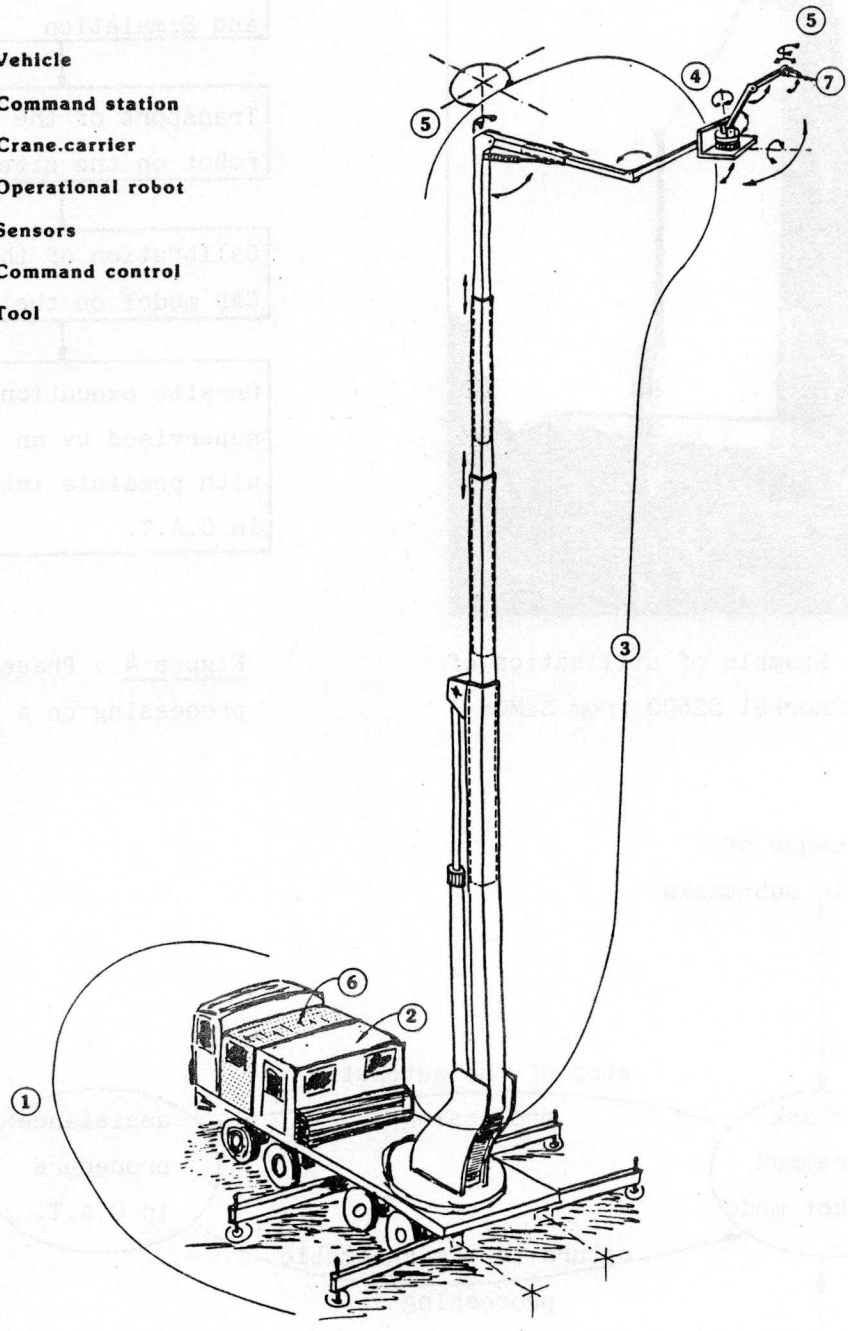


Figure 1 : General structure of the GEO robot

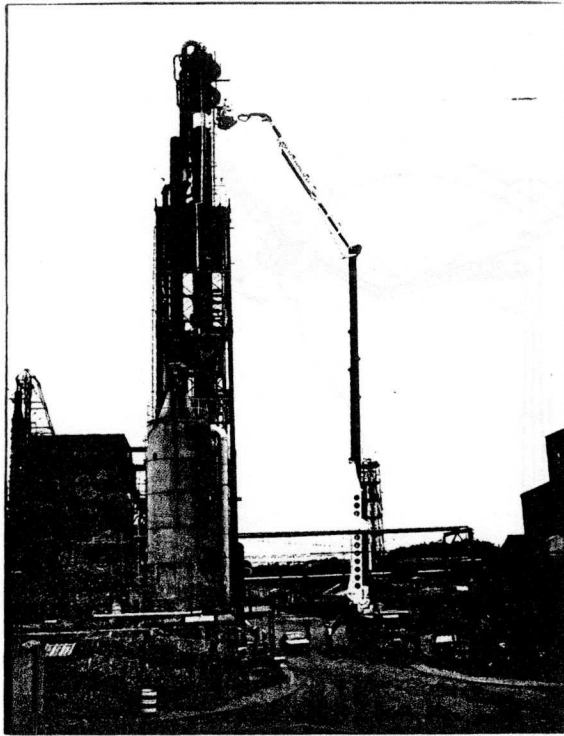


Figure 2 : Example of utilisation of the Super Snorkel SS600 from SIMON

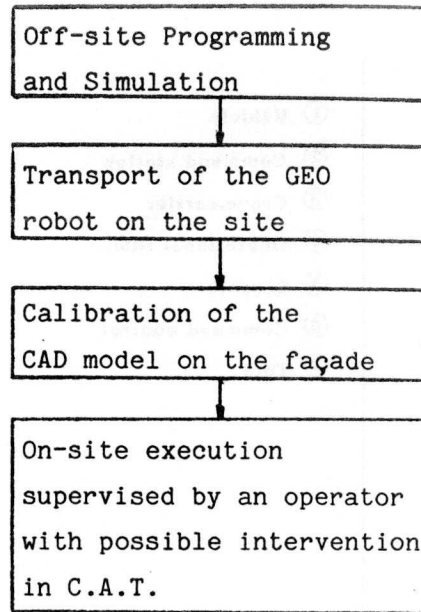


Figure 4 : Phases of the processing on a façade

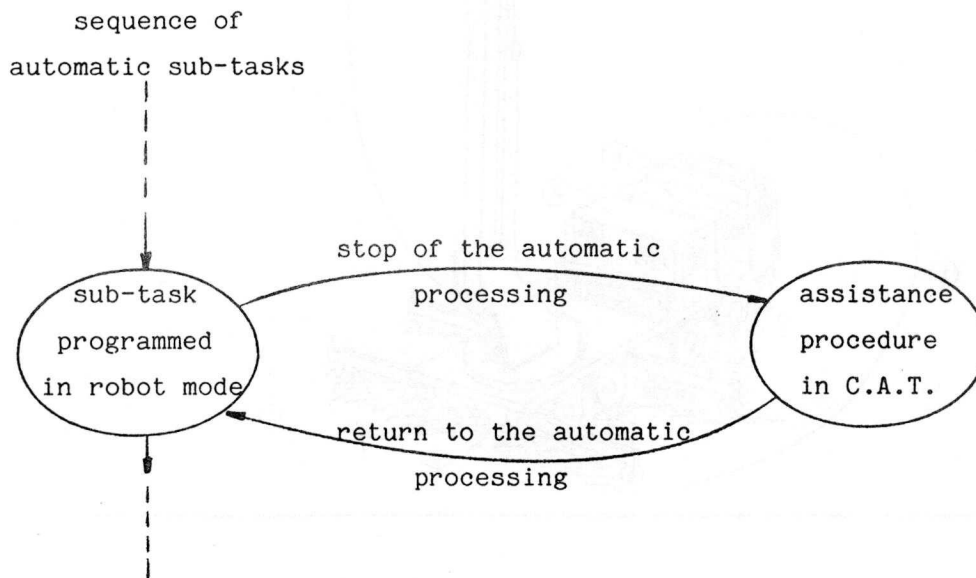


Figure 3 : Association of an assistance procedure to an automatic sub-task

MANIPULATORS IN THE DUTCH BUILDING INDUSTRY

C. Peter Verschuren, Director of the Research Institute for Labour Economy in the Building Trade (SAOB), EDE, The Netherlands

J. van der Eijk, Civil Engineer, Research Institute for Labour Economy in the Building Trade (SAOB), EDE, The Netherlands

In 1984 the Research Institute for Labour Economy in the Building Trade (SAOB) concluded an investigation into the feasibility of industrial automation in building on behalf of the Netherlands Ministry of Economic Affairs. An initial conclusion was that industrial automation for the production of base materials, semi-manufactures, products and elements has a low priority.

