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Modeling the Stability of the Housing and Construction Complex Based on Organizational and Economic Interaction of Entities

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ABSTRACT

The article addresses the structure of the socio-economic system of the housing and construction complex (HCC), focusing on the organizational and economic interaction of its participants against the backdrop of entropy-driven macroeconomic influences. The study **aims** to identify management methods, from a system-information approach, that allow the system to reach a new level of sustainable disequilibrium with the environment while maintaining homeostasis. Since the primary factor in the housing construction sector is the availability of built housing, the first research **task** was a detailed examination of household housing provision in Russia as a whole and in the Irkutsk region, based on census data from 2002, 2010, and 2020. As a result, the idea of the "best" structure of the housing stock in terms of the number of rooms corresponding to the composition of households was proposed. Achieving the "optimal" housing provision for the population requires timely organizational and economic changes, one of which is the introduction of project financing. To reach a new level of sustainable equilibrium in the HCC system, coordinated actions among all stakeholders are necessary to minimize the gap between the actual and the "optimal" housing stock structure. The second research objective was to find a solution to the multi-criteria problem of aligning the interests of economic entities in housing construction. A genetic algorithm in MATLAB was used for this purpose. Acceptable options for all participants were selected from a set of Pareto-optimal alternatives based on the preferences of the decision-maker. The state was imperatively assigned this role, with the optimization criterion being the minimization of the gap between the "optimal" and actual housing provision for households of various sizes. The modeling results indicated that effective collaboration towards a common goal is possible; however, the cost factor is inevitably passed on to consumers. The study's findings will be of interest to students and graduate students studying construction economics, as well as to banking professionals, regional authorities, and specialists in the field of housing construction.

Keywords: housing construction; system-information approach; economic entities; interest alignment; economic-mathematical model; multi-criteria problem

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INTRODUCTION

The relevance of the topic of sustainable development of the investment and construction complex as a whole and the housing construction sector in particular is due to the necessity of achieving the goals and key parameters of national projects.[1] Thus, the Federal Project "Housing" of the national project "Housing and Urban Environment" envisions "increasing the volume of housing construction in Russia (at least 120 million square meters per year by 2030). Every fifth square meter in Russia by 2030 should be new". *Sustainable development* is currently understood and fashionable to interpret as a certain "abundant world" that meets the needs of a socially developed person while adhering to environmental standards and preserving the environment for future generations.

During the research, we did not operate in such a mainstream manner, but rather examined a more specific issue of the existence of the housing construction sector within the country's economic system. Classical system-informational and homeostatic approaches to managing complex socio-economic systems, as described, for example, by R.F. Abdeev, A.P. Nazaretyan, Yu. M. Gorsky, and others, were used [1–3]. R.F. Abdeev in his paper presented a generalized process of system management, which breaks down into contours of self-organization and self-development. Such a construct "firstly, is unified for all areas covered by cybernetics, and secondly, reveals the system-organizing, "negentropic" function of management in all these areas" [1].

The description of complex systems is based on key concepts such as *organization, information, and purpose*. The functioning, development, and existence of the system as a whole are largely determined by the processes of transmission, processing, and transformation of information.

As a result, a systemic-information approach to management is formed, the mechanism of which represents a purposeful information-management process consisting of a controlled object and a controlling subject, united by direct and feedback information connections. Through such a mechanism, self-organization of open stable systems occurs, which actively interact with the environment but do not dissolve in it, preserving their individuality (stability) or *non-equilibrium, i.e., protection against entropic processes.*

The contour of self-regulation (homeostasis) is formed as a qualitative ordering of connections — in response to the influence of external conditions, incoming information causes a deviation, which is neutralized through feedback [4].

The contour of self-development essentially involves the purposeful accumulation of data followed by its ordering and structuring, which may include modeling and programming possible interaction scenarios with the selection of the most stable states at a new level of system self-organization. In other words, *development* is the creation of something new in the very process of the system's interaction with the environment as a result of selective reflection and selection of information about this interaction.

Having defined the key concepts, we identified the housing sector of the investment and construction complex (ICC) as a separate complex self-organizing socio-economic system and named it the housing construction complex (HCC). The main system-forming factor of the HCC, according to systems engineering in construction,[2] is the result of its activities, i.e., the constructed housing. Overcoming entropy processes in relation to this socio-economic system means that timely organizational and economic changes (OEC) are necessary to maintain its stable non-equilibrium with the environment (to prevent entropy and preserve effective interaction) [5]. For example,

[1] National projects of Russia. URL: https://xn-80aapampemcchfmo7a3c9ehj.xn — p1ai/projects/zhile-i-gorodskaya-sreda/zhile/ (accessed on 12.08.2024).

[2] System Engineering in Construction. Encyclopedic Dictionary edited by A.A. Gusakov. Moscow: New Millennium Foundation. 1999; 432 p.

the introduction of project financing by one of the participants — the state — to overcome the entropic influence of the existing phenomenon of deceived shareholders, which arose due to the disruption of self-regulation in the management of construction companies due to the lack of controlling (disrupting homeostasis, and thus forcing it to maintain) influence from the external environment — the state.

Interactions within the system have changed, and the role of one previously considered a peripheral participant t— the bank — has significantly increased, with its level of control almost equal to that of the state. To reach a new level of sustainable imbalance, the system needs a tool to reconcile the interests of all its parties.

ANALYSIS OF HOUSING PROVISION IN THE RUSSIAN FEDERATION AND IRKUTSK REGION

The authors of this article have already written about the structure of the housing sector and its participants (banks, construction organizations, the state, and the population) [6]. The organizational and economic interaction of the latter essentially constitutes the structure of the socio-economic system of the housing cooperative, the goal of which is constructed housing. However, the main question arises here: what and in what quantity should be built for this system to continue functioning stably, i.e., for all its subjects to interact harmoniously in terms of maintaining a stable imbalance with the environment (self-regulation) and further self-development?

