Methodical Approach to Calculation of the Maintenance Cost for 3D Built Printing Equipment

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Abstract. The issues related to the feasibility study of the effectiveness of the use of 3D printing technology in residential construction are considered. The criteria for efficiency are indicated such as minimum human labor and minimum direct costs per m² of the total area of a residential facility. It is noted that direct costs include the cost of materials, human labor, the operation of machinery. In the process of calculating performance indicators, the greatest difficulty arises with determining the cost of 3D printer, the value of which depends on the annual fund of the printer operation time, its performance and the cost of operation machine-hour. The cost of a machine-hour contains the cost of depreciation, human labor costs, the replacement of high-wear parts and units of machines, for energy, maintenance, relocation and installation of machines on the construction site. For each of the indicated cost elements, methodical approaches are proposed and corresponding calculation schemes are presented. From the data obtained as a calculation result, it follows that to the greatest extent, the cost of operating machines per m³ of concrete mix, depends on the printer’s performance, and in the cost structure of a machine-hour the depreciation costs comprise the maximum share determined as a percentage of the cost of the unit. In this regard, as one of the strategic directions of expanding the use of 3D-additive construction technologies, the cost reduction of modern printers is indicated.

1. Introduction
In the near future, 3D printing technology can change the architectural paradigm and well-established ideas about the construction industry. It opens up broad prospects for reducing the time, complexity and cost of construction and, in addition, to impart individuality in space-planning and architectural solutions for various facilities [1, 2].

Today, three main areas of application of 3D-additive building technologies are considered:

1) housing;
2) special construction (hangars, pavilions, tunnels, reservoirs, pools, etc.);
3) the creation of objects of functional and decorative purposes.

At the same time, the widespread introduction of 3D printing into construction practice is hampered by a number of circumstances, the list of which should include the lack of qualified personnel with experience in working with robotized complexes, advanced logistics, ensuring the continuity of the construction process, the regulatory framework, and the high cost of printers and printed "mixes, lack of awareness of potential consumers of the real estate market about the possibilities of 3D-building technologies in the creation of individual residential facilities [3-13].
The use of 3D printing technology in a given field of construction will require justification of its effectiveness with regard to the specifics and location of the object, the availability of local raw materials and other parameters [2]. In this regard, the relevance of developing appropriate methodological approaches and techniques for determining the measure of the effectiveness of using 3D printing, especially in the fairly rapidly developing area of housing construction, is increasing.

2. Methods
As criteria for the effectiveness of 3D printing in residential construction, it is proposed to use a minimum of labor intensity and a minimum of direct costs, including material costs, workers remuneration, and machine operation, per m² of the total area of a residential facility. However, in the process of criterion assessment, certain problems arise due to the lack of effective operation of machinery and equipment (OME) standards for 3D construction technology.

The solution to this problem, in our opinion, will be facilitated by the following methodological approaches to calculating the cost of operating machines and mechanisms for a 3D printer.

As known, the magnitude of the cost of OMM depends on the following factors of the first order:
1) annual working time fund (F);
2) the cost of a machine-hour operation (C_{om})
3) performance (P).

Regarding the first factor, it should be noted that in the calculations it is more correct to use the effective (maximum possible) annual fund of working time of machines (F_{ef}), which is the difference between the number of calendar days and the number of non-working days per year, expressed in hours. In turn, holidays and weekends, time for relocation of machines from one construction object to another, duration of downtime due to meteorological conditions and unforeseen causes (force majeure), as well as time for maintenance and repair of machines are taken as a non-working period.

For construction using 3D printing as a non-working one, the duration of the winter period should also be taken, since the features of the application of this technology at negative temperatures at the present stage remain poorly understood and unexplored.

The duration of the winter period should be determined taking into account the construction zone and recommendations of the current methodology for estimating additional costs in the production of construction, installation and repair and construction works in winter, approved by the Ministry of Construction and Housing and Communal Services of the Russian Federation. The number of holidays and weekends can be identified by the production calendar of the corresponding year of calculation. And for all the remaining periods of downtime for the stated reasons, it is proposed to take into account using a single coefficient of use of the nominal running time of the machines (k_{run}), the value of which is generally determined by the mode of operation and the type of equipment.

