Determining a numerical efficiency indicator for a mobile bricklaying robot

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Abstract. Evaluation of a technical solution in construction usually is based on technical and economic indicators. However, this approach does not always give a full assessment. It does not take into account a number of factors accompanying the process of capital construction. In particular, technical and economic indicators used for analysis of construction from blocks are based on regulatory documentation, namely, the cost and labor input per cubic meter of masonry. At the same time, the efficiency of labor is not taken into account. This article presents a model of numerical evaluation of the effectiveness of using a mobile bricklaying robot. This model takes into account a variety of factors and allows you to more accurately assess the applicability of such a robot for the construction of a specific object.

1. Introduction
Evaluation of technical and economic indicators (TEI) is an important stage designing during the construction process. It is used for determining the cost of construction and installation works, as well as the final cost of the capital construction project for consumers [1,2].

Modern building standards use the two basic indicators as TEI, the costs and the complexity of the implementation per a single unit of production [3]. In turn, the costs include the wages of workers, the cost of using the construction machinery, mechanisms and materials. The complexity is affected by the speed of the process and the number of workers involved in it.

So, there are two main options for the organization of construction and installation process with the specified TEI:

1) reducing costs while increasing construction time. In this case a smaller number of workers and equipment are usually involved into construction for a longer period of time;

2) increasing costs while reducing construction time. In this case a large number of workers and equipment are usually involved into construction for a shorter time.

In some cases, the use of only normative indicators can lead to an incorrect feasibility study. For example, savings on wages with fewer workers can be leveled by long and thus expensive rental of construction equipment. In turn, a large number of workers may not ensure the growth of labor productivity due to technological features of construction or poor labor organization. Thus, it is necessary to create improved methods of evaluation effectiveness of construction and introduce some
new criteria for it. Such criteria should allow more fully describe the efficiency of the process, in particular, allow evaluating the joint change of costs and laboriousness.

2. The rationale for the efficiency indicator

The article [4] presents the rationale of efficiency of a mobile bricklaying robot from the point of view of the organization, productivity and economics of construction. However, an accurate assessment requires introducing an improved criteria that would numerically describe the robot’s efficiency.

The article [5] introduces a new model for assessing the efficiency of a mobile bricklaying robot. The model is based on the comparison of volume of bearing walls with the total walls volume in a building. The introduced coefficient is calculated with the equation:

\[ K_{\text{EF}} = \frac{V_{\text{BW}}}{V} \]  

(1)

where \( K_{\text{EF}} \) is a coefficient of efficiency of using a mobile bricklaying robot; \( V_{\text{BW}} \) is the brickwork volume for bearing walls; \( V \) is the total brickwork volume in a building.

The presented dependence is based on economic indicators of the construction from blocks according to [3]. It was shown that using a mobile bricklaying robot for building bearing walls reduces its cost 4 times comparing to manual labor [4]. With that, the cost of making partitions is the same for both cases, manual and robotic work. That is the reason why this parameter is not taken into account in the equation (1). However, this model should be improved, since it does not take into account other factors affecting the production efficiency. These factors include:

- the presence of openings (windows, doors);
- the type of masonry (multirow, hollow, etc.);
- the presence of other structural elements (overlaps, lintels, etc.).

Each of these factors is considered in more details below.

1. The influence of the total volume of door and window openings can be estimated by its ratio to the total volume of bearing walls. So, the final volume of bearing walls is:

\[ V_{\text{BW}} = V_{\text{BWT}} - V_{\text{OP}} \]  

(2)

where \( V_{\text{BW}} \) is the brickwork volume for bearing walls without openings; \( V_{\text{BWT}} \) is the total volume of bearing walls; \( V_{\text{OP}} \) is openings volume.

2. Operation of a mobile bricklaying robot is based on a masonry plan of the object being constructed. As result, masonry type does not affect the operation of the robot, namely the speed of laying bricks. Thus, the initial estimation of the robot efficiency at a certain object requires taking into account this parameter. For these purposes, it can be taken into account with a coefficient \( K_{T} \). Such coefficients for different masonry types are shown in the table 1. The values are assigned based on the number of blocks per a single unit of volume [6].