To model an accurate response, the housing situation in the country as a whole and in the Irkutsk region in particular was first assessed in terms of the needs of households of different sizes. Such work had already been carried out based on the results of the 2002 and 2010 censuses [4].

This article reflects the dynamics taking into account the results of the 2020 census.

Tables 1 and *2* present a comparative analysis of housing provision based on the results of the population censuses of 2002, 2010, and 2020 across the subjects of the Russian Federation, depending on the composition of households.

The breakdown by federal districts (*Table 1*) shows that the average provision over the past 10 years (from 2010 to 2020) increased only in three districts (North Caucasian Federal District, Volga Federal District, and Siberian Federal District by 2, 3, and 2 m^2/person, respectively); remained unchanged in three (Southern Federal District, Ural Federal District, and Far Eastern Federal District), and even decreased in two central districts (Central Federal District and Northwestern Federal District) by 2 and 1 m^2/person, respectively.

Such trends cannot be explained without analyzing the structure of households (*Table 2*). Undoubtedly, we observe a constant decrease in the share of those that include three or more people. However, this dynamic depends on the numerical composition. Families that choose to have many children are the most stable: the share of families with five or more people has decreased by 1–2 percentage points (pp) over the past 10 years and usually constitutes 5–7% of the total number of households. The exceptions are the Far Eastern Federal District (a slight increase in percentage share) and the North Caucasian Federal District, where families are traditionally large. However, the decline is more significant — from 39.8% in 2010 to 26.5% in 2020. The decrease in the share of households with four people (which account for 9 to 11% in all districts, except for the Southern Federal District and the North Caucasian Federal District — where it is 12% and 14% respectively) is uniformly between 2 to 4 percentage points. The most catastrophic situation from a demographic perspective is for households of three people: their decline is 6 to 7 percentage points (2 percentage points in the North Caucasian Federal District); their share in the total number in 2020 is from 15 to 17%. This means that an increasingly smaller number of families are even deciding to have one child!

Table 1

Average housing provision per citizen in the Russian Federation by federal districts (based on the 2002, 2010 and 2020 census data)

<table>
<tr><th rowspan="2">Indicator</th><th colspan="3">Average household size, pers.</th><th colspan="3">Average housing provision, м²/pers.</th></tr>
<tr><th>2002</th><th>2010</th><th>2020</th><th>2002</th><th>2010</th><th>2020</th></tr>
<tr><td>Russian Federation</td><td>2.7</td><td>2.6</td><td>2.2</td><td>19</td><td>19</td><td>19</td></tr>
<tr><td>Central Federal District</td><td>2.6</td><td>2.5</td><td>2.1</td><td>20</td><td>19</td><td>17</td></tr>
<tr><td>Northwestern Federal District</td><td>2.6</td><td>2.4</td><td>2.1</td><td>20</td><td>19</td><td>18</td></tr>
<tr><td>Southern Federal District</td><td rowspan="2">3.1</td><td>2.7</td><td>2.3</td><td rowspan="2">18</td><td>20</td><td>20</td></tr>
<tr><td>North Caucasus Federal District</td><td>3.7</td><td>3.4</td><td>18</td><td>20</td></tr>
<tr><td>Volga Federal District</td><td>2.7</td><td>2.5</td><td>2.2</td><td>19</td><td>19</td><td>22</td></tr>
<tr><td>Ural Federal District</td><td>2.6</td><td>2.5</td><td>2.2</td><td>18</td><td>19</td><td>19</td></tr>
<tr><td>Siberian Federal District</td><td>2.7</td><td>2.6</td><td>2.2</td><td>18</td><td>19</td><td>21</td></tr>
<tr><td>Far East Federal District</td><td>2.6</td><td>2.5</td><td>2.2</td><td>19</td><td>19</td><td>19</td></tr>
</table>

Source: Compiled and calculated by the authors based on the results of the 2002, 2010 and 2020 censuses.

Table 2

Share of households with 3 or more people by federal districts (based on 2002, 2010 and 2020 census data)

<table>
<tr><th rowspan="3">Indicator</th><th colspan="9">Share of total number of households, %</th></tr>
<tr><th colspan="3">Households of 3 people</th><th colspan="3">Households of 3 people</th><th colspan="3">Households with 5 or more people</th></tr>
<tr><th>2002</th><th>2010</th><th>2020</th><th>2002</th><th>2010</th><th>2020</th><th>2002</th><th>2010</th><th>2020</th></tr>
<tr><td>Russian Federation</td><td>23.78</td><td>22.51</td><td>15.91</td><td>16.97</td><td>14.49</td><td>10.79</td><td>9.40</td><td>8.77</td><td>7.15</td></tr>
<tr><td>Central Federal District</td><td>23.22</td><td>22.66</td><td>15.17</td><td>15.51</td><td>13.64</td><td>9.4</td><td>7.89</td><td>7.71</td><td>6.22</td></tr>
<tr><td>Northwestern Federal District</td><td>24.4</td><td>22.31</td><td>15.53</td><td>15.58</td><td>12.8</td><td>9.65</td><td>6.97</td><td>6.30</td><td>5.19</td></tr>
<tr><td>Southern Federal District</td><td rowspan="2">21.14</td><td>22.33</td><td>17.08</td><td rowspan="2">18.82</td><td>16.02</td><td>12.01</td><td rowspan="2">17.79</td><td>10.63</td><td>7.81</td></tr>
<tr><td>North Caucasus Federal District</td><td>17.82</td><td>15.2</td><td>18.91</td><td>14.26</td><td>39.81</td><td>26.54</td></tr>
<tr><td>Volga Federal District</td><td>24.19</td><td>22.85</td><td>16.60</td><td>18.11</td><td>15.03</td><td>11.59</td><td>8.62</td><td>7.78</td><td>5.96</td></tr>
<tr><td>Ural Federal District</td><td>24.89</td><td>22.96</td><td>15.84</td><td>17.43</td><td>14.57</td><td>11.14</td><td>7.59</td><td>6.88</td><td>5.55</td></tr>
<tr><td>Siberian Federal District</td><td>25.08</td><td>23.13</td><td>16.00</td><td>17.26</td><td>14.44</td><td>10.90</td><td>8.73</td><td>7.73</td><td>6.04</td></tr>
<tr><td>Far East Federal District</td><td>25.67</td><td>22.98</td><td>16.23</td><td>16.09</td><td>13.33</td><td>11.20</td><td>8.01</td><td>6.85</td><td>7.06</td></tr>
</table>

Source: Compiled and calculated by the authors based on the results of the 2002, 2010 and 2020 censuses.