Processing on the building site and on the work floor on the other hand has the highest priority.

As regards the latter an analysis has been carried out in respect of the tasks performed by the eleven most important trades. This resulted in an order of importance and probability based on ergonomic aspects and relative costs.

The criteria involved here were:

- reduction of costs
- lightening the physical load (humanization of labour)
- increasing accuracy.

The operations of the carpenter, the reinforcement fixer, the bricklayer and the concrete worker proved to be areas that would enter into consideration for industrial automation.

The conclusion is that for these operations unmanned, automatic handling devices (robots) do not present any chance of success, but that sophisticated manned handling devices (manipulators) do have a chance of success.

Efforts to develop this equipment have already resulted in one operational type, but more will have to follow.

The principal activities of the building industry

The feasibility study incorporates a review of the building industry as a whole. Building is a production industry. Before examining which areas

within the industry would enter into consideration for automation of production, it is important first to define the principles of operation of the existing production processes taking place in this industry.

The end product of the overall production process is generally a building or some civil-engineering project. The realization of this end product takes place on a well-defined location and in a predetermined position within that location.

What, in effect, the realization of a building amounts to is placing building materials in a predetermined place and position. This principle is not affected in any way by the fact that this process requires a lot of auxiliary materials and equipment, and that many building materials must first undergo certain operations, because they cannot be used in the realization process in the form in which they are supplied.

The realization of a building takes place at and around the predetermined position of that building. The work place where the processing of building materials takes place is situated at this predetermined position.

The area around the work place is referred to as the building site, which is used for, among other things, supply, temporary storage and distribution of building materials.

The infrastructure outside the building site is used to transport base materials, semi-manufactures, finished products and elements, collectively referred to as building materials, to the building site.

The production and manufacture of such building materials as referred to above take place at the production locations and in factories.

The principal activities are diagrammatically represented in figure 1.

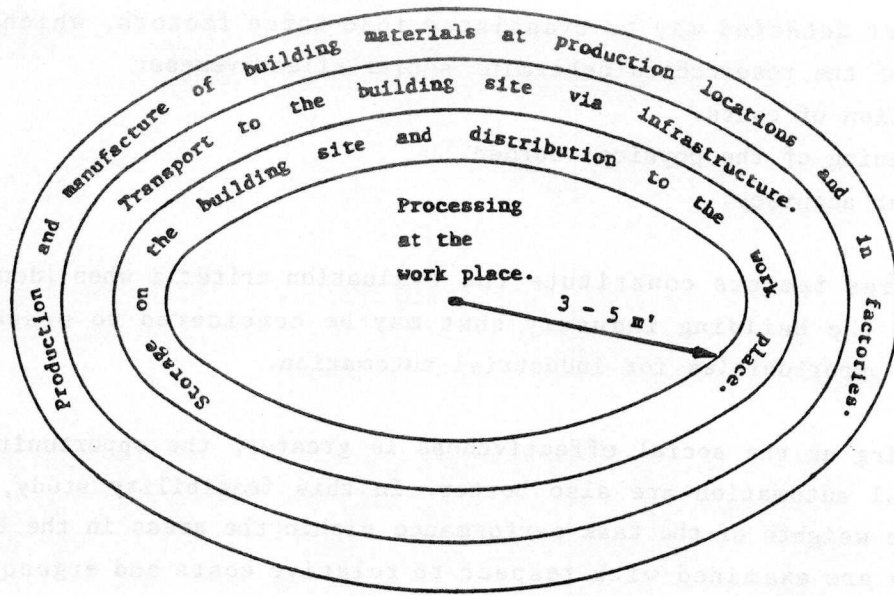


Figure 1.

The reality content of the investigation

The feasibility study is aimed at man, working in the building trade or in the supplying industry. All kinds of production processes, in their widest variety, and certainly those on the building site, are reflected in many years of practical experience.

For this reason the researchers deem it wise to adhere to the assumption that the various production processes, and certainly those on the building site, should generally be maintained for the time being. Hence, this investigation does not present any Utopias and consequently no suggestions are put forward for instance to make drastic changes in the building industry in order to make way for the introduction of robots still to be developed.

