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Modeling Volumetric Block Types in Residential Building Construction

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Abstract: The article focuses on the erection of residential buildings from large-sized volumetric blocks as a modern and progressive trend in housing construction. It is noted that one of the major tasks in the development of this promising area of construction is to justify the choice of type of volumetric blocks. The authors propose a method of type formation that, depending on the set objective, can either be composed of large-sized volumetric blocks only, or include combinations of large-sized and smaller-sized blocks. The article details the steps and procedure of modeling the type of volumetric blocks, which comprises three stages. At the first stage, the parameters of boundary blocks are determined, and then, by changing these parameters step by step, the parameters of blocks between the boundary blocks are set. The second stage involves developing options for the placement of blocks in accordance with the space and layout design solutions employed in the residential buildings to be erected. At the third stage, blocks are selected, and their actual type is approved. The stages of modeling of the volumetric blocks type are illustrated by practical examples, tables, and figures.

Keywords: volumetric blocks; large-sized blocks; volumetric block type; space and layout design solutions; modeling block types; heavy-load installation cranes; residential building

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1. Introduction

The first residential buildings made of three-dimensional blocks began to be erected in the second half of the twentieth century (Figure 1). Factory-made blocks, as a rule, were designed to accommodate one with at least two rooms. Such reinforced concrete blocks had dimensions in plan from 2.4 × 4.8 m to 3.6 × 6.0 m, and their weight varied between 6 and 10 tons. Since 1961, the mass introduction of residential five-storey buildings made of three-dimensional blocks has begun in Krasnodar, Minsk, Perm, etc. Therefore, in Krasnodar, blocks consisting of three walls and a bottom were used, and in the Minsk version, blocks of four walls were used, but without a bottom. At the same time, in Perm, volumetric-reinforced concrete blocks were divided into residential, sanitary, kitchen, and staircase blocks with the same dimensions of 3.2 × 5.2 × 2.7 m. These reinforced concrete volumetric blocks had a fairly high level of factory readiness. Hence, glazed windows, doors, and wall cabinets were installed in them, and engineering networks with plumbing and electrical appliances were installed.

Bulk blocks were delivered to the construction site using trailers, and installation was carried out, as a rule, from wheels. At the same time, the duration of the construction of an apartment building was reduced by an average of three–four times. From 7 to 10 blocks were installed in one shift, and with three shifts, a 5-storey residential building with 60 apartments was erected in 10–12 working days.

Due to the active development of panel and monolithic housing construction, as well as the lack of high-power equipment for construction, block construction has not been engaged for many years.

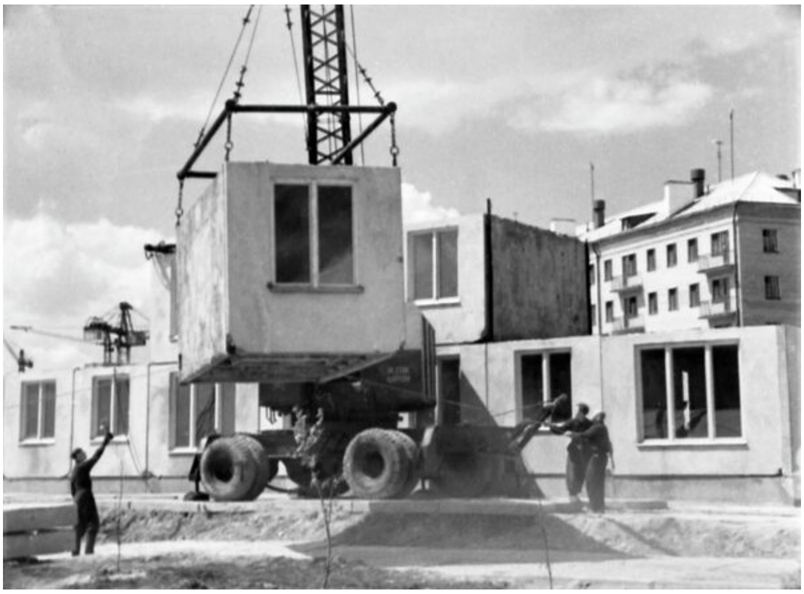

Figure 1. Installation of volumetric blocks.