Table 3 presents a comparative analysis of the living conditions of households in the Russian Federation and the Irkutsk region, which, based on the number of rooms per person, can be divided into three groups: good, average, and poor. In 2002, slightly more than 23% of all households had good and very good conditions: 23.17% in the Russian Federation and 23.68% in the Irkutsk region; poor conditions accompanied the lives of approximately 40% of households: 38.72% in the Russian Federation and 39.45% in the Irkutsk region, and by 2010, the percentage indicators for this group had hardly changed. And the share of families with good and very good conditions increased by approximately 1%. At the same time, the percentage of households with average conditions decreased (by 1.38% and 0.66% respectively), while poor conditions increased (by 0.22% and 0.85%). Neither the mortgage boom (2005–2006) nor the development of the Federal Target Program "Housing" managed to change the situation over 8 years.

In 10 years, by 2020, the situation was as follows: the share of families with very good living conditions hardly changed (a decrease of about 1 percentage point) — just over 3% of households with three or more people. The share with good living conditions decreased by about 2 percentage points — 17.7% and 18.9% of households in Russia and the Irkutsk region, respectively. Further trends are more noticeable. The share of families with average living conditions decreased by 6 percentage points and reached about 30% in both the Irkutsk region and Russia as a whole. Approximately the same percentage of households have poor living conditions — their share decreased, with a more significant drop in Russia — by 6 percentage points compared to the Irkutsk region (4 percentage points). This single positive change is offset by the increase in the share of families living in similar conditions, taking into account those who did not specify the number of rooms and those who rent housing. An increase of more than 6 percentage points means that almost half of households with three or more people are forced to rent housing or live in cramped conditions (47.1% and 46.5% in Russia and the Irkutsk region, respectively).

Tables 4 and *5* present information on the average housing provision not in rooms but in square meters by household types in the Irkutsk region and in the Russian Federation, respectively, and the trends turned out to be similar. The share of singles in the population has doubled over the past 10 years (from 2002 to 2010, the increase was 1 percentage point) — to 18% of the population, however, the provision in square meters decreased from 40 to 33 m^2/person in 2020. This means that single citizens are living in apartments of increasingly smaller size. The number of two-person families increased by 2 percentage points in the Irkutsk region; in the Russian Federation, their share did not change, and housing provision fell to 22 and 23 m^2 per person, respectively. The living conditions of households with three or more people deteriorated in 2020 by approximately one square meter (in the Russian Federation — 16, 14, and 11 m^2 per person for families of three, four, five, and more people, respectively), which no longer complies with the existing standard. Conclusion: about 60% of the population in both the Russian Federation and the Irkutsk region live in conditions where there is less than 18 m^2 per person. This indicator decreased by almost 7 percentage points since 2020, but this happened simply due to the reduction of large families and their share in the total population. The number of three-person families decreased particularly noticeably (by 5 percentage points), meaning that citizens are increasingly less likely to decide to have even their first child.

In order for the housing conditions of all households to transition to the "good" category (*Table 3*), we defined the concept of the "optimal structure" of the housing stock, which implies the presence of the recommended (ideally desired) number of apartments, provided that parents and

Table 3

Housing conditions of households consisting of 3 or more people

Indicator	Census 2002		Census 2010		Census 2020	
	Russian Federation	Irkutsk region	Russian Federation	Irkutsk region	Russian Federation	Irkutsk region
Number of households with 3 or more people, units	25 435 908	463 196	25 190 405	431 421	21 689 345	346 670
The share of households with housing conditions, %:						
Very good, $k^a > n^b$	3.82	3.22	4.22	3.42	3.76	3.09
Good, $k=n$	19.35	20.46	19.71	21.03	17.67	18.87
Average, k= $n-1$	38.12	36.86	36.74	36.20	29.82	30.54
Poop, n-2 ³ k	34.92	34.63	35.14	35.48	29.04	31.07
Poor considering those who are renting and did not specify the number of rooms and type of apartments.	38.72	39.45	39.33	39.35	47.13	46.54

Source: Compiled and calculated by the authors based on the results of the 2002, 2010 and 2020 censuses.

Note: a — n —number of household members; b — k — number of rooms.

children over 18 live separately (intergenerational households are divided into separate families). The structure of apartments, where the number of rooms corresponds to the quantitative composition of the household, is called "optimal" [7]. The authors of this article compared such housing structures in individual houses and apartments for the Irkutsk region based on the census data of 2010 [8] and 2020 (see *Figure*).

According to the *Figure*, the quantitative composition of families has changed significantly over the decade; there is a need to increase housing consisting of one room and to reduce two-, three-, four-, and more-room residential spaces (as confirmed by the data in *Tables 4* and *5*).

A detailed institutional analysis of the reasons why Russian households need to have their own housing was conducted by R.M. Nureev and O.A. Gulyaeva [9].

Questions arise: Is it necessary for developers to focus on the trends identified above; will the population be able to acquire the housing they need, and will the state be able to create an institutional framework in which favorable interaction between economic entities in the housing construction sector will take place; is there even a possibility of reconciling their divergent interests?

For a more comprehensive solution to this problem, mathematical modeling methods were used [6].

