Organization of recycling of construction scrap with the use of mobile crushing plants in Russia

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Abstract. The issues of recycling construction scrap during the demolition of buildings, taking into account the specifics of the work on the demolition of buildings in Russia. The feasibility of the formation of "distribution cards" demolished buildings with an indication of the type and predicted amount of construction scrap. A typical extended set of construction and road machines has been proposed, which should be used when using mobile crushers. Suggestions are given on the mechanism for forming a set of machines according to the criterion of specific reduced costs. The calculated dependencies are given. It indicates which machines should be considered when choosing a kit, and which machines can be excluded from the analysis.

1. Introduction
Recycling issues are becoming more and more relevant given the complex economic and environmental approaches in the production of building materials. In many countries, the possibility of multiple use of resources in the chain of the life cycle is considered not as a lucky coincidence of circumstances, but as an obligatory requirement for organizations involved in the liquidation of previous facilities. Thus, in Russia, the Federal Law “On Production and Consumption Wastes” (clause 8 of Article 12) established [1]: “The dumping of waste, which includes useful components to be disposed of, is prohibited.” Given this, some large construction companies do not they simply talk about the possibility of such work, but highlight this problem as a priority and position it as a separate type of their activity.

The issue of multiple processing of materials is particularly relevant for regions in which large-scale work is underway to reconstruct existing facilities, demolish other buildings and structures planned for recycling and construction in their place. It is in such places that it is possible to use construction scrap (or, as it is sometimes incorrectly called “construction waste”, which is not the same thing) for its subsequent use as a filler for building materials in the future.

World practice shows that such questions are analyzed most actively in regions with active construction activities at the site of demolished old buildings. This is especially important for regions with dense buildings, among which are both European [2] and Asian countries [3], including those in the zone of possible ecological disasters of natural genesis [4].

Despite the fact that demolishing of civil buildings is extensively conducted in large Russian cities and has been described for a long time [5], almost no one solves the issues of assessing the life cycle of buildings and city blocks compared to demolition and renovation with repairs, as is customary in world
practice [6]. Also, the issues of reducing mixed construction waste during demolition of buildings are not widely analyzed, which is relevant for dense building conditions [7].

A separate important problem is the fact that it is Russian modern scientific research that is necessary for the full implementation of the construction waste recycling scheme. This applies to the study of the bearing properties of composite masonry, built from waste secondary destruction of buildings, as well as the actual development of building materials from construction and demolition waste. Foreign work in this area [8, 9, 10] can only be used as a technique. It is impossible to use them fully due to the fact that buildings and structures demolished in Russian megalopolises have a different character and composition of construction scrap from those studied in the above-described works.

It should also be noted that some related issues [11] are not dealt with at all in Russia. There is no production of secondary reinforcing iron. Energy and carbon emissions during the processing of construction scrap and secondary products are not assessed.

Also, the specifics of using mobile crushers is a wide range of climatic temperatures, which has a greater impact on mobile equipment in comparison with stationary ones. This is due to the high level of hydridification of mobile equipment drives. This causes a change in the performance of technology in the transition from summer to winter temperatures.

Despite the above, today the situation is changing for the better, but the pace seems to be not high enough. But at the same time, it is impossible not to regret that the technology of crushing of construction scrap and the secondary production of materials directly at the construction site is not widely used. This is largely due to the fact that over the past years construction waste in Russia was simply dumped to landfills for disposal, despite the fact that this had a significant negative effect on the environment. The issues of preserving the territories used for landfills also seemed insignificant.

Today in the Russian market there are several manufacturers of crushing equipment in the mobile version. The most well-known suppliers in the Russian market are Rubble master, Resta, Sandvik. Also in our market there is a manufacturer “Drobmash”, among whose products there are self-propelled crushing and screening machines, which are popular both in the Russian and foreign markets. At the same time, there is practically no scientific work on crushers of various degrees of mobility in Russia. And the analysis of their application is taken mostly from foreign literature [12, 13]. There are no books similar to [14] in Russian practice.

Also a significant deterrent is the fact that the practice of using sets of machines for this type of work is not accumulated, and there is also no clear understanding, in particular, expressed in the evaluation criteria, of when it is expedient to use stationary crushing equipment, both factory-made and mounted at the construction site, and when self-propelled crushing plants.

In this regard, we have begun work on the creation of sets of machines, as well as groups of criteria for the selection of such sets, which could be used in the demolition of buildings and structures of various sizes in terms of the volume of construction scrap formed during demolition.

2. Materials and methods
The solution of the task can be carried out in different ways, but in our opinion the solution is promising by drawing up a “distribution map” (area) of potential demolished (dismantled) objects. At the same time, it is necessary to classify buildings and structures by the type of material and the volume of construction scrap. It is also advisable to work out two possible "distribution cards":
- complete «distribution map» containing all objects potentially demolished in the near future;
- «distribution map2 of objects, the demolition of which is possible only with the formation of construction scrap.

The analogue of maps of the first type can be built on the basis of existing maps for large cities, which contain information about both demolished objects and those that are subject to reconstruction and restoration.
Maps oriented to the demolition of buildings are also being worked out by various organizations on the basis of various mapping software (Figure 1) [15] and can be used as a basis for development.