**Table1. Values of the coefficient describing the type of masonry.**

| Masonry type                  | Value of \( K_{T} \) |
|------------------------------|----------------------|
| Multirow homogeneous         | 0.6...1              |
| Multirow heterogeneous       | 0.6...1              |
| Hollow                       | 0.7...1              |

3. If precast overlaps and lintels are used, they almost do not affect the bricklaying speed of the mobile bricklaying robot. However, if they are made of monolithic reinforced concrete at the construction site, then additional time is required for the construction to set the minimum permissible strength. Only after that the robot will be able to continue its work on the corresponding masonry area
[7, 8]. This is significantly longer than the time required for laying one row of blocks. Since the mobile bricklaying robot uses layer-by-layer technology for laying bricks, it leads to forced downtimes. Forced downtimes reduce the economic efficiency of the robot. In cases where precast overlaps and lintels are not used, the coefficient $K_{DT}$ can be used to estimate the influence of this factor. Its value is 1 when precast overlaps and lintels are used, and 0.7...0.8 when they are made of monolithic reinforced concrete, depending on parameters of used concrete.

Thus, taking into account the equation (2) and the coefficients $K_T$ and $K_{DT}$, the equation (1) can be written:

$$K_{EF} = \left[ \frac{(V_{wT}-V_{op})}{V} \right] \cdot K_T \cdot K_{DT}$$

It should be noted that the equation (3) does not take into account installation of insulation and reinforcing mesh, because operations can be performed in parallel with the operation of the robot.

3. **An example of calculation and interpretation of result**

An example of calculation based on the described equations for a single typical floor of a multi-storey living building is shown below. The plan of the floor is shown in the figure1.

The parameters of the object are:

- outside walls thickness is 690 mm (external wall of 250 mm, insulation layer of 60 mm and internal wall of 380 mm);
- inside walls thickness is 380 and 510 mm;
- floor height is 2.5 m;
- total volume of walls is 234,3 m$^3$ (outside walls – 160 m$^3$, inside walls – 74,3 m$^3$);
- total volume of opening is 29,7 m$^3$ (in outside walls – 25,7 m$^3$, in inside walls – 4m$^3$);
- masonry type of outside walls is hollow, $K_T$ is 1;
- masonry type of inside walls is multirow, $K_T$ is 0.8;
- precast overlaps and lintels, $K_{DT}$ is 1.

![Figure 1. Plan of a typical floor of a multi-storey living building.](image-url)
Substituting the initial data in equation (3), we calculate the efficiency of using the robot when building the object:

\[ K_{EF} = \left[ \frac{(234,3 - 29,7)}{234,3} \right] \cdot 0,8 \cdot 1 \cdot 1 = 0,7 \]

Thus, the efficiency of using the mobile bricklaying robot in the given conditions is 70%.

Choosing a certain value of each coefficient in equation (3) from the ranges mentioned in the table 1 depends on complicity of brickwork of a certain type in each case. Such assessment is given by a specialist subjectively depending on experience of bricklaying using manual labor and automatic means.

Regarding to interpretation of calculated values of \( K_{EF} \), there are different approaches to estimation of performance of construction equipment [9]. The developed method gives a relative assessment that compares efficiency of applying the bricklaying robot with cases, where its efficiency is maximal. The maximal efficiency can be reached with thick full-body bricks without openings. So, calculation of \( K_{EF} \) will be useful for making decisions about using a mobile bricklaying robot at a certain object after obtaining enough statistic data about its operation. Analysis of such data will allow determine limits that divide economically justified and unjustified use if mobile bricklaying robots depending on parameters of objects.

4. Conclusion
The presented methodology for calculating the numerical indicator of the efficiency of the mobile bricklaying robot allows implementing adequate assessment of construction production along with technical and economic indicators. However, improving the robot, in particular improving its operation algorithms, may require including additional indicators for estimating its efficiency.

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