Table 4

Average housing provision by household type in the Irkutsk region according to census data 2002, 2010, 2020

Household size, pers.	Average housing supply, m²/pers.			Number of households			Share in the region's population, %		
	2002	2010	2020	2002	2010	2020	2002	2010	2020
1	41	40	33	181 367	213 235	416 471	7.16	8,93	18,12
2	23	24	22	256 971	268 973	276 131	20.29	22.54	24.02
3	17	17	16	231 282	211 907	165 732	27.39	26.63	21.63
4	14	14	13	165 352	139 452	114 290	26.11	23.37	19.89
5 and more	11	10	10	86 598	78 224	66 648	19.04	18.53	16.35
3–5 and more	< 18			483 232	429 583	346 670	72.54	68.53	58.00

Source: Compiled and calculated by the authors based on the results of the 2002, 2010 and 2020 censuses.

Table 5

Average housing provision by household type in the Russian Federation according to census data 2002, 2010, 2020

Household size, pers.	Average housing provision, m²/pers.			Number of households			Share in the region's population, %		
	2002	2010	2020	2002	2010	2020	2002	2010	2020
1	42	40	33	11 41 449	14 018 754	26159856	8.22	9.95	18,28
2	24	24	23	14 534 669	15 563 868	16225383	20.36	22.08	22,68
3	18	17	16	1 2536 743	12 284 058	10194710	26.35	26.14	21,37
4	15	14	14	8 943 575	7 907 406	6 912 897	25.06	22.44	19,32
5 and more	12	12	11	4 954 939	4 786 541	4 581 738	20.01	19.39	18,35
3–5 and more	< 18			13 898 514	25 190 405	21689345	45.07	67.97	59.04

Source: Compiled and calculated by the authors based on the results of the 2002, 2010 and 2020 censuses.

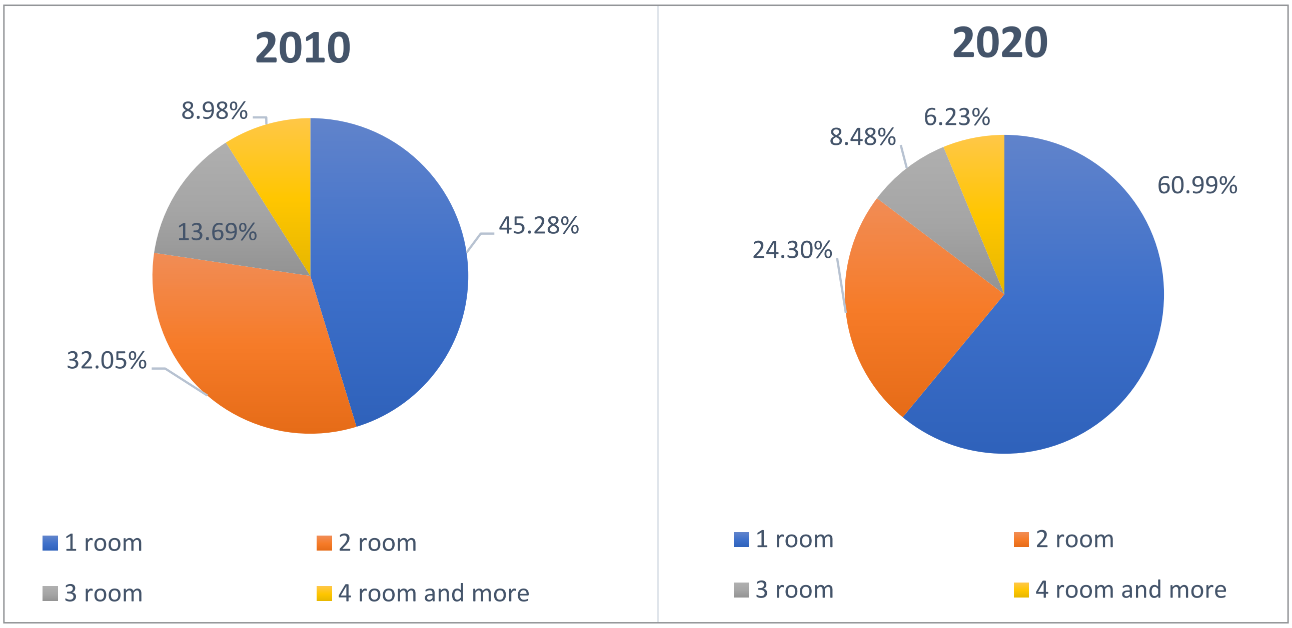

Fig. **"Optimal" structure by in number of rooms in individual houses and apartments for the Irkutsk region, based on the 2010 and 2020 census data**

Source: Compiled by the authors.

MODELING OF ORGANIZATIONAL-ECONOMIC INTERACTION OF PARTICIPANTS IN HOUSING CONSTRUCTION

Systemic modeling of the economic interaction of participants in the housing construction sector has been conducted by Russian scientists such as D.A. Makarov and M.N. Yudenko [10]. Foreign researchers M. Liu, Y., Yi Hu, Bo Xia, M. Skitmore, and X. Gao analyzed and systematized 103 articles from 41 peer-reviewed journals from 1997 to 2016 on system dynamics modeling in the construction industry [11].

Among foreign authors, the approach related to agent-based modeling is the most popular. For example, M.J. Smith focused on the behavior of individual agents (such as homebuyers, sellers, developers, and investors) and demonstrated how their interactions influence market trends, pricing, and housing availability [12]. J. Smith and A. Brown in their work [13] examined the relationships between developers and government bodies and their role in the development of residential real estate. W. Kirsch and M. Shilling paid special attention to how agent-based models help predict housing market behavior and take into account complex socio-economic factors [14]. To apply such models, a clear understanding of which criteria determining market behavior will prevail among different agents (economic entities) is needed.

The decision-making process concerning a wide range of practical tasks is viewed as a continuous flow of actions — from the moment the initial data is presented to the stages of design, selection, verification, and testing of the obtained results. In this process, one has to take into account the constantly growing number of often conflicting criteria that are at odds with each other [15].

A multi-criteria optimization problem arises, which usually has several constraints [16].