However, with the development of technology and improvement of the quality of construction, it has become possible to build houses from blocks, and it becomes more technologically advanced, high-quality and economically attractive compared to classical construction methods.

Modern technology for the construction of residential buildings from bulk blocks is characterized by the transition to large-sized bulk blocks of high or full factory capacity [1–3]. Such blocks are, as a rule, designed to accommodate an apartment with a total area of about 100 square meters. For example, the basic large-sized block manufactured at the MonArch Combine of Innovative Technologies is 15.5 m long, 7.5 m wide and 3.75 m high. Such a block weighs 65 tons and is 98% prefabricated [4,5]. Since the majority of the work is transferred to industrial enterprises, building assembly in construction is reduced to three main processes: installation of volumetric blocks, assembly of vertical and horizontal joints, and post-assembly work to connect utility systems [6–9].

At the same time, there are a wide range of architectural and design solutions for residential buildings, characterized by a broad variety of geometric dimensions [10–13]. For this reason, it is not always feasible to cover such solutions using only large-sized volumetric blocks. Therefore, the type of volumetric blocks for the formation of various series of residential buildings should consist not only of large-sized, but also of other, less dimensional blocks [14–17].

To determine them, the following method of modeling the type of volumetric blocks is proposed, depending on the planned application of specific series of residential buildings. The formation of such a technique will increase the architectural expressiveness of the building, allow developing a system of mass housing construction and accordingly reduce the cost of construction.

2. Materials and Methods

Development of the type of volumetric blocks is based on architectural-planning solutions for residential buildings and available technical capabilities of means of mechanization for installation work.

Architectural and design solutions for residential buildings erected in different regions of Russia Federation have their specific features, largely determined by the regional climate and environment. For example, the residential building projects developed by the Parametrica and AMC-project architectural studios (St. Petersburg, Russia) are notable for their diverse range of design solutions for sections. Residential buildings of any configuration can be formed from such sections. However, it should be borne in mind that sections can have multivariant space and layout design solutions for block placement.

At present, installation cranes are typically an uncompetitive choice for the assembly of residential buildings from large-sized blocks due to the limited lifting capacity of existing cranes.

The closest cranes are Liebherr (Switzerland: Buhl (Fribourg)), Terex (Norwalk, CT, USA) Demag (Dusseldorf, Germany), XCMG QY (China: Xuzhou, Jiangsu), Manitowoc (Manitowoc, WI, USA), and others (see Table 1). Experience shows that Russian builders prefer Liebherr cranes due to their high operational reliability. For instance, the Liebherr LTM 1650 crane with the maximum lifting capacity of 650 tons is available in two configurations, T3 and T3Y. In the T3Y configuration, the telescopic boom is between 33.9 and 54 m long, and its maximum lifting height is 54 m. With a minimum outreach of 5 m the boom length is 33.9 m, and with a maximum outreach of 52 m the boom length is 54 m.

Table 1. Technical specifications of heavy-load installation cranes (excerpt).

Type and Size of the Installation Crane	Technical Specification		
	Lifting Capacity (t)	Boom Length (m)	Jib Length (m)
Liebherr LTM 1500	500	50	6–91
Liebherr LTM 1650	700	80	73
Liebherr LTM 1750	750	60	91
Liebherr LTM 11200	1200	100	60
Terex Demag AC 500	500	56	6–91
Terex Demag AC 700	700	60	6–90
LG 1750	750	136	57

The uniqueness and high cost of installation cranes make it also necessary to supplement the aforesaid indicators (lifting capacity, hook height, boom outreach as well as an economic factor—the machine's working shift cost) with one more—the average daily number of assembled blocks. This indicator is required to calculate the duration of large-sized blocks installation.

Production of volumetric blocks involves forming a parallelepiped with wall panels, as its faces and slabs for the upper and lower levels of the blocks. The design of wall panels of blocks assumes built-in pylons (support columns), connected on the top and at the bottom by tie beams. Together, these beams and pylons constitute the frame structure of the building. The technology for the production of inner walls in the space between pylons anywhere in the longitudinal direction makes it possible to build doorways and window apertures and creates space for open plan apartments.