The evaluation criteria

The effect of deployment of industrial automation generally finds expression in:

- a. Improvement of working conditions.
- b. Strengthening of human capacities as a result of:
 1. Increased action radius.
 2. Greater power and speed.
 3. Greater accuracy.
 4. Reduced physical burden.
 5. Greater stability of a position.

The effect detected may be translated into three factors, which in the opinion of the researchers determine social effectiveness:

- a. Reduction of costs.
- b. Lightening of the physical burden.
- c. Greater accuracy.

The three factors constitute the evaluation criteria when identifying areas in the building industry that may be considered to present favourable opportunities for industrial automation.

According as the social effectiveness is greater, the opportunities for industrial automation are also better. In this feasibility study, therefore, the weights of the task performance within the areas in the building industry are examined with respect to relative costs and ergonomic aspects.

The line of the study and the place of the evaluation criteria along this line are diagrammatically represented in figure 2.

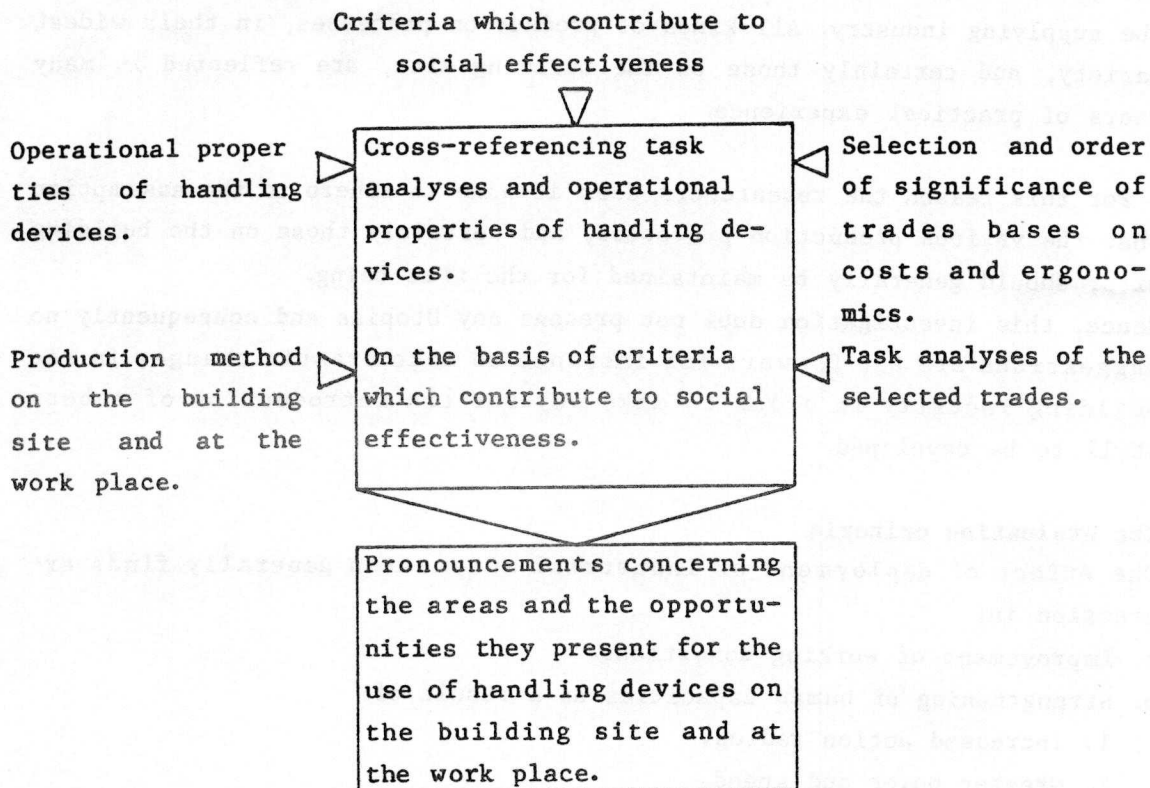


Figure 2. Inventory of those tasks on the building site capable of being automated.

For frequently occurring types of housing and commercial buildings the percentage share in the total labour volume has been ascertained, divided over the various trades, on the strength of data gathered over a number of years.