In the paper [17], it was shown that it has a solution. Unlike [6], where the results of numerical calculations were presented by first selecting criteria for two (pairwise) and then for three (the developer, the bank, and the consumer) economic

Table 6

Solution of a multicriteria problem based on 2023 data

Optimal solution				Value of criteria at the optimal point			
X_1	X_2	X_3	X_4	*B(X)*	*S(X)*	*N(X)*	*G(X)*
240 268.75	42 063.63	151 339.67	6 327.95	7 911 725 452.87	14 665 895 740.50	114 540.58	15 954 371.15
73 507.54	12 870.42	351 631.45	1 990.60	7 594 778 513.33	11 905 033 903.46	108 265.90	16 074 781.63
65 334.33	11 442.98	361 317.30	1 905.39	7 579 247 904.26	11 769 749 848.82	107 958.43	16 080 766.68
93 848.13	16 428.92	327 289.56	2 433.38	7 633 435 555.77	12 241 767 775.77	109 031.20	16 059 915.62
220 610.17	38 621.51	174 976.66	5 791.66	7 874 361 604.17	14 340 426 631.20	113 800.88	15 968 389.24
128 639.69	22 522.36	285 393.90	3 444.05	7 699 563 399.93	12 817 794 172.24	110 340.35	16 034 598.18
0.79	**0.25**	**439 997.99**	**0.97**	**7 455 069 208.15**	**10 688 053 954.49**	**105 500.03**	**1128 928.86**
11 610.28	2 033.31	426 026.89	329.52	7 477 134 968.19	10 880 264 396.72	105 936.87	16 120 333.44
269 212.80	47 128.83	116 638.99	7 019.39	7 966 734 843.70	15 145 071 640.43	115 629.62	15 933 819.68
79 349.69	13 898.57	344 405.69	2 346.05	7 605 887 631.77	12 001 803 200.67	108 485.83	16 070 501.20
262 395.39	45 935.37	124 827.59	6 841.65	7 953 777 645.98	15 032 204 065.63	115 373.10	15 938 651.19
309 153.19	54 120.24	68 691.47	8 035.10	8 042 645 155.00	15 806 311 125.70	117 132.43	15 905 629.82
14 967.80	2 620.54	422 014.94	396.72	7 483 515 741.51	10 935 846 047.81	106 063.20	16 117 851.44
84 110.36	14 726.85	338 884.59	2 278.19	7 614 930 607.77	12 080 574 666.09	108 664.85	16 067 024.95
69 894.68	12 237.05	356 004.98	1 863.29	7 587 910 993.60	11 845 212 336.55	108 129.94	16 077 428.53
295 096.93	51 659.97	85 558.10	7 685.00	8 015 930 187.08	15 573 602 499.17	116 603.55	15 915 528.08
324 177.16	56 749.73	50 669.87	8 403.24	8 071 199 156.98	16 055 039 346.64	117 697.73	15 895 077.28
122 955.29	21 526.56	292 247.72	3 270.43	7 688 758 894.04	12 723 678 324.41	110 126.45	16 038 724.76
116 361.79	20 371.79	300 186.77	3 079.65	7 676 226 758.10	12 614 513 394.28	109 878.35	16 043 516.02
55 320.06	9 686.24	373 486.11	1 507.60	7 560 211 036.92	11 603 923 507.38	107 581.55	16 088 118.35
30 406.82	5 325.79	403 375.55	891.84	7 512 861 739.39	11 191 473 058.66	106 644.17	16 106 450.29
76 081.80	13 321.52	348 521.47	2 075.22	7 599 671 617.41	11 947 656 773.44	108 362.77	16 072 896.77
41 243.06	7 220.62	390 443.63	1 092.69	7 533 454 935.81	11 370 856 440.06	107 051.86	16 098 469.35
279 976.66	49 012.80	103 726.13	7 284.41	7 987 192 328.42	15 323 272 615.85	116 034.62	15 926 203.17

Table 6 (continued)

Optimal solution				Value of criteria at the optimal point			
X_1	X_2	X_3	X_4	*B(X)*	*S(X)*	*N(X)*	*G(X)*
6 108.27	1 069.79	432 648.13	173.81	7 466 677 483.23	10 789 171 327.39	105 729.84	16 124 405.00
197 724.02	34 615.72	202 439.21	5 221.05	7 830 864 763.67	13 961 534 313.93	112 939.76	15 984 767.96
143 246.36	25 079.61	267 842.34	3 831.69	7 727 325 095.50	13 059 620 816.75	110 889.96	16 024 013.73
205 241.76	35 931.72	193 412.23	5 414.29	7 845 152 948.66	14 085 995 850.07	113 222.63	15 979 380.64
347 204.72	60 780.87	23 014.32	9 000.09	8 114 965 326.82	16 436 277 954.63	118 564.18	15 878 957.62
216 146.90	37 839.96	180 345.16	5 667.97	7 865 878 494.24	14 266 531 908.37	113 632.94	15 971 578.56
19 632.18	3 438.00	416 377.76	552.06	7 492 381 797.37	11 013 076 485.06	106 238.72	16 114 403.76
341 096.93	59 711.75	30 346.02	8 845.29	8 103 356 981.03	16 335 159 755.49	118 334.36	15 883 226.71
25 011.53	4 378.60	409 959.30	650.57	7 502 604 694.35	11 102 126 114.73	106 441.10	16 110 433.20
51 482.97	9 014.71	378 087.27	1 415.05	7 552 918 453.04	11 540 399 253.02	107 437.18	16 090 936.89
133 047.39	23 294.09	280 095.24	3 563.28	7 707 940 809.48	12 890 768 179.87	110 506.20	16 031 401.44
138 998.02	24 334.33	273 004.92	3 662.74	7 719 249 085.04	12 989 272 306.67	110 730.07	16 027 090.65
183 349.32	32 098.01	219 753.06	4 799.62	7 803 542 866.00	13 723 538 637.65	112 398.86	15 995 089.21
102 707.73	17 980.72	316 616.31	2 695.24	7 650 274 993.44	12 388 452 742.91	109 364.57	16 053 454.51
61 945.49	10 846.16	365 525.91	1 682.44	7 572 803 450.90	11 713 613 424.28	107 830.85	16 083 255.40
189 634.81	33 199.57	212 157.06	5 008.55	7 815 490 335.02	13 827 610 721.39	112 635.39	15 990 572.61
32 953.86	5 772.07	400 301.51	972.57	7 517 703 060.58	11 233 644 822.91	106 740.01	16 104 572.19
46 630.36	8 165.09	383 920.32	1 284.22	7 543 695 452.19	11 460 059 527.79	107 254.59	16 094 504.29
37 844.72	6 627.23	394 466.37	1 061.68	7 526 997 578.59	11 314 607 671.43	106 924.02	16 100 969.86
181 210.47	31 723.45	222 326.96	4 739.12	7 799 477 615.46	13 688 127 155.65	112 318.38	15 996 627.07
85 250.50	14 930.59	337 355.90	2 463.01	7 617 101 748.33	12 099 487 148.22	108 707.83	16 066 187.97
347 204.72	**60 780.87**	**23 014.32**	**9 000.09**	**8 114 965 356.95**	**16 436 278 006.33**	**118 564.18**	**15 878 957.62**
161 980.37	28 359.28	245 337.78	4 322.57	7 762 931 137.04	13 369 777 869.01	111 594.86	16 010 476.64
96 602.41	16 914.31	323 857.87	2 625.42	7 638 673 641.32	12 287 395 512.37	109 134.90	16 057 903.40