The second type map will allow to exclude buildings and structures whose demolition is possible with the help of lifting equipment without forming construction scrap (mainly such objects include dwellings of panel structures), which will allow optimizing the solution of logistic tasks when moving mobile crushing complexes. Analogues of the second type of cards currently do not exist, but for their basis you can also use the maps and software products described above, filling the information base of the escort with data on the nature of buildings and buildings, the type and predicted volume of waste generated during the demolition of a building.

The resulting "distribution map" allows us to predict the feasibility of using mobile crushing plants, the rational use of which is limited by a number of factors, including: the presence of stationary crushers near the demolished objects, the volume of work performed and the coordination of the performance of the mobile crushing complex with both the scope of work and performance set of machines that provide the demolition of the object. The latter will significantly improve the efficiency of the aggregate set of machines, by reducing downtime or crushing complex, or machines for demolition.

Previously, the scheme of forming a set of machines for processing construction scrap generated during the demolition of a building can be determined by technological operations with the chosen method of work production (Figure 2). At the same time, with an economically based application of a mobile crusher, the sequence of operations "demolition - preliminary crushing - final crushing - delivery to the consumer" turns out to be shorter by one operation compared to the crushing process at a stationary installation.

It is obvious that this efficiency will be realized only in the conditions of the demolition of several buildings localized in proximity to each other. At the same time, in case the transportation of the received crushed stone will be carried out for a short distance, then it will be expedient not even automobile transportation, but conveyor transport. This is confirmed by data obtained in related industries in the extraction of ore materials by the open method [16] when analyzing the transportation of different volumes of the product to different distances (Figure 3).

For the economically feasible formation of a set of machines used in the processing of construction scrap during the demolition of a building, methods were used to form optimal sets of machines based
on a single-bucket excavator [17]. Despite the fact that the processing of construction scrap is conducted by a mobile crushing plant, it is the excavator that is the “supporting” machine of sets of machines of different composition, using various specialized equipment.

The economic substantiation of the set of machines was carried out according to the criterion of the specific reduced costs of $Y_{CP}$, which are calculated as the ratio of the total costs $C_S$ to the performance of the set of machines $P_{set}$. The productivity of a set of machines was understood as work on the production of the final product, for example, secondary rubble.

![Image of construction site](image)

**Figure 2.** Comparison of technologies for processing construction scrap during the demolition of the building.

![Graphs showing cost comparison](image)

**Figure 3.** The cost of transporting products at a distance of 1.0 km (a) and 5.0 km (b) [16].

3. **Research results**

From Figure 3 it is clearly seen that increasing the transportation distance significantly reduces the efficiency of using the conveyor already at the initial stage. The economic effect with a transportation distance of 5.0 km is manifested in long-term use. However, at a distance of 1.0 km the effect can be traced from the initial stage.

Given that the demolition of the building and the use of recycled rubble are rarely in substantial proximity, the conveyor delivery of the finished product to the place of use can be recommended in a limited number of cases. Thus, with the exception of special situations, the main method of transportation will be the use of dump trucks.
Formed sets of machines for operations for schemes with stationary (located at the processing plant) and mobile (located at the construction site) crushers.

Typical equipment presented in the table.
Table 1. The distribution of sets of machines on operations.

| Operations                                                                 | Sets of machines                          | Set 1 | Set 2 |
|---------------------------------------------------------------------------|-------------------------------------------|-------|-------|
| Building demolition equipment                                             | Excavator with multi-processors (primary   |       | +     |
|                                                                          |   pulverizers)                            |       |       |
| Equipment for the primary crushing of construction scrap for the crusher  | Excavator with pulverizers (secondary      |       | +     |
|                                                                          |   pulverizers)                            |       |       |
|                                                                          |   Excavators with hammers                 |       |       |
| Equipment for loading crushed construction scrap into a dump truck        |                                           | +     |       |
| Equipment for loading ground construction scrap into a mobile crusher      |                                           |       | +     |
| Equipment for the delivery of construction scrap to the crusher           | Dump trucks                               |       | +     |
| Equipment for the final crushing of construction scrap                     | Stationary crusher                        | +     |       |
| Equipment for loading the final product in the dump truck                 | Mobile crusher                            |       | +     |
| Equipment for the delivery of the final product to the consumer           | Loaders                                   |       | +     |
| Equipment for the delivery of equipment to the construction site          | Excavator Loaders                         |       | +     |
|                                                                          | Dump trucks                               |       | +     |
|                                                                          | Trailers                                  |       | +     |
|                                                                          | Trucks                                    |       | +     |

Set 1 – a set of machines with a stationary crusher (located at a processing plant)
Set 2 – a set of machines with a mobile crusher (located at the construction site)

As noted above, the economic rationale for a set of machines was conducted according to the criterion of the specific reduced costs $Y_{CP}$. In general, this value can be determined by the formula:

$$Y_{CP}= (\sum n_{Cr} C_{Cr} + \sum n_{H} C_{H} + \sum n_{E} C_{E} + \sum n_{TP} C_{TP} + \sum n_{C} C_{C} + \sum n_{M} C_{M} + \sum n_{A} C_{A})/P_{Set}$$