Production of large-sized volumetric blocks on automated conveyor lines is performed in the following technological sequence: molding flat-reinforced concrete products; assembling flat products into large-size blocks on assembly jigs; finishing facade work as well as installation of internal engineering systems.

The structural section of large-sized volumetric blocks is made of self-compacting concrete (grade B70 or lower) and aggregates for heavy and fine-grained concrete.

Each volumetric block is equipped with a set of accessories. For instance, finished apartments are fitted with an in-floor convector with fans, a Radomir bathtub, a wall-hung sink, a semicircular sink, a wall-hung toilet system, a bottle siphon for the washbasin, a bathtub and washbasin mixer, a washing machine, a kitchen sink set, etc. This set of accessories is provided for each apartment.

Volumetric block-type modeling comprises three steps.

The first stage involves the following operations:

1. *Determining the baseline parameters of the blocks to be used*

   1.1. Setting limits on the weight and overall dimensions of blocks:

$$\text{Max Q at max(a,b)}$$

$$c \to const \quad (1)$$

Max Q at max(a,b)

where Q is the weight of the volumetric block in tons; a, b, and c are the overall parameters of the block (length, width, and height, respectively) in meters.

1.2. Choosing the increment of change for the length and width of blocks
α is the block length increment of change (the unit: m);
β is the block width increment of change (the unit: m).

2. *Modeling block options by incrementally changing the overall dimensions*

The dimensional parameters are changed as follows:

$$a_{j+1} = a_j - \alpha,\ j = 1,\ 2,\ 3, \ldots,\ m \quad (2)$$

$$b_{i+1} = b_i - \beta,\ i = 1,\ 2,\ 3, \ldots,\ n \quad (3)$$

where j is the block index by length; i is the block index by width.

Hence,

$$\max Q = Q_{11,} \quad (4)$$

with the block's overall dimensions being

$$\max a = a_1 \quad (5)$$

$$\max b = b_1 \quad (6)$$

The volume of this block is as follows:

$$V_{11} = a_1 \cdot b_1 \cdot c \quad (7)$$

where V_{11} is the volume of the baseline heaviest and the largest-sized block.

Similarly, the specifications for the baseline lightest block are established, i.e.,

$$\min Q = Q_{nm}, \quad (8)$$

with the block's overall dimensions being

$$\min a = a_n \quad (9)$$

$$\min b = b_m \quad (10)$$

and its volume equal to

$$V_{nm} = a_n \cdot b_m \cdot c \quad (11)$$

where V_{nm} is the volume of the baseline lightest block.

The total number of modeled blocks is written as:

$$u = n \cdot m \quad (12)$$

where u is the total number of modeled blocks.

3. *Construction of the block matrix*

To display all n ·m blocks, a matrix table is constructed (see Table 2). To display all n·m blocks, a matrix table is constructed (Table 2). Its rows, the number of which is equal to n, register changes in the width of blocks from b_1 to b_n, and columns, the number of which is equal to m, display incremental changes in the length of blocks from a_1 to a_m.

Table 2. Estimated circulation of volumetric blocks.

Width of Blocks, m	Length of Blocks, m				
	a_1	a_2	a_3	...	a_m
b_1	$\frac{1}{Q_{11}}$	$\frac{2}{Q_{12}}$	$\frac{3}{Q_{13}}$	......	$\frac{m}{Q_{1m}}$
b_2	$\frac{n+1}{Q_{21}}$	$\frac{n+2}{Q_{22}}$	$\frac{n+3}{Q_{23}}$	......	$\frac{2m}{Q_{2m}}$
b_3	$\frac{2n+1}{Q_{31}}$	$\frac{2n+2}{Q_{32}}$	$\frac{2n+3}{Q_{33}}$	......	$\frac{3m}{Q_{3m}}$
.	.	.	.	.....	.
.	.	.	.	.....	.
.	.	.	.	.....	.
b_n	$\frac{(m-1)n+1}{Q_{n1}}$	$\frac{(m-1)n+2}{Q_{n2}}$	$\frac{(m-1)n+3}{Q_{n3}}$	......	$\frac{nm}{Q_{nm}}$

Each table cell at the intersection of the *j*th row and the *i*th column contains the parameters of the block as a fraction, with the block number in the numerator and its weight in the denominator.

