Automation and Robotics in Construction XII
E.Budny, A.McCrea, K.Szymanski (Editors)



# TECHNOLOGICAL ASPECTS OF AUTOMATION AND ROBOTICS IN CONSTRUCTION

Juriy A. Villman

Doctor of Science, Professor at the Moscow State Civil Engineering University

**Abstract**

This paper discusses the theoretical concept and principles of the theory assessing the technological development of working tasks in construction. The relationship between the complexity of tasks, cost of manual labour, technological advancement of the equipment and other factors is studied and quantified. Using the Fisher-Pray models, the dependence is established and summing up conclusions are drawn.

## 1. INTRODUCTION

During recent years the Moscow State Civil Engineering University has been conducting the research into automation of several construction industry's tasks and processes. Especially two areas were under investigation: a manipulator for construction of reinforced concrete and brick buildings and excavating trenches of various width using automated excavator.

Since the increased level of sophistication in the mechanized equipment and mechanization and power availability per worker, in the civil and industrial installations the expected equivalent increase in productivity is not achieved and manual labour decreases because of the manual labour predominance in the working cycles of the mechanized processes. There is, however, a necessity in robotization of technological processes in construction, despite wide propagation of earthmoving, finishing and mounting machines in building production.

## 2. POTENTIAL FOR AUTOMATION IN EXCAVATION

The study of earthmoving and mounting operations used in finishing processes shows that the machines used in the corresponding types of work are not adapted technically to the arrangement of the structural units of buildings according to designed dimensions and specifications without manual labour of workers.

The most typical earth handling activities cover levelling up the ground surface to get rid of the ground unevenness, manual finishing according to landscape architects' design marks and the development of narrow trenches in the foundation excavations.

The above activities pose problems because the single bucket excavators due to the kinematics of working equipment provide the curved trajectory motion of working manipulator. This causes the bottom surface of foundations excavation to acquire the wavelike profile.

When working, the traditional buckets leave the groves from their teeth which break the intact condition of ground foundations and demand the further treatment.

Besides, due to the rigid unit size and structure of standard buckets with the width nearly 1 m, the width of the excavated trenches is increased twice in their design dimensions.

As a result labour and resource costs are increased to carry out the additional extent of work both in the process of excavating as well as in the following finishing activities.

Earthmoving machines do not carry out the excavations of trenches with the complicated configuration of design and a stepping of the bottom level because of number deficiencies in classification, prioritization and accuracy of the positioning of the working member.

## 3.POTENTIAL FOR AUTOMATION IN BUILDING

Installation of prefabricated reinforced structures assembled out of large panels involves attachment and detachment of units, orientation of elements in space, confinement, alignment, temporary fastening, position adjustment of horizontal joint seals, preparation of the following structure installation place, etc. These operations are carried out manually because the modern mounting cranes are not equipped in the controlled hoisting devices but only in the stationary hook casing fixed at the flexible ropes. Besides, the interaction between a crane and a building unit is carried out by a sling of a beam with hooks on the ropes of various length. In result the building unit is not oriented with respect to three linear and three angular coordinates of the mounting horizon.

Additionally, the use of crane devices with high speed of motion and large distance between a crane/drive and a place of unit installation leads often to the repeated closures of drives. It causes the rocking of the load and inaccurate installation bridging the limiting tolerances. The corrections of errors of unit delivery and installation positioned by cranes are carried out by the installers manually.

During finishing processes mainly by applying coatings made by so called "wet methods" which are extremely labour intensive type of surfaces treatment, the applying of finishing compounds and their complete development (rubbing after plastering or facing after painting, etc.) are carried out.

These operations carried out manually as the modern devices of so-called "small mechanization" are heavy, difficult to operate and demanding constant presence of additional operating staff.

The factors mentioned above influence greatly the process of labour costs forecasts in construction and characterize the factors of adaptability to manufacture despite the imperfection of the layout and arrangement as well as structural approach.

Level of mutual adaptation of building machinery and structural units to the process of construction of structures and buildings could, therefore, be greatly improved.

## 4. THEORETICAL APPROACH

To eliminate the influence of negative factors the following hypothesis has been set up: having investigated the technological processes and having explained the causes of labour input characteristics, having estimated the decisive factors and having studied and analyzed the performance of building tasks by simulating the functions of a human worker with sufficient level of adaptability to manufacture, accuracy of positioning and degree of mobility of the structural units of buildings should reach the design dimensions. Having applied positioning and working members with the given trajectories of motion and operating conditions using the technical means of the new created technology, the arrangement process of structural units of buildings will be more productive and less labour intensive.

According to the working hypothesis taken, the active six factors experiment has been conducted to find the mechanism of the stage by stage improvement of building processes, choice and feasibility study and the adequate mathematical model describing the dependence of output parameter from the varied input factors.