Source: compiled by the authors.

entities, in this article we propose a solution variant in which there are four criteria for optimization (each economic entity has its own).

The task looks like this:

$$F(X)=\{B(X),S(X),N(X),G(X)\}\rightarrow \text{exrt}, \quad (1)$$

$$B(X)=\sum_{i=1}^{n} r\beta X_i C+\sum_{i=1}^{n} h\gamma X_i P_i \rightarrow \max, \quad (2)$$

$$S(X)=\sum_{i=1}^{n}(P_i - C)X_i \rightarrow \max, \quad (3)$$

$$N(X)=\frac{\sum_{i=1}^{n} P_i X_i}{\sum_{i=1}^{n} X_i}\rightarrow \min, \quad (4)$$

$$G(X)=\sqrt{\sum_{i=1}^{n}(L_i \cdot U_i - X_i)^2}\rightarrow \min, \quad (5)$$

where $i = (1, n)$ — room type number;
In t- year, the following will be considered:
X_i — the amount of housing of i-type required to increase the housing stock (the sought value in the optimization problem, m^2;
U_i — the need for housing of i-type by households, units of apartments;
L_i — average area of housing of the i-type, m^2;
C — cost price of 1 m² of housing, rubles;
P_i — price for the consumer when purchasing 1 m² of apartment of the i-type, rubles;
β — share of borrowed funds issued by the bank to developers for project implementation, $0 < \beta \leqslant 0.9$;
r — interest rate on the loan for the developer;
γ —share of borrowed funds issued by the bank to the population for the purchase of housing, $0 < \gamma \leqslant 0.85$;
h — interest rate on mortgages for the population.
B(X) maximizes bank income; *S(X* maximizes developer profit; *N(X)* minimizes the average apartment price for the population; *G(X)* — reduces the gap between housing demand and supply to increase the housing stock.

The set of feasible solutions is defined by the constraint on the amount of housing being constructed and non-negativity conditions:

$$\sum_{i=1}^{n} X_i \le V, \; X_i \ge 0. \quad (6)$$

It is required to determine such a vector $X = (X_1, X_2, \dots, X_n)$ from this set for which the value of the vector function of the *F(X)* vector argument reaches its extremum (maximum or minimum).

To solve the aforementioned problem, it is important to simultaneously consider several criteria and constraints [18]. In this study, we used MATLAB (version R 2019), which is a high-tech software product [19], utilizing its multi-objective genetic algorithm (gamultiobj). Such a choice was made because "genetic algorithms are an effective tool and can be applied to solve a wide range of applied problems in multi-criteria conditional optimization" [15].

Table 7

Solution of a multicriteria problem based on 2020 data

Optimal solution				Value of criteria at the optimal point			
X_1	X_2	X_3	X_4	*B(X)*	*S(X)*	*N(X)*	*G(X)*
0.00	**70219.53**	**335306.00**	**599147.47**	**11240842963.57**	**23949177254.78**	**72328.78**	**16 011 903.69**
130751.37	127278.04	278830.17	467813.42	11484320449.32	26070061314.53	74439.80	15 904 877.48
122047.34	123479.69	282589.73	476556.23	11468112317.19	25928875519.26	74299.27	15 911 944.86
113087.03	119569.51	286459.98	485556.48	11451426951.08	25783532594.62	74154.61	15 919 228.92
58072.62	95561.80	310222.51	540816.07	11348982347.69	24891158035.76	73266.38	15 964 141.66

Table 7 (continued)