(1)

$n_{Cr}$ and $C_{Cr}$ – the number of excavators with multi-processors (primary breakers) and reduced costs for their work;

$n_{H}$ and $C_{H}$ – number of excavators with hammers and with pulverizers (secondary pulverizers) and reduced costs for their work;

$n_{E}$ and $C_{E}$ – number of bucket excavators and reduced costs for their work;

$n_{TP}$ and $C_{TP}$ – number of dump trucks transporting construction scrap to the stationary crusher (primary dump trucks) and reduced costs for their work;

$n_{C}$ and $C_{C}$ – number of crushers and reduced costs for their work;

$n_{L}$ and $C_{L}$ – number of loaders and reduced costs for their work;

$n_{TS}$ and $C_{TS}$ – number of dump trucks transporting the final product to the consumer (secondary dump trucks) and reduced costs for their work;

$n_{S}$ and $C_{S}$ – number of machines that provide delivery of equipment to the construction site, and the costs of their work;

$n_{M}$ and $C_{M}$ – number of auxiliary workers and reduced costs for their work;

$n_{A}$ and $C_{A}$ – amount of auxiliary equipment and reduced costs for its work.

Auxiliary workers and equipment include personnel and equipment, the involvement of which in the technological process may be required taking into account the specific situation. In this case, any equipment that does not fit into the standard equipment (see table) can be used: lifting, mounting equipment, power tools, etc.

The analysis of the technology of work shows that part of the machinery and equipment performs the scope of work unrelated to the method of crushing of construction scrap (equipment for demolishing...
a building and; equipment for primary crushing of construction scrap for a crusher). Such machines can be excluded from the analysis of the effectiveness of the kit. At the same time, excluding operations that are similar in essence (equipment for loading the final product into a dump truck, equipment for delivering the final product to the consumer, etc.) should not be excluded because these operations will differ in cost, since such parameters as: transportation, the structure of access roads and, perhaps, even the model of the equipment used. Equipment for the delivery of equipment to the construction site can be partially excluded, since the delivery of tracked excavators will be present in both schemes of work, and the delivery of a mobile crushing plant - only in the second.

Considering the above, formula (1) will be converted for set 1:

\[ Y_{CP1} = \frac{(\Sigma n_{E1} \cdot C_{E1} + \Sigma n_{TP} \cdot C_{TP} + \Sigma n_{CS} \cdot C_{CS} + \Sigma n_{L1} \cdot C_{L1} + \Sigma n_{TS1} \cdot C_{TS1} + \Sigma n_{M1} \cdot C_{M1} + \Sigma n_{A1} \cdot C_{A1})}{P_{Set1}} \] (2)

for set 2:

\[ Y_{CP2} = \frac{(\Sigma n_{E2} \cdot C_{E2} + \Sigma n_{CM} \cdot C_{CM} + \Sigma n_{L2} \cdot C_{L2} + \Sigma n_{TS2} \cdot C_{TS2} + \Sigma n_{SC} \cdot C_{SC} + \Sigma n_{M2} \cdot C_{M2} + \Sigma n_{A2} \cdot C_{A2})}{P_{Set2}} \] (3)

\[ n_{CS} \text{ and } C_{CS} - \text{number of stationary crushers and reduced costs for their work}; \]
\[ n_{CM} \text{ and } C_{CM} - \text{number of mobile crushers and reduced costs for their work}; \]
\[ 0.6C_{SC} \text{ and } C_{SC} - \text{number of machines ensuring the delivery of mobile crushers to the construction site, and the reduced costs of their work.} \]

In the case of the use of mobile screens at the construction site in order to divide the resulting crushed stone into fractions, the list of used machines should be expanded. In this case, in addition to taking into account the screeners themselves, it is necessary to take into account the method of their delivery to the construction site. This can be either an additional trailer or a trailer delivering a mobile crusher. During the calculations, this value can be taken into account as part of the crushing equipment or as ancillary equipment.

4. Conclusions:

1. The creation of “distribution maps” of demolished buildings with an indication of the type and predicted volume of construction scrap is effective for megacities.

2. Construction plans for buildings, roads, and other facilities should be consistent with the building demolition plan in order to minimize costs by using construction scrap directly from the dismantling facility without interim storage.

3. In the context of a comprehensive demolition plan for housing concentrated in one area, followed by building up the released areas, it is advisable to organize the production of secondary crushed stone and its subsequent use directly close to the demolished objects using mobile crushers.

4. In terms of the dismantling of a stand-alone building, the feasibility of using a mobile crusher should be confirmed by the economic justification in comparison with the classical scheme.

5. In the conditions of transportation of recycled rubble to the place of its further use at distances up to 1.0 km, it is advisable to use a conveyor. The efficiency of the conveyor will be the higher, the smaller the distance, and the greater the volume of the transported material.

6. Calculation of the economic efficiency of the use of a set of machines should be carried out without taking into account the cost of using machines that perform work unrelated directly to the method of crushing of construction scrap.

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