Taking into account the fact that one of the requirements for the organization of production using 3D-additive construction technologies is to ensure the continuity of the "printing" process of a building, and in the absence of the possibility of conducting work without interruptions - reducing their duration to a minimum, to carry out calculations on the cost of operating machines and mechanisms, the k_{run} can be adopted in the range of 0.85 ÷ 0.92, which corresponds to units operating on a discontinuous schedule of work (in 2 shifts), but with a high degree of load during the shift. Thus, the effective annual working time for a 3D printer is calculated according to

\[ F_{ef} = (N - n_{wp} - n_{wh}) \cdot s \cdot T_{sh} \cdot k_{run} \]  

where
- \( N \) – number of calendar days per year;
- \( n_{wp} \) – the duration of the winter period, days;
- \( n_{wh} \) – the number of weekends and holidays per year during the summer period, days;
- \( s \) – the number of weekends and holidays per year during the summer period, days;
- \( T_{sh} \) – duration of one shift, hr;
- \( K_{run} \) – utilization rate of the nominal running time of a 3D printer.

Regarding the cost factor of a machine-hour of printer operation, it should be indicated that in general terms and in accordance with the current methodology for determining the estimated prices for the
operation of machines and mechanisms (annex to the Ministry of Construction and Housing and Communal Services of the Russian Federation from 20 December 2016 N 999 / pr) it is calculated on the basis of the value of depreciation deductions \((C_d)\), as well as the cost of labor of the workers controlling the machines \((C_{c,lb})\), the replacement of wearing parts and components \((C_{rp})\), on energy \((C_e)\), technical service (washing machine and controlling the technical condition of its mechanisms and instruments, checking and fixing units, adjustment mechanisms, lubrication of working elements and refueling) \((C_{as})\), relocation and installation of machinery on site \((C_{rc})\):

\[
C_{om} = C_d + C_{c,lb} + C_{rp} + C_e + C_{as} + C_{rc}
\] (2)

Determining the values of the terms included in formula (2) requires appropriate explanations. It should be noted that calculations are carried out taking into account the value of the effective annual fund of working time.

Thus, the assessment of depreciation is carried out on the basis of data on the cost of a 3D printer \((A_{3D})\) and the depreciation rate \((R_d)\):

\[
C_d = \frac{A_{3D} \cdot R_d}{F_{ef} \cdot 100}
\] (3)

Prices for printers of various types are available on the websites of manufacturing organizations, and the depreciation rate, taking into account the main consumer property of a 3D printer - laying concrete mixes, can be adopted based on the method of comparative analogies the same as for “machines for preparing and supplying hard solutions” in 16.7%. This, in our opinion, is quite reasonable, since the functional purpose of 3D printers, and, to a certain extent, their appearance, are quite similar, for example, with concrete spreaders of various designs used in the manufacture of concrete products (see Error! Reference source not found.,2).

![Figure 1](image1.png)  
**Figure 1.** Construction 3D-printers: a – boom arm; b - as a bridge crane.

![Figure 2](image2.png)  
**Figure 2.** Concrete distributors used in the production of precast concrete products.
Wage costs for workers managing a 3D printer should be based on the average hourly wages of workers in construction.

\[ C_{ch} = n \cdot W_{wk} \]  
(4)

where \( n \) – the number of workers managing a 3D printer, persons;
\( W_{wk} \) – average hourly wages of workers in construction, rubles per hour;

The cost of replacing worn parts and components of the printer in accordance with the current method of calculating the value of working capital can be determined at a rate of 4% of the cost of this equipment.

The cost of energy for a 3D printer depends mainly on the amount of electricity it consumes and the current tariff. Then, the magnitude of the cost of electricity for 1 hour will be

\[ C_e = 1.1 \cdot P \cdot T_{el} \cdot K_{pf} \]  
(5)

where 1.1 – coefficient taking into account the starting torque of the printer motor;
\( P \) – power consumption of a 3D printer, kW;
\( T_{el} \) – electricity tariff, r / kW ∙ hr;
\( K_{pf} \) – power factor of the electric motor (0.8 ÷ 0.85).