The ergonomist then classified the ergonomic weight per trade by drawing up so-called ergograms. Apart from the energetic load and the dorsal load, other physical aspects are also weighed, as well as the work environment, the working conditions and other burdening factors, such as eye strain, mental exertion, noise level, etc.

For the ultimate selection and order of significance weighting factors have been calculated by multiplying the percentage share in the labour volume by the ergonomic weight.

This produces the result shown below, where the order of significance is indicated on the strength of the size of the weighting factors.

| HOUSEBUILDING | | COMMERCIAL BUILDING | |
|----------------------------|-----------|----------------------------|-----------|
| Carpenter (main structure) | 18.30.540 | Carpenter (main structure) | 15.30.750 |
| Bricklayer | 16.28.448 | Concrete worker | 12.30.360 |
| Concrete worker | 9.30.270 | Reinforcement fixer | 10.28.280 |
| Hodman | 8.30.240 | Joiner (finishing) | 12.23.276 |
| Joiner (finishing) | 9.23.207 | Bricklayer | 8.30.240 |
| Plasterer | 6.30.180 | Scaffolding erector | 4.30.120 |
| Reinforcement fixer | 5.28.140 | Hodman | 4.29.116 |
| Plumber | 6.16.96 | Floorlayer | 4.28.112 |
| Decorator | 5.19.95 | Tiler | 4.28.112 |
| Floorlayer | 3.28.84 | Roofer | 4.28.112 |
| Tiler | 3.28.84 | C.H. fitter | 6.14.84 |
| Scaffolding erector | 2.30.60 | Electrician | 4.12.48 |
| Electrician | 5.12.60 | Plasterer | 1.30.30 |
| C.H. fitter | 4.14.56 | Decorator | 1.19.19 |
| Rooftiler | 1.28.28 | Plumber | 1.16.16 |

The order of significance has now been determined, but limits are still to be established in order to select those trades on which attention must be focussed in the further study.

9000
Number
NIOSH
has some
type
numbers

| Miscellaneous operations | Base materials | Semi-manufactures | Finished products | Elements |
|--------------------------------|----------------|-------------------|-------------------|----------|
| Determining quantities | 0 | 0 | 0 | |
| Distributing materials | | 0 | 0 | 0 |
| Making auxiliary constructions | | 0 | 0 | 0 |
| Levelling work surfaces | | 0 | 0 | 0 |
| Working in teams | | 0 | 0 | 0 |
| Working alone | 0 | 0 | 0 | |
| Consultations | | 0 | 0 | 0 |

The miscellaneous operations require the most time in the trades of carpenter (main structure), bricklayer, concrete worker, reinforcement fixer and joiner (finishing), who for the greater part work up semi-manufactures and finished products.

Working up building materials

On average, 50 per cent. of the total time is used for actually working up the building materials. These operations come down to four basic activities: placing, positioning, setting up and fixing. However, to this should be added a multiple of activities relating to dimensioning, tolerance and fit.

| Working materials | Base materials | Semi-manufactures | Finished products | Elements |
|------------------------------------|----------------|-------------------|-------------------|----------|
| Dimensioning | | 0 | 0 | 0 |
| Formation | 0 | 0 | | |
| Setting up auxiliary constructions | | 0 | 0 | 0 |
| Placing | | 0 | 0 | 0 |
| Positioning | | 0 | 0 | 0 |
| Setting up | 0 | 0 | 0 | |
| Fixing | | 0 | 0 | 0 |
| Proportioning | 0 | 0 | | |

| Working materials | Base materials | Semi-manufactures | Finished products | Elements |
|-------------------|----------------|-------------------|-------------------|----------|
| Mixing/compaction | 0 | 0 | | |
| Sawing | | 0 | | |
| Cutting | | 0 | | |
| Burning | | 0 | | |
| Shearing | | 0 | | |
| Chipping | | 0 | | |
| Drilling | | 0 | | |

The semi-manufactures distinguish themselves from the finished products and elements in that in most cases they must be made to fit by dimensioning, fitting and working.