The block number is calculated using the following formula:

$$N_{ij} = (i-1)n + j \tag{13}$$

where N_{ij} is the block number at the intersection of the *j*th row and the *i*th column.

The weight of the block is determined using the ratio:

$$Q_{ij} = Q_{11} \cdot \frac{V_{ij}}{V_{11}} \tag{14}$$

where Q_{ij} is the weight of the block at the intersection of the *j*th row and the *i*th column; V_{ij} is the volume of the block at the intersection of the *j*th row and the *i*th column.

3. Results

Having carried out calculations according to the proposed methodology, the calculated types of volumetric blocks were formed. Thus, for each volumetric block, its full specification is given: number in the type, weight, and overall dimensions (Table 3).

Table 3. Calculated types of volumetric blocks (fragment).

Width (m)	Length (m)						
	15.0	**14.7**	**14.4**	**14.1**	**13.8**	**13.5**	**13.2**
6.5	1–65 t	2–63.7 t	3–62.4 t	4–61.1 t	5–59.8 t	6–58.5 t	7–57.2 t
6.4	29–64 t	30–62.7 t	31–61.4 t	32–60.2 t	33–58.9 t	34–57.6 t	35–56.3 t
6.3	57–63 t	58–61.7 t	59–60.5 t	60–59.2 t	61–58 t	62–56.7 t	63–55.4 t
6.2	85–62 t	86–60.8 t	87–59.5 t	88–58.3 t	89–57 t	90–55.8 t	91–54.6 t
6.1	113–61 t	114–59.8 t	115–58.6 t	116–57.3 t	117–56.1 t	118–54.9 t	119–53.7 t
6.0	141–60 t	142–58.8 t	143–57.6 t	144–56.4 t	145–55.2 t	146–54 t	147–52.8 t
5.9	169–59 t	170–57.8 t	171–56.6 t	172–55.5 t	173–54.3 t	174–53.1 t	175–51.9 t
5.8	197–58 t	198–56.8 t	199–55.7 t	200–54.5 t	201–53.4 t	202–52.2 t	203–51 t

The second stage involves developing options for space and layout design solutions in residential building sections by placing volumetric blocks based on the calculated block type. Figure 2 shows one of the volumetric blocks floor layout options in a two-section L-shaped rectangular residential building. The range of available volumetric blocks is given in Table 4.

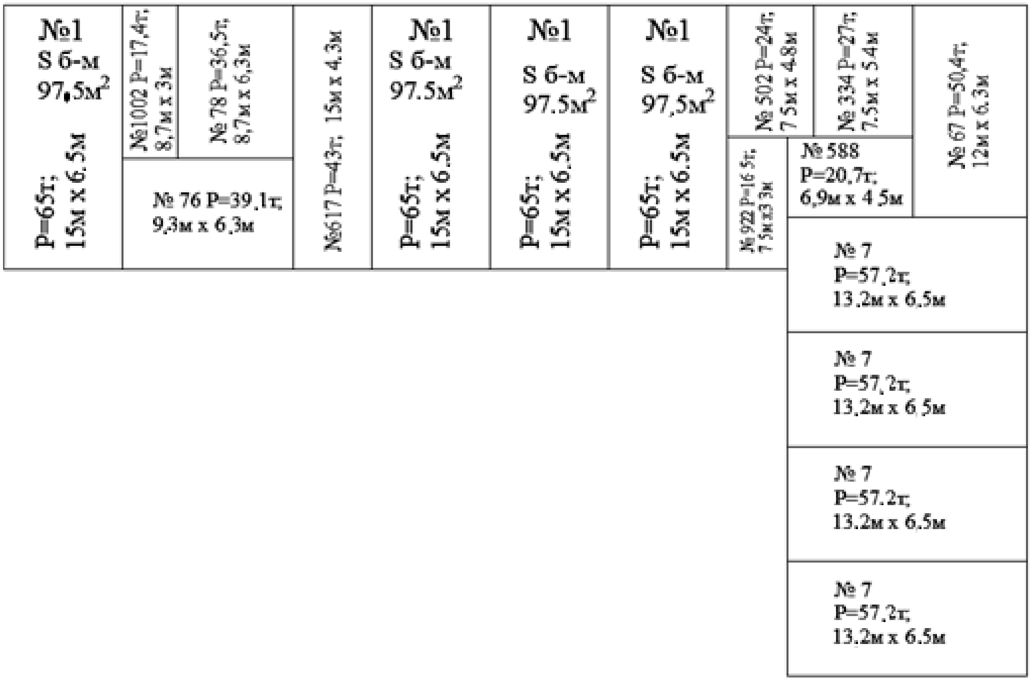

Figure 2. Floor layout of volumetric blocks for L-shaped buildings.