As an output parameter we take the indicator of improvement of building process technology (from mechanized technology to robotics). As the input factors of the system we take: the ratio of labour costs of work and productive costs of machine time in technical means such as the accuracy of positioning, etc.

Considering the possible variety of input parameters values outside the limits of + 1 to -1, as an optimal scheme of an experiment, the matrix of rotating scheme is taken.

The calculation was made by 1033 Computer in "MAKPL". For output parameter 8 forms of mathematical models were calculated: linear; inverted; exponential; polynomial of the first degree and the squares of factors; polynomial of the second degree; linear without free member; degree model, degree model without free member.

When calculating the screenings of unsubstantial factors according to the least value of the student, the test was taken place. The importance of equations was checked according to Fisher's [F] radio test. The final choice was made by the following aspects: coefficient of plural determination and correlation as well as mean error of approximation. The analysis of the mathematical models obtained showed that only two models describe the found mechanism of improvement of building process technology. The preference was given to the equation of polynomial of the 2nd degree according to the least value of mean error of approximation.

The equation obtained made it possible to compare the influence of various factors.

However, the comparison of factors having different units of measure is not sensible in this connection in the determination of the relative importance of each factor, the arranging values were calculated using the values of beta coefficients with computer calculations in NII "RUMB" programme.

The research conducted made it possible to bring out the basic principles of the theory - of technological development of work in construction (from low - mechanized work to automated one and robotics):

1. Technical advantage and economical efficiency of technology development in building production is defined by quantitative and qualitative relation of specific costs of manual labour and machine time of technical means affecting the material members when installing the structural units of buildings.

2. The mechanism of technology development of tasks in construction consists of decreasing the labour costs of workers taking part in technological process and of increasing the productive machine-time costs of technical means with the general decreasing of summed up labour costs and productive machine-time of technical equipment.

Besides, the rate of labour costs decrease is higher than the increase rate of machine-time productive costs of technical equipment.

3. The decrease of labour costs in technological processes is ensured by increasing the level of mutual adaptation of technical means and material components and the arrangement of structural components of buildings.

The level of such adaptation is defined by the minimum acceptable value of limiting deviation of material components from design conditions of structural components of buildings. The increase of the given parameter values is reached by the increase of level of adaptability to manufacture and a number of degrees of mobility of technical means as well as the decrease of the error of positioning.

4. The efficiency evaluation of working technology in construction is made by the least value of the integrated criterion value while the costs given are of small importance and labour input of manual works as well as productivity of technical means have the minimum and maximum specified value accordingly.

5. The efficiency analysis of variants of technologies with the minimum costs allocated depending on the value of manual labour costs and the productivity of technical means, is made by the mathematical expression of value labour costs and productivity represented in a differential form being an argument and the given costs being a function.

To define the meanings of parameters of the basic theoretical statements, the aligned graph is constructed (monograph).

The initial information of technical development of construction industry is taken as basis in the form of statistical rows transformed according to Fisher-Pray models and hyperbolic dependence [1].

The mathematical formulation of technology replacement models is taken according to assumption that the introduction rate of technological innovations in construction is proportional to the share of old technical means used.

The process of replacements leads to displacement of old technology by a new one (it is the main idea of Fisher-Pray model).

The proportion of a new technology increment (df/dt) to the absolute value (f) gives the comparative rate of the new technology extension.

$$df/dt * 1/f = (1 - f) \qquad (1)$$

The dependence reflecting the productive costs growth of machine time of technical equipment is expressed by logistic curve.

The logistic curve looks like an inclined symmetric reverse curve. The character of labour costs' change is expressed by hyperbolic curve.

The mechanisms revealed for construction industry are put into practice with the help of automation and robotics. For instance, the crane manipulator for construction of multi-storey buildings from precast reinforced elements is characterized by the following parameters.

Load - carrying capacity - 12 ....12,5 tones

Accuracy of positioning - E = 5 .... 10 mm

The position of the mounted building elements must be controlled and provided by all 6-dimensional coordinates - 3 linear and 3 rotational.

Executive unit of the manipulator must ensure the complete controlled space orientation and positioning within the given tolerances. In order to obtain this, the working member must carry out rigid catch of a building unit.

## 5.CONCLUSIONS

The high accuracy of positioning must be carried out at the expense of two-stages method of delivery and arrangement of units. At the first stage the unit mounted is replaced at high speeds from zone of its catch to the installation level with accuracy equivalent to the tenth of a meter.

At the second stage, with the help of additional orientating device, the unit mounted is oriented in space at low speeds and it is positioned with high accuracy required and installed in the design position.

The calculations showed the introduction of an innovative approach which offers the reduction in the number of manual workers as well as the reduction in the length of contract and improvement in the quality of work.

## REFERENCES

[1] D.Sahkal,'Technical progress: concepts, models, estimations'. Translation from English - M. Finance and Statistics, 1985 - 366 p.