Decisions concerning quality of the building materials to be worked up.

| Decision | Base materials | Semi-manufactures | Finished products | Elements |
|-------------|----------------|-------------------|-------------------|----------|
| Composition | 0 | 0 | | |
| Plasticity | 0 | 0 | | |
| Colour | 0 | 0 | 0 | |
| Shape | | 0 | 0 | |
| Cracks | | 0 | 0 | |
| Fracture | | 0 | 0 | |
| Smooth | | 0 | 0 | |
| Straight | | 0 | 0 | |
| Square | | 0 | 0 | |
| Dimensions | | 0 | 0 | 0 |

There are work patterns that take place in series. The characteristic feature being that the successive cycles take place in changing positions. An example in point is the tiler, who performs the activities of picking up the tile and setting it in the mortar layer in recurring cycles. Each cycle relates to a different position of the successive tiles. The conditions per position are not exactly the same. This requires information processing, which resembles that of the bricklayer and manifests itself in the form of skill and proficiency.

The weather conditions have an effect on the performance of tasks in the

form of unworkable days through rain, frost, wind and, although to a lesser extent, light conditions.

The trades that mostly work in "all kinds of weather" are:

- Carpenter (main structure)
- Bricklayer (outdoors)
- Concrete worker
- Reinforcement fixer
- Hodman
- Scaffolding erector
- Roofer
- Those who mostly work under sheltered conditions:
- Bricklayer (indoors)
- Joiner (finishing)
- Plasterer
- Floorlayer
- Tiler

Cross-referencing analyses and operational properties of handling devices

A. Unmanned handling devices (Industrial robots)

An economically justified use of the industrial robot as product or tool handling device imposes very stringent requirements with respect to:

- a. dimensional control;
- b. positioning control;
- c. the scheduling of all operations.

Moreover, the characteristic 'unmanned' is inherent in a high degree of repetition of the programmed activity or operation.

An essential difference between the familiar applications of robots and a possible application on the building site and at work place is that in all the known applications the robot is location-bound, while on the building site and at the work place mobility is a necessary condition.

The researchers have arrived at the following conclusions:

- The characteristics of everyday building practice on the building site and at the work place are far removed from the operational characteristics of unmanned handling devices.
- Intensive developments would still have to take place in such areas as logistic organization, physical distribution and 'make or buy' decision.

- A tendency already exists to have a growing amount of work done in factories by means of prefabrication.
- The resulting trend is that the processing of building materials on the building site and at the work place is more and more acquiring the nature of assembly.
- Technical developments in automation of production are still not so far advanced as to enable the mobility problem with respect to unmanned handling devices to be solved.

It has been established that with the existing process on the building site and at the work place automation of production by means of unmanned handling devices does not present any chance of success.

B. Manned handling devices (Manipulators)

In effect, the most important properties of manipulators are:

- a. The action radius of man is increased.
- b. The capacity is raised.
- c. The physical burden of man is reduced.
- d. The stability of a position is improved, i.e. the capacity to control the position of an object, regardless of shape, size and weight, for any length of time is enhanced.
- e. The accuracy with which activities or operations are performed is increased.

The analyses of the different tasks on the building site and at the work place indicate:

- a. that man is required to furnish a fairly considerable effort;
- b. that parts of this effort are repetative;
- c. that this effort cannot be made until after man has ascertained by means of observation the: wat, where, what with, how and when.

On the strength of the foregoing and in view of the operational characteristics the researchers have established that the use of manned handling devices (manipulators) on the building site and at the work place may be considered to have a good chance of success.

Having established these main outlines, the researchers present for each indication how the chances of applying manipulators compare within the trades and their different tasks.

Tot this end the tasks per trade have been plotted against criteria which

contribute to the chances of successful application. The criteria have been compiled as derivatives of:

- a. reduction of costs;
- b. lightening the physical burden;
- c. increased accuracy.

The relative evaluation pronounced represents the extent to which the criteria would be met if manipulators were to be applied.

The task analyses revealed that in a large number of cases there is question of:

- a. A repetition of an activity or operation, but in constantly changing positions.
- b. Disturbance of location and position of an object as a result of extraneous influences (e.g. wind).
- c. The loads to be handled exceeding by far, in shape, size and weight, the loads handled by the familiar, unmanned and manned handling devices.
- d. Weather conditions which have a direct influence on the manner in which the tasks are performed.