Table 4. Calculated types of volumetric blocks (fragment), where LSVB means large-sized volumetric block.

No.	Module Type Number	Dimensions, L × W × H (m)	Weight (P) (t)	Quantity (pcs)
1	LSVB No. 1	15.0 × 6.5 × 3.5	65.0	4
2	LSVB No. 7	13.2 × 6.5 × 3.5	57.2	4
3	LSVB No. 76	9.3 × 6.3 × 3.5	39.1	1
4	LSVB No. 78	8.7 × 6.3 × 3.5	36.5	1
5	LSVB No. 617	15.0 × 4.3 × 3.5	43.0	1
6	LSVB No. 1002	8.7 × 3.0 × 3.5	17.4	1
7	LSVB No. 922	7.5 × 3.3 × 3.5	16.5	1
8	LSVB No. 502	7.5 × 4.8 × 3.5	24.0	1
9	LSVB No. 67	12.0 × 6.3 × 3.5	50.4	1
10	LSVB No. 334	7.5 × 5.4 × 3.5	27.0	1
11	LSVB No. 588	6.9 × 4.5 × 3.5	20.7	1

To simplify the calculations, it is assumed that one block covers the entire width of the section. Hence,

for a 6 m long section, there are 2 possible combinations;
for a 10 m long section, there are 97 possible combinations;
for a 15 m long section, there are 5503 possible combinations;
for a 20 m long section, there are 346,295 possible combinations;
for a 25 m long section, there are 18,537,226 possible combinations.

At the third stage the actual types of volumetric blocks are selected from the calculated types of volumetric blocks and approved, depending on the set goal and objectives. For example, for the initial stage, MonArch Group of Companies plans to produce only a limited range of large-sized blocks (Table 5).

Table 5. Planned range of manufacture of large-sized blocks.

Block Code	Block Specification				Planned Share of Output (%)
	Length (m)	Width (m)	Height (m)	Weight (t)	
Basic	15	6.5	3.5	65	72
Common facilities	15	6.5	3.5	65	18
Staircase and elevator section	7	3.2	3.5	15	10

For this purpose, an experiment was conducted in New Moscow on the construction of a four-storey building with a plan size of 28.8 × 15.5 m. As a result, the space-planning solutions amounted to seven blocks per floor (Table 6). The location and sequence of installation of the blocks were the same for all floors. The main works included rigging (traverse preparation and slinging) and installation (lifting, aiming, installation, alignment, and fixing).

Table 6. Parameters of the volumetric blocks of the experimental building.

Block Number	Number of Blocks (pcs)	Block Parameters		
		Block Dimensions (m)	Block Volume (м^3)	Block Weight (t)
1	2	14.4 × 6.3	301	50.9
2	2	9.2 × 8.0	245	43.9
3	2	9.2 × 3.7	113	22.6
4	1	9.2 × 7.0	215	42.7

The total installation time of the experimental building was 17.3 h, including the installation of the roof.

The timing results were summarized in a report form (Table 7).

Table 7. Report on the timing of a residential building (fragment).