Optimal solution				Value of criteria at the optimal point			
X_1	X_2	X_3	X_4	*B(X)*	*S(X)*	*N(X)*	*G(X)*
23436.49	80446.96	325183.00	575606.54	11284484997.56	24329334446.82	72707.17	15 992 584.89
190225.28	153231.83	253141.45	408074.44	11595069255.77	27034772201.76	75400.03	15 856 807.39
390237.75	240515.15	166749.51	207170.59	11967520667.87	30279122524.71	78629.29	15 698 010.83
272214.25	189010.94	217727.73	325720.08	11747744281.95	28364694022.18	76723.76	15 791 175.72
202676.98	158665.61	247763.14	395567.26	11618256078.64	27236748005.51	75601.06	15 846 792.21
184343.29	150664.99	255682.08	413982.64	11584116152.13	26939361899.48	75305.06	15 861 544.32
323704.10	211480.57	195487.57	274000.76	11843625639.78	29199897467.00	77555.08	15 750 339.17
164787.47	142131.03	264128.87	433625.63	11547700454.47	26622151970.52	74989.33	15 877 320.39
74374.43	102675.74	303181.24	524441.58	11379338627.43	25155585572.57	73529.58	15 950 799.15
164787.47	142131.03	264128.87	433625.63	11547700454.47	26622151970.52	74989.33	15 877 320.39
312444.89	206567.17	200350.79	285310.14	11822659409.07	29017264822.24	77373.30	15 759 243.59
429542.97	257667.53	149772.30	167690.20	12040712551.13	30916682395.02	79263.88	15 667 332.14
143739.68	132946.00	273220.10	454767.22	11508506496.92	26280741199.13	74649.50	15 894 346.70
36322.44	86070.26	319617.14	562663.16	11308480453.31	24538354088.36	72915.22	15 981 987.92
335134.21	216468.55	190550.53	262519.71	11864910119.41	29385302363.46	77739.62	15 741 314.10
16192.68	77285.84	328311.85	582882.63	11270995999.05	24211834464.01	72590.22	15 998 549.73
110822.37	118581.24	287438.17	487831.22	11447209839.84	25746798200.90	74118.04	15 921 071.29
96455.42	112311.65	293643.73	502262.20	11420456542.36	25513755552.30	73886.08	15 932 772.21
433968.89	**259598.96**	**147860.59**	**163244.55**	**12048954230.65**	**30988474128.53**	**79335.34**	**15 663 888.58**
47092.53	90770.21	314965.18	551845.08	11328535876.45	24713052907.97	73089.11	15 973 144.61
86497.38	107966.07	297944.92	512264.63	11401913270.24	25352228791.08	73725.31	15 940 895.45

Source: compiled by the authors.

Input data for calculations for 2023 are as follows:
$n = 4$ — number of apartment types, units;
$V = 440\,000$[3] — planned housing input, m²;
$C = 81\,209$ — cost price of 1 m² of housing;
$P = [120\,510; 114\,330; 105\,500; 105\,500]$; — price for the consumer when purchasing 1 m² of an apartment of the i-type, rub.;
$\beta = 0.85$ — share of borrowed funds for developers;
$r = 0.07$ — interest rate on loans for developers;
$\gamma = 0.7$ — share of borrowed money for the population;
$h = 0.164$ — interest rate on mortgages for the population;
$L = (33; 42; 54; 72)$ — average apartment area, m²;
$U = [421\,416; 167\,879; 58\,568; 43\,071]$ — the need for housing for households of the i-type, units of apartments.

The found Pareto-optimal solutions are presented in *Table 6*.

Since all points in the Pareto-efficient set in the solution space are equivalent from the perspective of multi-criteria optimization theory, the decision-maker plays a crucial role.

In this set of solutions, the choice is obvious: with maximum values of criteria

$B(X)$ and $S(X)$ and minimum $G(X)$ the solution is found at point $X = (347205; 60781; 23014; 9000)$, which indicates how many square meters of apartments of different room counts need to be built. In *Table 6*, this row is highlighted in yellow, and the value $N(X)$ in it is not the smallest. However, it is precisely the population that is forced to make this compromise, even though, in the context of the average weighted price per 1 m², the point highlighted in orange in *Table 6* is more advantageous for them, i.e., from the citizens' perspective, it is more reasonable to build three-room apartments.

The calculation option based on the 2020 data is presented in *Table 7*.

Initial information for 2020:

$r = 0.07$; $\beta = 0.85$; $\gamma = 0.7$; $h = 0.085$; $C = 48\,491$;
$P = (84\,357; 80\,031; 71\,750; 71\,750)$;
$L = (33; 42; 54; 72)$;
$U = (421\,416; 167\,879; 58\,568; 43\,071)$;
$V = 1004673$ [20].

The best for the state, developers, and banks is highlighted in yellow, for the population in orange. The maximum values of the criteria $B(X)$ and $S(X)$ and the minimum $G(X)$ are achieved at the point $X^* = (433969; 259599; 147861; 163245)$[4]

From the population's perspective, it is more reasonable $X^* = (0; 70220; 335306; 599147)$[5]

The comparison of the structure of solutions obtained in 2020 and 2023 is presented in *Table 8*.

CONCLUSION

Based on the results of the work, it can be concluded that the research task has been solved. The authors of the article have shown that there are points where the interests of economic entities align, and the decision-maker has options to choose from. Among the four entities considered, developers, banks, and the state are more active, making decisions and influencing their parameters. The opportunities for the population are limited in terms of cost: the consumer pays for everything. However, the obtained results can be explained differently: in essence, the criterion $G(X)$ serves not only the interests of the state but primarily those of the population. Who, if not households, is interested in reducing the gap between the actual and "optimal" structure of the housing stock? The tendency of this indicator towards zero indirectly indicates the complete correspondence of the household composition to the required

[3] In the Irkutsk region, they plan to build 460 thousand square meters of new housing in 2023. The regional. 01.07.2023. URl: https://www.ogirk.ru/2023/07/01/v-irkutskoj-oblasti-planirujut-postroit-460-tys-kv-m-novogo-zhilja-v-2023-godu/ (accessed on 04.07.2024).

[4] * means the optimal value of the value X.

[5] The same thing.

Table 8

Structure of decisions in 2020 and 2023, %

	2020		2023	
Economic subjects	**Developers, banks, state**	**Population**	**Developers, banks, state**	**Population**
One-room apartments	43	0	79	0
Two-room apartments	26	7	14	0
Three-room apartments	15	33	5	100
Four-room (and larger) apartments	16	60	2	0

Source: Compiled and calculated by the authors.

number of rooms in the apartments. The only thing is, the model does not provide a definite answer as to who acquires these apartments. The minimum price factor (orange line) confirms the market truth: the larger the living space, the cheaper the square meter. However, this does not mean that all households should acquire 3- and 4-room apartments. In such a situation, only additional state regulation can help minimize the gap between the real situation and the ideal housing needs of the population. In this case, the presented model becomes a necessary tool for reconciling the interests of all participants in the housing construction complex to maintain the sustainability of its existence in a challenging macroenvironment.