For this reason the researchers, in pronouncing the relative evaluation, started out from an imaginary, sophisticated, manned handling device, which:

1. As product handling device:

- a. Regardless of shape, size or weight, brings and keeps the object in the desired place and position by means of an operator.
- b. Is stable, even in a strong wind.
- c. Is capable of applying foreseeable corrections to place and position by remote control.
- d. May be operated from a sheltered control space.
- e. Is provided with audio-visual means.

2. As tool-handling device:

Apart from the above-mentioned characteristics, it must moreover be capable of:

- f. Dumping any manipulation electronically.
- g. Correcting parts of programmes by reprogramming.

- h. Performing a dumped operating cycle, as and when required, at reference points still to be defined.
- i. Enabling position patterns to be programmed by means of playback technique or pre-programming.

The derived criteria are designated by means of a letter as follows:

- a. Reduction of loss of adjustment.
- b. Reduction of physical burden.
- c. Increased accuracy.
- d. Reduction of rest.
- e. Reduction of influence of rain and frost.
- f. Reduction of influence of wind.
- g. Increased quality.
- h. Increased continuity.
- i. Reduction of use of auxiliary equipment.
- j. Reduction of miscellaneous operations.

The scale of relative scores has been drawn up as follows:

- 0. No contribution.
- 1. Very slight contribution.
- 2. Slight contribution.
- 3. Moderate contribution.
- 4. Large contribution.
- 5. Very large contribution.

Results of cross-referencing

We present the score as trade means with their distribution:

| | Order of importance |
|--------------------------------------|---------------------|
| Carpenter (main structure) 28(18-38) | 1 |
| Bricklayer 21(16-26) | 4 |
| Concrete worker 26(20-32) | 3 |
| Reinforcement fixer 27(24-30) | 2 |
| Joiner (finishing) 21(16-26) | 5 |
| Hodman 19(17-21) | 7 |
| Plasterer 17(15-19) | 10 |
| Scaffolding erector 19(17-21) | 8 |
| Floorlayer 17(15-19) | 11 |
| Tiler 18(14-22) | 9 |
| Roofer 21(18-24) | 6 |

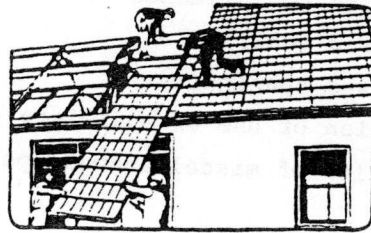
The overall mean of all the tasks is:

23(16-30)

If the limit for indicating the chance of success per task or activity is taken to be equal to the overall mean of 23, the following trades and tasks within these trades may be considered to have a good chance of success for the application of sophisticated, manned handling devices.

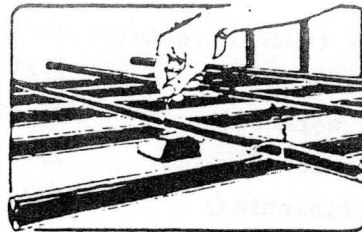
a. Carpenter (main structure):

- Placing shuttering,
- Placing sections,
- Placing casings and fronts,
- Placing joists, purlins and trusses,
- Placing roof elements,
- Placing exterior wall elements,
- Placing stairs.



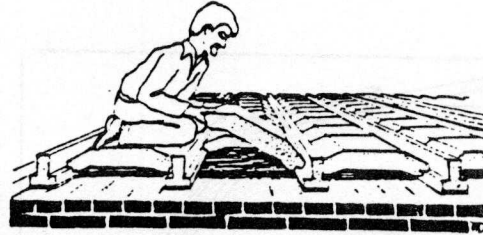
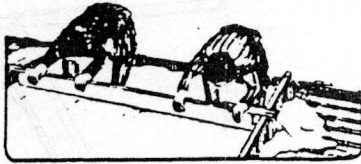
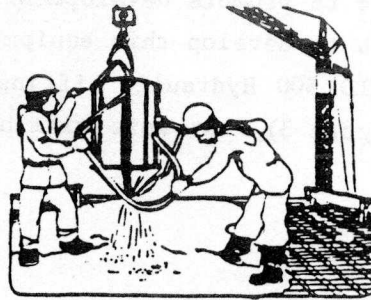
b. Reinforcement fixer:

- Dimensioning,
- Placing loose bars,
- Fitting wire ties and spacers,
- Placing prefab cages and netting.