No.	Name of the Operation	Beginning of the Operation	End of the Operation	Duration (min)
1	2	3	4	5
54	Strapping of block B2	17–47	17–51	4
55	Feeding unit B2 to the installation site in the design position	17–51	18–02	11
56	Spreading block B2 and turning the crane boom to the next block	18–02	18–10	8
57	Slinging and lifting of block B3 to the installation site in the design position	18–10	18–29	19
58	Spreading block B3 and turning the crane boom to the next block	18–29	18–36	7
59	Strapping of block B4 "from wheels"			
60	Break	18–36	18–50	14
61	Feeding unit B4 to the installation site in the design position	18–50	19–20	30
62	Spreading block B4 and turning the crane boom to the next block	19–20	19–27	7
63	Feeding unit B3 to the installation site in the design position	19–27	19–39	12
64	Unpacking block B3 and turning the boom of the crane to the next trawl	19–39	19–42	3

It should be particularly noted that, despite the identity of the floor solutions of the experimental building, there was a significant variation in the duration and production of work on each floor during the installation of the blocks. For example, the duration of the first floor was about 5.0 h, and that of the fourth floor was 3.1 h. The analysis showed that the main reason for such a spread of indicators was the lack of practical experience. In this regard, two estimates of the duration of the construction of a residential building from large-sized volumetric blocks are proposed:

optimistic (having experience):

$$T = 0.48 \cdot \text{m} \quad (15)$$

pessimistic (lack of experience):

$$T = 0.76 \cdot \text{m} \quad (16)$$

where T is the duration of the construction of the building in the unit of hour and m is the number of large–sized blocks (pcs).

At the same time, the complexity of installing large-sized volumetric blocks was defined as the sum of labor costs:

$$Q = (q_1 + q_2) \cdot p + q_3 + \sum_{j=1}^{m} q_{4j} \quad (17)$$

where Q is the complexity of the installation of blocks (person-hour); q_1 is labor costs for the crane delivery to the facility (person-hour); q_2 is labor costs of machinists and crane maintenance workers (person-hour); q_3 is labor costs of installers for the preparation of technological equipment (person-hour); q_{4j} is labor costs of installers for the installation of blocks on the jth floor (person-hour); p is the number of taps.

In addition, it became possible to accurately calculate the duration of the installation crane's stay on the construction site, which was expressed as:

$$T = tH + r1 + r2 + r3 + r4 \quad (18)$$

where T is the duration of the crane's stay at the facility (day); t_H is the duration of installation of the aboveground part of a residential building (day); r_1 is the duration of installation and dismantling of the crane (day); r_2 is the duration of maintenance and repair of the crane (day); r_3 is the duration of time loss under adverse meteorological conditions, (day); r_4 is the number of weekends and holidays (day).

4. Discussion

The results of the experiment confirmed the expediency of the adopted stages of modeling the type of volumetric blocks, which makes it possible to form both large-sized and smaller blocks in one system. This combination of blocks ensures reliable and flexible satisfaction of almost any architectural and planning solutions for residential and public buildings. At the same time, in each specific case, taking into account the specifications of the respective regions and manufacturers, it is necessary to approve its nomenclature of volumetric blocks based on the general scheme given (Tables 2 and 3).

It should be particularly noted that, despite the identity of the floor solutions of the experimental building, there was a significant variation in the duration and production of work on each floor during the installation of the blocks. For example, the duration of the first floor was about 5.0 h, and that of the fourth floor was 3.1 h. The analysis showed that the main reason for such a spread of indicators is the lack of practical experience.

The results of the timing of the construction of the experimental building allowed us to substantiate the relevant organizational and technological parameters of the construction of buildings from volumetric blocks—the duration and complexity of installation, the structure of private flows for the installation of blocks, the installation of joints, and the performance of installation work on the connection of engineering communications. As a result, appropriate recommendations were developed on linking the delivery of blocks and the installation of buildings from vehicles, calculating the composition of work crews and drawing up a detailed methodology for the entire complex process of delivery, installation of bulk blocks, and commissioning of facilities.

5. Conclusions

Erection of buildings from large-sized volumetric blocks is a promising avenue in industrial residential construction. One of the priority tasks in the pursuit of this direction is to form the types of volumetric blocks, depending on the specific series of residential buildings to be constructed.

We have proposed a method of volumetric block-type formation from both large-sized blocks and smaller-sized blocks, depending on the set objective. The algorithm of volumetric block-type modeling makes it possible to fully automate all relevant processes.

The proposed method will allow organizations to perform building design to clearly define the shapes and sizes of blocks and make their own series.

To automate the development of volumetric block types, a complex software product was created on the basis of a nesting algorithm, which is widely used in mechanical engineering for laying out machine parts.

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