The norms of the annual costs of all types of repair, maintenance and diagnostics of a 3D printer can be taken, in our opinion, as for stationary machines with electric drive (concrete and mortar mixers, plastering stations, etc.) for the Far North regions - 11%, for all other territories - 8.3% of the cost of the printer (annex to the Ministry of Construction and Housing and Communal Services of the Russian Federation from 20 December 2016 N 999 / pr).

The cost of relocating a 3D printer from one construction site to another can also be calculated as a percentage of the cost of the printer. It should be borne in mind that the 3D printer is transported on the bench with disassembly and subsequent installation at the construction site and carrying out the necessary commissioning works. In addition, loading onto a trailer is carried out using a crane of the appropriate size group. As a result of the analysis and, based on existing recommendations and rules for the development and application of prices for the operation of construction machines, designed for practical guidance in setting contract prices, as well as budgeting for contract trading («Recommendations for determining the cost of operating hours for construction machines and mechanisms»), the cost of relocating a 3D printer can be taken depending on its price in the following percentage: for printers worth 2 mln r. - 6%, 5 mln.r - 3.1%, 10 mln.r - 2.7%, 15 mln.r - 2.4%, 20 mln.r - 2%, 30 mln.r and more - 1.6%. After estimating the cost of a machine-hour operation of a 3D printer in accordance with FIR 81-02-06-2001 “Concrete and reinforced concrete structures monolithic”, the obtained value should be recalculated for 1 m³ of concrete mix, which will require the use of the third factor previously indicated - printer performance (P):

\[ C_{omm} = \frac{C_{con}}{P} \]  
(6)

where \( C_{omm} \) – the cost of operating a 3D printer, p. / m³;
\( P \) - 3D printer performance, m³ / hr.

3. Results and discussions
The described methodological approaches were used in determining the cost of the OME for various domestic building 3D-printers produced by Russian company <<AMT-SPECAVIA>>. The results of the calculations are presented in the table.

From the data obtained, it follows that the costs associated with the operation of machines and mechanisms per m³ of the concrete mix to a large extent depend on the printer’s performance, and in the cost structure of a machine-hour, the maximum share is the depreciation of the unit. Together with the maintenance costs, the share of this element of the cost of the OME, calculated from the price of the considered types of printers, is in the range of 40% to 70%.
Table 1. The cost of operating machinery for various domestic 3D construction printers.

| The printer types                        | Purpose                                         | Technical specifications                                                                 | The cost of mach.-hr, р. | OME costs, р./м³ |
|------------------------------------------|-------------------------------------------------|------------------------------------------------------------------------------------------|--------------------------|-----------------|
| Portal construction 3D printer AMT S-1160| PortPrint of one-storey buildings, on one-storey buildings on a foundation, up to 140 m² of building construction AMT S-1160 3D printer | Productivity is 0.6 m³/hr; working area 11.5 × 11.6 × 27 m; power consumption 7.5 kW; weight 1880 kg | 885.84                   | 1476.4          |
| Portal construction 3D - medium format printer AMT S-6044 LONG 2 | Printing one-storey buildings on a foundation of up to 55 m² | Productivity is 0.6 m³/hr; working area 7.5 × 7.4 × 2.7 m; power consumption 1.6 kW; weight 1520 kg | 737.47                   | 1229.1          |
| Portal Construction 3D Large Format Printer series AMT S-300 | Printing of elements of buildings, 1-2 storey buildings with height up to 6 m on the foundation to 120 m² | Performance 2.5 m³/hr; working area 11.5 × 11.0 × 6.0 m; power consumption 12 kW; weight 3800 kg | 1513.47                  | 605.4           |
| Portal Construction 3D Large Format Printer series AMT S-500 | Printing of buildings and constructions of height up to 80 m on the foundation to 340 m² | Performance 2.5 m³/hr; max working area 31.0 × 11.0 × 80.0 m; power consumption 27 kW; weight 5600 kg | 2147.14                  | 858.0           |

4. Conclusions
The proposed approaches to estimating the cost of operating machines and mechanisms for 3D printers provide a feasibility study of the feasibility and effectiveness of using 3D additive technologies in building the necessary methodological base. In the process of the study, it was additionally possible to establish that the cost of OME printers is more dependent on their cost and performance. Thus, one of the strategic directions for expanding the use of 3D printing in construction should be to reduce the cost of modern printers, both domestic and foreign.

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