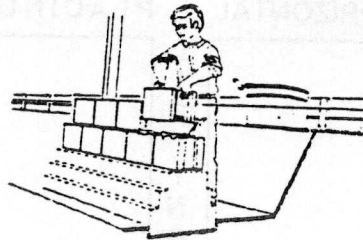
c. Concrete worker:

- Placing shuttering,
- Placing cassette floors,
- Placing combination floors,
- Placing prefab concrete elements,
- Placing and levelling off concrete.



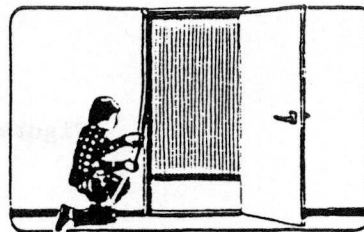
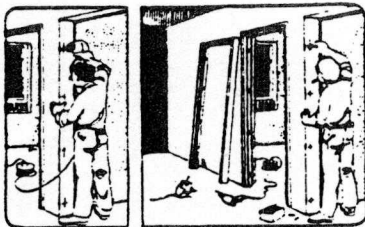
d. Bricklayer:

- Placing blocks,
- Placing slabs.



e. Joiner (finishing):

- Placing door casings,
- Hanging doors,
- Fitting hardware,
- Placing partition walls.



Efforts to promote development

Efforts to develop this equipment have already resulted in one operational type HLD 300 Hydraulic Lifting Device capable of lifting loads up to 300 kg (figure 3), but more will have to follow.

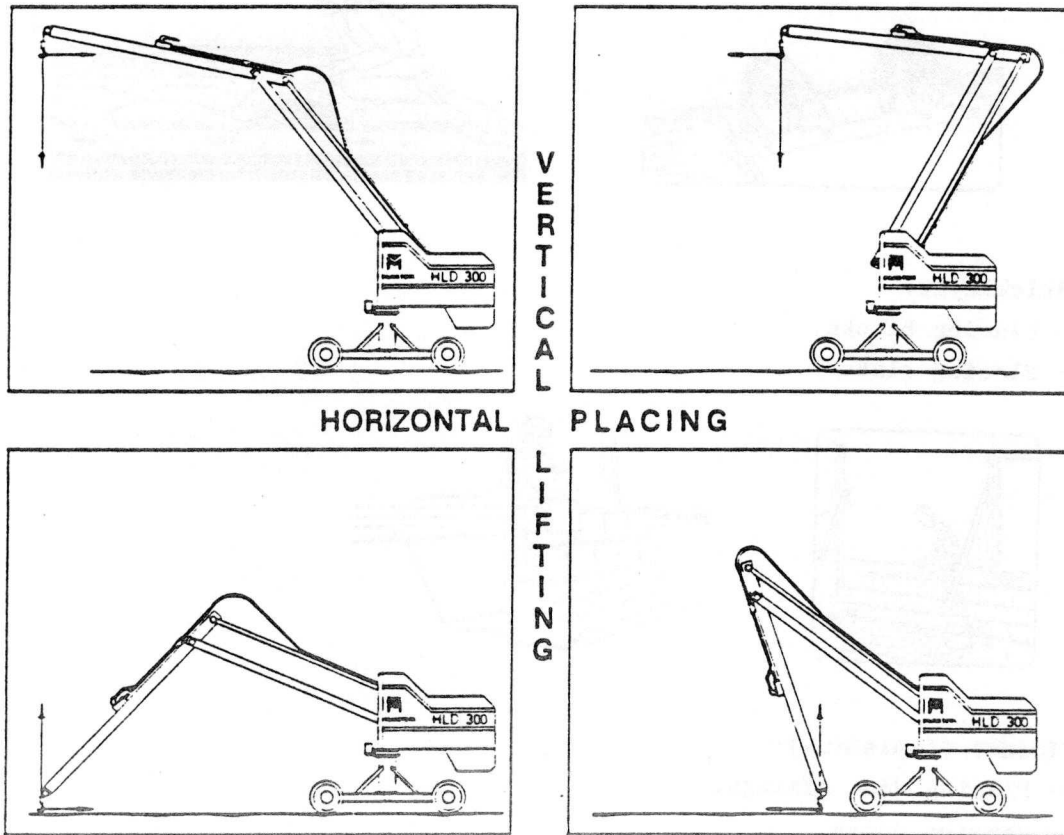


Figure 3.