REFERENCES

1. Abdeev R.F. Philosophy of information civilization. Moscow: VLADOS; 1994. 336 p. (In Russ.).
2. Nazaretyan A.P. The nonlinear future: Singularity of the 21st century as an element of megahistory. *Vek globalizatsii = Age of Globalization*. 2015;(2):18–34. (In Russ.).
3. Gorskii Yu.M., Astaf'ev V.I., Kaznacheev V.P., et al. Homeostatics of living, technical, social and economic systems. Novosibirsk: *Nauka;* 1990. 350 p. (In Russ.).
4. Grushina O.V. Strategy for ensuring housing affordability in the Russian Federation. Irkutsk: Baikal State University; 2017. 218 p. (In Russ.).
5. Kolodyazhny S.A., et al. Organizational and economic changes in the investment and construction complex on an innovative basis as a process of ensuring its sustainable development. Voronezh: Voronezh State University of Architecture and Civil Engineering; 2014. 147 p. (In Russ.).
6. Shelomentseva N.N., Grushina O.V., Krasnoshtanova T.A. Simulation of interest coordination of economic subjects in housing construction. *Mir novoi ekonomiki = The World of New Economy*. 2023;17(1):103–116. (In Russ.). DOI: 10.26794/2220-6469-2023-17-1-103-116
7. Shelomentseva N.N. Formation of a strategy for housing supply by developers in the context of project financing. Cand. econ. sci. diss. Synopsis. Irkutsk: Baikal State University; 2021. 24 p. (In Russ.).
8. Grushina O.V., Shelomentseva N.N. On the problem of providing people with comfortable and affordable housing. *Aktual'nye problemy ekonomiki i menedzhmenta = Actual Problems of Economics and Management*. 2019;(1):17–25. (In Russ.)

9. Nureev R.M., Gulyaeva O.A. Institutional analysis of housing in Russia. *Terra Economicus.* 2021;19(2):39–57. (In Russ.). DOI: 10.18522/2073-6606-2021-19-2-39-57
10. Makarov D.A. Yudenko M.N. Systemic modelling of economic interaction in sphere of housing construction. *Ekonomika stroitel'stva = Economics of Construction.* 2021;(2):28–38. (In Russ.).
11. Liu M., Le Y., Hu Y., Xia B., Skitmore M., Gao X. System dynamics modeling for construction management research: Critical review and future trends. *Journal of Civil Engineering and Management.* 2019;25(8):1–12. DOI: 10.3846/jcem.2019.10518
12. Smith M.J. Dynamic modeling of housing markets: An agent-based approach. *Journal of Economic Dynamics and Control.* 2011;35(9):1454–1471. DOI: 10.1016/j.jedc.2011.03.002
13. Crooks A., Heppenstall A., Malleson N., Manley E. Agent-based modeling and the city: A gallery of applications. In: Shi W., Goodchild M.F., Batty M., Kwan M.P., Zhang A., eds. Urban informatics. Singapore: Springer-Verlag; 2021:885–910. (The Urban Book Series). DOI: 10.1007/978-981-15-8983-6_46
14. Steinbacher M., Raddant M., Karimi F., et al. Advances in agent-based modeling of economic and social behavior. *SN Business & Economics.* 2021;1(7):99. DOI: 10.1007/s43546–021–00103–3
15. Prokhorova I.A., Averyanova S.S. Application of genetic algorithms in solving multicriteria problems. In: Science of SUSU: Proc. 72nd sci. conf. Chelyabinsk: South Ural State University; 2020:112–120. URL: https://www.researchgate.net/publication/351023529_PRIMENENIE_GENETICESKIH_ALGORITMOV_PRI_RESENII_MNOGOKRITERIALNYH_ZADAC (accessed on 16.08.2024). (In Russ.).
16. Nan Y., Ishibuchi H., Shu T., Shang K. Analysis of real-world constrained multi-objective problems and performance comparison of multi-objective algorithms. In: Proc. genetic and evolutionary computation conf. (GECCO'24). New York, NY: Association for Computing Machinery; 2024:576–584. DOI: 10.1145/3638529.3653994
17. Shelomentseva N.N. Multicriteria problem in housing construction. In: Antonik V.G., ed. Dynamic systems and computer science: Theory and applications (DYSC 2023). Proc. 5th Int. conf. (Irkutsk, September 18–23, 2023). Irkutsk: Irkutsk State University Publ.; 2023:221–222. (In Russ.).
18. Zhu X., Meng X., Zhang M. Application of multiple criteria decision making methods in construction: A systematic literature review. *Journal of Civil Engineering and Management.* 2021;27(6):372–403. DOI: 10.3846/jcem.2021.15260
19. Kholodnov V.A., Lebedeva M. Yu., Krasnoborodko D.A., Kulishenko R. Yu. Open alternatives to MATLAB to solve multi-purpose optimization problem. *Izvestiya Sankt-Peterburgskogo gosudarstvennogo tekhnologicheskogo instituta (tekhnicheskogo universiteta) = Bulletin of the Saint Petersburg State Institute of Technology (Technical University).* 2020;(54):80–86. (In Russ.). DOI: 10.36807/1998-9849-2020-54-80-80-86
20. Kulikova A. In the Irkutsk region in 2021, 8.9% more housing was commissioned than in 2020. Sibdom. 2022. URL: https://irk.sibdom.ru/news/17339/ (accessed on 04.07.2024). (In Russ.).

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Authors' declared contribution
N.N. Shelomentseva — construction of the best structure by the number of rooms in individual houses and apartments for the Irkutsk region based on the 2010 and 2020 censuses; development of a multi-criteria economic and mathematical model for coordinating the interests of economic entities in housing construction and numerical experiments on the model.
O.V. Grushina — development of the general concept of the article, justification for the application of a system-information approach to managing the sustainability of the housing construction complex, analysis of housing provision by households based on the 2002, 2010 and 2020 censuses.

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